STAND STRUCTURE AND SITE CHARACTERISTICS OF KHAIR (*Acacia catechu* Willd.) WORKING CIRCLE IN NURPUR FOREST DIVISION OF HIMACHAL PRADESH

Thesis

by

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CERTIFICATE–I

This is to certify that the thesis titled, **"Stand structure and site characteristics of Khair (*Acacia catechu* Willd.) working circle in Nurpur Forest division of Himachal Pradesh"** submitted in partial fulfilment for the award of the degree of **DOCTOR OF PHILOSOPHY (FORESTRY) SILVICULTURE** to Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (HP) 173230 is a bonafide research work carried out by **Mr. DHIRENDER KUMAR (F-2017-14-D)** S/o Sh. Virender Kumar under my supervision and no part of this thesis has been submitted for any other degree or diploma.

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

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CERTIFICATE-II

This is to certify that the thesis titled, **"Stand structure and site characteristics of Khair (*Acacia catechu* Willd.) working circle in Nurpur Forest division of Himachal Pradesh"** submitted by **Mr. DHIRENDER KUMAR (F-2017-14-D) S/o Sh. Virender Kumar** to Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (HP)- 173230 India in partial fulfilment of the requirements for the award of degree of **DOCTOR OF PHILOSOPHY (FORESTRY)** in the discipline of **SILVICULTURE** has been approved by the Advisory Committee after an thesis viva-voce examination of the student in collaboration with the External Examiner.

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CONTENTS

ABBREVIATIONS USED

ABG	:	Above Ground Biomass
a.m.s.l.	:	Above Mean Sea Level
BA	:	Basal Area
BD	:	Bulk Density
BEF	:	Biomass Expansion Factor
BGB	:	Below Ground Biomass
C	:	Carbon
C.D. 0.05	:	Critical Difference at P = 0.05
C ha^{-1}	:	Carbon per hectare
Cm	:	Centimeter
^0C	:	Degree Celsius
CFS	:	Co-operative Forest Society
DBH	:	Diameter at Breast Height
DPF	:	Demarcated Protected Forest
E	:	East
e.g.	:	For Example
etc.	:	Etcetera
et al.	:	Co- workers
FSI	:	Forest Survey of India
G	:	Gram
GHG	:	Green House Gas
Ha	:	Hectare (10,000 m^2)
IPCC	:	Intergovernmental Panel on Climate Change
IVI	:	Importance Value Index
i. e.	:	That is
Kg	:	Kilogram
K	:	Potassium
M	:	Meter
Mg ha^{-1}	:	Mega gram per hectare
Mg c ha^{-1}	:	Mega gram carbon per hectare

Mm	:	Milimeter
MT	:	Metric Tone
N	:	North
N	:	Nitrogen
OC	:	Organic Carbon
P	:	Phosphorus
PD	:	Particle Density
pH	:	puissance d' Hydrogen
pp.	:	Pages
Ppm	:	Parts per million
RF	:	Reserve Forest
SOC	:	Soil Organic Carbon
spp.	:	Species
SOCD	:	Soil Organic Carbon Density
$t\ c\ ha^{-1}$	:	Tonne Carbon per hectare
%	:	Percent
UF	:	Un-class Forest
UPF	:	Un-demarcated Protected Forest

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Chapter-1

INTRODUCTION

Terrestrial ecosystems, particularly forests with their abundant biodiversity and carbon storage capacity, are critical for sustainable development and can help to achieve the United Nations Sustainable Development Goals (SDGs) concurrently, the nature-based solutions that forests may provide are not explicitly stated in Agenda 2030 (UN, 2015). Forests are capable of sequestering atmospheric carbon into woody biomass, accounting for about 45 percent (900 pentagrams) of the terrestrial carbon pool and sequestering 2.4 pentagrams of carbon every year (PgC/yr) (Pan *et al*., 2011). As a result, preserving or restoring standing forests is a relatively low-hanging fruit in terms of reducing human greenhouse-gas emissions (Seddon *et al*., 2020). Forests, in addition to acting as carbon sinks, are vital repositories of terrestrial biodiversity, sustaining a diverse array of species, including thousands of endangered and unique plants and animals (FAO and UNEP, 2020).

Forests not only act as carbon sinks but also as carbon sources when subjected to deforestation and unsustainable biomass harvest (Pearson *et al*., 2017). Forest ecosystem services are inextricably linked to climate change (SDG 13), since deforestation is the second greatest source of human carbon dioxide emissions on a global scale (Van Der Werf *et al*., 2009). With one-third of the world's population (2.5 billion people) relying on biomass fuels (International Energy Agency, 2017), wood is the primary source of bioenergy worldwide. Deforestation and forest degradation have recently been linked to zoonotic disease outbreaks (White and Razgour, 2020), such as the recent pandemic caused by COVID-19. Forests, particularly those in tropical and subtropical regions, are threatened by deforestation, degradation, and fragmentation; these concerns jeopardise both the capacity for carbon sequestration and other ecosystem functions reliant on biodiversity. Thus, preserving biodiversity and increasing carbon sequestration in forests are two critical strategies for developing resilient and sustainable forest ecosystems in the face of climate and natural disasters. Biomass measurements of individual trees and whole stands have long been of principal interest but complete tree utilization concept including biomass assessment of individual tree components is one of recent approaches in Indian context. Biomass determination provides the estimates of total yield and basis for determining the feasibility of complete tree utilization (Grote, 2002). It is also important for understanding the dynamic forest ecosystem and different forms of productivity. Quantitative information on biomass helps not only to understand energy accumulation within forest ecosystems but also serves as an ecological indicator for sustainability as it helps in assessing forest productivity, carbon pools and carbon sequestration in biomass components (Chave *et al.,* 2005). Biomass analysis is an important element in the carbon cycle and carbon sequestration (Devagiri *et al.*, 2013); being increasingly used to help quantify pools and fluxes of greenhouse gases (GHG) from terrestrial biosphere (Cairns *et al*., 2003). Most studies estimating above ground biomass (AGB) concentrate on stem biomass because it constitutes around 83% of the total AGB and biomass of different tree components constitutes the remainder and sequestration of carbon in biomass is presently considered as the most promising approach to mitigate green house effect (Kimble *et al.,* 2002). Tree carbon is a significant component of forest carbon (DFRS, 2015); its proportion in the forest carbon pool varies by location and forest (Pan *et al*., 2011). At a broader regional scale, tree carbon is dependent on climatic factors such as temperature, precipitation, and light availability, all of which influence net primary production. At the forest stand level, tree carbon is influenced by interactions between climatic, edaphic, and topographic variables, as well as those linked to land use and disturbance (Arasa *et al.,* 2018; Xu *et al*., 2015 and Yuan *et al*., 2018). Protected forest, in general, are significant carbon sinks. However, not all protected areas are equally effectively maintained, and their contribution to carbon sequestration varies (Collins and Mitchard, 2017). Numerous indices of species variety, stand structural diversity, and functional diversity, as well as disturbance and environmental factors, have been used to forecast tree carbon (Li *et al*., 2019; Shen *et al*., 2016 and Yuan *et al*., 2018). According to certain research, matrices of structural diversity outperform measures of species diversity (Aponte *et al*., 2020 and Yuan *et al*., 2018); whereas others find that diversity matrices have a considerably greater prediction value for tree carbon (Aponte *et al*., 2018; Liu *et al*., 2018 and Zhang *et al*., 2017). Among the stand diversity indicators, huge trees are critical structural components that mostly predict forest carbon (Ali *et al*., 2019; Lutz *et al*., 2018 and Stephenson *et al*., 2014).

These carbon pools are dynamic and change in response to changes in land use. Thus, deforestation and forest degradation have a significant influence on the forest carbon pool. Mineral extraction (mostly oil and coal), illegal felling, and conversion of forest area to agricultural land are the principal human-induced disturbances that continue to exist in tropical and subtropical forest, impairing ecosystem function and a regional CO_2 cycle.

Anthropogenic activities (e.g., logging, farming, mining, etc.) and natural forces (e.g., wildfire, species invasion, floods, etc.) are some of the recognized causes of decreased biodiversity (Lu *et al*., 2020; Martnez *et al*., 2016 and Morris, 2010).

Invasion of plants in natural communities are commonly associated with reduced species diversity and altered ecosystem structure and function also termed environmental weeds (Richardson *et al*., 2000). Across varying habitats, modification of key ecosystem processes has been ascribed to *Lantana camara* L. (Verbenaceae), an invasive neotropical shrub species of great concern worldwide including India, China, Southern Africa, Australia, and New Zealand (Zalucki *et al.*, 2007). Lantana affects other species by releasing a variety of chemicals (Arora and Kohli, 1993) and is capable of interrupting regeneration processes by decreasing germination, reducing early growth rates, and increasing mortality of indigenous species.

Among the country's total forest area of 32,87,469 square kilometers, reserve forest covers 4,34,705 square kilometres, protected forest covers 2,19,432 square kilometres, and unclassified forest covers 1,13,881 square kilometres. In Himachal Pradesh, the total area covered by forest is 37948 square kilometres, of which 1883 square kilometres are reserved forest, 12852 square kilometres are designated as protected forest, 16035 square kilometres are designated as Un-demarcated Protected Forest, 7160 square kilometres are managed by the forest department, and 18 square kilometres are designated as municipal or cantonment forests (Report, 2019).

Acacia catechu Willd. is a multipurpose moderate sized deciduous tree belonging to family Fabaceae found throughout the greater parts of India except in very humid and temperate regions. It is common in the sub-Himalayan tract up to the Indus, eastwards to Assam and throughout the peninsula, particularly in the drier regions, ascending up to 900 m and sometimes found at 1200 m above msl (Troup, 1921). It occurs in tropical moist deciduous forests, dry tropical forests and tropical thorn forests (Champion and Seth, 1968). There are 3 varieties of *A. catechu viz. catechu* (catechu proper)*, catechuoides* and *sundra* found in India. *Catechu* is found in Jammu and Kashmir, Uttar Pradesh and Himachal Pradesh where it is widely distributed in Mandi, Hamirpur, Kangra, Solan, Sirmaur, Una, Chamba, Shimla and Bilaspur districts below 1300 m elevation (Chauhan, 1999). Generally, it forms pure patches of khair forests but it is also found in association with *Acacia modesta, Pinus roxburghii, Mallotus philippensis, Dalbergia sissoo, Zizyphus mauritiana, Terminalia* *bellerica, T. chebula, Wendlandia exserta, Butea monosperma, Anogeissus latifolia, Lannea coromandelica* and *Shorea robusta* (Champion and Seth, 1968). The forests of the country as per the legal classification (Act, 1927) are classified into Reserve Forests, Protected Forests-Demarcated Protected Forests and Undemarcated Protected Forests, Village Forests and Un-Classed Forests to fulfill the different objectives of the management viz., developmental needs of the country, conservation of the natural resources and to meet out the social obligation of the masses. So far, no scientific study has been carried out to quantify how these forest management practices meet out these objectives in the Khair Working Circle in Nurpur Forest Division of Himachal Pradesh. The purpose of the present study is to test the hypothesis whether the different type of the forest management practices influence the stand structural features, biodiversity and forest ecosystem carbon stock of the Khair forests in a 'Khair working circle' or not? Keeping this in view, the present study entitled **"Stand structure and site characteristics of Khair (*Acacia catechu* Willd.) working circle in Nurpur Forest division of Himachal Pradesh"** was undertaken with the following objectives:

1. To study the floristic composition under different legal forest classes of Khair working circle;
2. To work out the compartmental variation in biomass production and C-storage potential under different forest classes;
3. To study the relationship between site characteristics and natural regeneration in Khair working circle;
4. To determine the status of *Lantana camara* infestation and its impact on stand structure.

Chapter-2

REVIEW OF LITERATURE

The cohesiveness in representation of the research has been reviewed to the present investigation entitled **“Stand structure and site characteristics of Khair (*Acacia catechu* Willd.) working circle in Nurpur Forest division of Himachal Pradesh”** in this chapter under the following headings:

2.1 Stand structure, regeneration and biodiversity

2.2 Biomass and carbon stock

2.3 Site characteristic and lantana infestation

2.1 STAND STRUCTURE, REGENERATION AND BIODIVERSITY

Sharma and Raghubanshi (2006) evaluated tree population structure, regeneration and expected future composition at different levels of *Lantana camara* L. invasion in the Vindhyan tropical dry deciduous forest of India. A total of 90 quadrats, distributed over three sites, differing in lantana cover (low; 0-30%, medium; 31-60% and high; 61-100%), were used to enumerate the tree species. A total of 37 species with 14851 stems were enumerated from the three study sites, which were in gradient of lantana cover. Number of species varied from 21 to 30, while the number of individuals varied from 3408 to 7458 per site with former in high and later in low lantana cover. PCA ordination and Bray-Curtis cluster analysis revealed that the sites were not very unique with tree composition but showed marked uniqueness of sites in terms of seedling composition. The distinctness of species composition in the seedling stage is indicative of marked temporal dynamics, of this lantana invaded forest. The site wise regeneration analysis with the relative density of tree species at each life cycle stage (adult, sapling and seedling) showed that regeneration of species was poor at high-invaded site. The least invaded site indicated good regeneration with many new species emerging. Such differential change in vegetation composition at different lantana cover may be attributed to changed light and fire regime and also due to increased allelopathic suppression of tree seedlings. The study concluded that the lantana cover was suppressing regeneration and reducing availability of forest resources, which is of serious human concern.

Chauhan *et al.* (2008) compared regeneration, tree diversity and floristic diversity of natural and planted tropical deciduous forests dominated by *Shorea robusta* and *Tectona grandis*, *Acacia catechu* and *Syzygium cumini,* respectively in Katarniaghat Wildlife Sanctuary, Uttar Pradesh. Species diversity as well as species evenness was higher in natural forests than in planted forests. Natural forest sites also had higher mature tree, pole, sapling and seedling densities compared with planted forests. In spite of differences in diversity, natural and planted forests did not differ strongly in species composition, fifty-six species occurred in both sites. This may reflect similar soil types but differences in soil moisture, organic carbon, available nitrogen, phosphorus, potassium and soil pH in natural and planted forests. Dominant families in both forest types are Fabaceae, Euphorbiaceae, Verbenaceae, Rubiaceae and Caesalpiniaceae (5 species each), followed by Moraceae, Mimosaceae and Combretaceae. Of the 126 species found in both sites, 32.5% showed good regeneration, 19.8% fair, 24.6% poor and 11.1% lacked regeneration. The remaining 11.9% of species were present only as seedlings. Species richness and diversity differed between natural and planted forest and regeneration of some important tree species also varied because of variation in their microclimate and edaphic characteristics.

Reddy and Ugle (2008) studied the regeneration status of tropical dry and moist deciduous forest in Mudumalai Wildlife Sanctuary, Western Ghats. Out of the 104 species (young and mature trees) recorded, 28.8% showed good regeneration, 5.8% fair, 33.7% poor and 29.8% showed no regeneration at all in moist deciduous forest. In case of dry deciduous forest, 33.7% showed good regeneration, 3.5% fair, 16.3% poor and 17.4% showed no regeneration at all. Absence of younger type of species infers impact of anthropogenic disturbances such as recurrent forest fires, cattle grazing and biological invasion of exotic weeds on natural regeneration.

Regeneration success, persistence strategies (seedlings *vs.* coppicing), and population trend of *Acacia* spp. were tested by Traore (2008) under two land-use regimes in eastern Burkina Faso: (i) protected areas shielded to livestock grazing pressure, to logging, and using early annual fire as a management system; (ii) areas with high human impact (heavily and extensive livestock grazing, harvesting for wood and for medicinal plants). Generally, a good regeneration rate of *Acacia* species was observed in protected areas and a poor regeneration rate in areas with high human impact. Nevertheless, some species affiliated to the subgenus *Aculeiferum* as *A. dudgeon* and *A. polyacantha* showed a good regeneration under both land use regimes. Juvenile plants less than 25 cm height of *A. dudgeon* and *A. gourmaens is* increased by 116 to 50 % in areas with human impact as compared to their populations in protected areas. The protected *Acacia* woodland displayed a stable population structure due to abundance of recruitment and coppicing persistence (more common in the subgenus *Aculeiferum*) favoured by early annual fire. Consequently, the protected areas are favourable for *Acacia* woodland regeneration. Conversely, in areas of anthropogenic regime a declining population especially more marked with the subgenus *Acacia* due to permanent seed and seedling removal by livestock grazing was observed. Nevertheless, the number of seedlings of some species was higher in areas under human pressure than in protected areas, especially for the subgenus *Aculeiferum*, improving the genetic variability and thus the long-term maintenance of the population.

Chandra (2009) determined the tree species composition, regeneration and diversity status of miscellaneous forest in Tarai region of Kumaon Himalaya. He found that the total tree basal area ranged from 2325.0 to 2974.7 cm^2 and density from 4.7 to 7.0 plants 100 m^{-2} for tree layer, 8.0 to 18.4 individuals 100 m^{-2} for saplings and 58.8 to 146.3 individuals 100 m^{-2} for seedlings. Shannon-wiener index (diversity) values for tree layer ranged 2.408 to 2.862, concentration of dominance ranged 0.163 to 0.205 and equitability between 8.58 and 11.23. The data on population structure recognized a total of four patterns out of which *Mallotus philipinensis* showed expanding population structure however the absence of lower girth classes of *Dalbergia sissoo* indicated that this early successional species was failing to regenerate with increasing density of forest cover. *Tectona grandis* and *Cassia fistula* were represented only by seedlings indicating they had invaded recently.

Tree layer analysis was carried out by Khurana (2009) in a tropical dry deciduous forest of Hastinapur, Uttar Pradesh. The forest was characterized by the presence of xerophytic species and open canopy due to disturbances. Regeneration studies showed that *Acacia nilotica* was the important species with individuals of all size classes while *Acacia nilotica*, *Prosopis juliflora* and *Tectona grandis* were the dominant tree species of the forest type.

Pokhriyal *et al.* (2010) studied the regeneration status of tree species in forests of Phakot and Pathri Rao watersheds in Garhwal Himalaya. In general, both the forests were regenerating, although seedling and sapling population was higher in Phakot watershed. However, Pathri Rao watershed comes under protected area and thus the forest has good canopy cover, which might have affected the survival of seedlings due to absence of light.

A study was carried out to investigate the potential of monoculture plantations of *Acacia auriculiformis*, *Casuarina equisetifolia* and *Anacardium occidentale* to foster the regeneration of native woody species with respect to proximity to human settlements and natural forest (NF) as the major factors in Kudremukh National Park of South India by Nagaraja *et al*. (2011). A total of 80 plots were laid down in three monoculture plantations in nearby NF and abandoned pasture. A total of 32 naturally regenerated woody species were recorded beneath all plantation stands with a density ranging from 4600 to 17,100 ha^{-1}. The plantation of *C. equisetifolia* support a greater number of species and diversity with more canopy cover (71–87.5%) and also more litter depth (10.8–11.67 cm). Sorenson's index of similarity (IS) values indicated that *C. equisetifolia* and *A. auriculiformis* stands exhibited the highest similarity whereas, in NF, *C. equisetifolia* showed high degree of similarity. The soils of all plantations were acidic in nature however, higher level of nutrients was observed in *C. equisetifolia* plantation.

Nirola and Jha (2011) studied the vegetation structure and composition of Shiwalik range in Nepal. A total number of 137 flowering plants and 8 pteridophytes were reported. *Shorea robusta*, *Terminalia alata* and *Semecarpus anacardium* were the most dominant species of the study area. Degraded sites like mine spoils on hill slopes are characterized by poor soil physico-chemical environments and instability. Reclamation of such areas using low-cost bioengineering and vegetative methods were carried out in the lower western Indian Himalayas and the impact of these measures on vegetation diversity, secondary succession and growth of seeded *Acacia catechu* Willd. after two decades of protection are reported by

Raizada and Juyal (2012) studied how the introduction of fast-growing leguminous species affected species diversity and hampered the regeneration and growth of native vegetation, due to the dense shade of the overstorey component. The study revealed that species diversity (H') levels increased with the opening of the canopy at different elevations, with the highest diversity (1·624) being recorded on the hilltop with *Acacia catechu* and *Wendlandia exserta* dominating the area. Enumeration of various species in the growth stages indicated a large population in the pole stage followed by tree and sapling stage indicating scattered regeneration mostly of 1-2 species. Tree associations in the lower, middle and upper reaches were of *Leucaena leucocephala*- *A. catechu*, *A. catechu – Boehemeria rugulosa* and *A. catechu-W. exserta*, respectively.

Bajpai *et al.* (2012) studied the association pattern of tree species in Katerniaghat Wildlife Sanctuary (KWS) a tropical moist deciduous forest of Terai region of Uttar Pradesh, India. The cluster and PCA analyses grouped the forests of KWS into three major forest types: Sal Forest, miscellaneous forest and teak plantation. The different forest type exhibit differences in tree dominance and diversity: Sal Forest is dominated by *Shorea robusta*, miscellaneous forest by *Mallotus philippensis* and teak plantation by *Tectona grandis*. The tree species richness has been found 48.07 species ha^{-1} in teak plantation, 52.63 in miscellaneous forest and 55.35 in Sal Forest. The tree density has been found 769.23 $stemha^{-1}$in teak plantation, 742.86 in Sal Forest and 671.05 in miscellaneous forest. The basal cover was observed 1260.75 m^2ha^{-1}in miscellaneous forest, 3533.61 in Sal Forest and 4933.97 in teak plantation. The diversity indices (Shannon diversity and Fisher-alpha diversity) have been found maximum (2.666 and 12.390) in miscellaneous forest, moderate (2.152 and 8.677) in Sal Forest and low (1.134 and 6.482) in teak plantation. The species heterogeneity has been found maximum (0.862) in miscellaneous forest, moderate (0.785) in Sal Forest and minimum (0.399) in teak plantation.

Eltahir and Wagner (2012) assessed regeneration situation in natural and plantation parts of a reserved forest in Sudan. The forest was diverse in terms of species structure and composition. The natural part is dominated by *Albizia amara* and *Terminalia brownie* while plantation part of the forest is artificially dominated by *Acacia senegal*. The lower proportion of other species indicate their rarity and poor establishment of their regeneration due to competition, termite infection and wild animal's effect.

Chaubey and Sharma (2013) studied regeneration potential of *Shorea robusta* and its associates in Satpura Tiger Reserve, Madhya Pradesh. The results indicated that the average number of regenerations of sal seedlings/ha were 6372 ha^{-1}, which was quite adequate. The distribution pattern of individuals of *Shorea robusta* was uninterrupted which is a healthy sign of establishment.

Dutta and Devi (2013) investigated the plant population structure and the phytosociological and regeneration status in two disturbed tropical forests in Assam Province, the Hojai Reserve Forest and Kumorakata Reserve Forest. A total of 166 species (80 trees, 20 shrubs and 66 herbs) of 136 genera and 63 families were recorded in both study sites. The disturbance index at the two sites, Kumorakata Reserve Forest and Hojai Reserve Forest, were recorded at 11.4 and 3.70 percent respectively. The both study sites showed reverse J-shaped population curve and recorded the exploitation of tree species in higher girth classes. In the girth classes (10−30 cm, 30−60 cm, 60−90 cm and 90−120 cm in size) the percentage of cut stump density was higher than the percentage of individual living trees. The 18 percent (Kumorakata Reserve Forest) and 7 percent (Hojai Reserve Forest) species were recorded as "not regenerating."

Dutta and Devi (2013) explored the floristic composition in protected area of tropical forests of Assam, northeast India. The study was conducted in four tropical forests namely, Lumding reserve forest (LRF), Doboka reserve forest (DRF), Hojai reserve forest (HRF) and Kumorakata reserve forest (KRF) located towards the South of Nagaon district of Assam. The quadrat method for the collection of phytosociological data during 2009-2010 had been used. In each site 50 quadrats of 10×10 m size for adult tree, 50 quadrats of 5×5 m size for shrubs and 100 quadrats of 1×1 m size for herbs were randomly laid followed by stratified random sampling approach. A total of 208 (82 tree, 32 shrubs, 94 herb) species belonging to 165 genera and 71 families were recorded in four reserve forest. The highest 117 (59 tree, 19 shrubs, 39 herb) species was recorded in LRF belonging to 97 genus and 55 families and lowest 69 (17 tree, 14 shrubs, 38 herb) species was recorded in KRF belonging to 64 genus and 31 families. Overall Euphorbiaceae was the dominant family with 16 species followed by Poaceae with 13 species. *Trewia nudiflora* and *Bauhinia variegata* were the dominant tree species recorded in LRF. In both DRF and HRF *Shorea robusta* along with *Dillenia pentagyna* and *Careya arborea* were recorded as dominant tree species, whereas *Ficus nervosa* was the dominant tree species in KRF. The dominating species might show variations in different tropical forests depending on existing disturbance, forest type and elevation. Shannon-Wiener diversity index of tree species ranged from 3.63 (LRF) to 1.52 (HRF). Highest Similarity index between DRF and HRF may be due to presence of same dominated species *Shorea robusta* and its common associated species.

Pala *et al*. (2013) investigated the regeneration status of tree species in five sacred and protected forests of Garhwal Himalaya. Seedling and sapling density was used as an indicator of regeneration status of present species. A total of 47 species of trees were recorded from five sacred and protected forests, among which only 7 species showed either good or fair regeneration in all the five sites, whereas a majority (17 species) showed either poor or no regeneration. The dominant species were *Quercus spp*., *Rhododendron arboreum*, *Myrica esculenta*, and *Lyonia ovalifolia*. Sapling density ranged from 8.84 to 15.2 saplings per 100 m^2 and seedling density ranged from 11.36 to 18.74 seedlings per100 m^2 in different study sites. The study further showed that regeneration status of lesser (auxiliary) species in the forests was low as compared to dominant ones. Girth class distribution of individuals showed a reverse J-shaped curve for all the species at all the sites.

Adem *et al.* (2014) studied diversity, regeneration status and population structure of resin bearing woody species in Ethiopia. A total of 27 woody species of 12 families and 14 genera were recorded including species of the genera *Acacia*, *Boswellia*, *Commiphora* and *Sterculia*. Diversity of entire woody species assemblage was slightly higher. However, natural regeneration of these species was at rapid decline.

Floristic composition, diversity and stand structure of four natural tropical forests *viz*. dry mixed deciduous forest, dry dipterocarp forest, dry forest and dry hill/evergreen forest in Popa mountain park, Myanmar was studied by Aye *et al*. (2014). The average stem density ranges from 1293 trees ha^{-1} in dry dipterocarp forest to 804 $treesha^{-1}$in dry evergreen forest. The highest number of species was recorded in dry mixed deciduous forest (74 $speciesha^{-1}$) and lowest number of species (40 $speciesha^{-1}$) in dry forest. Dry mixed deciduous forest occupied the highest value on Shannon-Weiner index and Simpson diversity index while lowest was in dry forest indicating that dry mixed deciduous forest is the most complex whereas dry forest is the simplest community.

Ballabha *et al.* (2014) studied regeneration status of two forest types in Garhwal Himalaya of Uttarakhand. The overall regeneration status was fairly good in both forest types although regeneration was better at *Anogeissus latifolia* forest with its high seedling and sapling density than *Pinus roxburghii* forest. Diameter class distribution of tree species in both forest types showed the highest number of individuals in lower diameter classes suggesting a good regeneration potential. *Acacia catechu, Aegle marmelos*, *Anogeissus latifolia, Bauhinia variegata, Lannea coromandelica, Ougeinia oojeinensis, Phyllanthus emblica* and *Syzygium cumini* showed good regeneration while *Pinus roxburghii*, *Terminalia alata* and *Erythrina variegates* have fair regeneration.

Khali and Bhatt (2014) studied on community structure of montane forest along the altitudinal gradient in Garhwal Himalaya in four forest types *viz*., chirpine forest, pine-oak forest, oak-pine forest and oak-mixed forest. A total of 21 tree, 11 shrubs and 28 herb species were recorded. The species diversity of these forests was quite low as compared to any other montane forest owing to anthropogenic disturbances.

Pilania *et al.* (2014) studied the species diversity and phytosociology of some important plants of tropical dry deciduous forest of Dahod district of Gujarat, India. A total of 65 species of 57 genera belonging to 31 families were documented. Taxonomically dominant family was Mimosaceae. Importance Value Index of species was calculated and interrelated. The results of abundance to frequency ratio showed that most of them were having contagious distribution. Concentration of dominance varied from 0.08 to 0.52, Shannons index (0.81 to 2.85), Species evenness (0.7 to 0.93) and Species richness (2.8 to 30.84).

Sharma and Kant (2014) conducted study on sub tropical forests of Jammu district of Jammu and Kashmir with objective of determining floristic composition, species diversity and structure of woody vegetation in drier Kandi Shivaliks. A total of 112 species comprising 65 trees and 47 shrubs belonging to 92 genera and 48 families were recorded. The vegetation analysis revealed the dominance of *Mallotus philippensis*, *Acacia modesta* and *Pinus roxburghii* in Northern Dry Mixed Deciduous forests ($5B/C_2$), Himalayan Subtropical Scrub ($9/C_1/DS_1$) and Himalayan Sub tropical Pine Forest ($9/C_{1a}$) respectively.

Sharma and Kant (2014) carried out a study to characterize the species composition, vegetation structure and floristic diversity by land use categories, in Arnigad micro-watershed in Mussoorie hills of Garhwal Himalayan region. In all, 64 species belonging to 63 genera and 56 families were found to be growing in the micro-watershed. The vegetation analysis revealed that *Quercus leucotrichophora, Acacia catechu, Eucalyptus* spp. and *Juglans regia* were found to be dominant in forest, scrub forest, degraded and agriculture lands respectively for the tree stratum. Similarly, *Berberis aristata* and *Lantana camara* were observed to be dominant in the shrub communities of forest and scrub forests respectively. *Lantana camara* was also found to be dominant in the shrub communities of degraded land. Results of the diversity index, concentration of dominance and equability indicated that maximum diversity was observed in forest with respect to tree stratum followed by scrub forest and degraded lands, whereas in case of shrub and herb strata, scrub forest showed the maximum diversity. The maximum values on dominance were recorded for all the three strata of vegetation on degraded land indicating the presence of single or few species. The vegetation recorded on scrub forest was found to be more equitable compared to vegetation on forest and degraded land.

Aime *et al*. (2015) conducted a study in three tropical rain forests which were distinguished by their type of management in Azaguie area: Yapo protected forest, a Natural

Voluntary Reserve and community forests. The main objective was to assess the aboveground biomass (AGB) and diversity of tree species in these forests. The data consisted of d.b.h measurement of all tree individuals with d.b.h ≥ 10 cm in plots of 500 m^2. Species richness, Shannon diversity index, Pielou evenness, stem density, basal area, and AGB were calculated for each forest type and compared using one-way ANOVA. A total of 2375 stems and 164 tree species with diameter ≥10 cm was recorded in these forests. The Shannon diversity index was significantly higher in Yapo protected forest (5.78) and natural voluntary reserve (5.06) than in community forests (4.64). Evenness did not differ between Yapo protected forest (0.81) and community forests (0.83) but it was differed significantly in natural voluntary reserve (0.71). The mean AGB values were significantly higher in Yapo protected forest (347.17 ± 101.70 t ha^{-1}) and natural voluntary reserve (245.09 ± 31.68 t ha^{-1}) than in community forests (35.69 ± 17.12 t ha^{-1}). For the three forests, structure described by diameter distribution was inverse J-shaped. The study showed that trees species in community forests were most equitable than protected area which have higher stems density and AGB.

Lal *et al*. (2015) studied the regeneration status, species composition in natural and plantation forests of sub-humid tropics in Barnawapara Wildlife Sanctuary during 2009-2010. A total of 33 species of 17 families were observed. Closed natural forest (960 stems ha^{-1} of seedlings and 220 stems ha^{-1} of saplings) displayed the better regeneration followed by open natural forest (350 stems ha^{-1} of seedlings and 90 stems ha^{-1} of saplings) and teak plantations (340 stems ha^{-1} of seedlings and 40 stems ha^{-1} of saplings) respectively. However, under teak plantation *Lagerstroemia parviflora* had shown better regeneration. Tree stand density varied from 520 to 990 stems ha^{-1} having basal area ranging from 21.50 to 47.30 m ha. It was evident that natural forest had an edge over plantation forest in terms of regeneration, species composition.

Diversity and composition of tree species of secondary Dipterocarp hill forests in Chunati Wildlife Sanctuary of Chittagong, Bangladesh was studied by Mamun *et al*. (2015). A total of 993 individual trees of 99 species belonging to 73 genera and 36 families were recorded from the forests of Chunati. The forest has diverse floristic resources as indicated from the Shannon Wiener's diversity index (3.353), Margalef's richness index (14.201) and Simpson's dominance index (0.090). Total basal area of tree species was 12.47 m^2ha^{-1}, whereas *Dipterocarpus turbinatus* showed highest basal area (2.62 m^2ha^{-1}) followed by *Acacia auriculiformis* (1.39 m^2ha^{-1}). Importance Value Index (IVI) was found maximum

(40.11) for *Acacia auriculiformis* followed by *Tectona grandis* (16.46) plantation species. On the other hand, Importance Value Index was highest for *Dipterocarpus turbinates* (25.10) followed by *Ficus hispida* (19.76) for natural species.

Neelo *et al.* (2015) studied stand structure, diversity and regeneration status woody species under open and enclosed woodland sites in Botswana. A total of 47 species, representing 16 families and 24 genera, were recorded in study sites. The most diverse genus was *Acacia*. A majority of species exhibited hampered regeneration and thus, unhealthy regeneration mainly due to human disturbance, heavy overgrazing, *etc.*

Biswas and Mukhopadhyay (2016) conducted phytosociological studies at Katoria Forest Range comprising of three beats namely Chandan, Katoria and Suiya of Banka Forest Division exposed to anthropogenic activities. A total 60285 individuals were recorded during vegetation enumeration for 2333.4 ha of forested area. Total basal area for the entire tree species recorded was 595472.469 cm^2 ha^{-1}. Important Value Index is highest for *Shorea robusta* at Chandan and Katoria beat while it is highest for *Tectona grandis* at Suiya beat. Species diversity Index ranges between 0.001 – 0.370. Dominance index and evenness ranges between 0.166-0.264 and 0.296-0.332 respectively. These values indicated presence of severe anthropogenic disturbances. Maximum number of tree individual fall under diameter at breast height (d.b.h) class of 0-10 cm. Total carbon stock of top most 10 tree species is found to be 0.064 kg ha^{-1} with total volume of 0.103 m^3 ha^{-1}. Lowered tree volume had been recorded due to lowered tree height and dbh. Further, the study inferred that tree height and d.b.h are significant indicators for net crop volume contributing to greater C stock amount.

Malik and Bhatt (2016) investigated the regeneration status of tree species and survival of naturally emerged seedlings along an altitudinal gradient in a protected area of Western Himalaya, India. A total of 44 tree species of 36 genera and 25 families were recorded from the study area. Regeneration status of species was determined based on population size of seedlings and saplings while seedling survival was determined by silver foil tagging method. Seedling density and Shannon-Wiener diversity index (H) ranged from 1670 to 7485 individual ha^{-1} and 1.91 to 3.32, respectively, while sapling density and Shannon-Wiener diversity index (H) varied from 1850 to 5600 ind ha^{-1} and 1.23 to 2.57 respectively. Although the majority (27-56 %) of species showed good regeneration, a good percentage (19-45 %) of tree species showed poor regeneration while fair regeneration was shown by 7-30 percent of species and new regeneration by 0-14 percent. Diameter density distribution showed that lower diameter classes had the highest frequency with a gradual decrease in the number of individuals in the higher classes resulting in the formation of an inverse-J curve that was considered to be an indication of good regeneration status. Survival of seedlings in different forests varied from 0- 8 percent (mortality varied from 12-100 %).

Akash *et al*. (2018) assessed the structure, composition, vegetation pattern and diversity as well as the conservation strategies in Rajaji Tiger Reserve, Haridwar-Pauri Forest Divison (29°15’ to 30°31’ N, 77°52’ to 78°22’ E, altitude 250–1100 m) in a tropical forest. The site represents the different combination of dominant and co-dominant species. In trees, shrubs and herbs, most of the species showed contiguous pattern of distribution while only a few reported random and regular distribution. The Shannon index for tree was 2.51, 1.07 for shrubs and 2.99 for herbs, whereas, the Simpson index was 0.097 for trees, 0.46 for shrubs and 0.06 for herbs. The Margalef Richness index was 0.69 for trees, 1.94 for shrubs and 4.82 for herbs. The Evenness Index was 0.68 for trees, 0.43 for shrubs and 0.88 for herbs in the study area.

Bhadouria *et al*. (2018) examined the effects of light and nutrient with and without grass on the growth of seedlings of four common dry tropical plant species, viz., *Acacia catechu, Acacia nilotica ssp. indica, Ziziphus mauritiana and Terminalia arjuna*. The growth parameters including height, girth, total dry weight, leaf area and number of leaves, relative growth rate in terms of height, diameter and dry weight were recorded for each species under different treatment combinations. All the species behaved differently under studied treatment combinations. Seedlings were more responsive to the nutrient addition in presence of light. Presence of grass had overall negative effect on growth of tree seedlings. Survival was found highest for *A. nilotica sp. indica* and lowest for *Z. mauritiana* while reverse trend was observed for overall growth. The results inferred that supplementation of nutrients had strong positive effect over the seedling survival and growth even under reduced light and presence of grass competition. Moreover, the findings also revealed that the regular weeding and nutrient supplementation under the existing forest vegetation might help in regeneration of the dry tropical vegetation by reducing seedling mortality even under dense canopy conditions.

Shahid and Joshi (2018) studied two different forest types, Dry Shiwalik Sal Forest and Moist Shiwalik Sal Forest in Barkot and Lachchiwala of Doon Valley, Western Himalaya. Volume equations, destructive sampling and laboratory analysis were done to estimate the carbon stock in different carbon pools like trees, shrubs, herbs and soils. Considerable variations were observed in terms of carbon stocks in different forest types. In Dry Shiwalik Sal Forest, carbon stock density varied between 129.81 and 136.00 Mg C ha^{-1} while in Moist Shiwalik Sal Forest, carbon stock density ranged from 222.29 to 271.67 Mg C ha^{-1}. Tree species like *Shorea robusta*, *Syzygium cumini*, *Miliusa velutina*, *Acacia catechu*, and *Mallotus philippensis* had significant role in carbon sequestration. *Shorea robusta* had contributed highest in carbon stock due to highest density. Total of 2,338,280.165 Mg carbon stock had been calculated in all the forest types.

Chen *et al*. (2019) mapped structure and function parameters for forest condition assessment in the Changbai Mountain National Nature Reserve (CMNNR). The mapping algorithms, including statistical regression, random forests, and random forest kriging, were employed with predictors from Advanced Land Observing Satellite (ALOS)-2, Sentinel-1, Sentinel-2 satellite sensors, digital surface model of ALOS, and 1803 field sampled forest plots. Combined predicted parameters and weights from principal component analysis, forest conditions were assessed. The models explained spatial dynamics and characteristics of forest parameters based on an independent validation with all r values above 0.75. The root mean square error (RMSE) values of canopy closure, stand density, stand volume, forest age and soil fertility were 4.6, 33.8, 29.4, 20.5, and 14.3 percent, respectively. The mean assessment score suggested that forest conditions in the CMNNR were mainly resulted from spatial variations of function parameters such as stand volume and soil fertility. The study provided a methodology on forest condition assessment at regional scales, as well as the up-to-date information for the forest ecosystem in the CMNNR.

Meena *et al*. (2019) estimated 90.51 Mg ha^{-1} biomass and 63.49 Mg C ha^{-1} carbon in the semi-arid forest of Delhi, India. The lower diameter classes showed highest tree density in the range 240 and 328 individuals ha^{-1} (11–20 cm), basal area, i.e., 8.7 (31–40 cm) and 6.08 m^2 ha^{-1} (11–20 cm), and biomass, i.e., 24.25 and 23.57 Mg ha^{-1} (11–20 cm) in NRF and CRF, respectively. Furthermore, a significant contribution of biomass (7.8 Mg ha^{-1}) in DBH class 81–90 cm in NRF suggested the importance of mature trees in biomass and carbon storage. The forests were predominantly occupied by *Prosopis juliflora* (Sw.) DC which also showed the highest contribution to the (approximately 40%) tree biomass. Carbon allocation was maximum in aboveground (40–49%), followed by soil (29.93–37.7%), belowground or root (20–22%), and litter (0.27–0.59%).

Pradhan *et al*. (2019) studied the tree species diversity, biomass and biomass carbon stock of two different forests in Western Odisha: a wildlife sanctuary and a sacred forest, from September 2015 to January 2016. The wildlife sanctuary is entirely managed by the Forest Department, whereas the sacred forest is jointly managed by the local community and the Forest Department. Our results showed that the sacred forest had a greater species richness, density and diversity compared to the wildlife sanctuary. The density in different diameter classes showed that the sacred forest is regenerating with a good regeneration potential, but the wildlife sanctuary had a poor regeneration potential with lower numbers of saplings than adults. However, the biomass and carbon content of the wildlife sanctuary were higher than in the sacred forest which may be due to the presence of a higher proportion of old trees in the wildlife sanctuary compared to the sacred forest. Biomass values can be used to emphasize the role of management in maintaining the carbon stock in forest ecosystems and helpful in framing conservation strategies and action plans for forest patches in India and globally.

Luna-Kamyshev *et al*. (2020) carried out floristic study of the woody plant species diversity and composition at the Billy Barquedier National Park (BBNP) to develop an ecosystemic baseline for the assessment of the originally implemented conservation strategies. A thorough floristic survey was performed from May to August 2015 in 42 rectangular plots (500 m^2) randomly allocated along the 100 to 500 m elevation gradient of the BBNP. Species richness, diversity, composition, and aboveground biomass had been assessed. *Terminalia amazona* and Corozo palm (*Attalea cohune*) were the most important species in the reserve, in terms of abundance, frequency, and biomass. A clear trend between biodiversity metrics, elevation, and aboveground biomass was also noted. The study contributed to understand relevant ecological topics as well as provides key elements for the management and conservation of the BBNP area and Belize.

According to Aichi Biodiversity Target 11, most Forest-protected area (FPAs) were distinguished from reserved forest (RF) areas in Bangladesh to ensure better protection and conservation of biodiversity. Compared with traditionally managed RF areas, FPAs involve the engagement of different stakeholders in forest management and the status of biodiversity was compared between RF areas and FPAs. In this regard, Chunati Forest Range (CFR) (based on the conventional top–down bureaucratic approach) and Chunati Wildlife Range (CWR) (based on co-management for the last decade but previously managed under conventional top-down approach inside Chunati Forest Range) were selected. Biodiversity was compared through community structure analysis of vascular plants and birds. The effect of micro environmental variables was also evaluated to assess habitat influence. Finally, conservation implications were hypothesized in terms of the current state of deforestation by analyzing land-use change. Biodiversity analysis revealed that CWR was more diverse than CFR. Tri-plot scores were strongly correlated with elevation, canopy height, and canopy coverage for CWR, whereas disturbance scores had a stronger relationship with CFR. On the other hand, CFR is experiencing deforestation at the rate of 0.9 percent per year. Therefore, co-management of conservation implications can be adopted for the remaining part of traditionally managed forest areas for better conservation of biodiversity (Masum *et al*., 2020).

Singh *et al*. (2021) undertook a study to examine the phytosociology and regeneration status of tree species in 39 permanent preservation plots spread across 22 different forest sub-types in Madhya Pradesh, India. A total of 975 quadrates were laid with a sampling intensity of 2.42 percent and 109 tree species were recorded. Density range varied from 516 individuals per hectare (ind ha^{-1}) in southern tropical dry deciduous forests to 3,412 ind ha^{-1} in dry grassland forests. Most of the forest sub-types showed log normal distribution owing to relatively high species richness, diversity and evenness, but a low dominance. Out of 62,228 live stems recorded, 68.52 percent were poles followed by saplings (26.39 %), young trees (5.01 %) and mature trees (0.08 %). The result also showed high seedling density in each forest sub-type ranging from 1,040 ind ha^{-1} to 51,124 ind ha^{-1}, indicating a healthy population of mature reproducing adults. The diameter distribution in all the forest sub-types showed negative slope and followed the classic inverse J-shaped curve frequently observed in natural forests.

2.2 BIOMASS AND CARBON STOCK

Toky and Bisht (1993) studied the above-ground and below-ground biomass in 6 year old trees of nine species, *Acacia catechu, A. nilotica* subsp. *indica, Albizia lebbeck, Azadirachta indica, Dalbergia sissoo, Melia azedarach, Morus alba, Prosopis cineraria* and *Ziziphus mauritiana* from arid north-western India. They revealed that the above-ground biomass (kg/tree) varied from 11·6 in *Z. mauritiana* to 37·5 in *Melia azedarach.* Maximum biomass (39-65%) was allocated to the boles and a lesser amount to the branches (22-40%) and roots (9-29%). Root biomass (kg/tree) ranged from 2·2 in *A.*

catechu to 8·7 in *Albizia lebbeck.* Net primary production was from 0·98 to 9·33 kg/tree/year across the species.

Giril *et al*. (2001) investigated the vegetation composition and biomass production in riverine forest of the Royal Bardia National Park (Nepal) having 35 percent land as riverine forest. Vegetation composition and biomass production in Evergreen Riverine Forest (ERF), and Deciduous Riverine Forest (DFW) of the RBNP were studied by lying quadrats of 25 m x 25 m. The ERF was mainly dominated by *Syzygium cumini*, *MalIotus philippensis*, *Ficus racemosa*, *Bombax ceiba* and *Adina cordifolia*, whereas, DRF was dominated by *A. catechu* and *Dalbergia sissoo*. *Syzygium cumini* possessed higher density and basal area in ERE; whereas *Acacia catechu* had higher density and basal area in DRF. Density diameter distribution curves of stems showed that most of the stems were between 10-25 cm in diameter. The aboveground biomass was 459.74 t h^{-1} in ERF and 150.65 t h^{-1} in DRF.

Oo *et al.* (2006) assessed the biomass of the planted forests of 2 main species (*Eucalyptus camaldulensis* and *Acacia catechu*) and biotic climax of shrub and grass communities in the central dry zone of Myanmar to provide a potential level of carbon sequestration by planted forests under the drier climatic conditions (mean annual rainfall of 637 mm). The biomass including roots of the 9 planted *Eucalyptus camaldulensis* forests of 6 to 11-year-old (at the 4 × 4 m planting spacing) ranged from 3.80 to 27.68 Mg ha^{-1}, averaging 14.83 Mg ha^{-1} whereas the mean annual increment (MAI) was estimated as 1.68 Mg ha^{-1} y^{-1}. The biomass of the planted *Acacia catechu* forest of 7-year-old (at the 4 × 8 m planting spacing) was estimated as 10.62 Mg ha^{-1} and its MAI was 1.52 Mg ha^{-1} yr^{-1}. The results show that the productivity of the planted forests is much lower than that of other places with more favorable conditions. The sum of biomass and litter weight of biotic climax of shrub and grass communities ranged from 2.36 to 23.14 Mg ha^{-1}, averaging 11.00 Mg ha^{-1}.

Rawat *et al.* (2008) conducted a study to estimate the biomass and nutrient distribution in *Acacia catechu* Willd. plantations of Punjab at six sites of different ages (20, 22, 23, 24, 28, 32 years). They revealed that the biomass ranged from 39.4 kg/tree to 738.98 kg/tree and from 77.29 to 223.46 t ha^{-1} in all sites where as the productivity ranged from 2.57 t ha^{-1} yr^{-1} (at 32 yrs) to 9.31 t ha^{-1} yr^{-1} (at 24 yrs). The contribution of individual tree components to total biomass varied as: leaf 1.41 to 4.29%; twig 2.92 to 6.31%, branch 10.95 to 19.98%, bark 6.65 to 10.69%, root 15.29 to 20.61% and bole 42.86 to 56.33%. The amount of various nutrients varies from N- 482.19 to 1041.04 kg ha^{-1}, P- 30.32 to 92.72 kg ha^{-1}, K-

194.81 to 767.05 kg ha^{-1}, Ca - 523.3 to 1425.59 kg ha^{-1} and Mg - 27.27 to 80.13 kg ha^{-1}, respectively. The percentage contribution of different nutrients to total nutrients are as; N (29.78 to 35.61%), P (1.61 to 2.76%), K (11.36 to 22.79%), Ca (38.64 to 54.86%) and Mg (2.01 to 2.61%), respectively.

Tangki and Chappell (2008) studied biomass variation across selectively logged forest within a 225 km^2 region of Borneo. The study used fifty 0.1 ha plots to quantify mean tree biomass of eight logging coupes (each 450–2500 ha) and two similarly sized areas in un-logged forest. The data was then correlated with the spectral radiance of individual Landsat-5 TM bands over the 15 km study area. Explanation of the differences in radiance between the ten forest sites was supported by measurements of the relative reflectance of selected leaves and canopies from ground and helicopter platforms. The results inferred a marked variation in the stand biomass from 172 t ha^{-1} in coupe C88 that was disturbed by high-lead logging to 506 t ha^{-1} in a similarly sized area of protection forest. A two-parameter linear model of Landsat TM radiance in the near-infrared (NIR) band was able to explain 76 percent of the variation in the biomass at this coupe-scale. The local-scale measurements indicated that the differences in the mean radiance of each coupe (in cloud-free areas) might relate to a change in the proportion of climax tree canopy relative to a cover of either pioneer trees or ginger/shrubs; the canopies of climax trees have the lowest NIR radiance of the vegetation characteristic of selectively logged forest.

Singh *et al.* (2011) studied the Biomass and carbon sequestration rate of a young mixed plantation of *Dalbergia sissoo Roxb*., *Acacia catechu Willd*., and *Albizia lebbeck Benth*. growing in Terai region of central Himalaya. The allometric equations for both above and below ground components were developed for all three tree species. The density of trees in the plantation was 1322 trees ha^{-1}. The diameters of trees were below 10 cm, five diameter classes were defined for *D. sissoo* and *A. catechu* and 3 for *A. lebbeck* from where 5 trees were harvested in each diameter class. Individual tree allometry was exercised for developing the allometric equations relating tree component (low and above ground) biomass to d.b.h. Post analysis equations were highly significant ($P > 0.001$) for each component of all species. In the plantation, *Holoptelia integrifolia Roxb*. (Family Ulmaceae) has been reduced to shrub form because of frost. Only the aboveground biomass of *H. integrifolia* and other shrubs were estimated by destructive harvesting method. Herbaceous forest floor biomass and leaf litter fall were also estimated. The total forest vegetation biomass was 10.86 Mg ha^{-1} in 2008 which increased to 19.49 Mg ha^{-1} in 2009. The forest is sequestering carbon at the rate of 4.32 Mg ha^{-1} yr^{-1}.

Devi *et al.* (2013) conducted a study to estimate biomass production and carbon sequestration potential of different plantation ecosystems in north western Himalaya, India. Biomass, carbon density of biomass, soil, detritus, carbon sequestration and CO_2 mitigation potential were studied under different plantation forest ecosystems comprising of eight different tree species viz. *Quercus leucotrichophora, Pinus sroxburghii, Acacia catechu, Acacia mollissima, Albizia procera, Alnus nitida, Eucalyptus tereticornis* and *Ulmus villosa*. The study revealed that above (185.57 ± 48.99 t ha^{-1}) and below ground (42.47±10.38 t ha^{-1}) biomass was maximum in *Ulmus villosa*. The vegetation carbon density was maximum in *Albizia procera* (118.37 ± 1.49 t ha^{-1}) and minimum (36.50 ± 9.87 t ha^{-1}) in *Acacia catechu*. Soil carbon density was maximum (219.86 ± 10.34 tha^{-1}) in *Alnus nitida*, and minimum (170.83 ± 20.60 t ha^{-1}) in *Pinus roxburghii*. Detritus was found to be higher in *Pinus roxburghii* (6.79 ± 2.0 tha^{-1}). Carbon sequestration (7.91 ± 3.4 t ha^{-1}) and CO_2 mitigation potential (29.09 ± 12.78 t ha^{-1}) was maximum in *Ulmus villosa*.

Sundarapandian *et al.* **(**2013) assessed aboveground biomass, belowground biomass and carbon stocks of trees and soil in four sites of tropical dry forests in India. The carbon in woody plants of study sites ranged 33.9 Mg C ha^{-1} - 58.99 Mg C ha^{-1}. The soil organic carbon stocks upto 30 cm soil depth in these forests ranged 33.36 Mg C ha^{-1} - 48.82 Mg C ha^{-1}. A significant positive correlation was found between basal area and total woody biomass as well as between woody biomass and total carbon. They found that higher carbon stock occurred on the site having larger tree size and higher clay content in soil. Further, among different tree species they reported that *Acacia leucophloea* has the greatest total woody biomass and maximum carbon stock potential (13.98 Mg C ha^{-1}).

Arora *et al.* (2014) reported that the growth rate of diameter at breast height and height of *Populus deltoides* was higher in trees of 4 to 7 years and 2 to 5 years, respectively. The total aboveground biomass (AGB) increased with age and reached its maximum (180.2 Mg ha^{-1}) at 11 years of age. Mean carbon concentration in aboveground components varied from 39.7% to 51.7%. Aboveground carbon stocks in *P. deltoides* increased from 0.5 Mg ha^{-1} at 1 year to 90.1 Mg ha^{-1} at 11 years. The amount of total carbon stock (AGB and soil) increased from 64.4 Mg ha^{-1} at 1 year to 173.9 Mg ha^{-1} at 11 years.

Kandel *et al*. (2014) estimated above ground biomass (AGB) and carbon stock by integrating 5 percent airborne light detection and ranging (LiDAR) sampling, wall-to-wall Rapid Eye satellite image and a representative field inventory in 23500 km^2 Terai arc landscape (TAL) area of Nepal. The average 1.26 m^{-2} LiDAR point density recorded by the scanner was used to measure canopy height and build a model using LiDAR variables and model coefficients. The developed LAMP model successfully estimated the AGB of the study area. The findings revealed that the study area comprises almost 50 percent forest cover with an average 211.63 t ha^{-1} AGB. Standing carbon stock was converted from AGB by multiplying the 0.47 which is default carbon fraction. Average standing carbon stock was 99.47 t ha^{-1}. The LAMP method found that the standing total AGB was 214.85-208.41 t ha^{-1} at a 95 percent confidence level and the field-based Forest Resource Assessment (FRA) Nepal field-plot AGB estimate is 210.09 ha^{-1}.

Rao and Rao (2015) estimated the standing biomass and carbon sequestration potential of tropical deciduous forests of Nallamalais, a centre of plant diversity located in the state of Andhra Pradesh, India. A total of 30 randomly stratified sample sites comprising 12 ha area were inventoried following a non-destructive method. The total standing biomass and carbon stocks of the study area had been estimated as 56.047 Mt and 26.34 Mt respectively. Among all life forms, trees were found to be main contributors of standing biomass and carbon stocks accounting for 96.72 percent of the above-ground live biomass. The carbon stock accounted for Nallamalais was equivalent to 97.568 Mt of sequestered atmospheric carbon dioxide.

Mandal *et al*. (2016) assessed species-wise carbon sequestration in Tropical and Subtropical plant species in collaborative and community forests of Nepal in two periods. Three collaborative and three community forests had been selected for the study. The selected forests were surveyed using GPS and mapped and stratified into tree, pole, and regeneration. Specifically, 32, 33, and 31 samples were collected from Banke-Maraha, Tuteshwarnath, and Gadhanta-Bardibash collaborative forests, respectively, while 30, 25, and 22 samples were collected from Chureparwati, Buddha, and Chyandanda community forests correspondingly. The sample plots were of 25 m × 20 m for tree strata. The diameter and height of plants were measured and samples were collected for three consecutive years. The estimated carbon stock of *Shorea robusta* was the highest 35.93 t ha^{-1} in 2011 which was slightly decreased to 34.43 t ha^{-1} in 2012 and reached 32.02 t ha^{-1} in 2013 in Banke-Maraha collaborative forest but it was found least 7.97, 8.92, and 10.29 t ha^{-1} in 2011, 2012, and 2013, respectively, in

Chyandanda community forest. The highest carbon sequestration was recorded about 5.02 t ha^{-1} of *Shorea robusta* in Chyandanda community forest in between 2013 and 2012.

Gogoi *et al*. (2017) assessed the biomass and carbon allocation pattern in the different compartments of the rainforest. They stratified the study area into least disturbed (LD), mildly disturbed (MD) and highly disturbed (HD) sites based on visual assumption, and later disturbance index of the sites had been calculated. Vegetation analysis for various ecological indices was carried out. Biomass and carbon stock in different pools were estimated adopting suitable regression equations developed earlier for similar ecological regions. The total plant biomass showed a gradual decrease from LD to HD site and was 425.70 ± 29.71 Mg ha^{-1} in the LD site, followed by 236.08 ± 5.82 Mg ha^{-1} in the MD site and 127.38 ± 4.74 Mg ha^{-1} in the HD site. Amongst the different pools, aboveground biomass constituted the largest compartment in all the three sites for C stock and biomass. Tree density and basal area were highest in the LD sites. Soil organic Carbon (SOC) stock in 0 - 45 cm depth was also recorded maximum in the LD (72.48 ± 5.11 Mg C ha^{-1}) followed by MD (40.13 ± 2.50 Mg C ha^{-1}) and HD (32.38 ± 1.66 Mg C ha^{-1}) sites. Total carbon stock was also found highest (306.61 ± 17.14 Mg C ha^{-1}) in the LD site followed by 169.97 ± 2.59 Mg C ha^{-1} in the MD and 102.43 ± 3.18 Mg C ha^{-1} in HD site. Forest disturbance thus showed a significant inverse relation with carbon storage in all the pools. Therefore, the study concluded that carbon sequestration in forest ecosystems was influenced by the anthropogenic disturbances.

Rai and Gupta (2018) conducted a study to estimate biomass and carbon stock in differently managed *Quercus leucotrichophora* forests along the elevation gradient revealed that the biomass and carbon stock parameters of the tree layer showed the precedence of Reserved Forest > Protected Forest > Unclassified Forest > Musterqua Forest. Aboveground biomass and its associated carbon stock of shrubs decreased significantly in the order of Reserved Forest > Musterqua Forest > Protected Forest > Unclassified Forest. Whereas, it's belowground, total biomass and carbon stock decrease as: Reserved Forest > Protected Forest > Musterqua Forest > Unclassified Forest. Aboveground biomass and carbon stock of herbage was recorded as: Reserved Forest > Protected Forest > Unclassified Forest > Musterqua forest. While, belowground biomass, total biomass and its related carbon stock decreased significantly in the order of Reserved Forest > Protected Forest > Musterqua Forest > Unclassified Forest. Along elevation gradient, tree layer had shown significant variation in biomass and carbon stock parameters where it decreased with an increase in elevation but a ziz-zag pattern and non-significance level was recorded for shrubs and herbs layer respectively. Thus, management strategies and elevation had greatly influenced the biomass and carbon stock in a forest ecosystem at different layers.

Raha *et al*. (2020) selected three tropical dry deciduous forest types namely dry deciduous teak forest (DDTF), dry deciduous mixed forest (DDMF) and Boswellia forest (BF) in Madhya Pradesh, Central India, to assess the biomass and C stocks. The total tree biomass (above ground and below ground) ranged from 70.4 (DDTF) to 296.6 (BF) Mg ha^{-1} with a mean of 184.1 Mg ha^{-1}, whereas the tree C ranged from 35.3 (DDTF) to 140.9 (BF) Mg C ha^{-1} with a mean value of 87.4 Mg C ha^{-1}. The greatest biomass (220.4 Mg ha^{-1}) and C stocks (104.7 Mg C ha^{-1}) have been observed in BF type, whereas the least biomass (160.9 Mg ha^{-1}) and C (76.4 Mg C ha^{-1}) have been observed in DDTF type, with the mean biomass and C stock values of 184.1 Mg ha^{-1} and 87.4Mg C ha^{-1}, respectively. In both DDTF and DDMF types, *Tectona grandis* contributed 76.5 and 26.4 percent of C, whereas in BF type, *Boswellia serrata* contributed 73.6 percent of C to the total C stock. A significant positive ($R^2 = 0.951$; $p<0.01$) relationship had been observed between basal area and tree C stock.

2.3 SITE CHARACTERISTIC AND LANTANA INFESTATION

Raghubanshii (1991) conducted a study in three dry tropical forest soils along a topographic sequence to determine the seasonal dynamics of microbial C, N, and P. The lowest microbial biomass was found in forest soils at the foot of the hill followed by mid slope forest soils. The hilltop soil, which had the finest particles, water-holding capacity, organic C, and total N, reflected the presence of greater amounts of microbial C, N, and P. Mean annual microbial C, N, and P ranges were 466-662, 48-72 to 21 - 30 gg g^{-1}, respectively. The seasonal pattern of microbial biomass, C, N, and P was similar at all sites, the values being greatest during the dry season and lowest during the wet season. The seasonal values for microbial biomass C, N, and P were positively correlated with each other and a negative correlation was found between microbial biomass and the fine root mass in these forest soils.

Soil characteristics of vegetated coal mine spoil land under plantations of five exotic tree species were assessed by Dutta and Agrawal (2002). They observed organic carbon and total nitrogen concentrations were higher in the plantation stands in comparison to the bare overburden dumps. Available nitrogen (NO_3 – N and NH_4 – N) was highest in the plots of Eucalyptus hybrid in all the three seasons. Bulk density was highest in the plots of *Casuarina equisetifolia* and lowest in *Gravellia pteridifolia* plots. Soil moisture content was also higher under different plantations. Water holding capacity and soil moisture content were highest in the *Eucalyptus hybrid* plots. The plantations enhanced the nutrient status of the degraded mine spoil land.

The impact of *Lantana camara* invasion on native vegetation in Northern Gonarezhou National Park (GNP), Zimbabwe had been assessed using stratified random sampling with three categories; uninvaded, moderately invaded and heavily invaded. The distribution of *L. camara* in Northern GNP was mapped using GIS. Soil properties and vegetation attributes were assessed in each category. A total of 41 native woody species and 27 native herbaceous species had been identified and significant differences (ANOVA, $P<0.05$) in soil nitrogen, phosphorus, potassium and moisture among the three categories were observed. Soil nitrogen and phosphorus levels were highest in the heavily invaded category and lowest in the uninvaded category while soil potassium and moisture levels were highest in the uninvaded category and lowest in the heavily invaded. For native vegetation attributes; basal area, canopy cover, herbaceous cover, woody plant density, species diversity (H') and species richness (S) varied significantly (ANOVA, $P<0.05$) among the categories of *L. camara* intensity. These variables were highest in the uninvaded category and lowest in the heavily invaded category. The uninvaded category was the most diverse (H'=1.875) while the heavily invaded category was the least diverse (H'=1.334). The significant differences in soil and vegetation variables suggested that *L. camara* had altered soil properties and native vegetation structure and composition in GNP to the detriment of wildlife management (Chatanga, 2007).

Mehta *et al*. (2008) investigated the effects of human forest use on ecosystem functions in Bandipur National Park (BNP) in Peninsular India and reported the impacts on surface soils. The soils were sampled from 200 locations covering four watersheds within the park. These samples spanned a degradation gradient measured by a field disturbance index (FDI). Soil physical, nutrient and hydraulic properties were measured. Cation exchange capacity (CEC) and saturated hydraulic conductivity (Ks) were analyzed as key response variables describing nutrient availability and infiltration respectively. Soil nutrient availability was negatively impacted by disturbance, resulting from negative impacts on soil organic carbon (SOC) and clay content. Available water capacity (AWC) and saturated moisture content (SMC) were significantly higher in protected watersheds, attributed to reduced clay content in degraded watersheds. These results provided ground-based and remotely sensed evidence that forest disturbance within the park had negative impacts on soil organic matter, nutrient availability and hydraulic characteristics.

Oladoye *et al.* (2008) studied the nutrient dynamics and litter decomposition in *Leucaena leucocephala* (Lam.) plantation in the Nigerian Derived Savanna. They observed that the nutrient concentration in *Leucaena leucocephala* followed the trend N > P > Mg > Ca > K > Na for leaf litter and seed components. Nutrient concentration in twigs and pods ranked N > Mg > P > Ca > K > Na. Among all the litter components, leaf litter contributed more nutrients, especially nitrogen, than other litter components. High potassium concentration during the dry season was due to lack of rainfall to leach out the element. Lower magnesium content in leaf litter was due to chlorophyll decay. High N-flux reflected the quantity and quality of nitrogen in the soil. The litter decomposition rate was at 0.6% per day. High rate of decomposition at the early stage was due to less moisture content in the soil and high temperature. Litter decomposed more during the wet season than the dry season.

Dobhal *et al*. (2010) determined the impact of *L. camara* invasion on basal area cover, density, frequency and abundance of various plant species. It was found that the invasion changed the composition, distribution, growth in number and size of different species and also found to have some relation with native-exotic nature and different plant habits (like tree and herbs) of local flora. The determination of various ecological indices showed significant loss of species richness and diversity in invaded localities. In total, there was a 28.4 percent decrease in species richness of invaded localities. Excluding *L. camara*, nearly 63 percent loss of basal area of vegetation was recorded in the invaded localities compared to not invaded ones.

The chemical and microbiological properties of the soil beneath the exotic species Lantana (*Lantana camara* Linn.) and its effect on the growth of three plant species were investigated to evaluate whether Lantana is a harmful invader in southern China. Soils were sampled from underneath (IN) Lantana canopy, on the edge of the canopy (ON) and 2–5 m away (OUT) from the Lantana individuals. Soil chemical properties, respiration, enzyme activities, microbial biomass and functional diversities based on the community level physiological profiles (CLPP) assay with BIOLOG EcoPlates™ were determined. Biomass accumulation of Italian ryegrass (*Lolium multiflorum*), mungbean (*Vigna radiata*) and radish (*Raphanus sativus*) grown in the soils was compared. The IN soils had significantly higher pH, total N, total P, available N and available P than the ON and OUT soils. Soil respiration, enzyme activities and microbial biomass N and P were also significantly higher in the IN soils. Biomass accumulation of Italian ryegrass and radish was significantly increased in the IN soils compared to the ON and OUT soils while mungbean was not significantly affected. The results indicated that Lantana improved soil fertility, accelerated N and P cycles, utilized carbon substrates more effectively, had higher functional diversity and did not inhibit the growth of the studied species (Fan *et al*., 2010).

Sheikh and Kumar (2010) analysed the soils of two forest types i.e., oak (*Quercus leucotrichophora* A. Camus) and pine (*Pinus roxburghii* Sargent) for physico-chemical properties. They concluded that the higher percent of moisture and water holding capacity was in oak forest and lower in pine forest. The forest types indicate that the soil of oak forest was acidic and slightly acidic to pine forest. The average SOC in oak forest was 2.19% followed by 1.63% in pine. The nitrogen for oak and pine forests was 0.15 and 0.19%, respectively. The available phosphorus in oak forest was higher (17.99 kg ha^{-1}) than in pine forest (16.88 kg ha^{-1}). The exchangeable potassium was 188.92 kg ha^{-1} in oak forest and 166.43 kg ha^{-1} in pine forest. The maximum contribution among the nutrients was of potassium followed by phosphorus and nitrogen in both the forests. Oak forests were rich in nutrients than pine forest.

The carbon sequestration rate (i.e., carbon sequestrated in wood products and by the substitution of biomass for coal) in mature *Populus deltoides* plantations (7-11 years) varied from 5.8 to 6.5 Mg C ha^{-1} per year. Soil carbon stocks increased with age (1-11 years) from 61.2 to 66.8 Mg ha^{-1} and decreased with soil depth. Soil carbon stock in different ages of plantations varied from 63.9 to 83.8 Mg ha^{-1} at 0-30 cm depth, 57.5 to 60.1 Mg ha^{-1} at 30-60 cm depth, and 55.5 to 59.7 Mg ha^{-1} at 60-90 cm depth (Arora *et al.* 2014).

Gupta *et al.* (2015) reported that eucalyptus plantation growing in Uttarakhand was having 31.94%, khair plantation 17.98% and shisham 41.83% higher soil organic carbon (SOC) stock as compared to similar plantations growing in Haryana. Only poplar plantation was 5.32% higher SOC stock in Haryana as compared to poplar plantations growing in Uttarakhand. SOC stock under shisham and eucalyptus plantations growing in Uttarakhand have statistically significant differences with the SOC stock under similar plantations growing in Haryana.

Wang *et al*. (2015) compared the soil chemical properties, enzyme activities and the diversity of soil microorganisms in control soil, rhizosphere soil and non-rhizosphere soil beneath the *L. camara* invaded area. *L. camara* invasion significantly increased contents of the soil organic matter, total N, P, K, available N, P and K and also enhanced the level and activities of urease, protease, invertase, cellulase and catalase. The BIOLOG results showed that Shannon index, McIntosh index, Simpson index and Richness index of the rhizosphere soil microbial communities were significantly higher than those of non-rhizosphere and control soil. *L. camara* invasion thus modified the soil characteristics which in turn favour its invasion.

Bol and Tokuchi (2018) assessed the impact of forest disturbances on soil properties in a tropical evergreen forest ecosystem in Myanmar. Soil samples were collected from the sites with three different types of forest disturbance, namely shifting cultivation (≥15 years post-abandonment), landslide (20 years post-landslide), selective logging (30 years post-logging), and old growth forest (no recorded history of disturbance over the last 80 years), to determine the effects of forest disturbances on soil carbon (C), nitrogen (N), available phosphorus (AP), pH, and bulk density (BD). Soil C, N, and AP concentrations were significantly higher in old growth forest soils than in the other disturbed forests, while BD was lowest in old growth forest soils. There were no significant differences in soil properties between soil depths, except in BD. Selective logging area soils had the lowest C, N, and pH values, and AP may be severely depleted in areas of shifting cultivation. Further the results confirmed that forest disturbances may alter soil properties and that the impacts differ among forest disturbance types.

Sahoo *et al*. (2019) quantified active and passive carbon pools from total soil organic carbon (TOC) in seven different land use systems of northeast India. The results showed that the TOC was highest (2.75 %) in natural forest and lowest in grassland (1.31 %) and it decreased with increasing depth in different pools of lability. Whereas, Very Labile Carbon (VLC) fraction ranged from 36.11 to 42.74 percent of TOC across different land use system. Active carbon (AC) pool was highest in Wet Rice Cultivation (61.64 %) and lowest (58.71 %) in natural forest. Higher AC pools (VLC and less labile) in most land use systems barring natural forests suggest that the land use systems in the region are vulnerable to land use change and must adopt suitable management practice to harness carbon sequestration.

Kumar *et al*. (2020) estimated the effect of two invasive alien species, *Lantana camara* and *Ageratina adenophora* on the understory vegetation composition and species diversity of chir pine (*Pinus roxburghii*) forests in the central Himalaya. Three sites had been selected in pine forests and each site was divided into three subsites viz. non-invaded (NI), *Lantana camara* invaded (LI) and *Ageratina adenophora* invaded (AI). In each subsite, 10 random quadrats for herbs (1×1 m) and shrubs (5×5 m) were laid down. In all the study sites, native herbs and shrubs species richness, diversity, and evenness changed due to invasive species. The presence of both the invasive species caused a reduction in native understory herbs and shrubs species number by 29–40 percent indicating a strong effect on native vegetation. Shrub density ranged from 6720 to 9680 individuals ha^{-1} and 8960 to 12000 individuals ha^{-1} in LI and AI sites, respectively. Total shrub basal area varied between 1.64 and 2.52 m^2 ha^{-1} in LI sites and 1.76 and 2.24 m^2 ha^{-1} in AI sites. Shrub density and basal area in NI sites (4200–6960 individual ha^{-1} and 0.60–0.96 m^2 ha^{-1}) were 2–3 times lower than LI and AI sites. Higher shrub density and basal area in LI and AI sites altered the vegetation composition and diversity of understory vegetation in pine forests. The dominance of invasive species also altered the soil physico-chemical properties and showed the adverse impact of invasion on native species.

Lone *et al*. (2021) assessed the changes in the flora and soil properties following the invasion by *Lantana camara* in Central Indian Forest ecosystems. Three study sites were selected and each site was further divided into two subsites: Lantana-invaded (LI) and uninvaded (UI). In total, 60 plots of 0.25 ha each (10 plots in each subsite) were laid randomly. Within each plot floristic structure, composition, diversity and soil SOC, STN, M percent, pH and bulk density were assessed. The results revealed that Lantana-invaded sites showed a significant decrease in density (D), basal area (BA), species richness (SR) and evenness (E) of seedlings (< 3cm diameter at breast height (DBH)), juveniles (> 3-9.9cm DBH), and herbs. In LI sites, a reduction of 57 and 25 percent has been observed in lower DBH class of trees (< 3cm and > 3-9.9cm). In all LI sites, a significant increase of soil organic carbon (SOC), soil total nitrogen (STN) and soil moisture (M%) and a significant decrease of pH and bulk density (BD) were recorded.

Chapter-3

MATERIALS AND METHODS

The present investigation entitled **"Stand structure and site characteristics of Khair (*Acacia catechu* Willd.) working circle in Nurpur Forest Division of Himachal Pradesh"** was conducted during the year 2018-2020. Field studies were conducted in different forest classes of Khair working circle in Nurpur Forest Division. Laboratory studies were conducted at Department of Silviculture and Agroforestry, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (HP). This chapter provides details of experimental sites, materials used, and methods adopted during the course of study period. Sampling designs, data collection methods, and analysis methods that helped to draw necessary conclusions have been discussed as below:

3.1 EXPERIMENTAL SITE

After reviewing the literature from working plan of Nurpur Forest Division, five different legal forest classes under Khair working circle were selected randomly. The different forest classes selected under present study can be defined as:

1. **Reserve Forest:** are constituted under the Indian forest Act 1927. These forests are exclusive property of the Govt. and subject to complete protection.
2. **Protection forest:** is a legal term for an area subject to limited degree of protection and constituted as such under provision of Indian Forest Act 1927. These are further classified into
    a. **Demarcated Protected forest:** means protected forest under the control of the Forest Department, of which the boundaries have already been demarcated by means of pillars of stone or masonry or by any other conspicuous mark.
    b. **Un-demarcated Protected forest:** are the protected forest under the control of the Forest Department, of which the boundaries have not been demarcated between the forest and private land.
3. **Co-operative Forest Society:** are the forest are the state forest assigned to local community and managed for supply of forest produce to local community

4. **Un-class forest:** are the forest owned by Govt. but not constituted into any of the above mentioned forest class.

The study area extends between the latitude 75.77º N to 76.02º E and longitude 32.23º N to 32.40º E. The map of study area is shown in Figure 1 and the detail of compartments under different forest classes is given in Table 1.

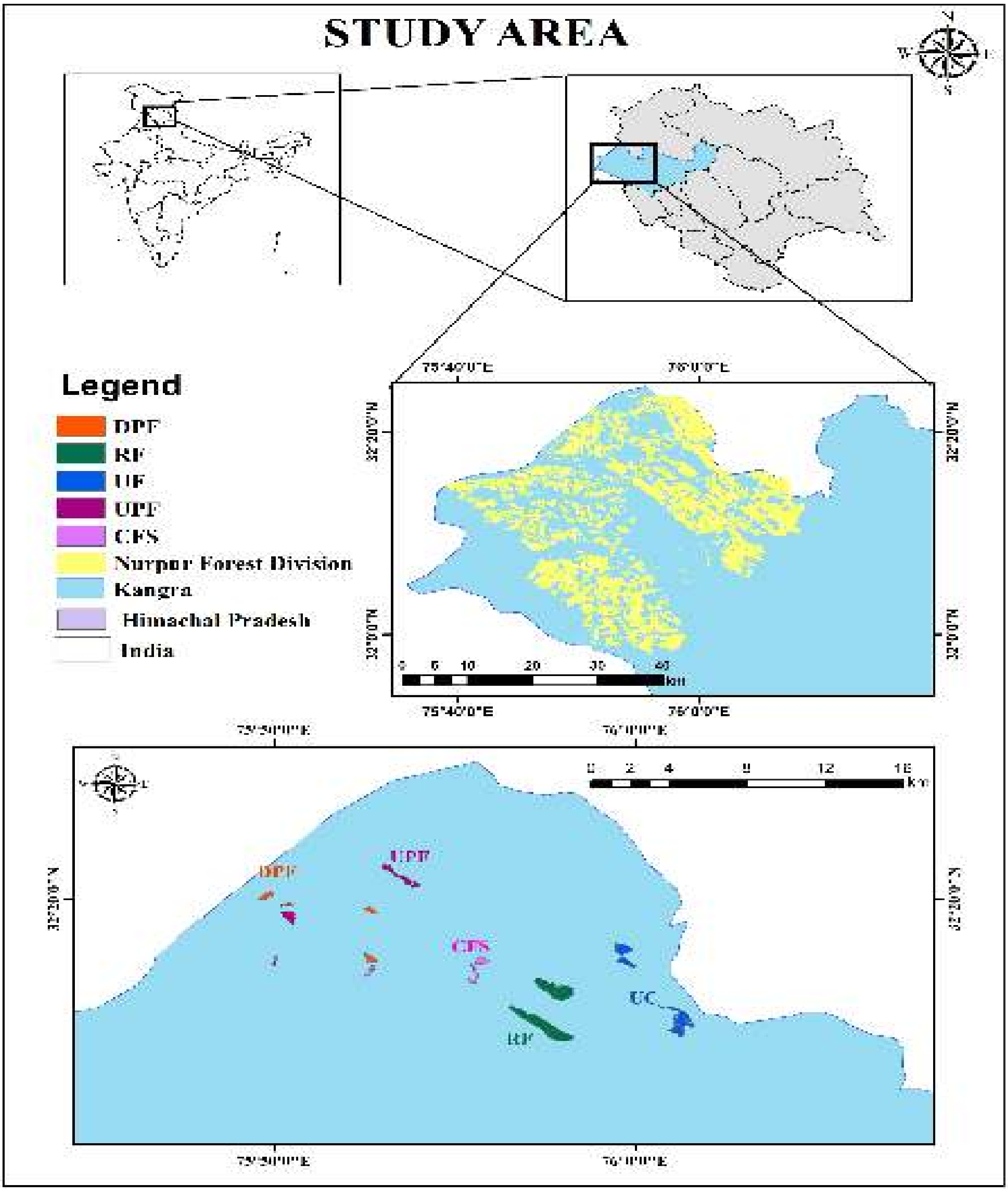


Figure 1: Map of study area

Table 1: Details of compartments within Forest classes in Khair working circle of Nurpur Forest Division, Himachal Pradesh

Forest class	Compartment		Forest class	Compartment	
Reserve Forest (RF)	**RFC1**	C_1R_2N Mehdhar	**Demarcated Protected Forest(DPF)**	**DPFC1**	$C_2P_{35}N$ Kopra
	RFC2	C_2R_2N Mehdhar		**DPFC2**	$P_{32}N$ Bharnu
	RFC3	$C_{3B}R_1N$ Tatal		**DPFC3**	$P_{31}N$ Mehra
	RFC4	$C_{3C}R_1N$ Tatal		**DPFC4**	C_{26}Nurpur
Co-operative Forest Society (CFS)	**CFSC1**	P_1CFS Jach	**Un-class Forest (UF)**	**UFC1**	$C_{10}U_{20}$Punder
	CFSC2	P_2CFS Jach		**UFC2**	C_7U_{20}Punder
	CFSC3	U_8 CFS Gahin lagor		**UFC3**	$C_{15}U_{20}$Punder
	CFSC4	R_1CFS Gahin lagor		**UFC4**	C_3U_{20}Punder
Un-demarcated Protected Forest(UF)	**UPFC1**	C_6UP_{10}Sadwan			
	UPFC2	C_5UP_{10}Sadwan			
	UPFC3	$C_{11}UP_{14}$Thora			
	UPFC4	UPC_{31}Mehra			

3.2 EXPERIMENTAL DETAILS

Experiment I: To study the floristic composition, stand structure and plant carbon density under Khair working circle managed under different forest classes and compartments

a) LEGAL FOREST CLASSES

i) Reserve forest (RF)

ii) Demarcated Protected Forest (DPF)

iii) Un-demarcated Protected Forest (UPF)

iv) Co-operative Forest Society (CFS)

v) Un-class Forests (UF)

b) COMPARTMENTS :4

Replications: 3

Design : Two-way ANOVA

Sample plot size:

Trees: 31.62m × 31.62m

Shrubs: 5m×5m

Herbs: 1m×1m

Regeneration: 2m×2m

Experiment II: To study site characteristics under Khair working circle managed under different forest classes

a) LEGAL FOREST CLASSES

i) Reserve forest (RF)

ii) Demarcated Protected Forest (DPF)

iii) Un-demarcated Protected Forest (UPF)

iv) Co-operative Forest Society Forest (CFS)

v) Un-class Forests (UF)

b) SOIL DEPTH: 2 i.e. D_1: 0-20cm and D_2: 20-40cm

Replication: 4

Design: Two-way ANOVA.

3.3 EXPERIMENTAL METHODOLOGY

3.3.1 Vegetation analysis

a) Tree

Tree sample plots of 0.1ha (31.62 × 31.62 m^2) were marked in each compartment of different forest class for analyzing structural and functional parameters of tree vegetation. Density of trees was calculated by counting trees in each sample plot. Basal area of each tree in the sample plot was determined by tree caliper and height was measured by Spiegel Relaskope. Volume of tree was determined by using different allometric equation pertaining to different tree species as suggested by different workers (Appendix-I).

b) Shrubs

The shrub characteristics were studied by laying out sub-plots of size 5m x 5m in each sample plot. Density of shrubs was calculated by counting plants of different species in each sub-plot. Stratified sampling of each shrub species was done by grouping them into three categories by visual appearance viz., a) large b) medium and c) small on the basis of size and number of stems in each of them. In each category, numbers of plants were counted. Basal area of stem was determined by vernier calliper.

c) Herbs

Herbaceous vegetation in different forest classes were studied at its peak growth in the month of September by harvesting quadrates of size 1m x 1m within each sample plot. The vegetation from each quadrate was segregated species wise and identified. The help of herbarium in the university, experts, journals and research books was taken to identify them. The numbers of tillers in each herb species were counted to find out their density. Collar diameter of bundle of tillers of each herb species was measured to determine basal area of each species. Frequency of a species was determined by its presence in different quadrates sampled.

3.3.2 Density (N ha^{-1})

It measured the total number of individuals per unit area and calculated as:

$$\text{Density (D)} = \frac{\text{Total number of individual}}{\text{Total number of quadrates studied}}$$

3.3.3 Basal area (cm^2)

It measures the cross-section area of the stem and it is obtained by the following relationship with diameter/girth

$$\text{Basal Area} = \frac{\Pi d^2}{4}$$

Where:

d = Diameter at breast height (1.37m)

3.3.4 Frequency (%)

It measures the degree of occurrence of a species in sampling units, thus it expresses the distribution of various species in the community.

$$\text{Percent frequency (\%)} = \frac{\text{Number of sampling units in which the species occurs}}{\text{Number of sampling units studied}} \times 100$$

3.3.5 Relative density, relative basal area and relative frequency

These parameters were obtained from per cent frequency, density and basal area by using the following relationship:

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

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

$$\text{Relative frequency (RF)} = \frac{\text{Number of occurrence of individual species}}{\text{Number of occurrence of all species}} \times 100$$

3.3.6 Importance value index (1VI)

IVI is the sum total of relative density, relative basal area and relative frequency and was calculated for all herbs, shrubs and tree species separately at each study sites.

IVI = Relative basal area (RBA) + Relative density (RD) + Relative frequency (RF)

3.4 VEGETATION INDICES

Community diversity was assessed using non-parametric measures such as diversity indices, and these measures have gradually gained credibility (Magurran, 1988). Simpson diversity index (Simpson, 1949), Simpson concentration of dominance (Simpson, 1949), Margalef index of species richness (Margalef, 1958), the Importance Value Index (IVI) (Phillips, 1959), Shannon–Wiener diversity index (Shannon and Weaver, 1963), Species heterogeneity (Whittaker, 1972), Pielou equitability (Pielou, 1966) and species richness index of Menheink (Whittaker, 1977), were computed for each particular forest type with the below mentioned formulae:

a) Shannon-Wiener Index of diversity ($H^/$) = $-\sum pi \text{ In } pi$

b) Simpson's concentration of dominance index (Cd) = $\sum pi^2$

c) Simpson's diversity index (D)= 1-Cd

d) Margalef's Index of richness (MI) =(S-1)/lnN

e) Pielou equitability (Ep)= $\frac{H^/}{H^/_{max}} = \frac{H^/}{lnS}$

f) Menheink index of species richness (MeI) = $\frac{S}{\sqrt{N}}$

g) Species heterogeneity (Hg) = $\sqrt{Cd}$

Where,

pi= ni/n (ni= IVI value of ith species, n= Total IVI value)

S= total number of species

N= total density per ha

3.5 BIOMASS ESTIMATION

3.5.1 Tree biomass

Volume of trees was transformed into biomass by multiplying it with specific gravity. Belowground biomass of trees was calculated following IPCC (1996) guidelines. The sum of aboveground and belowground biomass added up to determine total biomass of tree. The total biomass of trees in each elevation and aspect was calculated by adding up the biomass of every tree in it.

a) Shrub biomass

Each shrub samples were collected for studying the phyto-sociology and were brought to laboratory. They were segregated into leaves, branches and stem portion, washed and oven dried at 70ºC for 72 hours till the constant dry weight was obtained. Each sample was weighed to determine aboveground biomass (stem + branch + leaves) 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 samples for each species were brought to laboratory, packed in paper bags and dried at 70 ± 5ºC for 72 hours to determine their dry weight. Total biomass of a shrub species was calculated by adding its aboveground and belowground biomass.

b) Herbaceous biomass

The different species in each quadrate were packed in paper bags separately. Whole plants were uprooted with their root systems. In laboratory, these plants were segregated into shoot and root portion. The shoot portion was packed in paper bag and oven dried. The roots of different species were then washed in running water using fine mesh, packed in paper bags, oven dried at 70ºC for 72 hours till constant dry weight is attained and weighed to determine their dry weight. Total biomass was calculated by adding aboveground and belowground biomass of each species.

3.5.1.1 Stem biomass (t ha^{-1})

Stem biomass was calculated by multiplying specific gravity of stem wood with stem volume. Local volume equation developed for specific tree species and region was used for calculating the volume of trees in the sample plot (Appendices I).

Specific gravity: Specific gravity was determined from the available literature (Appendices I)

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

3.5.1.2 Above ground tree biomass (t ha^{-1})

The total tree biomass was calculated by multiplying the stem biomass with the biomass expansion factor of the species (Appendices I).

3.5.1.3 Below ground tree biomass (t ha^{-1})

Below ground biomass of trees was calculated by using the equation developed by Cairns *et al.* (1997).

$$\text{BGB t ha}^{-1} = \exp\{-1.059 + 0.884 \times \ln(\text{AGB}) + 0.284\}$$

3.5.1.4 Tree biomass (t ha^{-1})

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

3.5.2 Carbon Estimation

Carbon = Biomass x 0.5 (IPCC default value)

3.5.3 Carbon density (t ha^{-1})

Carbon density = Carbon in Mg per hactare

3.5.4 Total carbon [soil+plant (t ha^{-1})]

Total carbon was calculated by adding carbon density and plant carbon.

3.5.5 CO_2 mitigated

Carbon stock content was multiplied by 44/12 to estimate CO_2 mitigated as given by IPCC (2006).

3.6 REGENERATION STUDIES

Within each demarcated sample plot of 31.62× 31.62 m, the regeneration survey was carried out in a plot of size 2 × 2m by recording the number of seedlings (<0.5m) and sapling (0.5-2m) of tree species. The main object of regeneration survey is to assess whether or not there is adequate regeneration in the forest area. The adequacy of regeneration was judged on the basis of number of established plants in a unit area. According to Chacko (1965), the desired numbers of established plants are 2500 number ha^{-1} and the quadrate is considered fully stocked when it contained one established plant. For a detailed assessment of the status of regeneration following observations were made for each quadrate.

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:

$$\text{Recruits (r)/ha} = \frac{2500 \times \text{Total number of individuals}}{\text{Total number of quadrates studied}}$$

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

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

$$\text{Weighted average height (cm)} = \frac{\text{Total ht. of un-established regeneration} + (\text{Number of established plants} \times \text{establishment ht.})}{\text{Total number of recording units}}$$

On the basis of above estimates following indices were calculated:

$$\text{Established Index } (I_1) = \frac{\text{Weighted average height}}{\text{Establishment height}}$$

$$\text{Established Index } (I_1) = \frac{1}{2500} \times \frac{\text{Weighted average height}}{\text{Establishment height}} + \text{Established regeneration}$$

Regeneration success (%) = Stocking Index (I_2) × 100

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

3.7 PHYSICO-CHEMICAL ANALYSIS

The composite soil samples were collected from different layers viz; 0-20 cm and 20-40 cm for studying the soil physical analysis and depth–wise distribution of nutrient elements from each site. The composite soil samples were dried, ground with mortar and pestles and sieved with 2mm mesh sieve before analysis. Soil chemical analysis and laboratory studies were conducted in the Department of Silviculture and Agroforestry of Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (HP).Details of methodologies employed for estimating different soil physico-chemical parameters are given in Table 2 as below:

Table 2: Methods applied for soil physico-chemical analysis

Particular	Method employed
Soil pH	1:2.5 soil: water suspension, with the help of digital pH meter (Jackson, 1973).
EC	1:2.5 soil: water suspension, with the help of digital conductivity bridge (Jackson, 1973).
Bulk density (g cm^{-3})	Soil core sampler
Organic carbon (%)	Walkely and Black method (1934)
Soil carbon density (t ha^{-1})	[Soil bulk density (g cm-3) x Soil depth (cm) x Carbon] x 100 (Nelson and Sommers, 1996).
Labile soil carbon (%)	Difference in oxidizable organic C extracted between 18 N and 12 N H_2SO_4 (18 N–12 N H_2SO_4)
Non labile soil carbon (%)	Difference in organic C extracted with 24 N H_2SO_4 and TOC determined by CHN analyzer (TOC–24 N H_2SO_4).
Available nitrogen (kg ha^{-1})	Alkaline potassium permanganate method of Subbiah and Asija (1956).
Available phosphorus (kg ha^{-1})	Olsen method (Olsen *et al.* 1954).
Available potassium (kg ha^{-1})	Merwin and Peech method (Merwin and Peech *et al.*, 1951).
Zinc (ppm)	DTPA method
Copper (ppm)	
Iron (ppm)	
Calcium (cmol/kg)	

3.8 STATISTICAL ANALYSIS

Descriptive statistics, scattered plots and histograms were made directly from a spread sheet in window excel 2007. Analysis of variance and correlation coefficients were assessed by using Statistical Package for Social Sciences (SPSS) version 16.0 software. The least significant difference at 5 per cent level (<0.05) was used for testing the significant differences among treatments.

Chapter-4

RESULTS AND DISCUSSION

The results emerging out of the present investigation entitled **"Stand structure and site characteristics of Khair (*Acacia catechu* Wild.) working circle in Nurpur Forest Division of Himachal Pradesh"** was carried out in Nurpur Forest Division, Kangra, Himachal Pradesh. Phyto-sociological behavior of vegetation, stand structure, biomass production, regeneration status and soil physico-chemical properties under different forest management regimes have been described in this chapter under the following major heads and sub heads:

4.1 Floristic composition

4.2 Phyto-sociological studies

4.3 Diversity indices

4.4 Stand structure

4.5 Species wise distribution

4.6 Growth characteristics

4.7 Biomass and carbon stock

4.8 Regeneration status

4.9 Soil physico-chemical properties

4.10 Correlation studies

4.11 Status and impact of *Lantana camera* infestation

4.1 Floristic composition

4.1.1 Diversity of trees, shrubs and herbs

The flora of differently managed forest classes under Khair Working circle of Nurpur Forest Division constituted a total number of 43 genera with 50 species belonging to 27 family were recorded. Among them, 29 species of trees were from 14 family and 26 genera, and 12 species of shrubs from 12 genera and 12 families. However, 9 species of herbs from 7 family and 9 genera, respectively (Table 3).

Table 3: Floral distribution of trees, shrubs and herbs in Khair working circle of Nurpur Forest Division in Himachal Pradesh

	Species	Genus	Family
Trees	29	26	14
Shrubs	12	12	12
Herbs	9	9	7
Total	**50**	**43**	**27**

4.1.2 Floristic composition of trees, shrub and herbs

The floristic distribution of trees, shrubs and herbs within different forest classes is shown in Table 4, 5 and 6, respectively. In Reserve Forest, 17 tree, 9 shrub and 5 herb species were recorded. While in Demarcated protected Forest, 16 tree, 7 shrub and 3 herb species were found. In case of Un-demarcated Protected Forest 11 tree, 7 shrubs and 5 herb species were available whereas, in Co-operative Forest Society 13 tree, 6 shrubs and 4 herb species were recorded. In Un-class Forest, 11 tree, 6 shrub and 6 herb species were available.

The Reserve Forest and Demarcated Protected Forest had the maximum overall floristic composition while the Un-class forest had the least. This variation in floristic composition can be attributed to the management practices under different forest classes.

Tree density (number ha^{-1}) and Basal area (m^2 ha^{-1})

The data presented in Table 7 and 8 exhibits the compartmental variation in tree density and basal area. The tree density (number ha^{-1}) in Reserve Forest have shown a significant variation within compartment; the compartment RFC3 had significantly maximum density of 503.33 number ha^{-1} followed by RFC4 (406.67 number ha^{-1}). However, compartment RFC2 displayed the lowest tree density (323.33 number ha^{-1}) which was statistically at par with RFC1 (363.33 number ha^{-1}). In Demarcated Protected Forest (DPF) the maximum tree density was recorded in compartment DPFC2 (433.33 number ha^{-1}) which was statistically at par with DPFC3 (410.00 number ha^{-1}) whereas, the lowest tree density was found in compartment DPFC1 (183.33 number ha^{-1}). The compartment UPFC1 of Un-demarcated Protected Forest (UPF) represented the maximum tree density of 506.67 number ha^{-1}whereas, the lowest density was displayed by compartment UPFC4 (236.67 number ha^{-1}) which remained statistically at par with UPFC3 and UPFC2. The tree density in Co-operative Forest Society (CFS) was found highest in CFSC3 (356.67 number ha^{-1}) which was significantly different and followed by CFSC4 (246.67 number ha^{-1}). However, the

Table 4: Presence/absence of tree species among different Forest classes in Nurpur Forest Division of Himachal Pradesh

Sr. No.	Scientific name	Family	RF	DPF	UPF	CFSF	UF	Total
1	*Acacia catechu*	Fabaceae	+	+	+	+	+	5
2	*Aegle marmelos*	Rutaceae	+	-	+	+	-	3
3	*Albizia lebbeck*	Fabaceae	-	+	+	-	-	2
4	*Bombax ceiba*	Bombacaceae	+	+	-	-	-	2
5	*Broussonetia papyrifera*	Moraceae	-	-	-	+	-	1
6	*Butea monosperma*	Fabaceae	-	+	-	-	-	1
7	*Casearia tomentosa*	Salicaceae	+	+	-	-	-	2
8	*Cassia fistula*	Fabaceae	+	+	+	+	+	5
9	*Dalbergia sissoo*	Fabaceae	-	+	+	+	-	3
10	*Eucalyptus globulus*	Myrtaceae	-	-	-	-	+	1
11	*Ficus bengalensis*	Moraceae	+	-	+	-	+	3
12	*Ficus glomerata*	Moraceae	-	-	-	+	-	1
13	*Ficus palmata*	Moraceae	-	-	-	+	-	1
14	*Flacourtia indica*	Salicaceae	+	-	+	-	-	2
15	*Lannea coromandelica*	Anacardiaceae	+	+	+	+	+	5
16	*Leucaena leucocephala*	Fabaceae	-	-	-	+	-	1
17	*Mallotus phillippensis*	Euphorbiaceae	+	+	+	+	+	5
18	*Morus alba*	Moraceae	-	-	-	+	-	1
19	*Ougeinia oojeinensis*	Fabaceae	+	+	-	-	-	2
20	*Phyllanthus embelica*	Phyllanthaceae	+	+	+	-	-	3
21	*Pinus roxburghii*	Pinaceae	+	+	+	-	+	4
22	*Pistacia integerrima*	Anacardiaceae	-	+	-	-	-	1
23	*Pyrus pashia*	Rosaceae	+	-	-	-	+	2
24	*Stephegyne parvifolia*	Rubiaceae	-	-	-	-	+	1
25	*Syzygium cumini*	Myrtaceae	+	+	-	+	-	3
26	*Terminalia arjuna*	Combretaceae	+	-	-	-	-	1
27	*Terminalia bellirica*	Combretaceae	+	+	-	-	+	3
28	*Wendlandia exserta*	Rubiaceae	+	+	-	-	-	2
29	*Xylosma longifolium*	Flacourtiaceae	-	-	-	+	+	2
	Total		**17**	**16**	**11**	**13**	**11**	

Table 5: Distribution of shrub species among different Forest classes in Nurpur Forest Division of Himachal Pradesh

Sr. No.	Species	Family	RF	DPF	UPF	CFSF	UF	Total
1	*Adhatoda vasica*	Acanthaceae	-	+	+	+	+	**4**
2	*Asparagus adscendens*	Asparagaceae	+	-	-	-	-	**1**
3	*Carissa carandas*	Apocynaceae	+	+	+	+	+	**5**
4	*Cissampelos pareira*	Menispermaceae	+	-	+	-	+	**3**
5	*Ipomoea carnea*	Convolvulaceae	+	-	-	+	-	**2**
6	*Lantana camara*	Verbenaceae	+	+	+	+	+	**5**
7	*Murraya Koenigii*	Rutaceae	+	+	+	+	+	**5**
8	*Pogostemon plectrantoides*	Lamiaceae	+	-	-	-	-	**1**
9	*Ricinus communis*	Euphorbiaceae	-	+	+	+	-	**3**
10	*Rubus ellipticus*	Rosaceae	+	-	-	-	-	**1**
11	*Vitis parviflora*	Vitaceae	-	+	-	-	+	**2**
12	*Ziziphus mauritiana*	Rhamnaceae	+	+	+	-	-	**3**
	Total		**9**	**7**	**7**	**6**	**6**	

Table 6: Distribution of herb species among different Forest classes in Nurpur Forest Division of Himachal Pradesh

Sr. No.	Species	Family	RF	DPF	UPF	CFSF	UF	Total
1	*Achyranthes aspera*	Amaranthaceae	-	-	+	+	-	**2**
2	*Ageratum conyzoides*	Asteraceae	+	+	+	+	+	**5**
3	*Barleria cristata*	Acanthaceae	+	-	-	-	-	**1**
4	*Bidens pilosa*	Asteraceae	+	+	+	+	+	**5**
5	*Cassia tora*	Fabaceae	-	-	+	-	+	**2**
6	*Parthenium hysterophorus*	Asteraceae	+	+	+	+	+	**5**
7	*polygonum hydropiper*	Polygonaceae	-	-	-	-	+	**1**
8	*Polystichum*	Dryopteridaceae	-	-	-	-	+	**1**
9	*Urena lobata*	Malvaceae	+	-	-	-	-	**1**
	Total		**5**	**3**	**5**	**4**	**6**	

compartment CFSC4 remained statistically at par with CFSC1 (206.67 number ha^{-1}). The minimum density (190 number ha^{-1}) was displayed by compartment CFSC2 which further remained significantly at par with CFSC1. In case of Un-class Forest (UF) the highest density was recorded in compartment UFC2 (350 number ha^{-1}) which remain statistically at par with UFC4 (340 number ha^{-1}) further followed by UFC1 (280.00 number ha^{-1}) respectively. The minimum number of trees were recorded in compartment UFC3 (153.33 number ha^{-1}). The tree density between different forest classes was found significantly maximum (399.17 number ha^{-1}) in Reserve Forest followed by Demarcated Protected Forest (340 number ha^{-1}). The lowest tree density (250.00 number ha^{-1}) was reported in Co-operative Forest Society. However, the density of trees in Un-demarcated Protected Forest (308.33 number ha^{-1}) and Un-class Forest (280.83 number ha^{-1}) remains statistically at par with each other.

A significant variation in basal area of trees within compartments was observed except for Un-demarcated Protected Forest and Co-operative Forest Society. In Reserve Forest significantly maximum basal area (20.38 m^2 ha^{-1}) was recorded in RFC3 which was followed by RFC4 (16.50 m^2 ha^{-1}) and RFC1 (11.72 m^2 ha^{-1}). However, the minimum basal area was recorded in RFC2 (9.53 m^2 ha^{-1}) which was statistically at par with RFC1. In case of Demarcated Protected Forest, the maximum basal area was found in DPFC1 (18.82 m^2 ha^{-1}) followed by DPFC2 (11.31m^2 ha^{-1}) which remained statistically at par with DPFC3 (10.27m^2 ha^{-1}) whereas, the minimum value for basal area was recorded in DPFC4 (8.45m^2 ha^{-1}) which was also at par with DPFC3. Within Un-class Forest the significantly highest value for basal area was recorded in UFC4 (25.35m^2 ha^{-1}) which was followed by UFC2 (12.73m^2 ha^{-1}). However, the compartment UFC2 remained at par with UFC1 (10.52m^2 ha^{-1}). Significantly lowest value for basal area (6.07m^2 ha^{-1}) was recorded in UFC3. Overall, the variation in basal area of trees between the forest classes was significant except for Reserve Forest and Un-class Forest which remain statistically at par with each other. Further the trend followed by different forest classis as; RF≥UF>DPF>UPF>CFS respectively.

Density (number ha^{-1}) and Basal area (cm^2 ha^{-1}) of shrubs

The density and basal area of shrubs is presented in Table 9 and 10. In Reserve Forest the maximum density of shrubs was recorded in RFC1 and RFC4 both were represented by identical value of 3360.00 number ha^{-1} followed by RFC2 (3200.00 number ha^{-1}). However, the minimum value was displayed by RFC3 (2720.00 number ha^{-1}). In case of Demarcated Protected Forest, the maximum shrub density (4640.00 number ha^{-1}) was recorded in DPFC1.

Table 7: Compartmental variation in density (number ha^{-1}) of trees under different forest classes in Khair working circle of Nurpur Forest Division, Himachal Pradesh

Compartment	Reserve Forest (RF)	Compartment	Demarcated Protected Forest (DPF)	Compartments	Un-demarcated Protected Forest (UPF)	Compartments	Co-operative Forest Society (CFS)	Compartments	Un-class Forest (UF)
RFC1	363.33^{c}	**DPFC1**	183.33^{c}	**UPFC1**	506.67^{a}	**CFSC1**	206.67^{bc}	**UFC1**	280.00^{b}
RFC2	323.33^{c}	**DPFC2**	433.33^{a}	**UPFC2**	250.00^{b}	**CFSC2**	190.00^{c}	**UFC2**	350.00^{a}
RFC3	503.33^{a}	**DPFC3**	410.00^{a}	**UPFC3**	240.00^{b}	**CFSC3**	356.67^{a}	**UFC3**	153.33^{c}
RFC4	406.67^{b}	**DPFC4**	333.33^{b}	**UPFC4**	236.67^{b}	**CFSC4**	246.67^{b}	**UFC4**	340.00^{a}
Mean	**399.17^{a}**		**340.00^{b}**		**308.33^{c}**		**250.00^{e}**		**280.83^{d}**
CD $_{0.05}$ Within Forest class: 42.61 Between Forest class: 21.30									

Table 8: Compartmental variation in basal area (m^2 ha^{-1}) of trees under different forest classes in Khair working circle of Nurpur Forest Division, Himachal Pradesh

Compartment	Reserve Forest (RF)	Compartments	Demarcated Protected Forest (DPF)	Compartments	Un-demarcated Protected Forest (UPF)	Compartments	Co-operative Forest Society (CFS)	Compartments	Un-class Forest (UF)
RFC1	11.72	**DPFC1**	18.82	**UPFC1**	10.36	**CFSC1**	6.63	**UFC1**	10.52
RFC2	9.53	**DPFC2**	11.31	**UPFC2**	8.50	**CFSC2**	5.44	**UFC2**	12.73
RFC3	20.38	**DPFC3**	10.27	**UPFC3**	10.12	**CFSC3**	8.66	**UFC3**	6.07
RFC4	16.50	**DPFC4**	8.45	**UPFC4**	8.01	**CFSC4**	5.83	**UFC4**	25.35
Mean	**14.53**		**12.21**		**9.25**		**6.64**		**13.67**
CD 0.05 Within Forest class: 2.51 Between Forest class: 1.25									

Whereas, the minimum density was recorded in DPFC2 (3220.00 number ha^{-1}) which remained statistically at pat with DPFC3 and DPFC4. In Un-demarcated Protected Forest, the highest shrub density (3040.00 number ha^{-1}) was displayed by compartment UPFC4 which remains statistically at par with UPFC2 and UPFC3.Whereas, significantly lowest shrub density (2300.00 number ha^{-1}) was recorded in UPFC1. The maximum shrub density within Co-operative Forest Society was recorded in CFSC2 (3680.00 number ha^{-1}), whereas the other compartment i.e. CFSC1, CFSC3 and CFSC4 remained statistically at par with each other. The compartments of Un-class Forest did not show any significant variation for shrub density. Further, the density of shrub between forest classes was recorded significantly maximum (3725.00 number ha^{-1}) in Demarcated Protected Forest followed by Un-class Forest (3440.00 number ha^{-1}) which remain statistically at par with Co-operative Forest Society (3260.00 number ha^{-1}). Moreover, the shrub density in Co-operative Forest Society remains statistically at par with Reserve Forest (3160.00 number ha^{-1}). The significantly lowest shrub density (2775.00 number ha^{-1}) was recorded in Un-demarcated Protected Forest.

The basal area of shrubs (Table 8) shows that there was a significant variation between and within forest classes. The maximum basal area (104192.36 cm^2 ha^{-1}) under Reserve Forest was recorded in compartment RFC2 followed by RFC4 (92347.50cm^2 ha^{-1}) and RFC3 (88857.61 cm^2 ha^{-1}) whereas, the minimum basal area (82923.90 cm^2 ha^{-1}) was recorded in RFC1. In case of Demarcated Protected Forest, the maximum value for basal area (131626.20 cm^2 ha^{-1}) was recorded in DPFC1 followed by DPFC3 (102625.30 cm^2 ha^{-1}), DPFC4 (92781.70 cm^2 ha^{-1}) and DPFC2 (84879.20 cm^2 ha^{-1}), respectively. Within Un-demarcated Protected Forest, the maximum value for basal area was recorded in UPFC3 (97720.50 cm^2 ha^{-1}) followed by UPFC2 (93979.30 cm^2 ha^{-1}) and UPFC4 (87640.10cm^2 ha^{-1}) whereas, the minimum basal area (59300.40 cm^2 ha^{-1}) was displayed by UPFC1. In case of Co-operative Forest Society, the maximum basal area (112377.20 cm^2 ha^{-1}) was recorded in CFSC2 which remains statistically at par with CFSC1 and followed by CFSC3. The lowest value for basal area (77611.70 cm^2 ha^{-1}) was recorded in CFSC4. In case of Un-class forest the maximum basal area (111951.88 cm^2 ha^{-1}) was recorded in UFC3 which was followed by UFC4 (95522.23 cm^2 ha^{-1}) whereas, the minimum basal area (91158.10 cm^2 ha^{-1}) was found in UFC1, which remains statistically at par with UFC2 (92723.43 cm^2 ha^{-1}). Overall, a significant variation in shrub basal area was recorded between different forest classes and the trend is as follow; DPF>CFS>UF>RF>UPF, respectively.

Table 9: Compartmental variation in density (number ha^{-1}) of shrubs under different forest classes in Khair working circle of Nurpur Forest Division, Himachal Pradesh

Compartments	Reserve Forest (RF)	Compartments	Demarcated Protected Forest (DPF)	Compartments	Un-demarcated Protected Forest (UPF)	Compartments	Co-operative Forest Society (CFS)	Compartments	Un- class Forest (UF)
RFC1	3360.00	**DPFC1**	4640.00	**UPFC1**	2300.00	**CFSC1**	3200.00	**UFC1**	3360.00
RFC2	3200.00	**DPFC2**	3220.00	**UPFC2**	2800.00	**CFSC2**	3680.00	**UFC2**	3280.00
RFC3	2720.00	**DPFC3**	3440.00	**UPFC3**	2960.00	**CFSC3**	3040.00	**UFC3**	3680.00
RFC4	3360.00	**DPFC4**	3600.00	**UPFC4**	3040.00	**CFSC4**	3120.00	**UFC4**	3440.00
Mean	**3160.00**		**3725.00**		**2775.00**		**3260.00**		**3440.00**
CD 0.05 Within Forest class: 419.62 Between Forest class: 209.81									

Table 10: Compartmental variation in basal area (cm^2 ha^{-1}) of shrubs under different forest classes in Khair working circle of Nurpur Forest Division, Himachal Pradesh

Compartments	Reserve Forest (RF)	Compartments	Demarcated Protected Forest (DPF)	Compartments	Un-demarcated Protected Forest (UPF)	Compartments	Co-operative Forest Society (CFS)	Compartments	Un-class Forest (UF)
RFC1	82923.90	**DPFC1**	131626.20	**UPFC1**	59300.40	**CFSC1**	110086.70	**UFC1**	91158.10
RFC2	104192.36	**DPFC2**	84879.20	**UPFC2**	93979.30	**CFSC2**	112377.20	**UFC2**	92723.43
RFC3	88857.61	**DPFC3**	102625.30	**UPFC3**	97720.50	**CFSC3**	104645.90	**UFC3**	111951.88
RFC4	92347.50	**DPFC4**	92781.70	**UPFC4**	87640.10	**CFSC4**	77611.70	**UFC4**	95522.23
Mean	**92080.34**		**102978.10**		**84660.08**		**101180.38**		**97838.91**
CD 0.05 Within Forest class: 1839.61 Between Forest class: 919.80									

Density (number ha^{-1}) and Basal area (cm^2 ha^{-1}) of Herbs

The data pertaining to density of herbs presented in Table 11 shows that within Reserve Forest the compartment RFC3 had significantly maximum herb density (54400.00number ha^{-1}) followed by RFC2 (49200.00number ha^{-1}) which remained statistically at par with RFC1 (44400.00number ha^{-1}) whereas, the compartment RFC4 was documented with lowest herb density (26800.00number ha^{-1}). In case of Demarcated Protected Forest, the maximum value for herb density was recorded in DPFC3 (51600.00number ha^{-1}), whereas the other compartments did not show any significant variation i.e., remained at par with each other. Within Un-demarcated Protected Forest, the maximum herb density was found in UPFC1 (43200.00number ha^{-1}), however, the other compartments remained statistically at par with each other. A significant variation was observed between the compartments within Co-operative Forest Society where the maximum herb density was displayed by CFSC4 (42000.00number ha^{-1}) followed by CFSC3 (34000.00number ha^{-1}), CFSC2 (21200.00number ha^{-1}) and CFSC1 (10000.00number ha^{-1}) respectively. In case of Un-class Forest, the maximum herb density was found in UFC2 (45200.00number ha^{-1}), whereas, the lowest value for herb density was found in UFC4 (28400.00number ha^{-1}) which remains statistically at with UFC1 (28800.00number ha^{-1}) and UFC3 (29200.00number ha^{-1}). Overall, the density of herbs between forest classes follows the following trend; RF>DPF≥UF≥UPF>CFS, respectively.

Significant variation in basal area of herbs can be seen from the data presented in Table 12. In case of Reserve Forest, the maximum basal area of herbs (945.42 cm^2 ha^{-1}) was found in compartment RFC3 which remained statistically at par with RFC2 (797.39 cm^2 ha^{-1}), whereas, the minimum basal area (495.81 cm^2 ha^{-1}) was recorded in RFC4. Furthermore, the compartment RFC1 remained statistically at par with RFC2 and RFC4, respectively. The significantly maximum value for basal area under Demarcated Protected Forest was recorded in compartment DPFC3 (810.57 cm^2 ha^{-1}) whereas, the minimum basal area was found in DPFC4 (399.88 cm^2 ha^{-1}) which remained statistically at par with DPFC1 (431.54 cm^2 ha^{-1}) and DPFC2 (429.25 cm^2 ha^{-1}). Similarly, within Un-demarcated Protected Forest the maximum basal area was recorded in compartment UPFC1 (798.39 cm^2 ha^{-1}) whereas, the lowest value for basal area was found in UPFC3 (405.82 cm^2 ha^{-1}) which remains statistically at par with UPFC4 (452.86 cm^2 ha^{-1}) and UPFC2 (544.03 cm^2 ha^{-1}). In case of Co-operative Forest Society the maximum basal area was found in CFSC4 (709.16 cm^2 ha^{-1}) which was

Table 11: Compartmental variation in density (number ha^{-1}) of herbs under different forest classes in Khair working circle of Nurpur Forest Division, Himachal Pradesh

Compartments	Reserve Forest (RF)	Compartments	Demarcated Protected Forest (DPF)	Compartments	Un-demarcated Protected Forest (UPF)	Compartments	Co-operative Forest Society (CFS)	Compartments	Un-class Forest (UF)
RFC1	44400.00	**DPFC1**	29060.00	**UPFC1**	43200.00	**CFSC1**	10000.00	**UFC1**	28800.00
RFC2	49200.00	**DPFC2**	27600.00	**UPFC2**	28400.00	**CFSC2**	21200.00	**UFC2**	45200.00
RFC3	54400.00	**DPFC3**	51600.00	**UPFC3**	24800.00	**CFSC3**	34000.00	**UFC3**	29200.00
RFC4	26800.00	**DPFC4**	27200.00	**UPFC4**	27600.00	**CFSC4**	42000.00	**UFC4**	28400.00
Mean	**43700.00**		**33865.00**		**31000.00**		**26800.00**		**32900.00**
CD 0.05 Within Forest class: 5116.71 Between Forest class: 2558.35									

Table 12: Compartmental variation in basal area (cm^2 ha^{-1}) of herbs under different forest classes in Khair working circle of Nurpur Forest Division, Himachal Pradesh

Compartments	Reserve Forest (RF)	Compartments	Demarcated Protected Forest (DPF)	Compartments	Un-demarcated Protected Forest (UPF)	Compartments	Co-operative Forest Society (CFS)	Compartments	Un-class Forest (UF)
RFC1	651.02	**DPFC1**	431.54	**UPFC1**	798.39	**CFSC1**	207.09	**UFC1**	588.07
RFC2	797.39	**DPFC2**	429.25	**UPFC2**	544.03	**CFSC2**	405.16	**UFC2**	733.27
RFC3	945.42	**DPFC3**	810.57	**UPFC3**	405.82	**CFSC3**	566.70	**UFC3**	603.57
RFC4	495.81	**DPFC4**	399.88	**UPFC4**	452.86	**CFSC4**	709.16	**UFC4**	519.78
Mean	**722.41**		**517.81**		**550.28**		**472.03**		**611.17**
CD 0.05									
Within Forest class: 195.06 Between Forest class: 97.53									

statistically at par with CFSC3 (566.70 cm^2 ha^{-1}). Further, the compartment CFSC3 remains at par with CFSC2 (405.16 cm^2 ha^{-1}). The minimum basal area was recorded in CSFC1 (207.09 cm^2 ha^{-1}). Although, the compartments within Un-class Forest did not show any significant variation for basal area of herbs. Overall, the variation in herb biomass between forest classes was statistically significant where, the maximum value for basal area was recorded in Reserve Forest (722.41 cm^2 ha^{-1}) followed by Un-class Forest (611.17 cm^2 ha^{-1}) which remains statistically at par with Un-demarcated Protected Forest (550.28 cm^2 ha^{-1}) and Demarcated Protected Forest (517.81 cm^2 ha^{-1}). The minimum basal area was found in Co-operative Forest Society (472.03 cm^2 ha^{-1}) which also remains statistically at par with Un-demarcated Protected Forest and Demarcated Protected Forest.

4.2 Phyto-sociological studies

Reserve Forest (RF)

This forest was composed of *Acacia catechu* in association with *Lannea coromandelica, Mallotus phillippensis, Cassia fistula* and *Pinus roxburghii* (Table 13). In compartment RFC1, *Acacia catechu* was the main dominating tree species with maximum value for relative density (40.37 %) and IVI (91.05) followed by *Lannea coromandelica* (22.94 %, 74.23) and *Mallotus phillippensis* (13.76%, 37.71), respectively. Moreover, these three species were the most frequently occurring species with relative frequency of 16.67 %. The maximum contribution for relative basal area was displayed by *Lannea coromandelica* (34.63%) which was closely followed by *Acacia catechu* (34.01%). However, *Casearia tomentosa* had the lowest value for relative density (0.92%), relative basal area (0.56%) and IVI (7.03) which was followed by *Ougeinia oojeinensis*, *Wendlandia exserta* and *Phyllanthus embelica,* respectively. In Compartment RFC2, *Acacia catechu* had the highest value for relative density and frequency (26.80%, 14.29%) followed by *Cassia fistula* (20.62%, 14.29%), *Lannea coromandelica* (17.53%, 14.29%) and *Pinus roxburghii* (13.40%, 14.29%) whereas, *Pinus roxburghii* had the maximum relative basal area of 37.35% followed by *Lannea coromandelica* (19.41%) and *Acacia catechu* (15.69%). The lowest identical value for relative density (1.03%) and relative frequency (4.76%) was recorded for *Casearia tomentosa* and *Ficus bengalensis*. However, *Carearia tomentosa* (0.69 %) and *Bombax ceiba* (2.00 %) had the lowest value for the relative basal area. Moreover, *Pinus roxburbhii* had the maximum IVI value (65.03) followed by *Acacia catechu* (56.78) and *Lannea corromandelica* (51.22). The lowest value of IVI was reported for *Casearia tomentosa* (6.48) followed by

Table 13: Phyto-sociological studies of Reserve Forest (RF) in Khair working circle of Nurpur Forest Division, Himachal Pradesh

Species	RFC1				RFC2				RFC3				RFC4			
	RD	RF	RBA	IVI	RD	RF	RBA	IVI	RD	RF	RBA	IVI	RD	RF	RBA	IVI
Trees																
Acacia catechu	40.37	16.67	34.01	91.05	26.80	14.29	15.69	56.78	23.84	17.65	29.77	71.26	36.89	18.75	38.61	94.24
Aegle marmelos	-	-	-	-	-	-	-	-	1.32	5.88	0.50	7.70	-	-	-	-
Bombex ceiba	-	-	-	-	3.09	4.76	2.00	9.86	-	-	-	-	-	-	-	-
Casearia tomentosa	0.92	5.56	0.56	7.03	1.03	4.76	0.69	6.48	-	-	-	-	-	-	-	-
Cassia fistula	4.59	11.11	5.30	21.00	20.62	14.29	9.99	44.89	27.81	17.65	18.06	63.52	20.49	18.75	11.03	50.27
Ficus bengalensis	-	-	-	-	1.03	4.76	3.55	9.34	-	-	-	-	-	-	-	-
Flacourtia indica	2.75	5.56	2.34	10.65	-	-	-	-	-	-	-	-	-	-	-	-
Lannea coromandelica	22.94	16.67	34.63	74.23	17.53	14.29	19.41	51.22	21.19	17.65	29.18	68.02	13.93	18.75	11.42	44.10
Mallotus phillippensis	13.76	16.67	7.28	37.71	9.28	9.52	4.63	23.44	15.23	17.65	8.64	41.52	20.49	18.75	11.56	50.81
Ougeinia oojeinensis	1.83	5.56	2.01	9.40	-	-	-	-	-	-	-	-	-	-	-	-
Phyllanthus embelica	3.67	5.56	2.16	11.38	5.15	14.29	2.57	22.01	-	-	-	-	0.82	6.25	0.51	7.58
Pinus roxburghii	-	-	-	-	13.40	14.29	37.35	65.03	3.31	5.88	7.86	17.05	7.38	18.75	26.87	52.99
Pyrus pashia	-	-	-	-	-	-	-	-	2.65	5.88	1.49	10.02	-	-	-	-
Syzygium cumini	-	-	-	-	2.06	4.76	4.12	10.94	3.31	5.88	3.74	12.94	-	-	-	-
Terminalia arjuna	-	-	-	-	-	-	-	-	1.32	5.88	0.76	7.97	-	-	-	-
Terminalia bellirica	7.34	11.11	9.39	27.84	-	-	-	-	-	-	-	-	-	-	-	-
Wendlandia exserta	1.83	5.56	2.31	9.70	-	-	-	-	-	-	-	-	-	-	-	-
Total	**100.00**	**100.00**	**100.00**	**300.00**	**100.00**	**100.00**	**100.00**	**300.00**	**100.00**	**100.00**	**100.00**	**300.00**	**100.00**	**100.00**	**100.00**	**300.00**
Shrubs																
Asparagus adscendens	11.90	18.18	0.32	30.41	7.50	10.00	0.07	17.57	-	-	-	-	-	-	-	-
Carissa carandas	16.67	18.18	9.37	44.22	-	-	-	-	14.71	20.00	5.12	39.82	11.90	14.29	5.61	31.80
Cissampelos pareira	9.52	9.09	0.12	18.74	-	-	-	-	-	-	-	-	-	-	-	-
Ipomoea	-	-	-	-	-	-	-	-	-	-	-	-	4.76	14.29	3.21	22.26
Lantana camara	54.76	45.45	87.07	187.28	60.00	50.00	90.24	200.24	55.88	50.00	84.99	190.87	50.00	35.71	76.22	161.94
Murraya koenigii	7.14	9.09	3.12	19.35	17.50	30.00	9.42	56.92	29.41	30.00	9.90	69.31	19.05	14.29	9.33	42.66
Pogostemon plectrantoides	-	-	-	-	15.00	10.00	0.28	25.28	-	-	-	-	-	-	-	-
Rubus ellipticus	-	-	-	-	-	-	-	-	-	-	-	-	7.14	7.14	3.77	18.06
Ziziphus mauritiana	-	-	-	-	-	-	-	-	-	-	-	-	7.14	14.29	1.87	23.30
Total	**100.00**	**100.00**	**100.00**	**300.00**	**100.00**	**100.00**	**100.00**	**300.00**	**100.00**	**100.00**	**100.00**	**300.00**	**100.00**	**100.00**	**100.00**	**300.00**
Herbs																
Ageratum conyzoides	45.05	37.84	55.42	138.30	51.22	42.11	62.90	156.23	52.21	42.50	60.30	155.00	59.70	64.29	61.69	185.68
Barleria cristata	11.71	16.22	9.18	37.11	16.26	21.05	11.53	48.85	-	-	-	-	-	-	-	-
Bidens pilosa	34.23	29.73	29.74	93.71	32.52	36.84	25.56	94.92	25.74	32.50	16.32	74.56	-	-	-	-
Parthenium hysterophorus	-	-	-	-	-	-	-	-	22.06	25.00	23.38	70.44	40.30	35.71	38.31	114.32
Urena lobata	9.01	16.22	5.66	30.88	-	-	-	-	-	-	-	-	-	-	-	-
Total	**100.00**	**100.00**	**100.00**	**300.00**	**100.00**	**100.00**	**100.00**	**300.00**	**100.00**	**100.00**	**100.00**	**300.00**	**100.00**	**100.00**	**100.00**	**300.00**

Ficus benghalensis (9.34) and *Bombax ceiba* (9.86), respectively. In compartment RFC3, *Cassia fistula* was documented with highest value for relative density of 27.81% which was closely followed by *Acacia catechu* (23.84%), whereas, *Aegle marmelos* and *Terminalia arjuna* was reported to have lowest identical value for relative density (1.32%). The maximum identical value for relative frequency (17.65%) was recorded for *Acacia catechu, Cassia fistula, Lannea coromandelica* and *Mallotus phillippensis* whereas minimum value (5.88%) was recorded for *Aegle marmelos, Pinus roxburghii, Pyrus pashia, Syzygium cumini* and *Terminalia arjuna.* The relative basal area was found maximum for *Acacia catechu* (29.77%) which was closely followed by *Lannea coromandelica* (29.18%). Whereas, *Aegle marmelos* had the lowest value for relative basal area (0.50%) which was followed by *Terminalia arjuna*. The IVI of maximum value (71.26) was recorded for *Acacia catechu* which was closely followed by *Lannea coromandilica* (68.02). *Aegle marmelos* had the lowest IVI value (7.70). The compartment RFC4 was represented by *Acacia catechu* with highest value for relative density (36.89%), relative frequency (18.75%), relative basal area (38.61%) and IVI (94.24), which was followed by *Pinus roxburghii*. Whereas, *Phyllanthus embelica* had the lowest value for all the phyto-sociological parameters.

Lantana camara was the most dominating shrub species in compartment RFC1 with maximum value of relative density (54.76%), relative frequency (45.45%), relative basal area (87.07%) and IVI (187.28), respectively. The lowest value for relative density (7.14%) was reported for *Murraya koenigii*. However, *Cissampelos pareira* had the lowest value for relative basal area (0.12%) and IVI (18.74). The compartment RFC2 of Reserve Forest was also dominated by *Lantana camera* with relative density of 60.00 %relative frequency of 50%, relative basal area of 90.24% and IVI value of 200.24. Whereas, the lowest value of relative density (7.50%) was recorded for *Asparagus adscendens* with relative frequency of 10.00%, relative basal area of 0.07% and IVI value of 17.57 respectively. The compartment RFC3 was dominated by *Lantana camera* with the maximum value for relative density (55.58 %), relative frequency (50.00%), relative basal area (84.99%) and IVI (190.87), respectively. The minimum value for relative density (14.71%), relative frequency (20%), relative basal area (5.12%) and IVI (39.82) was recorded for *Carissa carandas* followed by *Murraya koenigii*. In compartment RFC4, *Lantana camera* had the maximum value for relative density of 50.00%, relative frequency of 35.71%, relative basal area of 76.22 %and IVI value of 161.94, respectively. Whereas, the lowest value for relative density (4.76 %) was reported for *Ipomoea* which was followed by *Rubus ellipticus* and *Ziziphus maruitiana*. However, the lowest value for relative basal area (1.87%) was recorded for *Ziziphus maruitiana.* Further, *Rubus ellipticus* was the least occurring species with minimum value of relative frequency (7.14 %) and IVI value (18.06).

In case of herb species within Reserve Forest, the compartment RFC1 was dominated by *Ageratum conyzoides* with maximum relative density of 45.05 %, relative frequency of 37.84%, relative basal area of 55.42 % and IVI value of 138.30 which was closely followed by *Bidens pilosa* with IVI value of 32.52. The minimum value of relative density (9.01 %), relative frequency (16.22 %), relative basal area (5.66 %) and IVI (30.88) was reported for *Urena lobata*. In compartment RFC2, *Ageratum conyzoides* had the maximum relative density (51.22 %), relative frequency (42.11 %), relative basal area (62.90 %) and IVI value (156.23), whereas, *Barleria cristata* had the lowest value for all the phyto-sociological parameters with IVI value of 48.85. The compartment RFC3, was reported to have three species of which *Ageratum conyzoides* was the main herb with maximum IVI value of 155 which was closely followed by *Bidens pilosa* and *Partinium hysterophorus*. In compartment RFC4 only two species were recorded among of which *Ageratum conyzoides* had the maximum dominance with IVI value of 185.68 followed by *Parthimium hysterophorus*.

Demarcated Protected Forest (DPF)

The phyto-sociological parameters of trees, shrubs and herbs presented in Table 14 reveal that the compartment DPFC1 under Demarcated Protected Forest was dominated by *Pinus roxburghii* with maximum value for relative density (60.00 %), relative basal area (87.37%) and IVI value of 170.46 followed by *Acacia catechu* (21.82%, 8.41% and 53.30). However, *Pinus roxburghii* in association with *Acacia catechu* and *Cassia fistula* was reported most frequently occurring species with identical relative frequency of 23.08 %. Whereas, *Bombax ceiba and Butea monosperma* had the lowest identical value for elative density (1.82 %) and relative frequency (7.69 %). Further, *Butea monosperma* had the minimum value for relative basal area (0.29%) and IVI (9.80). The Compartment DPFC2 was dominated by *Lannea coromandelica* with maximum relative density of 37.69%, relative basal area of 45.06 % and IVI of 104.18 %, respectively, which was followed by *Acacia catechu* and *Cassia fistula*. Whereas, *Bombax ceiba* had the lowest value for relative density (1.54 %), relative basal area (1.32 %) and IVI (10.01), respectively. In compartment DPFC3, *Mallotus phillippensis* was documented with highest relative density of 33.33% which was closely followed by *Acacia catechu* (24.39 %), whereas, *Casearia tomentosa* and *Phyllanthus*

Table 14: Phyto-sociological studies of Demarcated Protected Forest (DPF) in Khair working circle of Nurpur Forest Division, Himachal Pradesh

Species	DPFC1				DPFC2				DPFC3				DPFC4			
	RD	RF	RBA	IVI	RD	RF	RBA	IVI	RD	RF	RBA	IVI	RD	RF	RBA	IVI
Trees																
Acacia catechu	21.82	23.08	8.41	53.30	30.77	21.43	33.12	85.32	24.39	15.79	32.30	72.48	24.00	20.00	29.47	73.47
Albizia lebbeck	-	-	-	-	3.85	7.14	2.97	13.96	-	-	-	-	-	-	-	-
Bombax ceiba	1.82	7.69	0.74	10.25	1.54	7.14	1.32	10.01	7.32	10.53	6.69	24.53	-	-	-	-
Butea monosperma	1.82	7.69	0.29	9.80	-	-	-	-	-	-	-	-	-	-	-	-
Caseariatomentosa	-	-	-	-	-	-	-	-	2.44	5.26	2.41	10.11	-	-	-	-
Cassia fistula	9.09	23.08	2.07	34.24	19.23	21.43	12.61	53.27	-	-	-	-	15.00	20.00	10.96	45.96
Dalbergia sissoo	-	-	-	-	2.31	7.14	2.22	11.67	9.76	15.79	10.07	35.62	-	-	-	-
Lannea coromandelica	-	-	-	-	37.69	21.43	45.06	104.18	-	-	-	-	35.00	20.00	38.50	93.50
Mallotus phillippensis	5.45	15.38	1.11	21.95	-	-	-	-	33.33	15.79	27.35	76.48	19.00	20.00	13.50	52.50
Ougeinia oojeinensis	-	-	-	-	4.62	14.29	2.69	21.59	10.57	15.79	7.21	33.57	-	-	-	-
Phyllanthus embelica	-	-	-	-	-	-	-	-	2.44	5.26	2.06	9.76	-	-	-	-
Pinus roxburghii	60.00	23.08	87.39	170.46	-	-	-	-	-	-	-	-	-	-	-	-
Pistacia interrima	-	-	-	-	-	-	-	-	-	-	-	-	2.00	6.67	2.15	10.81
Syzygium cumini	-	-	-	-	-	-	-	-	-	-	-	-	5.00	13.33	5.41	23.75
Terminalia bellirica	-	-	-	-	-	-	-	-	0.81	5.26	2.06	8.13	-	-	-	-
Wendlandia exserta	-	-	-	-	-	-	-	-	8.94	10.53	9.85	29.32	-	-	-	-
Total	**100.00**	**100.00**	**100.00**	**300.00**	**100.00**	**100.00**	**100.00**	**300.00**	**100.00**	**100.00**	**100.00**	**300.00**	**100.00**	**100.00**	**100.00**	**300.00**
Shrubs																
Adhatoda vasica	12.07	20.00	2.62	34.69	25.00	33.33	8.96	67.29	-	-	-	-	13.33	14.29	6.91	34.53
Carissa carandas	-	-	-	-	-	-	-	-	11.63	23.08	3.26	37.97	15.56	21.43	5.71	42.69
Lantana camara	56.90	33.33	87.44	177.67	45.00	41.67	83.88	170.55	55.81	38.46	84.66	178.93	42.22	35.71	77.66	155.59
Murraya koenigii	13.79	13.33	7.06	34.18	20.00	16.67	5.65	42.32	20.93	23.08	10.56	54.57	8.89	7.14	3.95	19.99
Ricinus communis	10.34	20.00	1.23	31.57	10.00	8.33	1.51	19.85	-	-	-	-	20.00	21.43	5.77	47.20
Vitis parvifolia	-	-	-	-	-	-	-	-	11.63	15.38	1.52	28.53	-	-	-	-
Ziziphus mauritiana	6.90	13.33	1.66	21.89	-	-	-	-	-	-	-	-	-	-	-	-
Total	**100.00**	**100.00**	**100.00**	**300.00**	**100.00**	**100.00**	**100.00**	**300.00**	**100.00**	**100.00**	**100.00**	**300.00**	**100.00**	**100.00**	**100.00**	**300.00**
Herbs																
Ageratum conyzoides	15.49	24.24	18.70	58.44	57.97	60.71	71.25	189.94	100.00	100.00	100.00	300.00	60.29	55.17	72.13	187.60
Bidens pilosa	35.21	33.33	26.64	95.19	42.03	39.29	28.75	110.06	-	-	-	-	39.71	44.83	27.87	112.40
Parthenium hysterophorus	49.30	42.42	54.66	146.38	-	-	-	-	-	-	-	-	-	-	-	-
Total	**100.00**	**100.00**	**100.00**	**300.00**	**100.00**	**100.00**	**100.00**	**300.00**	**100.00**	**100.00**	**100.00**	**300.00**	**100.00**	**100.00**	**100.00**	**300.00**

embelica was reported to have lowest value for relative density (2.44 %). The maximum identical value for relative frequency (15.79 %) was recorded for *Acacia catechu, Dalbergia sissoo, Mallotus phillippensis* and *Ougeinia oojeinensis*. Whereas, the minimum value (5.26%) was recorded for *Casearia tomentosa, Phyllanthus embelica* and *Terminalia bellirica.* The maximum value for relative basal area was recorded for *Acacia catechu* (32.30 %) which was closely followed by *Mallotus phillippensis* (27.35%). However, *Phyllanthus embelica* and *Terminalia bellirica*had the lowest value for relative basal area (2.06%). The IVI of maximum value (76.48) was recorded for *Mallotus phillippensis* which was closely followed by *Acacia catechu* (72.48%) whereas, the lowest IVI value (8.13) was reported for *Terminalia bellirica.* The compartment DPFC4 is represented by *Lannea coromandelica* with highest value for relative density (35.00%) and relative basal area (38.50%), which was followed by *Acacaia catechu* (24.00%, 29.47 %) and *Mallotus phillippensis* (19.00%, 13.50%). Moreover, *Pistacia integerrima* had the lowest value of relative density (2.00%), relative basal area (2.15%) and IVI (10.81), respectively. The maximum IVI value (93.50) was reported for *Lannea coromandelica* which was followed by *Acacia catechu* (73.47).

The under-storey vegetation of compartments within Demarcated Protected Forest were extensively dominated by *Lantana camera* with IVI values of 177.67 (DPFC1), 170.55 (DPFC2), 178.93 (DPFC3) and 155.59 (DPFC4), respectively. However, in compartment DPFC1, the least dominating species was *Ziziphus maruitiana* with relative density of 6.90 %, relative frequency of 13.33 %, and relative basal area of 1.66 % and IVI value of 21.89. In compartment DPFC2, the lowest value for relative density (10%), relative frequency (8.33 %), relative basal area (1.51%) and IVI value (19.85) was recorded for *Ricinus communis*. In case of compartment DPFC3, *Adhotoda vasica* and *Vitis parvifolia* had the minimum identical value for relative density (11.63%) whereas, *Vitis parvifolia* had the lowest value of relative frequency (15.38%), relative basal area (1.52%) and IVI (28.53), respectively. In compartment DPFC4, the least dominating species was *Murraya koenigii* with relative density of 8.89%, relative frequency of 7.14%, relative basal area of 3.95% and IVI of 19.99, respectively.

In case of herb species, the compartment DPFC1was dominated by *Parthenium hysterophorus* with maximum value for relative density (49.30 %), relative frequency (42.24 %), relative basal area (54.64 %) and IVI value of 146.38. Whereas, the minimum value for relative density (15.49 %), and relative frequency (24.24 %), relative basal area (18.70 %) and IVI (58.44) was recorded for *Ageratum conyzoides*. In compartment DPFC2, a total number of two species were recorded out of which *Ageratum conyzoides* was the dominating herb with relative density of 57.97 %, relative frequency of 60.71 %, relative basal area of 71.25 % and IVI value of 189.94. The compartment DPFC3 was dominated by a single herb species i.e., *Ageratum conyzoides*. In case of compartment DPFC4, *Ageratum conyzoides* was the most dominating species with IVI value of 187.60 followed by *Bidens pilosa* with IVI value of 112.40.

Un-demarcated Protected Forest (UPF)

In compartment UPFC1 (Table 15) within Un-demarcated Protected Forest, *Mallotus phillippensis* was the most dominating tree species with maximum value for relative density (30.92 %), relative basal area (25 %) and IVI value of 73.57 which was followed by *Lannea coromandelica* (21.05 %, 24.17 % and 62.87) and *Acacia catechu* (19.74 %, 23.20 % and 60.58), respectively. However, *Pinus roxburghii* had the lowest value of relative density (4.61 %) relative basal area (6.08 %) and IVI (22.45) all were reported to have identical value (17.65 %) for relative frequency except *Pinus roxburghii* (11.76 %). In Compartment UPFC2, *Acacia catechu* contributes the maximum value for relative density (32.00 %) and relative frequency (23.08 %) which was closely followed by *Lannea coromandelica* (29.33 % and 23.08 %). Moreover, *Lannea coromandelica* had the highest value for relative basal area (34.68 %) and IVI (87.09) which was subsequently followed by *Acacia catechu* (31.79 % and 86.87 %). However, *Pinus roxburghii* had the minimum value for relative density (6.67 %) which was followed by *Mallotus phillippinensis* (15.38 %) although both species had shown the minimum frequency of 15.38 %. *Mallotus phillipinensis* also had the lowest value for relative basal area (7.52 %) and IVI (36.23), respectively. In compartment UPFC3, *Acacia catechu* was the most dominating species with maximum value for relative density (37.50 %), relative frequency (38.31 %), relative basal area (23.08 %) and IVI (98.89) which was closely followed by *Lannea coromandelica* (25 %, 23.08 %, 31.52 % and 79.60) and *Albizia lebbeck* (23.61 %, 23.08 %, 22.78 % and 69.47), respectively. Whereas, *Ficus benghalensis* had the lowest value for relative density (1.39 %) with relative frequency of 7.69 %, relative basal area of 0.40 % and IVI value of 9.48, respectively. In case of compartment UPFC4 also *Acacia catechu* was the dominating tree species with highest value for relative density (40.85 %), relative frequency (27.27 %), relative basal area (37.81 %) and IVI (105.92) which was followed by *Lannea coromandelica*. However; *Phyllanthus embelica* had the lowest value for relative density (2.82 %), relative frequency (9.09 %), relative basal area (1.96 %) and IVI (13.87) respectively. The understory shrub vegetation of Un-demarcated Protected Forest in

Table 15: Phyto-sociological studies of Un-demarcated Protected Forest (UPF) in Khair working circle of Nurpur Forest Division, Himachal Pradesh

Species	UPFC1				UPFC2				UPFC3				UPFC4			
	RD	RF	RBA	IVI	RD	RF	RBA	IVI	RD	RF	RBA	IVI	RD	RF	RBA	IVI
Trees																
Acacia catechu	19.74	17.65	23.20	60.58	32.00	23.08	31.79	86.87	37.50	23.08	38.31	98.89	40.85	27.27	37.81	105.92
Aeglemarmelos	-	-	-	-	-	-	-	-	4.17	7.69	2.11	13.97				
Albizialebbeck	-	-	-	-	-	-	-	-	23.61	23.08	22.78	69.47	21.13	27.27	21.60	70.00
Cassia fistula	14.47	17.65	13.71	45.83	18.67	23.08	10.49	52.23	-	-	-	-	-	-	-	-
Dalbergia sissoo	9.21	17.65	7.84	34.70	-	-	-	-	-	-	-	-	-	-	-	-
Ficusbenghalensis	-	-	-	-	-	-	-	-	1.39	7.69	0.40	9.48	-	-	-	-
Flacourtiaindica	-	-	-	-	-	-	-	-	5.56	7.69	3.56	16.81	-	-	-	-
Lanneacoromandelica	21.05	17.65	24.17	62.87	29.33	23.08	34.68	87.09	25.00	23.08	31.52	79.60	29.58	27.27	35.00	91.85
Mallotusphillippensis	30.92	17.65	25.00	73.57	13.33	15.38	7.52	36.23	-	-	-	-	5.63	9.09	3.64	18.36
Phyllanthusembelica	-	-	-	-	-	-	-	-	2.78	7.69	1.32	11.79	2.82	9.09	1.96	13.87
Pinusroxburghii	4.61	11.76	6.08	22.45	6.67	15.38	15.53	37.58	-	-	-	-	-	-	-	-
Total	**100.00**	**100.00**	**100.00**	**300.00**	**100.00**	**100.00**	**100.00**	**300.00**	**100.00**	**100.00**	**100.00**	**300.00**	**100.00**	**100.00**	**100.00**	**300.00**
Shrubs																
Adhatodavasica	-	-	-	-	-	-	-	-	10.81	18.18	3.04	32.03	21.05	23.08	5.53	49.66
Carissa carandas	6.90	14.29	3.48	24.67	13.89	27.27	5.68	46.84	-	-	-	-	-	-	-	-
Cissampelospariera	-	-	-	-	-	-	-	-	5.41	9.09	0.11	14.61	-	-	-	-
Lantana camara	48.28	28.57	85.89	162.74	69.44	45.45	87.31	202.21	64.86	36.36	93.13	194.36	57.89	38.46	88.68	185.03
Murraya koenigii	17.24	21.43	6.82	45.49	11.11	18.18	4.24	33.53	8.11	18.18	2.63	28.92	13.16	23.08	4.44	40.67
Ricinuscommunis	13.79	14.29	2.26	30.34	-	-	-	-	5.41	9.09	0.55	15.05	-	-	-	-
Ziziphusmauritiana	13.79	21.43	1.55	36.77	5.56	9.09	2.77	17.42	5.41	9.09	0.53	15.03	7.89	15.38	1.36	24.64
Total	**100.00**	**100.00**	**100.00**	**300.00**	**100.00**	**100.00**	**100.00**	**300.00**	**100.00**	**100.00**	**100.00**	**300.00**	**100.00**	**100.00**	**100.00**	**300.00**
Herbs																
Achyranthesaspera	-	-	-	-	9.86	17.65	14.32	41.82	3.23	7.14	5.48	15.85	-	-	-	-
Ageratum conyzoides	27.78	25.64	31.37	84.79	36.62	38.24	36.54	111.40	58.06	46.43	65.09	169.58	65.22	43.33	69.91	178.46
Bidenspilosa	16.67	25.64	8.80	51.10	-	-	-	-	32.26	35.71	19.23	87.20	26.09	33.33	17.33	76.75
Cassia tora	-	-	-	-	-	-	-	-	6.45	10.71	10.20	27.36	8.70	23.33	12.76	44.79
Partheniumhysterophorus	55.56	48.72	59.83	164.11	53.52	44.12	49.14	146.78	-	-	-	-	-	-	-	-
Total	**100.00**	**100.00**	**100.00**	**300.00**	**100.00**	**100.00**	**100.00**	**300.00**	**100.00**	**100.00**	**100.00**	**300.00**	**100.00**	**100.00**	**100.00**	**300.00**

different compartment was dominated by *Lantana camara* and the IVI value under different compartment is as follow:162.74 (UPFC1), 202.21 (UPFC2), 194.36 (UPFC3) and 185.03 (UPFC4), respectively. In compartment UPFC1, the lowest value for relative density (6.90%) with 14.29% of relative frequency and IVI value of 24.67 was reported for *Carissa carandas*. However, the lowest value for relative basal area (1.55%) was reported for *Ziziphus mauritiana*. In compartment UPFC2, *Ziziphus mauritiana* had the lowest value for relative density (5.56%), relative frequency (9.09%), relative basal area (2.77%) and IVI (17.42), respectively.

The minimum value for relative density (5.41%) and frequency (9.09%) in compartment UPFC3 was recorded identical for *Cissampelos pariera*, *Ricinus communis* and *Ziziphus marutiana*. Whereas, *Cissampelos pariera* had the minimum value for relative basal area (0.11 %) and IVI (14.61). *Ziziphus mauritiana* was the least dominating shrub in compartment UPFC4 with relative density of 7.89 %, relative frequency of 15.38 %, and relative basal area of 1.36 % and IVI value of 24.64, respectively.

In case of herb species, a total number 3 species were recorded in compartment UPFC1. Among them *Parthenium hysterophorus* had the maximum relative density of 55.56 % with relative frequency of 48.72 %, relative basal area of 59.83 % and IVI value of 164.11. Whereas; *Bidens pilosa* was the least dominating species with IVI value of 51.10. In compartment UPFC2, *Parthenium hysterophorus* with maximum value for relative density (53.52 %), relative frequency (44.12 %), relative basal area (49.14 %) and IVI value (146.78) was recorded. Whereas, the minimum value was recorded for *Achyranthes aspera*. The compartment UPFC3 was dominated by *Ageratum conyzoides* with IVI value of 169.58 followed by *Bidens pilosa* (87.20) whereas, *Achyranthes aspera* was reported to have lowest IVI value of 15.85. The compartment RFC4 had the total number of three species from which *Ageratum conyzoides* had the maximum value for relative density (65.22 %), relative frequency (43.33 %), relative basal area (69.91 %) and IVI value of 178.46, respectively. Whereas, *Cassia tora* was the leas contributing species with IVI value of 44.79.

Co-operative Forest Society Forest (CFSF)

The compartment CFSC1 falling under Co-operative Forest Society (Table 16) was dominated by *Acacia catechu* with maximum value for relative density (43.55 %), relative basal area (44.39 %) and IVI value of 107.94 followed by *Lannea coromandelica* (24.19 %, 32.87 % and 77.06) and *Leucaena leucocephala* (11.29 %, 8.55 % and 33.17), respectively.

However, *Morus alba* was the least contributing species with IVI value of 8.80. In Compartment CFSC2 also, *Acacia catechu* was the most contributing species in term of maximum value for relative density (42.11 %) and relative basal area (43.12 %) and IVI (103.98), respectively. This was followed by *Lannea coromandelica* with IVI value of 65.43. Further, *Ficus glomerata* had the minimum value for relative density (1.75 %) relative frequency (6.25 %), relative basal area (1.31 %) and IVI value of 9.31, respectively. The compartment CFSC3 comprise of five tree species of which *Acacia catechu* had the highest contribution of 40.19 % in relative density, 23.08 % in relative frequency, 41.98 % in relative basal area and 105.25 % in IVI, respectively. Whereas, *Aegle marmelos* was the least contributing species having the lowest value for relative density (1.87 %), relative frequency (7.69 %), relative basal area (1.23 %) and IVI value (10.79), respectively. The compartment CFSFC4 was represented by *Acacia catechu* with maximum value for relative density (48.65 %), relative frequency (30.00 %), relative basal area (53.78 %) and IVI (132.43), the maximum value for relative density was followed by *Dalbergia sissoo* (29.73 %) whereas, the relative basal area was followed by *Lannea coromandelica* (23.98 %).The minimum value for relative density (2.70 %), relative frequency (10.00 %), relative basal area (2.68 %) and IVI (15.38) was recorded for *Ficus palmata*.

The understory shrub vegetation of Cooperative Forest Society in compartment CFSC1 was dominated by *Lantana camara* with highest relative density of 67.50 %; relative frequency of 44.44 %; relative basal area of 92.06 % and IVI value of 204.00. However; the least dominating species was *Carissa carandas* with IVI value of 204.00. In compartment CFSC2, a total number of five species of shrubs were recorded of which *Lantana camera* had the maximum value for relative density (54.35 %), relative frequency (36.36 %), relative basal area (84.53 %) and IVI (175.25). The lowest identical value for relative density (8.70 %) was recorded for *Ipomoea* and *Ricinus communis*. However; the minimum percent relative basal area (0.91 %) was recorded for *Ricinus communis.* The lowest value for relative frequency (9.09 %) and IVI (21.92) was displayed by *Ipomoea*. The compartment CFSC3 was also dominated by *Lantana camera* with relative density of 57.89 %, relative frequency of 36.36 %, relative basal area of 84.53 % and IVI value of 178.79, respectively. Whereas, the minimum value was recorded for *Ipomoea*. In compartment CFSC4, *Lantana camera* was the most contributing shrub species with maximum IVI value of 161.29. Whereas, the lowest value for relative density (7.69 %) was recorded identical for *Adhatoda vasica*, *Ipomoea*, and

Table 16: Phyto-sociological studies of Co-operative Forest Society (CFS) in Khair working circle of Nurpur Forest Division, Himachal Pradesh

Species	CFSFC1				CFSFC2				CFSFC3				CFSFC4			
	RD	**RF**	**RBA**	**IVI**	**RD**	**RF**	**RBA**	**IVI**	**RD**	**RF**	**RBA**	**IVI**	**RD**	**RF**	**RBA**	**IVI**
Trees																
Acacia catechu	43.55	20.00	44.39	107.94	42.11	18.75	43.12	103.98	40.19	23.08	41.98	105.25	48.65	30.00	53.78	132.43
Aeglemarmelos	-	-	-	-	-	-	-	-	1.87	7.69	1.23	10.79	-	-	-	-
Broussonetiapapyrifera	-	-	-	-	5.26	12.50	4.37	22.13	-	-	-	-	-	-	-	-
Cassia fistula	-	-	-	-	14.04	18.75	8.06	40.85	23.36	23.08	18.42	64.87	-	-	-	-
Dalbergiasissoo	-	-	-	-	14.04	18.75	9.62	42.40	-	-	-	-	29.73	30.00	19.55	79.28
Ficusglomerata	4.84	13.33	5.70	23.87	1.75	6.25	1.31	9.31	-	-	-	-	-	-	-	-
Ficuspalmata	-	-	-	-	-	-	-	-	-	-	-	-	2.70	10.00	2.68	15.38
Lanneacoromandelica	24.19	20.00	32.87	77.06	19.30	18.75	27.38	65.43	6.54	23.08	19.66	49.28	18.92	30.00	23.98	72.90
Leucaenaleucocephala	11.29	13.33	8.55	33.17	-	-	-	-					-	-	-	-
Mallotusphillippensis	6.45	6.67	3.20	16.32	-	-	-	-	28.04	23.08	18.70	69.82	-	-	-	-
Morus alba	1.61	6.67	0.52	8.80	-	-	-	-	-	-	-	-	-	-	-	-
Syzygiumcumini	-	-	-	-	3.51	6.25	6.14	15.90	-	-	-	-	-	-	-	-
Xylosmalongifolium	8.06	20.00	4.78	32.84	0.00	0.00	0.00	0.00	-	-	-	-	-	-	-	-
Total	**100.00**	**100.00**	**100.00**	**300.00**	**100.00**	**100.00**	**100.00**	**300.00**	**100.00**	**100.00**	**100.00**	**300.00**	**100.00**	**100.00**	**100.00**	**300.00**
Shrubs																
Adhatodavasica	15.00	33.33	4.59	52.92	15.22	18.18	5.25	38.65	13.16	18.18	4.95	36.29	17.95	16.67	6.70	21.66
Carissa carandas	17.50	22.22	3.35	43.08	8.70	9.09	4.13	21.92	7.89	18.18	1.65	27.72	7.69	16.67	1.85	41.32
Ipomoea	-	-	-	-	-	-	-	-	-	-	-	-	7.69	11.11	2.85	26.21
Lantana camara	67.50	44.44	92.06	204.00	54.35	36.36	84.53	175.25	57.89	36.36	84.53	178.79	48.72	27.78	84.80	161.29
Murraya koenigii	-	-	-	-	13.04	18.18	5.17	36.40	21.05	27.27	8.87	57.20	7.69	11.11	2.54	21.34
Ricinuscommunis	-	-	-	-	8.70	18.18	0.91	27.79	-	-	-	-	10.26	16.67	1.26	28.18
Total	**100.00**	**100.00**	**100.00**	**300.00**	**100.00**	**100.00**	**100.00**	**300.00**	**100.00**	**100.00**	**100.00**	**300.00**	**100.00**	**100.00**	**100.00**	**300**
Herbs																
Achyranthesaspera	-	-	-	-	37.74	38.89	58.50	135.12	-	-	-	-	19.05	20.00	30.78	60.21
Ageratum conyzoides	100.00	100.00	100.00	300.00	-	-	-	-	34.12	36.36	40.74	111.22	37.14	40.00	48.34	126.07
Bidenspilosa	-	-	-	-	62.26	61.11	41.50	164.88	23.53	27.27	14.57	65.37	43.81	40.00	20.89	113.72
Partheniumhysterophorus	-	-	-	-	-	-	-	-	42.35	36.36	44.69	123.41	-	-	-	-
Total	**100.00**	**100.00**	**100.00**	**300.00**	**100.00**	**100.00**	**100.00**	**300.00**	**100.00**	**100.00**	**100.00**	**300.00**	**100.00**	**100**	**100**	**300**

Murraya koenigii. Furthermore, the minimum percent relative basal area (1.26 %) was recorded for *Ricinus communis*. The lowest value for IVI (21.34) was recorded minimum for *Murraya koenigii.*

In case of herb species, the compartment CFSC1 was fully dominated by single species (*Ageratum conyzoides*). In compartment CFSC2, a total number of two species were found of which *Bidens pilosa* have the maximum relative density (62.26 %), relative frequency (61.11 %), relative basal area (41.50 %) and IVI value (164.88) which was followed by *Achyranthes aspera* with IVI value of 135.12, respectively. The compartment CFSC3 was documented with three herb species of which *Parthinium hysterophorus* was the most dominating with maximum relative density of 42.35 %, relative frequency of 36.36 %, relative basal area of 44.69 % and IVI value of 123.41. However, the lowest value was displayed by *Bidens pilosa*. In compartment CFSC4, *Bidens pilosa* had the maximum value for relative density (43.81 %) and relative frequency (40.00 %) although it also displayed the minimum value for relative basal area (20.89 %). *Ageratum conyzoides* had the maximum relative basal area (48.34 %) with maximum IVI value of 126.07. Whereas, *Achyranthes aspera* was the least dominating herb with IVI value of 60.21.

Un-class (UF)

The compartment UFC1 within Un-class Forest (Table 17) was comprised of three species of which *Acacia catechu* had maximum relative density (84.52 %), relative frequency (50.00 %) relative basal area (83.12 %) and IVI value of 217.64. Whereas, *Terminalia bellirica* was the least dominating species with IVI value of 20.98. In Compartment UFC2, *Acacia catechu* contributes the maximum value for relative density (38.10 %), relative frequency (20.00 %) and relative basal area (48.28 %) with maximum IVI value of 106.37, respectively. However, *Xylosma longifolium and Stephegyne parvifolia* had the minimum identical value for relative density (0.95 %) and relative frequency (6.67 %%). The minimum value for relative basal area (0.35 %) and IVI (7.97) was reported for *Stephegyne parvifolia*. The compartment UFC3 was also dominated by *Acacia catechu* with maximum relative density of 80.43 %, relative frequency of 50.00 %, relative basal area of 56.58 % and IVI value of 187.02, respectively. Whereas, *Cassia fistula, Lannea coromandelica* and *Mallotus phillippensis* had the lowest identical value for relative density (6.52 %) and relative frequency (16.67 %). The minimum value for relative basal area (5.45 %) and IVI (28.64)

Table 17: Phyto-sociological studies of Un-class Forest (UF) in Khair working circle of Nurpur Forest Division, Himachal Pradesh

Species	UFC1				UFC2				UFC3				UFC4			
	RD	**RF**	**RBA**	**IVI**	**RD**	**RF**	**RBA**	**IVI**	**RD**	**RF**	**RBA**	**IVI**	**RD**	**RF**	**RBA**	**IVI**
Trees																
Acacia catechu	84.52	50.00	83.12	217.64	38.10	20.00	48.28	106.37	80.43	50.00	56.58	187.02	64.71	21.43	42.66	128.79
Cassia fistula	-	-	-	-	24.76	20.00	24.40	69.16	6.52	16.67	7.70	30.89	13.73	21.43	10.69	45.84
Eucalyptus globulus	-	-	-	-	2.86	6.67	6.34	15.86	-	-	-	-	-	-	-	-
Ficus benghalensis	-	-	-	-	-	-	-	-	-	-	-	-	0.98	7.14	0.20	8.32
Lannea coromandelica	-	-	-	-	3.81	13.33	4.54	21.68	6.52	16.67	30.26	53.45	6.86	14.29	11.55	32.70
Mallotus phillippensis	14.29	33.33	13.76	61.37	26.67	20.00	14.68	61.34	6.52	16.67	5.45	28.64	0.98	7.14	0.13	8.25
Pinus roxburghii	-	-	-	-	-	-	-	-	-	-	-	-	11.76	21.43	34.56	67.75
Pyrus pashia	-	-	-	-	1.90	6.67	0.84	9.41	-	-	-	-	-	-	-	-
Stephegyne parvifolia	-	-	-	-	0.95	6.67	0.35	7.97	-	-	-	-	-	-	-	-
Terminalia bellirica	1.19	16.67	3.12	20.98	-	-	-	-	-	-	-	-	-	-	-	-
Xylosma longifolium	-	-	-	-	0.95	6.67	0.58	8.20	-	-	-	-	0.98	7.14	0.22	8.34
Total	**100.00**	**100.00**	**100.00**	**300.00**	**100.00**	**100.00**	**100.00**	**300.00**	**100.00**	**100.00**	**100.00**	**300.00**	**100.00**	**100.00**	**100.00**	**300.00**
Shrubs																
Adhatodav asica	16.67	25.00	6.25	47.91	17.07	20.00	6.18	43.25	17.39	30.00	5.95	53.34	16.28	15.38	5.68	37.35
Carissa carandas	14.29	16.67	7.36	38.31	9.76	20.00	5.39	35.14	-	-	-	-	11.63	15.38	5.41	32.42
Cissampelos pareira	-	-	-	-	7.32	13.33	0.20	20.85	-	-	-	-	4.65	7.69	0.10	12.45
Lantana camara	50.00	33.33	80.17	163.51	51.22	33.33	81.54	166.09	60.87	30.00	87.38	178.25	53.49	38.46	82.69	174.64
Murraya koenigii	19.05	25.00	6.22	50.27	14.63	13.33	6.70	34.67	15.22	30.00	6.06	51.28	13.95	23.08	6.12	43.15
Vitis parviflora	-	-	-	-	-	-	-	-	6.52	10.00	0.61	17.14	-	-	-	-
Total	**100.00**	**100.00**	**100.00**	**300.00**	**100.00**	**100.00**	**100.00**	**300.00**	**100.00**	**100.00**	**100.00**	**300.00**	**100.00**	**100.00**	**100.00**	**300.00**
Herbs																
Ageratum conyzoides	34.72	37.93	35.21	107.87	33.63	27.03	41.46	102.11	54.79	30.43	54.90	140.13	42.25	42.11	47.81	132.17
Bidens pilosa	-	-	-	-	25.66	21.62	15.43	62.71	-	-	-	-	16.90	15.79	9.53	42.22
Cassia tora	-	-	-	-	-	-	-	-	13.70	34.78	17.14	65.62	-	-	-	-
Parthenium hysterophorus	48.61	48.28	43.67	140.56	35.40	43.24	40.38	119.02	31.51	34.78	27.96	94.25	40.85	42.11	42.66	125.61
Polystichum	-	-	-	-	5.31	8.11	2.74	16.15	-	-	-	-	-	-	-	-
Polygonum hydropiper	16.67	13.79	21.11	51.57	-	-	-	-	-	-	-	-	-	-	-	-
Total	**100.00**	**100.00**	**100.00**	**300.00**	**100.00**	**100.00**	**100.00**	**300.00**	**100.00**	**100.00**	**100.00**	**300.00**	**100.00**	**100.00**	**100.00**	**300.00**

Table 18: Diversity indices of trees, shrubs and herbs among different forest classes in Khair working circle of Nurpur Forest Division, Himachal Pradesh

Diversity indices	Trees					Shrubs					Herbs				
	RF	DPF	UPF	CFSF	UF	RF	DPF	UPF	CFSF	UF	RF	DPF	UPF	CFSF	UF
Simpson concentration of dominance index (Cd)	0.2	0.16	0.2	0.25	0.44	0.35	0.31	0.4	0.37	0.35	0.35	0.5	0.33	0.3	0.33
Simpson diversity index(D)	0.8	0.84	0.8	0.75	0.56	0.65	0.69	0.6	0.63	0.65	0.65	0.5	0.67	0.7	0.67
Shannon Wiener Index of diversity (H´)	1.91	2.13	1.85	1.78	1.24	1.45	1.48	1.32	1.3	1.31	1.24	0.85	1.25	1.29	1.29
Menheink index of species richness (Mel)	0.85	0.87	0.63	0.82	0.66	0.16	0.11	0.13	0.11	0.1	0.02	0.02	0.03	0.02	0.03
Margalef Index of species richness (MI)	2.68	2.58	1.75	2.18	1.78	0.99	0.73	0.76	0.62	0.61	0.37	0.19	0.39	0.29	0.48
Pielou Equitability (Ep)	0.67	0.77	0.77	0.69	0.52	0.66	0.76	0.68	0.73	0.73	0.77	0.78	0.78	0.93	0.72
Species heterogeneity (Hg)	0.44	0.39	0.44	0.5	0.66	0.59	0.56	0.63	0.61	0.59	0.59	0.71	0.57	0.55	0.57

was recorded for *Mallotus phillippensis*. A total number of seven tree species were recorded in compartment UFC4 of which *Acacia catechu* was the most dominating tree species with highest value for relative density (64.71 %), relative frequency (21.43 %), relative basal area (42.66 %) and IVI (128.79). The maximum relative density was followed by *Cassia fistula* and *Pinus roxburghii*. Whereas, the minimum identical value for relative density (0.98 %), and relative frequency (7.14 %) was reported for *Ficus benghalensis, Mallotus phillippensis* and *Xylosma longifolium*. The minimum value for relative basal area (0.13 %) and IVI (8.25) was recorded for *Mallotus phillippensis*. The shrub vegetation of compartment UFC1, UFC2 UFC3 and UFC4 were dominated by *Lantana camara* with maximum IVI value of 163.51, 166.09, 178.25 and 174.64, respectively. Whereas; the least dominating shrub species in UFC1 was *Carissa carandas* (IVI 38.31). In compartment UFC2 *Cissampelos pareira* had the lowest IVI value (20.85). Whereas, in compartment UFC3 *Vitis parviflora* (17.14) and in UFC4 *Cissampelos pareira* (12.45) was the least dominating shrub. In case of herb species, a total number of three species were recorded in compartment UFC1among of which *Parthinium hysterophorus* had the maximum relative density (48.61 %), relative frequency (48.28 %), relative basal area (43.67 %) and IVI (140.56), respectively. However; *Polygonum hydropiper* was the least dominating species with IVI value of 51.57. In compartment UFC2 a total number of four species was recorded. In this compartment *Parthenium hysterophorus* had the maximum value for relative density and IVI (35.40 % and 119.02) which was followed by *Ageratum conyzoides* (27.03 % and 102.11) with maximum relative basal area of 41.46 %. The minimum value of relative density (5.31 %), relative frequency (8.11 %), relative basal area (2.74 %) and IVI (16.15) was recorded for *Polystichum*. The compartment UFC3 was documented with three species of which *Ageratum conyzoides* had the maximum relative density of 54.79 %, relative basal area of 54.90 %and IVI value of 140.13. However, the least dominating shrub species was *Cassia tora* with IVI value of 65.62. The compartment UFC4 had the total number of three species form which *Ageratum conyzoides* was the most dominating herb species with IVI value of 132.17 which was followed by *Parthinium hysterophorus* respectively. However, *Bidens pilosa* was the least dominating herb with IVI value of 42.22.

4.3 Diversity Indices

The diversity indices of trees, shrubs and herbs shown in Table 18 depicts that the Shannon Index of diversity (H') for trees ranged from 2.13 (DPF) to 1.24 (UF), for shrub 1.48 (DPF) to 1.30 (CFS) and for herbs 1.29 (CFS, UF) to 0.85 (UF). The Simpson Index of diversity (D) ranged for trees from 0.84 (DPF) to 0.56 (UF), for shrub 0.69 (DPF) to 0.60 (UPF) and for herbs 0.70(CFS) to 0.50(DPF); the Simpson Index of dominance (Cd) for trees ranges from 0.44 (UF) to 0.16 (DPF), for shrub 0.40 (UPF) to 0.31 (DPF) and for herbs 0.50 (DPF) to 0.30 (CFS). Pielou's Equitability (Eq) varied from 0.77 (DPF, UPF) to 0.52 (UF) for trees,0.76 (DPF) to 0.66 (RF) for shrub and 0.93 (CFS) to 0.72 (UF) for herbs respectively; Margalef's Index of richness (MI) ranged for trees from 2.68 (RF) to 1.75 (UPF), for shrub 0.99 (RF) to 0.61 (UF) and for herbs 0.48 (UF) to 0.19 (DPF) and Species Heterogeneity (Hg) for trees ranges from 0.66 (UF) to 0.39 (DPF), for shrub 0.63 (UPF) to 0.56 (DPF) and for herbs 0.71 (DPF) to 0.55 (CFS), respectively.

Protected areas are the vital for conservation of biodiversity and minimizing biodiversity loss (Birben, 2019; Geldmann *et al.,* 2019 and Hoffmann *et al.,* 2018). However, the effectiveness of any protected area in biodiversity conservation depends on how a particular protected area is governed or managed (Cazalis *et al*., 2020). The variation between and within each forest class can be clearly seen in term of floristic distribution, density, basal area, IVI and diversity indices. This heterogeneity within and between forest classes signifies the different forest management regimes in term of forest classes and further their division into different compartments. In our study the tree density of 506.67 – 153.33 number ha^{-1} having basal area of 5.44 to 25.35 m^2 ha^{-1} were recorded. The basal area and stem density documented in response to forest class can represent the stand structure and is also a useful indicator of human impact on a forest stand (Ingram *et al.,* 2005). Chandra (2009) also observed the similar range for tree density (470 to 700 trees ha^{-1}) in miscellaneous forest in Tarai region of Kumaon Himalaya. However, the basal area recorded in present study is higher than 2325.0 to 2974.7 cm^2. Further, the difference in density and basal area may be attributed to the species composition, age structure and degree of disturbance (Sundarapandian and Swamy, 1997). Lal et al. (2015) studied the species composition in natural and plantation forests of sub-humid tropics in Barnawapara Wildlife Sanctuary where they reported a total of 33 tree species of 17 families which is near to findings of present study where we found 29 tree species belonging to 14 families. The range for total basal area and stand density from the present study had shown similar results with the earlier studies of Kukshal *et al.* (2009) from the tropical forest and (Akash *et al.,* 2018). The Shannon diversity Index (*H′*) for Indian forests ranged from 0.83 to 4.1 (Devi and Yadava, 2006). The value of the Shannon diversity Index (*H′*) in present study therefore lays within the range reported for tropical forests. The tree species diversity (*H′*) was reported higher in Demarcated Protected

Forest closely followed by Reserve Forest and Un-demarcated Protected Forest than in Un-class Forest and Co-operative Forest Society. This trend could be attributed to the management practice that restricts people from un-authorized access in DPF, RF and UPF leading to minimal species disturbance. However, inadequate resources could also be a reason for degradation leading to lower species diversity and composition in the Un-class forest and Co-operative Forest Society. The Shannon-Weaver diversity index values of 2.13 for DPF and 1.24 for UF were within and closer to the range of the values (1.85–5.68) reported from different tropical forests of the Eastern Ghats of India (Kadavul and Parthadarathy, 1999; Chittibabu and Parthadarathy, 2000; Reddy *et al.,* 2011; Panda *et al.,* 2013 and Naidu and Kumar, 2016). The value in current study was also found to be closer compared to the value (1.85–2.05) reported for tropical forests of Odisha (Panda *et al.,* 2013). This suggests that the forest managed under different practices, have had a significant influence on diversity and heterogeneity between the forest classes. The lower value of Simpson index indicates the better species diversity in an area. The lowest Simpson index value was found for the DPF (0.16). On the other hand, the higher value of Simpson index was calculated for UF (0.44) and CFS (0.25). In terms of relative frequency, *Acacia catechu* was found highly dispersed tree species followed by *Mallotus phillippensis, Cassia fistula, Lannea coromandelica and Pinus roxburghii* whereas, the rest of the other species exhibit accidental population structure. Findings of Biswas and Mukhopadhyay (2016) on sociology of plants in developing conservation and management strategies for forests suggest that the anthropogenic activities greatly influence the vegetation structure in term of Simpson dominance index and richness. They reported maximum value for Simpson dominance index in area with maximum disturbance whereas, the richness was higher in area with least disturbance. This study may have the fact to support the findings of present study for higher value of Simpson. The phyto-sociological attributes and diversity indices of differently managed forest are comparable with the other findings of community managed forests and government managed forests of Bangladesh. All over the world, the protected forests are considered to be the hotspots of plant biodiversity. The Demarcated Protected Forest showed rich floristic diversity as compared to other forest class. Shinwari and Khan (2000) conducted similar study on Margalla Hill and reported diverse plant communities in three different sites of same location and more floristic diversity was recorded in protected forest as compared to unprotected forest. They clearly indicate that species diversity among different forest types is the clear reflection of anthropogenic influences. The influence of anthropogenic effects was minimum in the reserved forest. Our results are in agreement with Shinwari and Khan (2000), they reported two different plant communities from Reserved and two unreserved forests. Rich floral diversity, species richness and maturity were recorded in reserved forest as compared to unreserved forest. The un-class and co-operative society forest showing highly disturbed habitat, which may be the main cause of scarcity of species diversity. Our findings show greater tree diversity in Protected Forest as compared to Reserve Forest. This may be explained as the tree diversity of the Reserved Forest reaching at climax through ecological succession. Only selected trees species exist in the Reserved Forest. Many tree species disappeared during the process of ecological succession. Moreover, in un-class and cooperative forest trees of human interest are cultivated. This ultimately increases the number of species dominance in the area. Aime *et al.* (2015) also reported higher Shannon diversity index in Yapo protected forest (5.78) and natural voluntary reserve (5.06) than in community forests (4.64). However, the evenness did not differ between Yapo protected forest (0.81) and community forests (0.83) but it differed significantly in natural voluntary reserve (0.71). In our study the maximum evenness for trees was reported for DPF and UPF (0.77) followed by CFS (0.69) and RF (0.67) however, the minimum value for evenness was recorded in UF (0.52). The apparent similarity in species evenness (Ep) distribution in the two habitats (DPF and UPF) was probably due to the spatial patterns of stands that enable them to effectively utilize resources such as sunlight, soil fertility, and species coexistence from the same functional group. However, our study contradicts the findings of Pradhan *et al.* (2019) where they reported greater species richness, density and diversity in sacred groove forest managed by local community as compared to the wildlife sanctuary. This was due to the awareness, religious believe and participation of local people in forest management activities which was opposite to our findings, the minimum species diversity and richness was recorded in Un-class and community managed forest which may be due to high anthropogenic pressure on forest.

The maximum value for shrub dominance index and heterogeneity was recorded in UPF whereas, the diversity index and evenness were maximum in DPF. The RF was reported to have maximum species richness. However, in case of herbs the diversity indices and evenness were maximum in CFS, the forest class UF was reported have rich diversity indices. The maximum dominance for herb was recorded in DPF. All these trends may indicate the influence of different forest management regimes. Beside this the dominance of *Lantana camera* behaving like an invasive plant could be another possible reason for the observed trend and lower shrub and herb diversity of different forest classes. The contribution in basal area and dominance of lantana self-explained its effect in native shrub and herb diversity. The drastically reduced native species diversity, evenness and richness of forest in Shiwalik hills of northwestern Himalaya due to invasion by exotics were reported by Dogra *et al.* (2009). Similar, patterns were observed in the case of riparian forests, where decrease in species richness was reported due to *Lantana camara* invaded localities. In different compartments *Lantana camera* had the maximum share of relative basal area as compare to other shrubs and herbs. Besides this, there was a decrease in density, frequency and basal area of other species with the increase in lantana density and basal area. This may be attributed to thick monoculture of *Lantana camara* that alter the microenvironment beneath its thickets, and inhibit the germination and growth of other species (Sharma and Raghubanshi, 2007). Many researchers supported the progressive reduction in density and Shannon diversity Index of native vegetation from undisturbed to highly disturbed (Rao *et al.,* 1990; Bhuyan *et al.,* 2003 and Mishra *et al*., 2004).

4.4 Stand structure

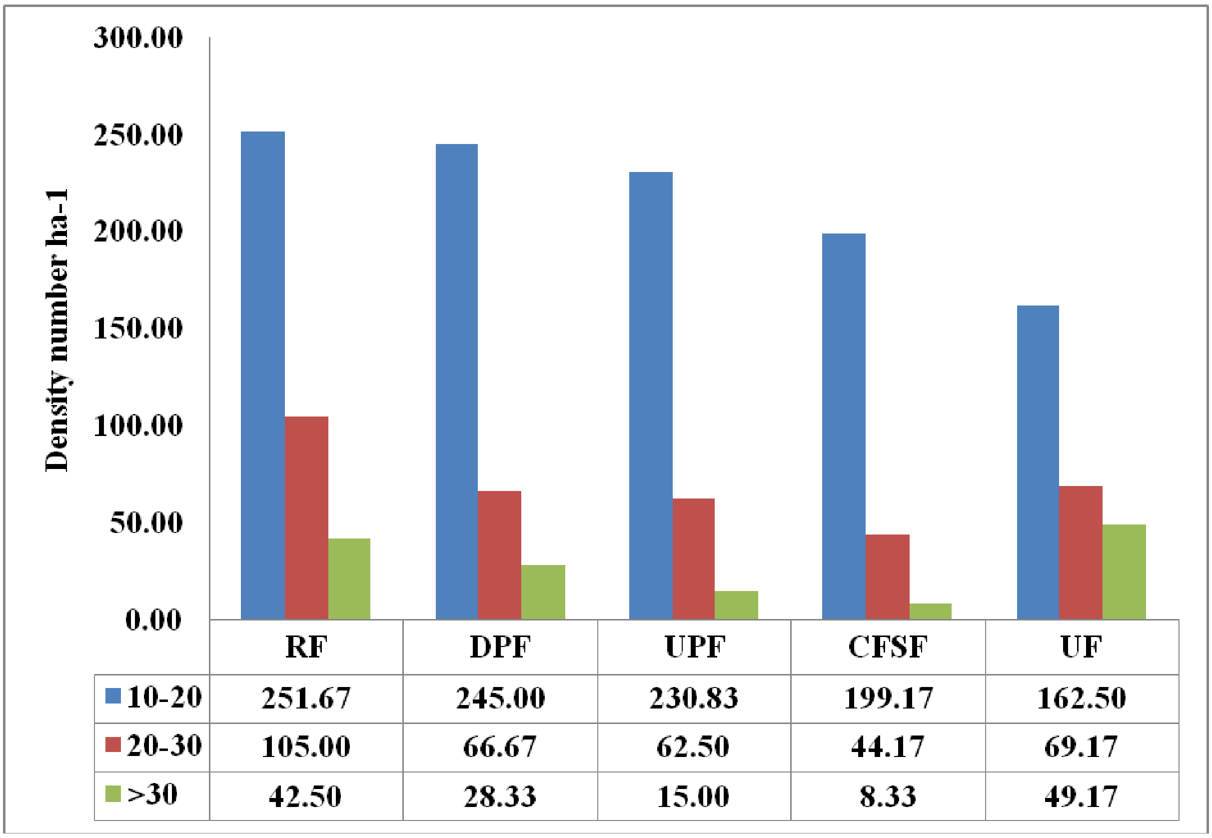
The stand structure within and between the forest class is based on distribution of tree diameter classes (Table 19). In case of Reserve Forest, a total tree density of 363.33 number ha^{-1}were recorded in RFC1 of which the majority of distribution (236.67 number ha^{-1}) was in D1 diameter class followed by D2 (110.00 number ha^{-1}) and D3 (16.67 number ha^{-1}) respectively. The total tree density of 323.33 number $ha^{-1}$was recorded in compartment RFC2 of which diameter class D1 (243.33 number ha^{-1}) had the maximum contribution followed by D3 (50.00 number ha^{-1}) and D2 (30.00 number ha^{-1}) respectively. Similar to compartment RFC1 the compartment RFC3 and RFC4 follow the same trend for distribution of trees among diameter classes having a total density of 503.33 and 406.67 number ha^{-1}. The distribution pattern of tree in diameter classes under compartment DPFC1 of DPF was opposite to other compartment where the maximum number of trees were recorded in D3(103.33 number ha^{-1}) followed by D1 (53.33 number ha^{-1}) and D2 (26.67 number ha^{-1}). However, in compartment DPFC2 and DPFC3 the majority of trees were present in diameter class D1 (333.33 and 343.33 number ha^{-1}) followed by D2 (93.33 and 63.33 number ha^{-1}) and very few individuals in D3 (6.67 and 3.33 number ha^{-1}), respectively. However, the distribution of tree under compartment DPFC4 had been restricted from D1 (250.00 number ha^{-1}) to D2 (83.33 number ha^{-1}). Similarly, in Un-demarcated Protected Forest, among the total density of 506.67 individual ha^{-1}in UPFC1, the majority of trees were present in

Table 19: Stand structure of compartments under different forest classes in Khair working circle of Nurpur Forest Division, Himachal Pradesh

Forest Class	Diameter class (cm)	Compartments			
		C1	C2	C3	C4
RF	10-20 (D_1)	236.67	243.33	270	256.67
	20-30 (D_2)	110	30	166.67	113.33
	>30(D_3)	16.67	50	66.67	36.67
	Total	**363.33**	**323.33**	**503.33**	**406.67**
DPF	10-20 (D_1)	53.33	333.33	343.33	250
	20-30 (D_2)	26.67	93.33	63.33	83.33
	>30(D_3)	103.33	6.67	3.33	-
	Total	**183.33**	**433.33**	**410**	**333.33**
UPF	10-20 (D_1)	483.33	166.67	130	143.33
	20-30 (D_2)	23.33	66.67	76.67	83.33
	>30(D_3)	-	16.67	33.33	10
	Total	506.67	250	240	236.67
CFSF	10-20 (D_1)	150	143.33	300	203.33
	20-30 (D_2)	46.67	40	46.67	43.33
	>30(D_3)	10	6.67	10	-
	Total	**206.67**	**190**	**356.67**	**246.67**
UF	10-20 (D_1)	190	210	103.33	146.67
	20-30 (D_2)	63.33	110	33.33	70
	>30(D_3)	26.67	30	16.67	123.33
	Total	**280**	**350**	**153.33**	**340**

diameter class D1 (483.33 number ha^{-1}) followed by D2 (23.33 number ha^{-1}) whereas, the trees having > 30cm diameter were absent from this compartment. Further, the compartment UPFC2, UPFC3 and UPFC4 had maximum number of trees under diameter class D1 followed by D2 and D3, respectively. The compartments of CFS and UF also follow the same trend except for compartment CFSC3 and UFC3. In case of CFS the tree in diameter class D3 were absent, whereas, in UF the diameter class D3 had a great number of trees as compare to D2. However, the absence or presence of higher number of trees in bigger diameter class of different compartment under DPF, UPF and CFS in present study may be due to poor management practices, encroachment and high anthropogenic pressure etc. which leads to abnormality in the forest.

Further, the overall distribution of trees between different forest classes clearly displays the characteristic of De liocourt's law where the stem frequencies decrease with the increase in diameter (Figure 2). In our study, reverse J-shaped curves were recorded for different forest classes. However, the distribution of tress in different diameter class was



	RF	DPF	UPF	CFSF	UF
10-20	251.67	245.00	230.83	199.17	162.50
20-30	105.00	66.67	62.50	44.17	69.17
>30	42.50	28.33	15.00	8.33	49.17

Figure 2: Stand structure under different forest classes in Khair working circle of Nurpur Forest Division, Himachal Pradesh

more even in Reserve Forest as compare to other forest classes. The reverse J-shaped curve indicates heavy exploitation in higher girth classes (Rao *et al*., 1990). Although, this shape of curve is a good indicator for development and regeneration of forest stand and the growth of forest are also indicated by the movement of trees in various diameter classes. According to Phillip (1993), a reverse 'J' shape is common for natural forests with active regeneration and recruitment. In general, trees belonging to bigger diameter classes contribute greater basal area, as compare to the lower diameter classes (Hailemariam and Temam, 2018). Moreover, the lesser number of trees in bigger diameter classes as compare to other forest class in Co-operative Forest Society (CFS) could be attributed to anthropogenic disturbances, including logging, fuel wood extraction, and encroachments of the area.

4.5 Species wise distribution

Reserve Forest

The species wise distribution of tree density, biomass and carbon stock within Reserve Forest is shown in table 20.

The compartment RFC1 within Reserve Forest had a total number of 363.33 individuals ha^{-1}contributing the total volume of 65.17 m^3 ha^{-1} were recorded, among of which *Acacia catechu* was the main species with maximum density of 146.67 number ha^{-1} followed by *Lannea coromandelica* (83.33 number ha^{-1}) and *Mellotus phillippensis* (50 number ha^{-1}). However, the maximum volume was contributed by *Terminalia bellerica* (20.17 m^3 ha^{-1}) which was followed by *Lannea coromandelica* (16.46 m^3 ha^{-1}) and *Acacia catechu* (15.16 m^3 ha^{-1}), respectively. Furthermore, *Acacia catchu* had the maximum value for above ground biomass (33.43 t ha^{-1}), below ground biomass (18.26 t ha^{-1}), total biomass (51.69 t ha^{-1}) and carbon stock (24.55 t ha^{-1}), this was followed by *Terminalia bellerica*, *Lannea coromandelica* and *Mellotus phillippensis,* respectively. However, the minimum contribution was of *Casearia tomentosa* with minimum value for density (3.33 number ha^{-1}), volume (0.36 m^3 ha^{-1}), AGB (0.40 t ha^{-1}), BGB (0.24 t ha^{-1}), TB (0.64 t ha^{-1}) and carbon stock (0.30 t ha^{-1}), respectively. In compartment RFC2, a total density of 323.33 number ha^{-1}, volume of 54.72 m^3 ha^{-1}, AGB of 50.70 t ha^{-1}, BGB of 28.01 t ha^{-1}, TB of 78.71 t ha^{-1} and carbon stock of 37.39 t ha^{-1} was recorded from which *Acacia catechu* had the maximum tree density (86.67 number ha^{-1}) followed by *Cassia fistula* (66.67 number ha^{-1}), *Lannea coromandelica* (5667 number ha^{-1}) and *Pinus roxburghii* (43.33 number ha^{-1}) whereas, the minimum density was recorded for *Ficus benghalensis* and *Casearia tomentosa* both displayed the identical value of 3.33 number ha^{-1}. However; *Pinus roxburghii* had the maximum contribution in term of volume (25.47 m^3 ha^{-1}), AGB (18.07 t ha^{-1}), AGB (9.22 t ha^{-1}), TB (27.29 t ha^{-1}) and carbon stock (12.96 t ha^{-1}) respectively, the contributionin volume by different species is in following order *Pinus roxburghii* > *Lannea coromendelica* >*Cassia fistula* >*Acacia catechu* > *Ficus benghalensis*> *Syzygium cumini* > *Mallotus phillippensis* > *Bombax ceiba* > *Phyllanthus embelica* and > *Casearia tomentosa,* respectively. However, the contribution for AGB, BGB, TB and carbon stock follows the following order; *Pinus roxburgii* > *Acacia catecu* >*Cassia fistula* > *Lannea coromendelica* > *Syzygium cumini* > *Mallotus phillippensis* > *Ficus benghalensis* > *Bombax ceiba* > *Casearia tomentosa* and >*Phyllanthus embelica.* A total density of 503.33 number ha^{-1}, volume of 102.83 m^3 ha^{-1}, AGB of 124.46 t ha^{-1}, BGB of 66.01 t ha^{-1}, TB of 190.47 t ha^{-1}, and carbon stock of 90.47 t ha^{-1} was recorded in RFC3. Among of which *Cassia fistula* had the maximum density (140 number ha^{-1}) was followed by *Acacia catechu* (120 number ha^{-1}), *Lannea coromandelica* (106.67 number ha^{-1}) and *Mallotus phillippensis* (76.67 number ha^{-1}) whereas, *Aegle marmelos* and *Termenalia arjuna* had the lowest density. The maximum volume was contributed by *Lannea coromandelica* (26.65 m^3

Table 20: Species wise density (number ha^{-1}), volume (m^{3} ha^{-1}) AGB (t ha^{-1}), BGB (t ha^{-1}), TB (t ha^{-1}) and carbon stock (t ha^{-1}) of trees under Reserve Forest in Khair working circle of Nurpur Forest Division, Himachal Pradesh

Species	RFC1						RFC2						RFC3						RFC4					
	D	V	AGB	BGB	TB	C	D	V	AGB	BGB	TB	C	D	V	AGB	BGB	TB	C	D	V	AGB	BGB	TB	C
Acacia catechu	146.67	15.16	33.43	18.26	51.69	24.55	86.67	5.33	11.75	6.66	18.41	8.75	120.00	24.15	53.25	26.68	79.93	37.97	150.00	21.80	48.07	25.06	73.12	34.73
Aegle marmelos	-	-	-	-	-	-	-	-	-	-	-	-	6.67	0.55	0.63	0.38	1.01	0.48	-	-	-	-	-	-
Bombax ceiba	-	-	-	-	-	-	10.00	1.04	0.48	0.32	0.79	0.38	-	-	-	-	-	-	-	-	-	-	-	-
Casearia tomentosa	3.33	0.36	0.40	0.24	0.64	0.30	3.33	0.36	0.40	0.24	0.64	0.30	-	-	-	-	-	-	-	-	-	-	-	-
Cassia fistula	16.67	2.24	2.51	1.44	3.95	1.87	66.67	6.36	7.12	4.29	11.41	5.42	140.00	18.24	20.41	11.81	32.22	15.30	83.33	9.82	10.99	6.42	17.41	8.27
Ficus benghalensis	-	-	-	-	-	-	3.33	3.22	1.86	0.92	2.78	1.32	-	-	-	-	-	-	-	-	-	-	-	-
Flacourtia indica	10.00	1.19	1.11	0.66	1.77	0.84	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lannea coromandelica	83.33	16.46	12.67	7.17	19.84	9.43	56.67	7.45	5.74	3.35	9.08	4.31	106.67	26.65	20.51	11.30	31.81	15.11	56.67	8.53	6.57	3.79	10.36	4.92
Mallotus phillippensis	50.00	4.62	4.43	2.70	7.13	3.39	30.00	2.29	2.20	1.37	3.56	1.69	76.67	10.38	9.96	5.81	15.77	7.49	83.33	10.47	10.05	5.85	15.90	7.55
Ougeinia oojeinensis	6.67	1.79	1.89	1.01	2.90	1.38	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Phyllanthus embelica	13.33	1.09	1.01	0.60	1.61	0.77	16.67	0.37	0.35	0.25	0.59	0.28	-	-	-	-	-	-	3.33	0.34	0.31	0.19	0.51	0.24
Pinus roxburghii	-	-	-	-	-	-	43.33	25.47	18.07	9.22	27.29	12.96	16.67	10.84	7.70	3.87	11.56	5.49	30.00	39.96	28.36	12.82	41.18	19.56
Pyrus pashia	-	-	-	-	-	-	-	-	-	-	-	-	13.33	1.89	2.14	1.23	3.36	1.60	-	-	-	-	-	-
Syzygium cumini	-	-	-	-	-	-	6.67	2.82	2.74	1.41	4.14	1.97	16.67	5.79	5.62	2.86	8.49	4.03	-	-	-	-	-	-
Terminalia arjuna	-	-	-	-	-	-	-	-	-	-	-	-	6.67	4.33	4.24	2.08	6.32	3.00	-	-	-	-	-	-
Terminalia bellirica	26.67	20.17	19.76	9.50	29.26	13.90	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Wendlandia exserta	6.67	2.09	2.20	1.16	3.37	1.60	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	**363.33**	**65.17**	**79.41**	**42.75**	**122.16**	**58.02**	**323.33**	**54.72**	**50.70**	**28.01**	**78.71**	**37.39**	**503.33**	**102.83**	**124.46**	**66.01**	**190.47**	**90.47**	**406.67**	**90.91**	**104.34**	**54.14**	**158.48**	**75.28**

D-density, V- volume, AGB- above ground biomass, BGB- below ground biomass, TB – total biomass and C- carbon stock.

ha^{-1}) which was followed by *Acacia catechu* (24.15 m^3 ha^{-1}) and *Cassia fistula* (18.24 m^3 ha^{-1}). However, the minimum value for volume was recorded for *Aegle marmelos* (0.55 m^3 ha^{-1}) closely followed by *Pyrus pashia* (1.89 m^3 ha^{-1}), *Treminalia arjuna* (4.33 m^3 ha^{-1}) and *Syzygium cumini* (5.79 m^3 ha^{-1}), respectively. Furthermore, *Acacia catechu* was recorded to have maximum storage potential AGB (53.25 t ha^{-1}) BGB (26.28 t ha^{-1}), TB (79.93 t ha^{-1}) and carbon stock (37.97 t ha^{-1}) which was followed by *Cassia fistula* and *Lannea coromandelica*. However, the minimum contribution was recorded for *Aegle marmelos* followed by *Pyrus pashia*. In case of RFC4 under Reserve Forest, a total density of 406.67 number ha^{-1}, volume of 90.91 m^3 ha^{-1}, AGB of 104.34 t ha^{-1}, BGB of 54.14 t ha^{-1}, TB of 158.48 t ha^{-1} and carbon stock of 75.28 t ha^{-1} was documented of which *Acacia catechu* contributes the maximum density (150 number ha^{-1}) followed by *Cassia fistula* and *Mellotus phillippensis* both exhibit a common value (83.33 number ha^{-1}), *Lannea coromandelica* (56.67 number ha^{-1}) and *Pinus roxburghii* (30 number ha^{-1}), respectively. However, *Pinus roxburghii* had the maximum volume contribution (39.96 m^3 ha^{-1}) followed by *Acacia catechu* (21.80 m^3 ha^{-1}), and *Mellotus phillippensis* (10.47 m^3 ha^{-1}). Further, *Phyllanthus embelica* had the minimum contribution in density (3.33 number ha^{-1}), volume (0.34 m^3 ha^{-1}), AGB (0.31 t ha^{-1}), BGB (0.19 t ha^{-1}), TB (0.51 t ha^{-1}) and carbon stock (0.24 t ha^{-1}), respectively. The maximum value for AGB (48.07 t ha^{-1}), BGB (25.06 t ha^{-1}), TB (73.12 t ha^{-1}) and carbon stock (34.73 t ha^{-1}) was displayed by *Acacia catechu*.

Demarcated Protected Forest

The data presented in Table 21 shows the distribution of density, above ground biomass (AGB), belowground biomass (BGB), total biomass (TB) and carbon stock among different species within Demarcated Protected Forest (DPF).

In DPFC1 of Demarcated Protected Forest, a total number of 183.33 individuals ha^{-1}, volume of 139.46 m^3 ha^{-1}, AGB of 33.53 t ha^{-1}, BGB of 39.73 t ha^{-1}, TB of 173.25 t ha^{-1} and carbon stock of 85.03 t ha^{-1} were recorded among of which *Pinus roxburghii* contributes the maximum value for density (110.00 number ha^{-1}), volume (128.69 m^3 ha^{-1}), AGB (115.53 t ha^{-1}), BGB (33.35 t ha^{-1}), TB (148.87 t ha^{-1}) and carbon stock (73.08 t ha^{-1}) respectively. This was followed by *Acacia catechu* and *Cassia fistula*. However, the minimum contribution for density, volume, biomass (AGB, BGB and TB) and carbon stock was recorded for *Butea monosperma* and *Bombax ceiba*. In case of DPFC2 a total density of 433.33 number ha^{-1}, volume of 51.07 m^3 ha^{-1}, AGB of 63.13 t ha^{-1}, BGB of 35.57 t ha^{-1}, TB of 98.71 t ha^{-1} and

Table 21: Species wise density (number ha^{-1}), volume (m^3 ha^{-1}) AGB (t ha^{-1}), BGB (t ha^{-1}), TB (t ha^{-1}) and carbon stock (t ha^{-1}) of trees under Demarcated Protected Forest in Khair Working circle of Nurpur Forest Division, Himachal Pradesh

Species	DPF C1						DPF C2						DPF C3						DPF C4					
	D	V	AGB	BGB	TB	C	D	V	AGB	BGB	TB	C	D	V	AGB	BGB	TB	C	D	V	AGB	BGB	TB	C
Acacia catechu	40.00	6.38	14.07	4.74	18.81	9.24	133.33	13.94	30.74	16.68	47.42	22.53	100.00	12.31	27.14	14.49	41.63	19.77	80.00	9.85	21.72	11.62	33.34	15.84
Albizia lebbeck	-	-	-	-	-	-	16.67	1.81	1.79	1.08	2.87	1.36	-	-	-	-	-	-	-	-	-	-	-	-
Bombex ceiba	3.33	1.02	0.47	0.27	0.74	0.35	6.67	0.79	0.37	0.24	0.60	0.29	30.00	4.10	1.89	1.21	3.10	1.47	-	-	-	-	-	-
Butea monosperma	3.33	0.30	0.21	0.13	0.34	0.16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Casearia tomentosa	-	-	-	-	-	-	-	-	-	-	-	-	10.00	1.17	1.09	0.65	1.74	0.83	-	-	-	-	-	-
Cassia fistula	16.67	1.92	2.15	0.68	2.83	1.40	83.33	8.33	9.32	5.58	14.90	7.08	-	-	-	-	-	-	50.00	6.67	10.51	5.83	16.34	7.76
Dalbergia sissoo	-	-	-	-	-	-	10.00	1.03	1.03	0.62	1.65	0.78	40.00	4.67	4.68	2.78	7.46	3.54	-	-	-	-	-	-
Lannea coromandelica	-	-	-	-	-	-	163.33	23.35	17.97	10.47	28.44	13.51	-	-	-	-	-	-	116.67	9.98	11.50	6.56	18.06	8.58
Mallotus phillippensis	10.00	1.15	1.10	0.54	1.65	0.79	-	-	-	-	-	-	136.67	16.97	16.29	9.50	25.79	12.25	63.33	7.86	10.50	5.92	16.43	7.80
Ougeinia oojeinensis	-	-	-	-	-	-	20.00	1.82	1.92	0.90	2.82	1.36	43.33	4.60	4.86	2.90	7.75	3.68	-	-	-	-	-	-
Phyllanthus embelica	-	-	-	-	-	-	-	-	-	-	-	-	10.00	1.05	0.97	0.58	1.55	0.74	-	-	-	-	-	-
Pinus roxburghii	110.00	128.69	115.53	33.35	148.87	73.08	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pistacia interrima	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6.67	2.91	5.07	2.74	7.81	3.71
Syzygium cumini	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	16.67	5.21	6.20	3.45	9.65	4.58
Terminalia bellirica	-	-	-	-	-	-	-	-	-	-	-	-	3.33	2.98	2.92	1.38	4.30	2.04	-	-	-	-	-	-
Wendlandia exserta	-	-	-	-	-	-	-	-	-	-	-	-	36.67	7.42	6.89	3.84	10.73	5.09	-	-	-	-	-	-
Total	**183.33**	**139.46**	**133.53**	**39.73**	**173.25**	**85.03**	**433.33**	**51.07**	**63.13**	**35.57**	**98.71**	**46.91**	**410.00**	**55.26**	**66.73**	**37.33**	**104.06**	**49.43**	**333.33**	**42.48**	**65.51**	**36.12**	**101.63**	**48.27**

D- density, V- volume, AGB- above ground biomass, BGB- below ground biomass, TB – total biomass and C- carbon stock.

carbon stock of 46.91 t ha^{-1} were recorded among of which *Lannea coromandelica* had the maximum density (163.33 number ha^{-1}) and volume (23.35 m^3 ha^{-1}) which was followed by *Acacia catechu* and *Cassia fistula*. However, *Acacia catechu* had the maximum contribution for AGB (30.74 t ha^{-1}), BGB (1668 t ha^{-1}), TB (47.42 t ha^{-1}), and carbon stock (22.53 t ha^{-1}) respectively. Moreover, *Bombax ceiba* was the least occurring species with minimum density of 6.67 number ha^{-1} and also had the lowest value for volume (0.79 m^3 ha^{-1}), AGB (0.37 t ha^{-1}), BGB (0.24 t ha^{-1}), TB (0.60 t ha^{-1}) and carbon stock (0.29 t ha^{-1}), respectively. In compartment DPFC3 among total density and volume of 410.00 number ha^{-1} and 55.26 m^3 ha^{-1}*Mallotus phillippensis* had the maximum contribution (136.67 number ha^{-1} and 16.97 m^3 ha^{-1}) which was followed by *Acacia catechu* (100 number ha^{-1} and 12.31 m^3 ha^{-1}), *Ougeinia oojeinensis* and *Dalbergia sissoo*. However, *Acacia catechu* had the maximum contribution in AGB (27.14 t ha^{-1}), BGB (14.49 t ha^{-1}), TB (41.63 t ha^{-1}) and carbon stock (19.77 t ha^{-1}) which was followed by *Mallotus phillippensis* respectively. The minimum contribution for density (10 number ha^{-1}), volume (1.05 m^3 ha^{-1}), AGB (0.97 t ha^{-1}), BGB (0.58 t ha^{-1}), TB (1.55 t ha^{-1}), and carbon stock (0.74 t ha^{-1}) was recorded for *Phyllanthus embelica*. The compartment DPFC4 of Demarcated Protected Forest had the total density of 333.33 number ha^{-1}, volume of 42.48 m^3 ha^{-1}, AGB of 65.51 t ha^{-1}, BGB of 36.12 t ha^{-1}, TB of 101.63 t ha^{-1} and carbon stock of 48.27 t ha^{-1} among of which *Lannea coromandelica* had the maximum density (116.67 number ha^{-1}) and volume (9.98 m^3 ha^{-1}) which was followed by *Acacia catechu, Mallotus phillippensis* and *Cassia fustula*. Although, *Acacia catechu* had the maximum contribution in AGB (21.72t ha^{-1}), BGB (11.62t ha^{-1}), TB (33.34t ha^{-1}) and carbon stock (15.84t ha^{-1}) which was followed by *Lannea coromandelica*, *Cassia fistula* and *Mallotus phillippensis,* respectively. *Pistacia interrima* had the least contribution among all the parameters.

Un-demarcated Protected Forest

The data presented in Table 22 shows the distribution of total density, volume, above ground biomass, below ground biomass, total biomass and carbon stock among different species.

In compartment UPFC1 a total density of 506.67 individuals ha^{-1}, having volume of 37.62 m^3 ha^{-1}, AGB of 56.60 t ha^{-1}, BGB of 33.85 t ha^{-1}, TB of 90.45 t ha^{-1} and carbon stock of 42.96 t ha^{-1} were recorded among of which *Mallotus phillippensis* had the maximum density (156.67 number ha^{-1}) and volume (9.32 m^3 ha^{-1}). The maximum density was followed

Table 22: Species wise density (number ha^{-1}), volume (m^{3} ha^{-1}) AGB (t ha^{-1}), BGB (t ha^{-1}), TB (t ha^{-1}) and carbon stock (t ha^{-1}) of trees under Un-emarcated Protected Forest in Khair Working circle of Nurpur Forest Division, Himachal Pradesh

Species	UFC1						UFC2						UFC3						UFC4					
	D	V	AGB	BGB	TB	C	D	V	AGB	BGB	TB	C	D	V	AGB	BGB	TB	C	D	V	AGB	BGB	TB	C
Acacia catechu	100.00	8.95	23.63	13.20	36.82	17.49	80.00	11.31	24.94	13.30	38.24	18.16	90.00	14.91	32.87	16.80	49.68	23.60	96.67	11.72	25.83	13.78	39.61	18.82
Aegle marmelos	-	-	-	-	-	-	-	-	-	-	-	-	10.00	0.61	0.68	0.43	1.11	0.53	-	-	-	-	-	-
Albizia lebbeck	-	-	-	-	-	-	-	-	-	-	-	-	56.67	14.01	13.87	7.48	21.35	10.14	50.00	9.33	9.23	5.20	14.43	6.85
Cassia fistula	73.33	7.55	10.33	6.16	16.49	7.83	46.67	5.50	6.16	3.66	9.82	4.66	-	-	-	-	-	-	-	-	-	-	-	-
Dalbergia sissoo	46.67	2.49	3.23	2.07	5.30	2.52	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ficus benghalensis	-	-	-	-	-	-	-	-	-	-	-	-	3.33	1.56	0.90	0.49	1.39	0.66	-	-	-	-	-	-
Flacourtia indica	-	-	-	-	-	-	-	-	-	-	-	-	13.33	1.90	1.76	0.95	2.71	1.29	-	-	-	-	-	-
Lannea coromandelica	106.67	6.91	6.25	4.01	10.26	4.87	73.33	14.35	11.04	6.35	17.40	8.26	60.00	14.64	11.27	6.07	17.33	8.23	70.00	12.26	9.43	5.29	14.73	7.00
Mallotus phillippensis	156.67	9.32	10.69	6.90	17.59	8.36	33.33	2.43	2.33	1.49	3.82	1.82	-	-	-	-	-	-	13.33	1.01	0.97	0.61	1.57	0.75
Phyllanthus embelica	-	-	-	-	-	-	-	-	-	-	-	-	6.67	0.58	0.54	0.33	0.87	0.41	6.67	0.80	0.75	0.44	1.18	0.56
Pinus roxburghii	23.33	2.39	2.47	1.52	3.99	1.89	16.67	5.73	5.50	2.94	8.44	4.01	-	-	-	-	-	-	-	-	-	-	-	-
Total	**506.67**	**37.62**	**56.60**	**33.85**	**90.45**	**42.96**	**250.00**	**39.33**	**49.98**	**27.75**	**77.72**	**36.92**	**240.00**	**48.20**	**61.89**	**32.55**	**94.44**	**44.86**	**236.67**	**35.11**	**46.21**	**25.31**	**71.52**	**33.97**

D- density, V- volume, AGB- above ground biomass, BGB- below ground biomass, TB – total biomass and C- carbon stock.

by *Lannea coromandelica* (106.67 number ha^{-1}), *Acacia catechu* (100.00 number ha^{-1}) and *Cassia fistula* (73.33 number ha^{-1}). However, *Acacia catechu* had the second highest volume (8.95 m^3 ha^{-1}) followed *by Cassia fistula* (7.55 m^3 ha^{-1}) and *Lannea coromandelica* (6.91 m^3 ha^{-1}), respectively. The maximum contribution in AGB (23.63 t ha^{-1}), BGB (13.20 t ha^{-1}), TB (36.82 t ha^{-1}) and carbon stock (17.49 t ha^{-1}) was recorded for *Acacia catechu* followed by *Mallotus phillippensis* and *Cassia fistula*. However, the minimum contribution for density (23.33 number ha^{-1}), volume (2.39 m^3 ha^{-1}), AGB (2.47 t ha^{-1}), BGB (1.52 t ha^{-1}), TB (3.39 t ha^{-1}) and carbon stock (1.89 t ha^{-1}) was documented for *Pinus roxburghii*. In case of compartment UPFC2, *Acacia catechu* had the maximum density (80 number ha^{-1}), AGB (24.94 t ha^{-1}), BGB (13.30 t ha^{-1}), TB (38.24 t ha^{-1}) and carbon stock (18.16 t ha^{-1}) followed by *Lannea coromandelica*. However, *Lannea coromandelica* had the maximum volume (14.35 m^3 ha^{-1}) contribution followed by *Acacia catechu* (11.31 m^3 ha^{-1}). The minimum contribution was reported for *Pinus roxburghii*. In compartment UPFC3, among all the parameters *Acacia catechu* had the maximum value for density (90 number ha^{-1}), volume (14.91 m^3 ha^{-1}), AGB (32.87 t ha^{-1}), BGB (16.80 t ha^{-1}), TB (49.68 t ha^{-1}) and carbon stock (23.60 t ha^{-1}) which was followed by *Lannea coromandelica* and *Albizia lebbeck*. However, the minimum value for density was recorded for *Ficus benghalensis* (3.33 number ha^{-1}) while *Phyllanthus embelica* had the lowest value for volume (0.58 m^3 ha^{-1}), AGB (0.54 t ha^{-1}), BGB (0.33 t ha^{-1}), TB (0.87 t ha^{-1}) and carbon stock (0.41 t ha^{-1}), respectively. The compartment UPFC4 under Un-demarcated Protected Forest had the total density of 236.67 number ha^{-1}, volume of 35.11 m^3 ha^{-1}, AGB of 46.21 t ha^{-1}, BGB of 25.31 t ha^{-1}, TB of 71.52 t ha^{-1}, and carbon stock of 33.97 t ha^{-1}. The maximum density was contributed by *Acacia catechu* (96.67 number ha^{-1}) which also had the maximum contribution in AGB (25.83 t ha^{-1}), BGB (13.78 t ha^{-1}), TB (39.61 t ha^{-1}) and carbon stock (18.82 t ha^{-1}). This was followed by *Lannea coromandelica* and *Albiziza lebbeck*. Moreover, the maximum volume production was recorded for *Lannea coromandelica* (12.26 m^3 ha^{-1}) which was followed by *Acacia catechu* (11.72 m^3 ha^{-1}) and *Albiziza lebbeck* (9.33 m^3 ha^{-1}), respectively. The minimum value for density (6.67 number ha^{-1}), volume (0.80 m^3 ha^{-1}), AGB (0.75 t ha^{-1}), BGB (0.44 t ha^{-1}), TB (1.18 t ha^{-1}) and carbon stock (0.56 t ha^{-1}) was reported for *Phyllanthus embelica*.

Co-operative Forest Society

In compartment CFSC1 under Co-operative Forest Society (Table 23), *Acacia catechu* was the most dominating species with maximum density of 90 number ha^{-1}, AGB of 24.39 t ha^{-1}, BGB of 12.98 t ha^{-1}, TB of 37.37 t ha^{-1} and carbon stock of 17.75 t ha^{-1}

respectively, this was followed by *Lannea coromandelica* and *Ficus palmata.* Furthermore, the maximum volume (12.02 m^3 ha^{-1}) was documented for *Lannea coromandelica* which was followed by *Acacia catechu* (11.06 m^3 ha^{-1}) and *Ficus palmata* (8.95 m^3 ha^{-1}). However, the lowest value for density (3.33 number ha^{-1}), volume (0.41 m^3 ha^{-1}), AGB (0.33 t ha^{-1}), BGB (0.20 t ha^{-1}), TB (0.53 t ha^{-1}) and carbon stock (0.25 t ha^{-1}) was recorded for *Morus alba,* respectively. In case of CFSC2, among a total density of 190 number ha^{-1}, volume of 31.58 m^3 ha^{-1}, AGB of 40.44 t ha^{-1}, BGB of 21.78 t ha^{-1}, TB of 62.22 t ha^{-1} and carbon stock of 29.56 t ha^{-1}*Acacia catechu* was the most contributing species (80 number ha^{-1}, 9.07 m^3 ha^{-1}, 20.01 t ha^{-1}, 10.65 t ha^{-1}, 30.66 t ha^{-1} and 14.56 t ha^{-1}) followed by *Lannea coromandelica* for density, and volume, *Broussonetia papyrifera* for AGB, BGB,TB and carbon stock. The lowest density (3.33 number ha^{-1}) was recorded for *Ficus glomerata* whereas; *Syzygium cumini* had the lowest value for volume (2.06 m^3 ha^{-1}), AGB (1.78 t ha^{-1}), BGB (0.96 t ha^{-1}), TB (2.74 t ha^{-1}) and carbon stock (1.30 t ha^{-1}). In compartment CFSC3 also *Acacia catechu* was the main contributing species which contributes the maximum density of 143.33 number ha^{-1}, volume of 14.20 m^3 ha^{-1}, AGB of 31.32 t ha^{-1}, BGB of 17.08 t ha^{-1}, TB of 48.40 t ha^{-1} and carbon stock of 22.99 t ha^{-1}, respectively. This was followed by *Mallotus phillippensis* for density and volume, *Cassia fistula* for AGB, BGB, TB and carbon stock. *Aegle marmelos* was the least contributing species. In case of CFSC4, a total number of four species contributing the total density of 246.67, volume of 27.58, AGB of 41.50, BGB of 22.81, TB of 64.31 and carbon stock of 30.55 were recorded. The species wise contribution for density is arranged in following order; *Acacia catechu >Dalbergia sissoo >Lannea coromandelica* and>*Ficus palmata* whereas, the contribution for volume and AGB by different species is arranged in following order; *Acacia catechu > Ficus palmata > Dalbergia sissoo >Lannea coromandelica.* Furthermore, for BGB, TB and carbon stock the species are arranged in the following order; *Acacia catechu >Dalbergia sissoo >Ficus palmata >Lannea coromandelica,* respectively.

Un-class Forest

The compartment UFC1 within Un-class Forest (Table 24) comprise only of three tree species which contributes the total density of 280 number ha^{-1}, volume of 43.83 m^3 ha^{-1}, AGB of 85.75 t ha^{-1}, BGB of 44.16 t ha^{-1}, TB of 129.91 t ha^{-1} and carbon stock of 61.71 t ha^{-1}. In this compartment, *Acacia catechu* had the maximum density (236.67 number ha^{-1}), Volume (35.08 m^3 ha^{-1}), AGB (77.35 t ha^{-1}), BGB (39.55 t ha^{-1}), TB (116.90 t ha^{-1}) and carbon stock

Table 23: Species wise density (number ha^{-1}), volume (m^3 ha^{-1}) AGB (t ha^{-1}), BGB (t ha^{-1}), TB (t ha^{-1}) and carbon stock (t ha^{-1}) of trees under Co-operative Forest Society in Khair working circle of Nurpur Forest Division, Himachal Pradesh

Species	CFSC1						CFSC2						CFSC3						CFSC4					
	D	V	AGB	BGB	TB	C	D	V	AGB	BGB	TB	C	D	V	AGB	BGB	TB	C	D	V	AGB	BGB	TB	C
Acacia catechu	90.00	11.06	24.39	12.98	37.37	17.75	80.00	9.07	20.01	10.65	30.66	14.56	143.33	14.20	31.32	17.08	48.40	22.99	120.00	12.75	28.10	15.21	43.31	20.57
Aegle marmelos	-	-	-	-	-	-	-	-	-	-	-	-	6.67	0.14	0.15	0.11	0.27	0.13	-	-	-	-	-	-
Broussonetia papyrifera	-	-	-	-	-	-	10.00	6.35	5.90	2.91	8.81	4.19	-	-	-	-	-	-	-	-	-	-	-	-
Cassia fistula	-	-	-	-	-	-	26.67	2.75	3.08	1.84	4.92	2.34	83.33	7.58	8.48	5.06	13.54	6.43	-	-	-	-	-	-
Dalbergia sissoo	-	-	-	-	-	-	26.67	2.19	2.20	1.36	3.56	1.69	-	-	-	-	-	-	73.33	4.72	4.74	3.02	7.76	3.68
Ficus glomerata	-	-	-	-	-	-	3.33	2.70	2.51	1.21	3.72	1.77	-	-	-	-	-	-	-	-	-	-	-	-
Ficus palmata	10.00	8.95	8.31	3.95	12.26	5.82	-	-	-	-	-	-	-	-	-	-	-	-	6.67	5.56	5.16	2.47	7.63	3.62
Lannea coromandelica	50.00	12.02	9.25	4.94	14.19	6.74	36.67	6.45	4.97	2.85	7.81	3.71	23.33	5.79	4.46	2.40	6.86	3.26	46.67	4.55	3.50	2.11	5.61	2.67
Leucaena leucocephala	23.33	2.23	1.84	1.14	2.99	1.42	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mallotus phillippensis	13.33	0.96	0.92	0.58	1.51	0.72	-	-	-	-	-	-	100.00	8.43	8.09	5.00	13.10	6.22	-	-	-	-	-	-
Morus alba	3.33	0.41	0.33	0.20	0.53	0.25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Syzygium cumini	-	-	-	-	-	-	6.67	2.06	1.78	0.96	2.74	1.30	-	-	-	-	-	-	-	-	-	-	-	-
Xylosma longifolium	16.67	1.76	1.63	0.99	2.63	1.25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	**206.67**	**37.39**	**46.68**	**24.79**	**71.46**	**33.95**	**190.00**	**31.58**	**40.44**	**21.78**	**62.22**	**29.56**	**356.67**	**36.14**	**52.50**	**29.66**	**82.16**	**39.03**	**246.67**	**27.58**	**41.50**	**22.81**	**64.31**	**30.55**

D- density, V- volume, AGB- above ground biomass, BGB- below ground biomass, TB – total biomass and C- carbon stock.

Table 24: Species wise density (number ha^{-1}), volume (m^3 ha^{-1}) AGB (t ha^{-1}), BGB (t ha^{-1}), TB (t ha^{-1}) and carbon stock (t ha^{-1}) of trees under Un-class Forest in Khair working circle of Nurpur Forest Division, Himachal Pradesh

Species	UFC1						UFC2						UFC3						UFC4					
	D	V	AGB	BGB	TB	C	D	V	AGB	BGB	TB	C	D	V	AGB	BGB	TB	C	D	V	AGB	BGB	TB	C
Acacia catechu	236.67	35.08	77.35	39.55	116.90	55.53	133.33	23.42	51.63	26.17	77.80	36.96	123.33	14.82	32.69	17.13	49.82	23.67	220.00	42.52	93.76	46.49	140.25	66.62
Cassia fistula	-	-	-	-	-	-	86.67	13.78	15.42	8.70	24.12	11.46	10.00	1.74	1.95	1.09	3.04	1.45	46.67	10.74	12.02	6.27	18.28	8.68
Eucalyptus globulus	-	-	-	-	-	-	10.00	1.55	1.44	0.80	2.24	1.06	-	-	-	-	-	-	-	-	-	-	-	-
Ficus benghalensis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.33	0.42	0.47	0.27	0.74	0.35
Lannea coromandelica	-	-	-	-	-	-	13.33	4.23	3.26	1.74	5.00	2.38	10.00	7.21	5.55	2.73	8.28	3.94	23.33	13.01	10.01	4.83	14.84	7.05
Mallotus phillippensis	40.00	8.74	8.39	4.60	12.99	6.17	93.33	11.75	11.28	6.47	17.75	8.43	10.00	1.78	1.71	0.97	2.68	1.27	3.33	0.13	0.15	0.10	0.26	0.12
Pinus roxburghii	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	40.00	65.63	58.92	25.77	84.69	40.23
Pyrus pashia	-	-	-	-	-	-	6.67	0.58	0.54	0.33	0.87	0.41	-	-	-	-	-	-	-	-	-	-	-	-
Stephegyne parvifolia	-	-	-	-	-	-	3.33	0.22	0.20	0.13	0.34	0.16	-	-	-	-	-	-	-	-	-	-	-	-
Terminalia bellirica	3.33	0.01	0.01	0.01	0.02	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Xylosma longifolium	-	-	-	-	-	-	3.33	0.42	0.39	0.23	0.63	0.30	-	-	-	-	-	-	3.33	0.45	0.50	0.29	0.79	0.38
Total	**280.00**	**43.83**	**85.75**	**44.16**	**129.91**	**61.71**	**350.00**	**55.95**	**84.16**	**44.58**	**128.74**	**61.15**	**153.33**	**25.56**	**41.90**	**21.93**	**63.83**	**30.32**	**340.00**	**132.90**	**175.83**	**84.03**	**259.86**	**123.43**

D- density, V- volume, AGB- above ground biomass, BGB- below ground biomass, TB – total biomass and C- carbon stock

(55.53 t ha^{-1}), respectively. This was followed by *Mallotus phillippensis* and *Terminalia bellerica*. In case of compartment UFC2, *Acacia catechu* had the maximum contribution in terms of density (133.33 number ha^{-1}), volume (23.42 m^3 ha^{-1}), AGB (51.63 t ha^{-1}), BGB (26.17 t ha^{-1}), TB (77.80 t ha^{-1}) and carbon stock (36.96 t ha^{-1}) which was followed by *Mallotus phillippensis* > *Cassia fistula* for density, *Cassia fistula* > *Mallotus phillippensis* for volume, AGB, BGB, TB and carbon stock. However, *Stephegyne parvifolia* had the least contribution. The compartment UFC3 had the total tree density of 153 number ha^{-1}, volume of 25.56 m^3 ha^{-1}, AGB of 41.90 96 t ha^{-1}, BGB of 21.93 96 t ha^{-1}, TB of 63.83 96 t ha^{-1} and carbon stock of 30.32 96 t ha^{-1}. Among this, *Acacia catechu* had the highest density (123.33 number ha^{-1}) which was followed by *Cassia fistula*, *Lannea coromandelica* and *Mallotus phillippensis* with lowest identical value of 10 individual ha^{-1}. Whereas, the contribution in AGB, BGB, TB and carbon stock by different species is in the flowing order; *Acacia catechu* >*Lannea coromandelica* > *Cassia fistula* and > *Mallotus phillippensis*. The pattern for volume contribution was also same except for *Mallotus phillippensis* and *Cassia fistula* where the earlier species had greater volume production. In case of UFC4, among the total density of 340.00 individuals ha^{-1} the contribution by different species is arranged in following order; *Acacia catechu* > *Cassia fistula* > *Pinus roxburghii* > *Lannea coromandelica* > *Ficus benghalensis* = *Mallotus phillippensis* = *Xylosma longifolium* respectively. Further, the contribution in total volume (132.90 m^3 ha^{-1}) is arranged as follow; *Acacia catechu* > *Pinus roxburghii* > *Lannea coromandelica* > *Cassia fistula* > *Xylosma longifolium* > *Ficus benghalensis* and > *Mallotus phillippensis,* respectively. Moreover, the contribution in AGB (175.83 t ha^{-1}), BGB (84.03 t ha^{-1}), TB (259.86 t ha^{-1}) and carbon stock (123.43 t ha^{-1}) by the above-mentioned species follows the following order; *Acacia catechu* > *Pinus roxburghii* > *Cassia fistula* > *Lannea coromandelica* > *Xylosma longifolium* > *Ficus benghalensis* and > *Mallotus phillippensis,* respectively.

4.6 Growth characteristics

Tree Diameter (cm)

The diameter of trees within and between different forest classes is shown in Table 25. Within Reserve Forest the maximum average diameter (24.02 cm) was recorded in compartment RFC4 which remain statistically at par with RFC3 (21.56 cm). However, the lowest average diameter (18.87 cm) recorded in compartment RFC2 was statistically at par with RFC1 (19.61 cm) and RFC3. The average diameter in Demarcated Protected Forest (DPF) was found significantly maximum in DPFC1 (24.62 cm) whereas, the minimum diameter was recorded in compartment DPFC2 (16.33 cm) which remain statistically at par with DPFC3 (17.67 cm) and DPFC4 (17.45 cm). In case of Un-demarcated Protected Forest (UPF) the highest value for average tree diameter was recorded in compartment UPFC3 (21.53 cm) which was statistically at par with UPFC2 (20.35cm) and UPFC4 (19.93cm). However, UPFC1 displayed the minimum average diameter (16.25) which was at par with UPFC4. The compartments within Co-operative Forest Society (CFS) did not show any significant variation for average tree diameter, although, the maximum average diameter (18.67 cm) was recorded in compartment CFSC3 and minimum in CFSC3 (17.06cm), respectively. In case of Un-class forest (UF) significantly maximum average diameter (30.02 cm) was recorded in compartment UFC4 followed by UFC1 (22.10 cm) and UFC3 (21.38cm). However, the lowest average diameter was displayed by compartment UFC2 (20.10 cm) which remains statistically at par with UFC3 and UFC1.

Overall, a significant variation was observed among different forest classes. The trend followed by different forest classes is as follow: UF>RF≥UPF≥DPF>CFS, respectively. Significantly maximum average diameter (23.40 cm) was recorded in UF followed by RF (21.01 cm) which remain statistically at par with UPF (19.52 cm). Moreover, the forest class UPF was also at par with DPF (19.02 cm), however significantly minimum diameter was recorded for CFS (17.89 cm).

Tree height (m)

The data presented in Table 26 delineates a slightly significant variation for tree height was observed within and between the forest classes. The maximum tree height (8.50 m) within Reserve Forest (RF) was recorded in compartment RFC2 which was followed by and remains statistically at par with RFC3 (8.46 m) and RFC4 (7.87 m). Whereas, the minimum tree height (6.85 m) was recorded in RFC1 which was statistically at par with compartment RFC4. In Demarcated Protected Forest significantly maximum tree height (8.89 m) was recorded in compartment DPFC1 whereas, DPFC3 had the minimum tree height (6.03 m) which remains statistically at par with DPFC2 (6.41m) and DPFC4 (7.04m), respectively. In case of compartment within Un-demarcated Protected Forest (UPF) the height parameter remains non-significant however, the maximum value was recorded in UPFC2 (7.37m) followed by UPFC3 (7.09m), UPFC4(7.02m) and UPFC1 (6.21m), respectively. The compartment within Co-operative Forest Society (CFS) also remains statistically at par with each other. The maximum tree height was recorded in compartment

CFSC1 (7.57 m) whereas the minimum was found in compartment CFSC3 (6.58 m). Significantly maximum value for tree height (8.95 m) within Un-class forest (UF) was found in compartment UFC4 followed by UFC2 (6.85 m) and UFC1 (7.48 m). However, the lowest value (6.79 m) was recorded in compartment UFC3 which remains statistically at par with UFC2 and UFC1.

Among different forest classes the maximum tree height (7.92 m) was reported in Reserve Forest which was statistically at par with Un-class Forest (7.52 m) followed by Demarcated Protected Forest (7.09 m) and Cooperative Forest society forest (7.05 m). Moreover, the lowest value for tree height was found in Un-demarcated Protected Forest (6.92 m) which remain statistically at par with Cooperative Forest society forest and Demarcated Protected Forest.

Volume (m^{-3} ha^{-1})

The volume of trees within and between forest classes had shown a significant variation (Table 27). The maximum volume (102.83 m^3 ha^{-1}) within Reserve Forest (RF) was recorded in compartment RFC3 which was statistically at par and followed by RFC4 (90.91 m^3 ha^{-1}). However, the lowest value for volume was found in compartment RFC2 (54.72 m^3 ha^{-1}) which remains at par with compartment RFC1 (65.17 m^3 ha^{-1}). In Demarcated Protected Forest (DPF) significantly maximum volume was recorded in compartment DPFC1 (139.46 m^3 ha^{-1}) whereas, the other compartment i.e., DPFC3 (55.26 m^3 ha^{-1}), DPFC2 (51.02 m^3 ha^{-1}) and DPFC4 (42.48 m^3 ha^{-1}) remains statistically at par with each other. In case of Un-demarcated Protected Forest (UPF) and Co-operative Forest Society (CFS) no significant variation for volume was observed within the compartments. However, in case of UPF the highest volume was recorded in UPFC3 (48.20 m^3 ha^{-1}) and minimum was found in UPFC4 (35.11 m^3 ha^{-1}). In Co-operative Forest Society, the maximum volume was in CFSC1 (37.39 m^3 ha^{-1}) and minimum was in CFSC4 (27.58m^3 ha^{-1}). Significantly maximum volume within Un-class forest (UF) was recorded in compartment UFC4 (132.90 m^3 ha^{-1}) followed by UFC2 (55.95 m^3 ha^{-1}) which remain statistically at par with UFC1 (43.83 m^3 ha^{-1}) whereas, the minimum volume was recorded in UFC3 (25.56 m^3 ha^{-1}) which was also statistically at par with UFC1.

Overall, the volume of trees between the forest classes the volume of trees follows the following trend: RF≥ DPF>UF>UPF≥CFS. The maximum volume (78.41 m^3 ha^{-1}) was reported in RF which was statistically at par with DPF (72.07 m^3 ha^{-1}), this was further followed by UF (64.56 m^3 ha^{-1}) which remains statistically at par with DPF. The lowest value for volume (33.17 m^3 ha^{-1}) was recorded in CFS which was observed to be statistically at par with UPF (40.06 m^3 ha^{-1}).

4.7 Biomass and Carbon stock

4.7.1 Stem biomass (t ha^{-1})

The stem biomass variation within and between the forest class is presented in Table 28. The maximum stem biomass within Reserve Forest was recorded in compartment RFC3 (68.46 t ha^{-1}) which was followed by and also remains statistically at par with RFC4 (56.46 t ha^{-1}). The minimum value for stem biomass was displayed by RFC2 (30.58 t ha^{-1}) at par with RFC1 (43.41 t ha^{-1}). The compartment DPFC1 under Demarcated Protected Forest had the significantly maximum stem biomass (68.71 t ha^{-1}) followed by DPFC3 (37.18 t ha^{-1}) and DPFC2 (33.81 t ha^{-1}) respectively. However, the lowest stem biomass was recorded in DPFC4 (31.89 t ha^{-1}) which remain statistically at par with DPFC2 and DPFC3, respectively. In Un-demarcated Protected Forest and Co-operative Forest Society no significant variation was observed within forest class and the compartments are arranged in following order: UPFC3>UPFC1>UPFC2>UPFC4 and CFSC3>CFSC1>CFSC2>CFSC4 respectively. In case of Un-class Forest significantly maximum stem biomass (83.47 t ha^{-1}) was recorded in compartment UFC4 whereas, the lowest value of stem biomass (19.11 t ha^{-1}) was recorded for UFC3. Further, the compartment UFC1 (36.29t ha^{-1}) and UFC2 (42.18t ha^{-1}) remains statistically at par with each other.

The maximum stem biomass between different forest classes was recorded in RF (49.73 t ha^{-1}) followed by and remains at par with UF (45.26 t ha^{-1}). Moreover, the Un-class Forest was also at par with DPF (42.90 t ha^{-1}). The lowest value for stem biomass (23.19 t ha^{-1}) was recorded for Co-operative Forest Society which remains statistically at par with UPF (28.54 t ha^{-1}).

4.7.2 Above Ground Biomass (AGB) (t ha^{-1})

The above ground biomass computed from stem biomass for different Forest classes are shown in Table 29 The maximum value for above ground biomass (124.46 t ha^{-1}) under Reserve Forest was recorded in compartment RFC3 followed by and remains at par with RFC4 (104.34 t ha^{-1}). However, significantly lowest value for AGB (50.70 t ha^{-1}) was recorded in RFC2. In Demarcated Protected Forest, the highest value for AGB (133.53 t ha^{-1})

was recorded in compartment DPFC1 which was followed by DPFC4 (65.51 t ha^{-1}) and DPFC3 (66.73 t ha^{-1}) whereas, the minimum value for AGB (63.13 t ha^{-1}) was reported in compartment DPFC2 which remains statistically at par with DPFC3 and DPFC4, respectively. Statistically no significant variation was recorded within compartments under Un-demarcated Protected Forest and Co-operative Forest Society and the trend followed was same as for stem biomass. In case of Un-class Forest, significantly maximum AGB (175.83 t ha^{-1}) was recorded in Compartment UFC4 followed by compartment UFC1 (85.75 t ha^{-1}) and UFC2 (84.16 t ha^{-1}). However, the compartment UFC1 and UFC2 remains statistically at par with each other. The significantly lowest value for AGB (41.90 t ha^{-1}) was displayed by compartment UFC3.

Overall, the AGB between forest classes follows the following trend: UF≥RF≥DPF>UPF≥CFS. The maximum AGB (96.91 t ha^{-1}) was recorded under UF which remains statistically at par with RF (89.73 t ha^{-1}) followed by DPF with at par value of 82.22 t ha^{-1}. However, the minimum value for AGB (45.28 t ha^{-1}) was recorded in CFS which remains statistically at par with UPF (53.67 t ha^{-1}).

4.7.3 Below Ground Biomass (BGB) (t ha^{-1})

The below ground biomass was computed from the AGB for different Forest classes is shown in Table 30.

Within Reserve Forest, significantly maximum value for BGB (66.01 t ha^{-1}) was recorded in compartment RFC3 followed by RFC4 (54.14 t ha^{-1}) and RFC1 (t ha^{-1}). However, significantly lowest value for BGB (28.01 t ha^{-1}) was recorded in RFC2. The BGB within Demarcated Protected Forest, Un-demarcated Protected Forest and Co-operative Forest Society did not show any significant variation between the compartments. However, the compartments within these forest classes are arranged in following decreasing order; DPFC1 > DPFC3 > DPFC4 > DPFC2; UPFC1 >UPFC3 > UPFC2 > UPFC4; CFSC3 > CFSC1 > CFSC4 > CFSC2, respectively. In case of Un-class Forest, the significantly maximum BGB (84.03 t ha^{-1}) was recorded in Compartment UFC4 followed by UFC1 (44.16t ha^{-1}) and UFC2 (44.58t ha^{-1}) however, both compartments (UFC1 and UFC2) remain statistically at par with each other. The significantly lowest value for BGB (21.93 t ha^{-1}) was displayed by compartment UFC3.

Table 25: Compartmental variation in tree diameter (cm) under different forest classes in Khair working circle of Nurpur Forest Division, Himachal Pradesh

Compartment	Reserve Forest (RF)	Compartment	Demarcated Protected Forest (DPF)	Compartment	Un-demarcated Protected Forest (UPF)	Compartment	Co-operative Forest Society (CFS)	Compartment	Un-class Forest (UF)
RFC1	19.61^{b}	**DPFC1**	24.62^{a}	**UPFC1**	16.25^{b}	**CFSC1**	18.04	**UFC1**	22.10^{b}
RFC2	18.87^{b}	**DPFC2**	16.33^{b}	**UPFC2**	20.35^{a}	**CFSC2**	17.79	**UFC2**	20.10^{b}
RFC3	21.56^{ab}	**DPFC3**	17.67^{b}	**UPFC3**	21.53^{a}	**CFSC3**	18.67	**UFC3**	21.38^{b}
RFC4	24.02^{a}	**DPFC4**	17.45^{b}	**UPFC4**	19.93^{a}	**CFSC4**	17.06	**UFC4**	30.02^{a}
Mean	$\mathbf{21.01^{b}}$		$\mathbf{19.02^{c}}$		$\mathbf{19.52^{bc}}$		$\mathbf{17.89^{c}}$		$\mathbf{23.40^{a}}$
CD $_{0.05}$ Within Forest class: 3.41 Between Forest class: 1.71									

Table 26: Compartmental variation in tree height (m) under different forest classes in Khair working circle of Nurpur Forest Division, Himachal Pradesh

Compartment	Reserve Forest (RF)	Compartment	Demarcated Protected Forest (DPF)	Compartment	Un-demarcated Protected Forest (UPF)	Compartment	Co-operative Forest Society (CFS)	Compartment	Un-class Forest (UF)
RFC1	6.85^{b}	**DPFC1**	8.89^{a}	**UPFC1**	6.21	**CFSC1**	7.57	**UFC1**	7.48^{b}
RFC2	8.50^{a}	**DPFC2**	6.41^{b}	**UPFC2**	7.37	**CFSC2**	7.28	**UFC2**	6.85^{b}
RFC3	8.46^{a}	**DPFC3**	6.03^{b}	**UPFC3**	7.09	**CFSC3**	6.58	**UFC3**	6.79^{b}
RFC4	7.87^{a}	**DPFC4**	7.04^{b}	**UPFC4**	7.02	**CFSC4**	6.78	**UFC4**	8.95^{a}
Mean	$\mathbf{7.92^{a}}$		$\mathbf{7.09^{b}}$		$\mathbf{6.92^{b}}$		$\mathbf{7.05^{b}}$		$\mathbf{7.52^{ab}}$
CD $_{0.05}$ Within Forest class: 1.17 Between Forest class: 0.59									

Table 27: Compartmental variation in volume (m^3 ha^{-1}) of trees under different forest classes in Khair Working circle of Nurpur Forest Division, Himachal Pradesh

Compartment	Reserve Forest (RF)	Compartment	Demarcated Protected Forest (DPF)	Compartment	Un-demarcated Protected Forest (UPF)	Compartment	Co-operative Forest Society (CFS)	Compartment	Un-class Forest (UF)
RFC1	65.17^{c}	**DPFC1**	139.46^{a}	**UPFC1**	37.62	**CFSC1**	37.39	**UFC1**	43.83^{bc}
RFC2	54.72^{c}	**DPFC2**	51.07^{b}	**UPFC2**	39.33	**CFSC2**	31.58	**UFC2**	55.95^{b}
RFC3	102.83^{a}	**DPFC3**	55.26^{b}	**UPFC3**	48.2	**CFSC3**	36.14	**UFC3**	25.56^{c}
RFC4	90.91^{b}	**DPFC4**	42.48^{b}	**UPFC4**	35.11	**CFSC4**	27.58	**UFC4**	132.90^{a}
Mean	**78.41^{a}**		**72.07^{ab}**		**40.06^{c}**		**33.17^{c}**		**64.56^{b}**

CD $_{0.05}$
Within Forest class: 18.83
Between Forest class: 9.42

Table 28: Compartmental variation in stem biomass (t ha^{-1}) of trees under different forest classes in Khair working circle of Nurpur Forest Division, Himachal Pradesh

Compartment	Reserve Forest (RF)	Compartment	Demarcated Protected Forest (DPF)	Compartment	Un-demarcated Protected Forest (UPF)	Compartment	Co-operative Forest Society (CFS)	Compartment	Un-class Forest (UF)
RFC1	43.41^{b}	**DPFC1**	68.71^{a}	**UPFC1**	31.36	**CFSC1**	24.57	**UFC1**	36.29^{b}
RFC2	30.58^{c}	**DPFC2**	33.81^{b}	**UPFC2**	26.59	**CFSC2**	21.56	**UFC2**	42.18^{b}
RFC3	68.46^{a}	**DPFC3**	37.18^{b}	**UPFC3**	32.39	**CFSC3**	26.55	**UFC3**	19.11^{c}
RFC4	56.46^{a}	**DPFC4**	31.89^{b}	**UPFC4**	23.84	**CFSC4**	20.09	**UFC4**	83.47^{a}
Mean	**49.73^{a}**		**42.90^{b}**		**28.54^{c}**		**23.19^{c}**		**45.26^{ab}**

CD $_{0.05}$
Within Forest class: 12.31
Between Forest class: 6.16

Overall, BGB between different forest classes is arranged in following order; UF≥RF>DPF>UPF>CFS, respectively. The maximum BGB (48.67 t ha^{-1}) was recorded under UF which remains statistically at par with RF (47.73 t ha^{-1}) significantly followed by DPF (37.19 t ha^{-1}) and UPF (29.86 t ha^{-1}). However, significantly minimum value for BGB (24.76 t ha^{-1}) was recorded in CFS.

4.7.4 Total biomass (TB) (t ha^{-1})

The Total tree biomass was computed by adding the AGB and BGB under different Forest classes and shown in Table 31. The maximum value of total tree biomass (190.47 t ha^{-1}) within Reserve Forest was recorded in compartment RFC3 followed by and remain statistically at par with RFC4 (158.48 t ha^{-1}). Further, the compartment RFC4 remains statistically at par with RFC1 (122.16 t ha^{-1}). Significantly lowest value for TB (78.71 t ha^{-1}) was recorded in RFC2. In case of Demarcated Protected Forest, the compartment DPFC1 had significantly maximum value for total tree biomass (173.25 t ha^{-1}) whereas, the lowest value was displayed by DPFC2 (98.71 t ha^{-1}) which remain statistically at par with DPFC4 (101.63 t ha^{-1}) and DPFC3 (104.06 t ha^{-1}) respectively. In Un-demarcated Protected Forest and Co-operative Forest Society the compartments remain statistically at par and the values for total tree biomass are arranged in following order: UPFC3>UPFC1>UPFC2>UPFC4 and CFSC3>CFSC1>CFSC4>CFSC2 respectively. In case of Un-class Forest, the significantly maximum total tree biomass (259.86 t ha^{-1}) was recorded in compartment UFC4 followed by UFC1(129.91 t ha^{-1}) and UFC2 (128.74 t ha^{-1}). However, both the compartments remain statistically at par with each other. The significantly lowest value for total tree biomass (63.83 t ha^{-1}) was displayed by compartment UFC3.

Overall, the total tree biomass for different forest classes is arranged in following order: UF≥RF≥DPF>UPF≥CFS, respectively. The maximum value for total tree biomass (96.91 t ha^{-1}) was recorded under UF which remains statistically at par with RF (89.73 t ha^{-1}) followed by DPF with at par value of 82.22 t ha^{-1}. The minimum value of total tree biomass (45.28 t ha^{-1}) was recorded for CFS which was at par with UPF (53.67 t ha^{-1}).

4.7.5 Tree carbon (t ha^{-1})

The tree carbon computed from the total tree biomass under different Forest classes is shown in Table 32. The maximum value of tree carbon (90.47 t ha^{-1}) within Reserve Forest was recorded in compartment RFC3 which was statistically at par and followed by RFC4

Table 29: Compartmental variation in above ground biomass (t ha^{-1}) of trees under different forest classes in Khair working circle of Nurpur Forest Division, Himachal Pradesh

Compartment	Reserve Forest (RF)	Compartment	Demarcated Protected Forest (DPF)	Compartment	Un-demarcated Protected Forest (UPF)	Compartment	Co-operative Forest Society (CFS)	Compartment	Un-class Forest (UF)
RFC1	79.41^{b}	**DPFC1**	133.53^{a}	**UPFC1**	56.6	**CFSC1**	46.68	**UFC1**	85.75^{b}
RFC2	50.70^{c}	**DPFC2**	63.13^{b}	**UPFC2**	49.98	**CFSC2**	40.44	**UFC2**	84.16^{b}
RFC3	124.46^{a}	**DPFC3**	66.73^{b}	**UPFC3**	61.89	**CFSC3**	52.5	**UFC3**	41.90^{c}
RFC4	104.34^{a}	**DPFC4**	65.51^{b}	**UPFC4**	46.21	**CFSC4**	41.5	**UFC4**	175.83^{a}
Mean	**89.73^{ab}**		**82.22^{b}**		**53.67^{c}**		**45.28^{c}**		**96.91^{a}**
CD $_{0.05}$ Within Forest class: 24.88 Between Forest class: 12.44									

Table 30: Compartmental variation in below ground biomass (t ha^{-1}) of trees under different forest classes in Khair working circle of Nurpur Forest Division, Himachal Pradesh

Compartment	Reserve Forest (RF)	Compartment	Demarcated Protected Forest (DPF)	Compartment	Un-demarcated Protected Forest (UPF)	Compartment	Co-operative Forest Society (CFS)	Compartment	Un-class Forest (UF)
RFC1	42.75^{c}	**DPFC1**	39.73	**UPFC1**	33.85	**CFSC1**	24.79	**UFC1**	44.16^{b}
RFC2	28.01^{d}	**DPFC2**	35.57	**UPFC2**	27.75	**CFSC2**	21.78	**UFC2**	44.58^{b}
RFC3	66.01^{a}	**DPFC3**	37.33	**UPFC3**	32.55	**CFSC3**	29.66	**UFC3**	21.93^{c}
RFC4	54.14^{b}	**DPFC4**	36.12	**UPFC4**	25.31	**CFSC4**	22.81	**UFC4**	84.03^{a}
Mean	**47.73^{a}**		**37.19^{b}**		**29.86^{c}**		**24.76^{d}**		**48.67^{a}**
CD $_{0.05}$ Within Forest class: 9.24 Between Forest class: 4.62									

Table 31: Compartmental variation in total biomass (t ha^{-1}) of trees under different forest classes in Khair working circle of Nurpur Forest Division, Himachal Pradesh

Compartment	Reserve Forest (RF)	Compartment	Demarcated Protected Forest (DPF)	Compartment	Un-demarcated Protected Forest (UPF)	Compartment	Co-operative Forest Society (CFS)	Compartment	Un-class Forest (UF)
RFC1	122.16^{b}	**DPFC1**	173.25^{a}	**UPFC1**	90.45	**CFSC1**	71.46	**UFC1**	129.91^{b}
RFC2	78.71^{c}	**DPFC2**	98.71^{b}	**UPFC2**	77.72	**CFSC2**	62.22	**UFC2**	128.74^{b}
RFC3	190.47^{a}	**DPFC3**	104.06^{b}	**UPFC3**	94.44	**CFSC3**	82.16	**UFC3**	63.83^{c}
RFC4	158.48^{ab}	**DPFC4**	101.63^{b}	**UPFC4**	71.52	**CFSC4**	64.31	**UFC4**	259.86^{a}
Mean	**137.45^{ab}**		**119.41^{b}**		**83.53^{c}**		**70.04^{c}**		**145.58^{a}**
CD $_{0.05}$ Within Forest class: 36.50 Between Forest class:18.25									

Table 32: Compartmental variation in tree carbon stock (t ha^{-1}) under different forest classes in Khair working circle of Nurpur Forest Division, Himachal Pradesh

Compartment	Reserve Forest (RF)	Compartment	Demarcated Protected Forest (DPF)	Compartment	Un-demarcated Protected Forest (UPF)	Compartment	Co-operative Forest Society (CFS)	Compartment	Un-class Forest (UF)
RFC1	58.02^{b}	**DPFC1**	85.03^{a}	**UPFC1**	42.96	**CFSC1**	33.95	**UFC1**	61.71^{b}
RFC2	37.39^{c}	**DPFC2**	46.91^{b}	**UPFC2**	36.92	**CFSC2**	29.56	**UFC2**	61.15^{b}
RFC3	90.47^{a}	**DPFC3**	49.43^{b}	**UPFC3**	44.86	**CFSC3**	39.03	**UFC3**	30.32^{c}
RFC4	75.28^{ab}	**DPFC4**	48.27^{b}	**UPFC4**	33.97	**CFSC4**	30.55	**UFC4**	123.43^{a}
Mean	**65.29^{ab}**		**57.41^{b}**		**39.68^{c}**		**33.27^{c}**		**69.15^{a}**
CD $_{0.05}$ Within Forest class: 17.34 Between Forest class: 8.67									

(75.28 t ha^{-1}). Moreover, the compartment RFC4 was at par with RFC1 (58.02 t ha^{-1}). The significantly lowest value for tree carbon (37.39 t ha^{-1}) was recorded in RFC2. The compartment DPFC1 within Demarcated Protected Forest had significantly maximum value for tree carbon (85.03 t ha^{-1}) whereas, the lowest value was recorded in DPFC2 (46.91 t ha^{-1}) which remain statistically at par with DPFC4 (48.27 t ha^{-1}) and DPFC3 (49.43 t ha^{-1}), respectively. In Un-demarcated Protected Forest and Co-operative Forest Society, the compartments remain statistically at par and the values are arranged in following order: UPFC3>UPFC1>UPFC2>UPFC4 and CFSC3>CFSC1>CFSC4>CFSC2, respectively. In case of Un-class Forest, the significantly maximum tree carbon (123.43 t ha^{-1}) was recorded in compartment UFC4 followed by UFC1 (61.71 t ha^{-1}) which remains statistically at par with UFC2 (61.15 t ha^{-1}). The significantly lowest value for tree carbon (30.32 t ha^{-1}) was displayed in compartment UFC3.

Overall, the tree carbon accumulated in different forest classes are arranged in following order; UF≥RF≥DPF>UPF≥CFS, respectively. The maximum value for tree carbon (69.15 t ha^{-1}) was recorded under UF which remains statistically at par with RF (65.29 t ha^{-1}) followed by DPF with at par value of 57.41 t ha^{-1}. The minimum value for tree carbon (33.27 t ha^{-1}) was recorded in CFS which was at par with UPF (57.41 t ha^{-1}).

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

4.7.6.1 Above ground shrub biomass (AGB) (t ha^{-1})

The above ground shrub biomass within and between different forest classes as shown in Table 33.

A significant variation was observed in aboveground biomass within different forest classes. In case of Reserve Forest, significantly maximum value for above ground shrub biomass (0.52 t ha^{-1}) was recorded in compartment RFC4 significantly followed by RFC3 (0.46 t ha^{-1}) and RFC1 (0.43 t ha^{-1}) whereas; significantly lowest value for above ground shrub biomass (0.37 t ha^{-1}) was found in RFC2. The compartment DPFC1 under Demarcated Protected Forest had significantly maximum value for above ground biomass of shrub (0.50 t ha^{-1}) followed by DPFC4 (0.46 t ha^{-1}) and DPFC3 (0.42 t ha^{-1}), respectively. However, significantly lowest value was recorded in DPFC2 (0.37 t ha^{-1}). In Un-demarcated Protected Forest maximum above ground shrub biomass was found in UPFC2 (0.37 t ha^{-1}) which was followed by and remains statistically at par with UPFC4 (0.35 t ha^{-1}) and further followed by

UPFC3 (0.32 t ha^{-1}). The lowest value of above ground shrub biomass was recorded in UPFC1 (0.23 t ha^{-1}). Within Co-operative Forest Society, the compartment CFSC2 displayed the maximum value for above ground shrub biomass (0.45 t ha^{-1}) which was significantly followed by CFSC1 (0.41 t ha^{-1}) and CFSC3 (0.39 t ha^{-1}). However, the compartment CFSC1 and CFSC3 remains statistically at par with each other. The significantly lowest value for above ground shrub biomass (0.36 t ha^{-1}) was recorded in compartment CFSC4. In case of Un-class Forest, maximum above ground shrub biomass (0.44 t ha^{-1}) was found in Compartment UFC1 followed by and remain statistically at par with UFC3 (0.42 t ha^{-1}). Furthermore, the compartment UFC3 was followed by and at par with UFC4 (0.41 t ha^{-1}). However, significantly lowest value for below ground shrub biomass (0.38 t ha^{-1}) was displayed by compartment UFC2.

Overall, slightly significant variation was observed between the forest classes which are arranged in following order; RF=DPF>UF≥CFS>UPF, respectively. The RF and DPF have the identical value for maximum above ground shrub biomass (0.44 t ha^{-1}). This was followed by UF (0.41 t ha^{-1}) which remains statistically at par with CFS (0.40 t ha^{-1}). However, significantly minimum value for above ground shrub biomass (0.31 t ha^{-1}) was recorded for UPF.

4.7.6.2 Below ground shrub biomass (BGB) (t ha^{-1})

The below ground shrub biomass within and between different Forest class are shown in Table 34.

Within Reserve Forest, significantly maximum value of below ground shrub biomass (0.34 t ha^{-1}) was reported in compartment RFC4 which was significantly followed by RFC3 (0.30 t ha^{-1}) and RFC1 (0.28 t ha^{-1}). Moreover, the significant lowest value for belowground shrub biomass (0.22 t ha^{-1}) was recorded in RFC2. The compartment DPFC1 within Demarcated Protected Forest displayed maximum value for below ground shrub biomass (0.32 t ha^{-1}) which was significantly followed by DPFC4 (0.30 t ha^{-1}) and DPFC3 (0.28 t ha^{-1}) respectively. The lowest value for below ground biomass was recorded in DPFC2 (0.24 t ha^{-1}). In Un-demarcated Protected Forest, the maximum below ground shrub biomass was recorded in UPFC2 (0.24 t ha^{-1}) which remains statistically at par with UPFC4 (0.23 t ha^{-1}). This was further significantly followed by UPFC3 (0.21 t ha^{-1}). The lowest value for below

Table 33: Compartmental variation in above ground shrub biomass (t ha^{-1}) under different forest classes in Khair working circle of Nurpur Forest Division, Himachal Pradesh

Compartment	Reserve Forest (RF)	Compartment	Demarcated Protected Forest (DPF)	Compartment	Un-demarcated Protected Forest (UPF)	Compartment	Co-operative Forest Society (CFS)	Compartment	Un-class Forest (UF)
RFC1	0.43^{c}	**DPFC1**	0.50^{a}	**UPFC1**	0.23^{c}	**CFSC1**	0.41^{b}	**UFC1**	0.44^{a}
RFC2	0.37^{d}	**DPFC2**	0.37^{d}	**UPFC2**	0.37^{a}	**CFSC2**	0.45^{a}	**UFC2**	0.38^{c}
RFC3	0.46^{b}	**DPFC3**	0.42^{c}	**UPFC3**	0.32^{b}	**CFSC3**	0.39^{b}	**UFC3**	0.42^{ab}
RFC4	0.52^{a}	**DPFC4**	0.46^{b}	**UPFC4**	0.35^{a}	**CFSC4**	0.36^{c}	**UFC4**	0.41^{b}
Mean	**0.44^{a}**		**0.44^{a}**		**0.32^{c}**		**0.40^{b}**		**0.41^{b}**
CD $_{0.05}$ Within Forest class : 0.02 Between Forest class : 0.01									

Table 34: Compartmental variation in below ground shrub biomass (t ha^{-1}) under different forest classes in Khair working circle of Nurpur Forest Division, Himachal Pradesh

Compartment	Reserve Forest (RF)	Compartment	Demarcated Protected Forest (DPF)	Compartment	Un-demarcated Protected Forest (UPF)	Compartment	Co-operative Forest Society (CFS)	Compartment	Un-class Forest (UF)
RFC1	0.28^{c}	**DPFC1**	0.32^{a}	**UPFC1**	0.15^{d}	**CFSC1**	0.26^{b}	**UFC1**	0.29^{a}
RFC2	0.22^{d}	**DPFC2**	0.24^{c}	**UPFC2**	0.24^{a}	**CFSC2**	0.29^{a}	**UFC2**	0.25^{c}
RFC3	0.30^{b}	**DPFC3**	0.28^{b}	**UPFC3**	0.21^{c}	**CFSC3**	0.25^{bc}	**UFC3**	0.28^{ab}
RFC4	0.34^{a}	**DPFC4**	0.30^{a}	**UPFC4**	0.23^{b}	**CFSC4**	0.24^{c}	**UFC4**	0.27^{b}
Mean	**0.28^{ab}**		**0.29^{a}**		**0.21^{c}**		**0.26^{b}**		**0.27^{b}**
CD $_{0.05}$ Within Forest Class : 0.01 Between Forest class : 0.01									

ground shrub biomass was recorded in UPFC1 (0.15 t ha^{-1}). In Co-operative Forest Society, compartment CFSC2 had the maximum value for below ground shrub biomass (0.29 t ha^{-1}) which was significantly followed by CFSC1 (0.26 t ha^{-1}). The lowest value was recorded in compartments CFSC4. However, the compartment CFSC3 (0.25 t ha^{-1}) was statistically at par with CFSC1 and CFSC4. In case of Un-class Forest maximum below ground shrub biomass (0.29 t ha^{-1}) was recorded in Compartment UFC1 which was followed by and remain statistically at par with UFC3 (0.28 t ha^{-1}). Moreover, the compartment UFC3 was statistically at par with UFC4 (0.27 t ha^{-1}). The significantly lowest value for below ground shrub biomass (0.25 t ha^{-1}) was recorded in compartment UFC2.

Overall, the below ground shrub biomass between different forest class is arranged in following order; DPF≥RF≥UF≥CFS>UPF. In this the maximum value for below ground shrub biomass (0.29 t ha^{-1}) was recorded in DPF which remains statistically at par with RF (0.28 t ha^{-1}). However, the below ground biomass recorded in UF (0.27 t ha^{-1}) was statistically at par with RF and CFS (0.26 t ha^{-1}). The minimum value for below ground shrub biomass (0.21 t ha^{-1}) was recorded for UPF.

4.7.6.3 Total Shrub biomass (t ha^{-1})

A perusal of data presented in Table 35 showed the total shrub biomass within and between different forest classes.

Within Reserve Forest, significantly maximum value for total shrubs biomass (0.85 t ha^{-1}) was recorded in compartment RFC4 which was significantly followed by RFC3 (0.76 t ha^{-1}) and RFC1 (0.71t ha^{-1}). However, significantly lowest value for total shrub biomass (0.61 t ha^{-1}) was found in RFC2. The compartment DPFC1 of Demarcated Protected Forest had the maximum value for total shrub biomass (0.82 t ha^{-1}) which was significantly followed by DPFC4 (0.76 t ha^{-1}) and DPFC3 (0.70 t ha^{-1}), respectively. However, the minimum value (0.61 t ha^{-1}) was recorded in DPFC2. In Un-demarcated Protected Forest maximum total shrub biomass was recorded in UPFC2 (0.61 t ha^{-1}) which remains statistically at par with UPFC4 (0.58 t ha^{-1}) and further followed by UPFC3 (0.53 t ha^{-1}). However, the significantly lowest value (0.38 t ha^{-1}) for total shrub biomass was reported in UPFC1. Within Co-operative Forest Society compartment CFSC2 had the maximum total shrub biomass (0.74 t ha^{-1}) which was significantly followed by CFSC1 (0.67 t ha^{-1}). However, the compartment CFSC1 was at par with CFSC3 (0.64 t ha^{-1}). The compartment CFSC4 had the lowest value of 0.60 t ha^{-1}. In case of Un-class Forest, maximum value for total shrub biomass (0.73 t ha^{-1}) was recorded in Compartment UFC1 which was followed by and remains statistically at par with UFC3 (0.70 t ha^{-1}). Furthermore, the compartment UFC3 was also followed by and statistically at par with UFC4 (0.68 t ha^{-1}). The lowest value for total shrub biomass (0.63 t ha^{-1}) was found in compartment UFC2.

Overall, the total shrub biomass between the forest classes had shown slightly significant variation and arranged in following order; RF=DPF>UF≥CFS>UPF. The maximum value for total shrub biomass was identical (0.73 t ha^{-1}) for both RF and DPF. This was followed by UF (0.68 t ha^{-1}) which remains at par with CFS (0.66 t ha^{-1}). However, the minimum value for total shrub biomass (0.52 t ha^{-1}) was recorded in UPF.

4.7.7. Herb biomass (t ha^{-1})

4.7.7.1 Above ground herb biomass (t ha^{-1})

The above ground herb biomass within and between the Forest class is shown in Table 36.

The compartments within different forest class were slightly significant except CFS and UF which shows significant variation within forest class. In case of Reserve Forest, the maximum value for above ground herb biomass was recorded in compartment RFC1, RFC2 and RFC3 with an identical value of 0.13 t ha^{-1}. However, significantly lowest value for above ground herb biomass (0.06 t ha^{-1}) was recorded in RFC2. Similarly, in Demarcated Protected Forest the compartment DPFC1 had significantly maximum value for above ground herb biomass (0.10 t ha^{-1}). However, the compartment DPFC1, DPFC2 and DPFC4 had the lowest identical value of 0.05 t ha^{-1}. In Un-demarcated Protected Forest maximum above ground herb biomass was recorded in UPFC2 (0.14 t ha^{-1}) which was followed by and remains statistically at par with UPFC4 (0.13 t ha^{-1}) and UPFC3 (0.12 t ha^{-1}), respectively. However, significantly lowest value for above ground herb biomass was displayed by UPFC1 (0.08 t ha^{-1}). The compartments within Co-operative Forest Society have shown significant variation in above ground herb biomass, the maximum value (0.33 t ha^{-1}) was recorded in CFSC4 which was significantly followed by CFSC2 (0.29 t ha^{-1}) and CFSC3 (0.06 t ha^{-1}), respectively. The compartment CFSC1 had the lowest above ground herb biomass (0.02 t ha^{-1}). In case of Un-class Forest, significantly maximum above ground herb biomass (0.14 t ha^{-1})

Table 35: Compartmental variation in total shrub biomass (t ha^{-1}) under different forest classes in Khair working circle of Nurpur Forest Division, Himachal Pradesh

Compartment	Reserve Forest (RF)	Compartment	Demarcated Protected Forest (DPF)	Compartment	Un-demarcated Protected Forest UPF)	Compartment	Co-operative Forest Society (CFS)	Compartment	Un-class Forest (UF)
RFC1	0.71^{c}	**DPFC1**	0.82^{a}	**UPFC1**	0.38^{c}	**CFSC1**	0.67^{b}	**UFC1**	0.73^{a}
RFC2	0.61^{d}	**DPFC2**	0.61^{c}	**UPFC2**	0.61^{a}	**CFSC2**	0.74^{a}	**UFC2**	0.63^{c}
RFC3	0.76^{b}	**DPFC3**	0.70^{b}	**UPFC3**	0.53^{b}	**CFSC3**	0.64^{bc}	**UFC3**	0.70^{ab}
RFC4	0.85^{a}	**DPFC4**	0.76^{a}	**UPFC4**	0.58^{a}	**CFSC4**	0.60^{c}	**UFC4**	0.68^{b}
Mean	$\mathbf{0.73^{a}}$		$\mathbf{0.73^{a}}$		$\mathbf{0.52^{c}}$		$\mathbf{0.66^{b}}$		$\mathbf{0.68^{b}}$
CD $_{0.05}$ Within Forest class : 0.04 Between Forest class : 0.02									

Table 36: Compartmental variation in above ground herb biomass (t ha^{-1}) under different forest classes in Khair working circle of Nurpur Forest Division, Himachal Pradesh

Compartment	Reserve Forest (RF)	Compartment	Demarcated Protected Forest (DPF)	Compartment	Un-demarcated Protected Forest (UPF)	Compartment	Co-operative Forest Society (CFS)	Compartment	Un-class Forest (UF)
RFC1	0.13^{a}	**DPFC1**	0.05^{b}	**UPFC1**	0.08^{c}	**CFSC1**	0.02^{d}	**UFC1**	0.06^{c}
RFC2	0.13^{a}	**DPFC2**	0.05^{b}	**UPFC2**	0.14^{a}	**CFSC2**	0.29^{b}	**UFC2**	0.09^{b}
RFC3	0.13^{a}	**DPFC3**	0.10^{a}	**UPFC3**	0.12^{a}	**CFSC3**	0.06^{c}	**UFC3**	0.14^{a}
RFC4	0.06^{b}	**DPFC4**	0.05^{b}	**UPFC4**	0.13^{a}	**CFSC4**	0.33^{a}	**UFC4**	0.05^{c}
Mean	$\mathbf{0.11^{b}}$		$\mathbf{0.07^{d}}$		$\mathbf{0.12^{b}}$		$\mathbf{0.18^{a}}$		$\mathbf{0.09^{c}}$
CD $_{0.05}$ Within Forest class: 0.02 Between Forest class: 0.01									

was recorded in Compartment UFC3 which was followed by UFC2 (0.09 t ha^{-1}). However, the lowest value for above ground herb biomass (0.05 t ha^{-1}) was recorded in compartment UFC4 which remains statistically at par with UFC1 (0.06 t ha^{-1}).

Significant variation for above ground herb biomass was observed between the forest classes which are arranged in following order; CFS>UPF≥RF>UF>DPF. The maximum value for above ground herb biomass (0.18 t ha^{-1}) was recorded in CFS which was significantly followed by UPF (0.12 t ha^{-1}). However, the UPF was statistically at par with RF (0.11 t ha^{-1}). This was further followed by UF (0.09 t ha^{-1}) and DPF with minimum value (0.07 t ha^{-1}).

4.7.7.2 Below ground herb biomass (t ha^{-1})

Variation in below ground herb biomass within and between the forest classes shown in Table 37 depicts that the variation was slightly significant within compartments except for CFS and UF while in case of between forest classes the variation was highly significant.

In case of below ground herb biomass within Reserve Forest, the compartments RFC1, RFC2 and RFC3 displayed the maximum identical value (0.08 t ha^{-1}) however, significantly lowest value (0.04 t ha^{-1}) was recorded in compartment RFC2. Similarly, the compartment DPFC3 within Demarcated Protected Forest represents significantly maximum below ground herb biomass (0.06 t ha^{-1}) whereas, the compartment DPFC1, DPFC2 and DPFC4 displayed the lowest identical value of 0.03 t ha^{-1}. In Un-demarcated Protected Forest maximum below ground herb biomass was recorded in compartment UPFC2 (0.08 t ha^{-1}) which was followed by and remains statistically at par with UPFC3 and UPFC3 both displayed the identical value of 0.07 t ha^{-1}. Significantly lowest value for below ground herb biomass was recorded in UPFC1 (0.05 t ha^{-1}). The compartment within Co-operative Forest Society had shown significant variation in belowground herb biomass where CFSC4 displayed the maximum value (0.19 t ha^{-1}) followed by CFSC2 (0.17 t ha^{-1}) and CFSC3 (0.04 t ha^{-1}), respectively. However, the compartment CFSC1 had the lowest value for below ground herb biomass (0.01 t ha^{-1}). In case of Un-class Forest, significantly maximum below ground herb biomass (0.08 t ha^{-1}) was recorded in Compartment UFC3 which was followed by UFC2 (0.05 t ha^{-1}). However, the lowest value of below ground herb biomass was recorded in compartment UFC4 and UFC1 both displayed the identical value of 0.03 t ha^{-1}).

Table 37: Compartmental variation in below ground herb biomass (t ha^{-1}) under different forest classes in Khair working circle of Nurpur Forest Division, Himachal Pradesh

Compartment	Reserve Forest (RF)	Compartment	Demarcated Protected Forest (DPF)	Compartment	Un-demarcated Protected Forest (UPF)	Compartment	Co-operative Forest Society (CFS)	Compartment	Un-class Forest (UF)
RFC1	0.08^a	**DPFC1**	0.03^b	**UPFC1**	0.05^b	**CFSC1**	0.01^d	**UFC1**	0.03^c
RFC2	0.08^a	**DPFC2**	0.03^b	**UPFC2**	0.08^a	**CFSC2**	0.17^b	**UFC2**	0.05^b
RFC3	0.08^a	**DPFC3**	0.06^a	**UPFC3**	0.07^a	**CFSC3**	0.04^c	**UFC3**	0.08^a
RFC4	0.04^b	**DPFC4**	0.03^b	**UPFC4**	0.07^a	**CFSC4**	0.19^a	**UFC4**	0.03^c
Mean	**0.07^b**		**0.04^c**		**0.07^b**		**0.10^a**		**0.05^c**
CD $_{0.05}$ Within Forest class: 0.01 Between Forest class: 0.01									

Table 38: Compartmental variation in total herb biomass (t ha^{-1}) under different forest classes in Khair working circle of Nurpur Forest Division, Himachal Pradesh

Compartment	Reserve Forest (RF)	Compartment	Demarcated Protected Forest (DPF)	Compartment	Un-demarcated Protected Forest (UPF)	Compartment	Co-operative Forest Society (CFS)	Compartment	Un-class Forest (UF)
RFC1	0.21^a	**DPFC1**	0.09^b	**UPFC1**	0.13^b	**CFSC1**	**0.03^d**	**UFC1**	0.09^c
RFC2	0.21^a	**DPFC2**	0.09^b	**UPFC2**	0.22^a	**CFSC2**	0.46^b	**UFC2**	0.14^b
RFC3	0.21^a	**DPFC3**	0.16^a	**UPFC3**	0.19^a	**CFSC3**	0.10^c	**UFC3**	0.22^a
RFC4	0.10^b	**DPFC4**	0.09^b	**UPFC4**	0.20^a	**CFSC4**	0.52^a	**UFC4**	0.09^c
Mean	**0.18^b**		**0.11^c**		**0.19^b**		**0.28^a**		**0.13^c**
CD $_{0.05}$ Within Forest class: 0.04 Between Forest class: 0.02									

Overall, the below ground biomass between forest classes is arranged in following statistical order; CFSF>RF=UPF>UF≥DPF respectively. The CFS had significantly maximum value (0.10 t ha^{-1}) for below ground herb biomass which was followed by RF and UPF both shares the common value of 0.07 t ha^{-1}. This was followed by UF (0.05 t ha^{-1}) which remains statistically at par with DPF (0.04 t ha^{-1}).

4.7.7.3 Total herb biomass (t ha^{-1})

The variation in total biomass (Table 38) within and between forest classes follows the similar trend as in above and below ground biomass of herbs.

Within Reserve Forest the compartments RFC1, RFC2 and RFC3 had the maximum identical value for total herb biomass (0.21 t ha^{-1}) whereas, significantly lowest value (0.10 t ha^{-1}) was displayed by compartment RFC2. In case of Demarcated Protected Forest, the compartment DPFC3 had significantly maximum value for total biomass of herb (0.16 t ha^{-1}) which was followed by DPFC1 and DPFC2 and DPFC4 with lowest identical value of 0.09 t ha^{-1}. In Un-demarcated Protected Forest, maximum total herb biomass was recorded in UPFC2 (0.22 t ha^{-1}) which remains statistically at par with UPFC3 (0.19 t ha^{-1}) and UPFC4 (0.20 t ha^{-1}), respectively. The significantly lowest value for total herb biomass was recorded in UPFC1 (0.13 t ha^{-1}). In Co-operative Forest Society, the compartment CFSC4 (65.07 t ha^{-1}) displayed significantly maximum value for total herb biomass which was followed by CFSC2 (0.46 t ha^{-1}) and CFSC3 (0.10 t ha^{-1}), respectively. However, compartment CFSC1 had significantly minimum value (0.03 t ha^{-1}). In case of Un-class Forest, the maximum total herb biomass (0.22 t ha^{-1}) was recorded in Compartment UFC3 which was significantly followed by UFC2 (0.14 t ha^{-1}). The lowest value for total herb biomass (0.09 t ha^{-1}) was recorded identical for compartment UFC4 and UFC1.

In case of total herb biomass between forest classes, CFS had the maximum value (0.28 t ha^{-1}) followed by UPF (0.19 t ha^{-1}) and RF (0.18 t ha^{-1}) both (UPF and RF) remains statistically at par with each other. Furthermore, the lowest value for total herb biomass (0.11 t ha^{-1}) was recorded in DPF which remains statistically at par with UF (0.13 t ha^{-1}).

4.7.8 Comparison of biomass and carbon stock between forest classes

The comparison of biomass and carbon stock between different forest classes is shown in Table 39. The tree biomass (AGB, BGB and TB) and over story carbon stock was recorded maximum for Un-class Forest which was closely followed by and remains statistically at par with Reserve Forest. Although, the biomass recorded in RF was statistically at par with Demarcated Protected Forest whereas, Co-operative Forest and Un-demarcated Protected Forest had the lowest biomass accumulation. Maximum shrub biomass was present in Reserve Forest and Demarcated Protected Forest whereas, the Un-demarcated Protected Forest had the minimum value among different forest classes. The maximum herb biomass recorded in Co-operative Forest Society was significantly followed by Un-demarcated Protected Forest and Reserve Forest. The lowest value was recorded in Demarcated Protected Forest. Overall, the total vegetation biomass in different forest classes is arranged in following order; UF≥RF≥DPF>UPF≥CFS respectively. The under-story carbon stock was recorded maximum in CFS which remains statistically at par with RF whereas, the significantly lowest value in Un-demarcated Protected Forest. However, the soil carbon stock between forest classes shows slightly significantly variation where the maximum soil carbon density was recorded in Demarcated Protected Forest which was closely followed by and remains statistically at par with Reserve Forest, however, the Reserve Forest remains at par with UPF, CFS and UF respectively.

The maximum ecosystem carbon stock potential and Co_2 mitigated was recorded in Un-class Forest which was closely followed by and remains statistically at par with reserve Forest and Demarcated Protected Forest, however, the minimum ecosystem carbon stock and Co_2 mitigated was recorded in CFS which was at par with UPF.

The tree height, volume, biomass and carbon stock of the study area varied significantly. The maximum tree height recorded under different compartments and in Reserve Forest can be attributed to vigorous growth due to crown opening in certain areas. Also, height growth can be attributed to site conditions of the area as tree height is the indicator of site quality (Luna 1995 and Kozlowski, 1979). We demonstrate that the present study area stores a large quantity of biomass (62.22 to 259.86 t ha^{-1}) and carbon stock (47.73 to 85.50 t ha^{-1}) which is considerably closer to as documented by Singh and Verma (2018) they reported the values for biomass ranges from 123.89 to 537.77 Mg $ha^{-1}$and carbon stock in the range of 58.23 and 252.75 Mg ha^{-1}. Findings of Raha *et al.* (2020) in tropical dry deciduous forest were also closer to (biomass; 70.4 to 296.6 Mg ha^{-1}) and within range (carbon stock; 35.3 to 140.9 Mg ha^{-1}) of our study. Further the variation in growth parameters within compartments may be due to variation in species composition, species richness and presence of single dominating species with bigger diameter. Shahid and Joshi (2018) also

Table 39: Comparison of biomass (AGB, BGB, and TB) and carbon stock potential between different forest classes in Khair working circle of Nurpur Forest Division, Himachal Pradesh

Forest Class	Above ground tree biomass (t ha^{-1})	Below ground tree biomass (t ha^{-1})	Total tree biomass (t ha^{-1})	Shrub biomass (t ha^{-1})	Herb biomass (t ha^{-1})	Total vegetation Biomass (t ha^{-1})	Over story carbon stock (t ha^{-1})	Under story carbon stock (t ha^{-1})	Soil carbon stock (t ha^{-1})	Ecosystem carbon stock (t ha^{-1})	CO_2 mitigated (t ha^{-1})
Reserve Forest (RF)	89.73^{ab}	47.73^{a}	137.45^{ab}	0.73^{a}	0.18^{b}	138.37^{ab}	65.29^{ab}	0.41^{a}	19.12^{ab}	84.82^{a}	311.28^{a}
Demarcated Protected Forest (DPF)	82.22^{b}	37.19^{b}	119.41^{b}	0.73^{a}	0.11^{c}	120.24^{b}	57.41^{b}	0.37^{b}	19.84^{a}	77.62^{a}	284.88^{a}
Un-demarcated Protected Forest (UPF)	53.67^{c}	29.86^{c}	83.53^{c}	0.52^{c}	0.19^{b}	84.24^{c}	39.68^{c}	0.32^{c}	17.08^{b}	57.08^{b}	209.48^{b}
Co-operative Forest Society (CFS)	45.28^{c}	24.76^{d}	70.04^{c}	0.66^{b}	0.28^{a}	70.80^{c}	33.27^{c}	0.42^{a}	16.04^{b}	49.73^{b}	182.52^{b}
Un-class Forest (UF)	96.91^{a}	48.67^{a}	145.58^{a}	0.68^{b}	0.13^{c}	146.40^{a}	69.15^{a}	0.37^{b}	15.98^{b}	85.50^{a}	313.79^{a}
$C.D._{0.05}$	**12.44**	**4.62**	**18.25**	**0.02**	**0.02**	**18.25**	**8.67**	**0.01**	**2.4**	**8.67**	**31.83**

reported that the carbon stock varied from 129.81 and 136.00 Mg ha^{-1} in Shiwalik hills whereas, Rao and Rao (2015) recorded lesser than the present study the total standing biomass and carbon stocks of 56.047 Mt and 26.34 Mt respectively. Meena *et al.* (2019) estimated 90.51 Mg ha^{-1} biomass and 63.49 Mg C ha^{-1} carbon in the semi-arid forest of Delhi. In our study the total biomass was within the range reported for Indian forest systems (27.4 to 251.8Mg ha^{-1}) (Chhabra *et al.,* 2002), but is higher than the average (40 Mg ha^{-1}) value reported for thorn forest system (Ravindranath *et al.,* 1997). The carbon stock for the present forests is higher than the range reported for tropical dry deciduous (12.79–62.48 Mg ha^{-1}), evergreen forests (18.85–48.58 Mg ha^{-1}) and thorn forests (4.91–13.3Mg ha^{-1}) in India (FSI, 2019).

The values of our study are well within the total biomass values reported by Gandhi and Sundarapandian (2017) in tropical dry deciduous forest of Eastern Ghats, Tamil Nadu, India(76.28–708.26 Mg ha^{-1}), Terakunpisut *et al.*(2007) in aboveground biomass of Thong Pha Phum national forest, Thailand (92.6–275.4 Mg/ha), but lesser than the mean values of the aboveground biomass in moist deciduous forests of Katerniaghat Wildlife Sanctuary, Uttar Pradesh (290.8 – 455.9 Mg ha^{-1}) (Behera *et al.,* 2017). The results of the present study are higher than the values reported in tropical deciduous forests of Madhya Pradesh, India (13–54 Mg ha^{-1}) (Salunkhe *et al.,* 2014), selected tropical forest patches of Tripura, Northeast India (37.8–85.9 Mg ha^{-1}) (Majumdar *et al.,* 2016) and a tropical dry forest of Ceara, Brazil (43.28 Mg ha^{-1}) (Prado-Junior *et al.,* 2016). The results observed in the current study are well within the global range of carbon stocks in tropical dry forests (14–123Mg ha^{-1}; Murphy and Lugo, 1986), tropical deciduous forests (39–334 Mg ha^{-1}; Becknell *et al.,* 2012), in woody species of tropical dry forest of Uttar Pradesh (15.6–151 Mg ha^{-1}, Chaturvedi *et al.,* 2011) and in two tropical forests of Assam (67.6–73.2Mg ha^{-1}; Borah *et al.,* 2015). Our results are higher than the reported values in tropical deciduous forest ecosystems of Madhya Pradesh, India (1.89–25.6Mg ha^{-1}) (Salunkhe *et al.,* 2014), in tropical dry deciduous forests, India (25.3–42.4Mg ha^{-1}, Singh *et al.,* 2016).

In the forest communities, shrub and herb biomass is an important component of the total biomass. Generally, the lack of accurate methodology and difficulty in estimation, they are omitted for biomass calculation studies (Karki, 2002 and Khanal, 2001). The biomass of herb and shrubs was recorded low within and between forest classes where the tree density was high. The area with scattered or lesser number of trees, first dominated by shrub and then under this the limited space and light is utilized by herbs. The density and biomass of herbs are inversely proportional to the shrub and tree density (Grunow *et al*., 1980; Sandford *et al*., 1982; Puri *et al.,* 1992 and Pandey *et al.,* 2000). The evidence can be clearly observed from Table 9 where the maximum diversity index for herb was opposite to shrub and trees. Thus, herbs can only play a substantial role for total biomass production in habitats with low tree density. In our study significantly maximum herb biomass was recorded in CFS where the trees were scattered due to high anthropogenic pressure. Grace *et al.* (2017) in their study also observe that the disturbance regimes may have increased herb biomass but decrease the overall ecosystem biomass. The exploitation of ecosystem was observed to change the vegetation composition and above ground biomass (Vitousek *et al.,* 1997). Forest protection in the reserve also led to the forest structural alteration with the observation of larger-sized trees and shorter herbs (Wang *et. al*., 2020).

However, the significant variation in overall biomass and carbon stock (Table 38) between different forest classes may be attributed to management practices. Forest carbon is considered as a function of tree size and tree density (Ali *et al.,* 2019; Lecina-Diaz *et al*., 2018; Van De Perre *et al*., 2018 and Yuan *et al*., 2018). Our study confirms that reserve and protected forest had positive impacts on biomass and carbon storage. We found that the Reserve Forest and Protected Forests have more biomass and tree carbon than the corresponding unprotected forests except for Un-class Forest. However, the maximum biomass and carbon stock recorded in Un-class Forest was due to bigger size tree and high Simpson dominance index (Table 18). The dominant species (*Acacia catechu*) present in this forest class had the maximum number of individuals as compare to other forest class (Table 24) further the high value of specific gravity and biomass expansion factor also plays a major role in estimation of biomass and carbon stock. Large diameter class of trees is the main drivers of biomass and carbon stock variation across the tropics (Slik *et al.,* 2013)and the heterogeneous distribution of large trees is influenced by basal area (Panzou *et al.,* 2018).The substantial effect of large sized trees on forest biomass and carbon had been commonly observed (Ali *et al*., 2019; Meyer *et al.,* 2018 and Slik *et al.,* 2013).The high basal area and carbon stock were more related to few trees with a large basal area, each containing a disproportionately large biomass and carbon stock, than to many small trees. This was attributed due to the greater number of trees in bigger diameters class which have the larger effect on the tree biomass and carbon, in agreement with other studies (Damptey *et al*., 2020; Srinivas and Sundarapandian, 2019; Lung and Espira, 2015). In comparison, the smaller trees in CFS may account for the lower value of volume and biomass (Padmakumar *et al.,* 2018). Although the value for biomass and carbon stock is higher in Un-class forest but the other factors like species diversity, richness and regeneration are also important for sustainable management. Whereas, the RF and DPF are rich in diversity, number of trees in each diameter class and the biomass and carbon stock is also at par with Un-class forest which shows the impact of management practices. Therefore, it is generally expected that forest protection reduces disturbance and biomass extraction. Extensive biomass extraction which generally occurs near settlements alters forest structure and had direct and negative consequences to vegetation biomass and carbon (Sapkota *et al*., 2018; Vaidyanathan *et al*., 2010). Structurally diverse forests were reported to have higher ecosystem productivity than simpler forests (Ali, 2019). We demonstrated that among the stand structural attributes, tree size have direct and positive effect on the tree carbon. Gogoi *et al.* (2017) also reported that the total plant biomass and diversity decrease from least disturbed to most disturbed site. Thus, it can be concluded that carbon sequestration in forest ecosystems was influenced by the anthropogenic disturbances in the present study. This difference in biomass and carbon stock values among these forest classes could be attributed to species variability, tree structure, basal area, heterogeneity in diameter class, soil characteristics, study site conditions and other anthropogenic factors (Lewis *et al.,* 2013; Dar and Sundarapandian, 2015; Slik *et al.,* 2010; Becknell *et al.,* 2012 and Sundarapandian *et al.,* 2013). The lower values could also be due to the illegal cutting of larger trees or small-scale extraction of timber in these forests, because of their nearness to human settlements (Pande, 2005 and Sagar *et al.,* 2003). Higher biomass and carbon stock in the UF, RF and DPF than CFS and UPF correspond mainly the higher tree density and basal area.

4.8 Regeneration studies

The regeneration status of Reserve Forest shown in Table 40 depicts that a total number of 1187.50 recruits ha^{-1} were recorded among of which *Mallotus phillippensis* (437.50 recruits ha^{-1}) had the maximum recruits followed by *Acacia catechu* (312.50 recruits ha^{-1}) >*Pinus roxburghii* (187.50 recruits ha^{-1}) >*Cassia fistula* and *Lennea coromandelica* (125 recruits ha^{-1}), respectively. However, among total un-established regeneration (750 individual ha^{-1}) and established regeneration (625 individual ha^{-1}), *Mallotus phillipensis* had the maximum number (437.50 individual ha^{-1} and 375 individual ha^{-1}) followed by *Acacia catechu* (187.50 individual ha^{-1} and 187.50 individual ha^{-1}) and *Cassia fistula* (125 individual ha^{-1} and 62.50 individual ha^{-1}) un-established and established regeneration of *Lannea* *coromandelica* and *Pinus roxburghii* was absent in Reserve Forest. Moreover, the establishment stocking percent and regeneration success (%) of Reserve Forest was 33.22 % and 32.50 % for which the species are arranged as follow; *Mallotus phiillippensis*>*Acacia catechu* and >*Cassia fistula*.

Table 41 showing the regeneration status of different species in Demarcated Protected Forest shows that a total number of 500 recruits ha^{-1} were recorded among of which *Acacia catechu* had the maximum recruits (250 recruits ha^{-1}) followed by *Mallotus phillippensis*, *Cassia fistula* and *Lannea coromandelica*. For un-established regeneration (812.50 individuals ha^{-1}) the maximum value was recorded for *Mallotus phillippensis* (312.50 individuals ha^{-1}) followed by *Acacia catechu*, *Cassia fistula*, *Lannea coromandelica* and *Pinus roxburghii* all had identical value of 125 individual ha^{-1}. A total number of 500 established regeneration ha^{-1} were recorded from which *Acacia catechu* and *Mallotus phillippensis* had the highest value (187.50 individual ha^{-1}) followed by *Cassia fistula* (125 individual ha^{-1}). Demarcated Protected Forest had the establishment stocking index of 28.65 percent and regeneration success of 28.15 percent. *Mallotus phillippensis* (12.45 %) had the highest establishment stocking index followed by *Acacia catechu* (9.95 %) and *Cassia fistula*

Table 40: Regeneration status of Reserve Forest in Khair working circle of Nurpur Forest Division, Himachal Pradesh

Sr. No.	Species	Recruits ha^{-1}	Un-established ha^{-1}	Established ha^{-1}	Establishment stocking (%)	Regeneration Success (%)
1	*Acacia catechu*	312.5	187.5	187.5	8.88	9.37
2	*Cassia fistula*	125	125	62.5	3.56	3.76
3	*Lannea coromandelica*	125	-	-	-	-
4	*Mallotus phillippensis*	437.5	437.5	375	20.78	19.37
5	*Pinus roxburghii*	187.5	-	-	-	-
	Total	**1187.5**	**750**	**625**	**33.22**	**32.5**

Table 41: Regeneration status of Demarcated Protected Forest in Khair working circle of Nurpur Forest Division, Himachal Pradesh

Sr No.	Species	Recruits ha^{-1}	Un-established ha^{-1}	Established ha^{-1}	Establishment stocking (%)	Regeneration Success (%)
1	*Acacia catechu*	250	125	187.5	9.95	8.75
2	*Cassia fistula*	62.5	125	125	6.25	6.25
3	*Lannea coromandelica*	62.5	125	-	-	1.25
4	*Mallotus phillippensis*	125	312.5	187.5	12.45	10.63
5	*Pinus roxburghii*	-	125	-	-	1.25
	Total	**500**	**812.5**	**500**	**28.65**	**28.13**

Table 42: Regeneration status of Un-demarcated Protected Forest in Khair working circle of Nurpur Forest Division, Himachal Pradesh

Sr. No.	Species	Recruits ha^{-1}	Un-established ha^{-1}	Established ha^{-1}	Establishment stocking (%)	Regeneration Success (%)
1	*Acacia catechu*	250	125	187.5	8.8	8.75
2	*Albizia lebbeck*	-	62.5	-	-	0.63
3	*Cassia fistula*	62.5	62.5	-	-	0.63
4	*Lannea coromandelica*	-	125	62.5	-	3.75
5	*Mallotus phillippensis*	187.5	125	187.5	11.22	8.75
	Total	**500**	**500**	**437.5**	**20.02**	**22.5**

(6.25 %). Whereas; the regeneration success of different species is arranged in following order; *Mallotus phillippensis* > *Acacia catechu* > *Cassia fistula* > *Lannea coromandelica*= *Pinus roxburghii.*

In Un-demarcated Protected Forest (Table 42) only three species were recorded with total number of 500 recruits ha^{-1} among of which *Acacia catechu* had the maximum recruits (250 recruits ha^{-1}) followed by *Mallotus phillippensis* (187.50 recruits ha^{-1}) and *Cassia fistula* (62.50 recruits ha^{-1}). For un-established regeneration of 500 individuals ha^{-1} (five species), *Acacia catechu*, *Lannea coromandelica* and *Mallotus phillippensis* had the maximum identical value (125 individual ha^{-1}) followed by *Albezia lebbeck* and *Cassia fistula* (62.50 individual ha^{-1}). The established regeneration (only three species) recorded in this forest was 437.50 individuals ha^{-1} among of which *Acacia catechu* and *Mallotus phillippensis* had identical value of 187.50 individual ha^{-1} followed by *Lannea coromandelica* (62.50 individual ha^{-1}). The establishment stocking per cent (20.02%) in UPF was low and only two species (*Mallotus phillippensis* and *Acacia catechu*) showed the maximum (11.22 %) and minimum value (8.80 %). The regeneration success of Un-demarcated Protected Forest was 22.50 per cent and the value for different species are arranged in following order; *Acacia catechu* = *Mallotus phillippensis* > *Lannea coromandelica* > *Albezia lebbeck* = *Cassia fistula* respectively.

The regeneration status of different species in Co-operative Forest Society is shown in Table 43. A total number of 312.50 recruits ha^{-1} were recorded among of which *Acacia catechu* had the maxumim recruits ha^{-1}(187.50) which was followed by *Cassia fistula* and *Dalbergia sissoo* (62.50 recruits ha^{-1}). The total un-established regeneration of 375 indivudual ha^{-1} in CFS, *Mallotus phillippensis* had the maximum number followed by *Acacia catechu*, *Cassia fistula*, *Lannea coromandelica* and *Syzygium cumini* all had identical value of 62.50 individual ha^{-1}. Only three species of established regeneration (*Acacia catechu*, *Dalbergia sissoo* and *Lannea coromandelica*) having identical value of 62.50 individual ha^{-1} were recorded. However, the establishment stocking per cent was only 7.87 per cent among of which *Acacia catechu* had the highest percentage value (2.87 %) followed by *Dalbergia sissoo* and *Leucaena leucocephala.* Furthermore, the regeneration success (11.25 %) of different species is arranged as follow; *Acacia catechu>Dalbergia sissoo = Leucaena leucocephala>Mallotus phillippensis>Cassia fistula = Lannea coromandelica = Syzygium cumini,* respectively.

Table 43: Regeneration status of Co-operative Forest Society in Khair working circle of Nurpur Forest Division, Himachal Pradesh

Sr. No.	Species	Recruits ha^{-1}	Un-established ha^{-1}	Established ha^{-1}	Establishment stocking (%)	Regeneration Success (%)
1	*Acacia catechu*	187.5	62.5	62.5	2.87	3.13
2	*Cassia fistula*	62.5	62.5	-	-	0.63
3	*Dalbergia sissoo*	62.5	-	62.5	2.5	2.5
4	*Lannea coromandelica*	-	62.5	-	-	0.63
5	*Leeucaena leucocephala*	-	-	62.5	2.5	2.5
6	*Mallotus phillippensis*	-	125	-	-	1.25
7	*Syzygium cumini*	-	62.5	-	-	0.63
	Total	**312.5**	**375**	**187.5**	**7.87**	**11.25**

Table 44: Regeneration status of Un-class Forest in Khair working circle of Nurpur Forest Division, Himachal Pradesh

Sr. No.	Species	Recruits ha^{-1}	Un-established ha^{-1}	Established ha^{-1}	Establishment stocking (%)	Regeneration Success (%)
1	*Acacia catechu*	125	-	62.5	4.38	2.5
2	*Cassia fistula*	62.5	125	-	-	1.25
3	*Mallotus phillippensis*	250	62.5	187.5	6.09	8.13
	Total	**437.5**	**187.5**	**250**	**10.47**	**11.88**

In Un-class forest (Table 44) total recruits (437.50 recruits ha^{-1}) of three species were recorded of which *Mallotus phillippensis* had the maximum number (250 recruits ha^{-1}) followed by *Acacia catechu* and *Cassia fistula*. However, un-established regeneration of only two species i.e., *Cassia fistula* (125 individual ha^{-1}) and *Mallotus phillippensis* (62.50 individual ha^{-1}) were present with a total number of 187.50 individual ha^{-1}. Furthermore, the established regeneration (250 individual ha^{-1}) with establishment stocking percent of 10.47 % for two species i.e., *Acacia catechu* (62.50 individual ha^{-1} and 4.38 %) and *Mallotus* *phillippensis* (187.50 individual ha^{-1} and 6.09 %) were also recorded. The regeneration success (11.88 %) of all the three species is as follow; *Mallotus phillippernsis* (8.13 %), *Acacia catechu* (2.50%) and *Cassia fistula* (1.25%), respectively.

Table 45: Regeneration status of under different Forest class in Khair working circle of Nurpur Forest Division, Himachal Pradesh

Sr. No.	Forest class	Recruits ha^{-1}	Un-established ha^{-1}	Established ha^{-1}	Establishment stocking (%)	Regeneration Success (%)
1	**Reserve Forest (RF)**	1187.5	750	625	33.23	32.5
2	**Demarcated Protected Forest (DPF)**	500	812.5	500	28.65	28.13
3	**Un-demarcated Protected Forest (UPF)**	500	500	437.5	20.02	22.5
4	**Co-operative Forest Society (CFS)**	312.5	375	187.5	7.87	11.25
5	**Un-class Forest (UF)**	437.5	187.5	250	10.47	11.88

Overall, the regeneration status of different forest classes is shown in Table 45. The highest number of recruits (1187.50 recruits ha^{-1}) were recorded in Reserve Forest followed by Demarcated Protected Forest and Un-demarcated Protected Forest (500 recruits ha^{-1}), Un-class Forest (437.50 recruits ha^{-1}) and Co-operative Forest Society (312.50 recruits ha^{-1}), respectively. The un-established regeneration ha^{-1} for different forest classes follow the following trend; RF>DPF>UPF>CFS>UF. Whereas; the established regeneration ha^{-1} in different forest classes is arranged in following order; RF>DPF>UPF>UF>CFS. Maximum value for establishment stocking percent and regeneration success was recorded in RF followed by DPF, UPF, UF and CFSF, respectively.

The wealth of any forest depends on the regeneration potential of the principal species of that forest in space and time (Jones *et al*., 1994; Rawat *et al*., 2018; Rocky and Mligo, 2012). Similarly, the number of saplings and seedlings of diverse species can help in forecasting future changes, regeneration, and status of flora biodiversity in any forest (Malik and Bhatt, 2016). The regeneration behavior of different species depends on the internal community processes and exogenic disturbances (Barker and Patrik, 1994). In the present study, 312.50 to 1187.50 recruits ha^{-1}, established regeneration of 187.50 to 625 number ha^{-1}, and un-established regeneration of 187.50 to 812.50 number ha^{-1} were recorded. The lowest value for recruits and established regeneration were found in CFS, whereas the Un-class forest had minimum un-established regeneration. This may be due to the fact that these forest classes are easily accessible by the local communities, therefore, can be considered as vulnerable. Further, within CFS the number of recruits and established regeneration were less than un-established regeneration which clearly indicates the degree of disturbance. According to Saxena and Singh (1984) grazing and trampling by cattle affect the soil structure by compacting it which leads to lower moisture content and lower permeability. This may alter the habitat and make it less suitable for the establishment of seedlings. The reduced canopy cover in CFS and Un-class Forest had a direct effect on seed production which may also indirectly affect regeneration through change in the understorey vegetation and soil properties (Vetaas, 2000). The values for regeneration in the present study was lower than the values reported (6,200 saplings ha^{-1}) in sub-tropical forest of Garhwal Himalaya (Kumar *et al*., 2004). Pokhriyal *et al*. (2010) recorded the sapling density of 7.01 to 3.70 individuals 100 m^{-2} and seedling density also varied from 33.20 to 23.29 individuals 100 m^{-2} in watershed area of sub- tropical region which are within the range of our findings. The reason for greater numbers of recruits, un-established and established regeneration in Reserve Forest and Demarcated Protected Forest as compare to other forest classes may be due to differences in management regimes which attributed to reduced disturbance and did not allow creating gaps and opening of canopies (Nagamastu *et al*., 2002). Patterns of forest regeneration, particularly in dry tropical forests, are often neglected in both research and policy development (Barrett *et al*., 2001). In the present study, based on criteria for regeneration success by Khana (1996), the overall maximum percentage of fair regeneration success was reported in RF followed by DPF and UPF while the poor regeneration success percentage was observed for UF and CFS respectively. Anthropogenic disturbances like fuel wood collection and grazing are the most common factors affecting the regeneration in forest area other than reserve and protected forest. Overgrazing by livestock harms the ground flora and impedes regeneration (Malik *et al.* 2014). Traore (2008) studies the regeneration success of Acacia spp. in eastern Burkina under two land use regimes and reported good regeneration rate of *Acacia* species in protected areas as compare to the areas with high human impact. Similarly, Fayiah *et al.* (2018) recorded a fair regeneration for two forests reserves inventoried in southern Sierra Leone and concluded that the regeneration potential may even get worsen if urgent measures are not put in place to curb the rate of forest resource exploitation within these two forest areas. According to various researchers (Poorter *et al*., 1996 and Whitemore, 1975) these problems have been dated back decades. On a larger scale, the regeneration of natural forests dramatically affected by abiotic (temperature, rainfall, and soil fertility) and biotic factors (diversity, composition and richness) (Khaine *et al*., 2018).

Majority of the species in the studied forest classes fails to regenerate. Further, regeneration success of different species among different forest classes was deficient however, *Mallotus phillippensis* which is a secondary species in all the forest classes had the overall maximum regeneration and establishment stocking index which clearly indicates that in near future the forest will be dominated by this species which may leads the forest to degrading stage. Reddy and Ugle (2008) in their study in tropical dry and moist deciduous forest of Western Ghats reported that out of the 104 species recorded, 28.8% showed good regeneration, 5.8% fair, 33.7% poor and 29.8% showed no regeneration in moist deciduous forest. In case of dry deciduous forest, 33.7% showed good regeneration, 3.5% fair, 16.3% poor and 17.4% showed no regeneration at all. Absence of new recruits in these forests may be due to the impact of anthropogenic disturbances and influence of exotic weeds on natural regeneration. Eltahir and Wagner (2012) also assessed regeneration situation in reserved forest of Sudan and concluded that the lower proportion of rarity and poor establishment of regeneration may be due to competition, termite infection and wild animal's effect.

The other possible reason for low regeneration status in different forest classes may be due to the presence of *Lantana camera*. Many of the studies have reported the impact of lantana on regeneration and establishment. *Lantana camara* had serious deleterious effect on some of endemic animal (Morton, 1994; Sharma *et al*., 2007) and plant species. It is also known to displace natural scrub communities as well as prevent natural regeneration of some tree species (Ambika *et al.*, 2003; Sharma and Raghubanshi, 2006 and Dobhal, 2010). Plant species with specific root and shoot distribution habits in relation to *Lantana camara* may come across different level of resource competition and allelopathic inhibition offered by this invasive (Dobhal *et al*., 2010). This could also be a plausible reason for observed variation in impact of *Lantana camara* invasion on different life forms. Although the forest had high regeneration potential, all established seedling did not get the chance to develop into sapling stage which may be due to high human interference like grazing, trampling, forest fire, lopping and unsustainable harvesting of forest resources. All seedlings cannot survive due to harsh environmental condition and cannot compete with grasses for limited resources

4.9 Site characteristic

4.9.1 Soil pH, electrical conductivity (dsm^{-1}) and bulk density (g m^{-3})

A significant variation in soil pH, electrical conductivity and bulk density was observed along the soil depth (Table 46) whereas, the variation between forest class except for electrical conductivity and the interaction between forest classes and soil depth was not significant. The soil pH of study area was found slightly acidic which increases significantly with soil depth i.e., 6.05 at 0-20cm and 6.26 at 20.40 cm soil depth. The maximum value for soil pH between the forest classes was recorded in UPF (6.30) followed by UF (6.14), RF and DPF both showed the identical value (6.17) whereas, the minimum soil ph was recorded in CFS (6.09). The soil electrical conductivity shows a significant decline in value along soil depth (1.66 dsm^{-2} at 0.20 cm and 0.65 ds m^{-2} at 20-40 cm). However, the variation between the forest classes was also significant which is arranged in following order; RF=CFS≥DPF≥UF>UPF, respectively. Furthermore, the bulk density increased significantly with the increase in soil depth from 0.93 to 0.96 g cm^{-3}. The variation between the forest classes was non-significant and the maximum value was recorded in UPF followed by RF and CFS, UF and DPF, respectively. The soil acidity along the soil depth may be attributed to decomposition of organic matter and release of organic matter acids during the decomposition (Saralch, 1994; Bhola, 1995 and Nayak, 1996). This corroborates the findings of Gebeyaw (2015) who observed higher values of pH in surface soil than in sub-soil. However, the increase in bulk density along soil depth may be due the presence of different species if trees and understory vegetation with differential root structure which alter the soil bulk density (Koutika *et al*., 2014)

4.9.2 Soil organic carbon and soil carbon fractions (labile and non-labile)

The soil organic carbon and fractions of soil carbon is presented in Table 47. A significant decreasing trend for soil carbon (1.38 % - 1.17 %), labile carbon (0.30% - 0.26%) and non-labile carbon (0.38% - 0.27%) was recorded along the soil depth (0 - 20 cm and 20 - 40 cm). However, a slightly significant variation in soil organic carbon and non-labile carbon was also observed between the forest classes. For soil organic carbon per cent DPF had the maximum value (1.48 %) which was at par with RF (1.37 %), furthermore, the RF was at par with UPF (1.20 %), UF (1.17 %) and CFS (1.16%). The non-labile carbon was also found highest in DPF (0.38%), which was at par with and followed by RF (0.37%), UF (0.33 %) and UPF (0.31 %) whereas; the minimum value was reported in CFS (0.24 %) which remained at par with UPF. The interaction between the soil depth and forest class was not significant. The higher amount of soil organic carbon on the surface than the sub surface may be attributed to higher litter accumulation on the surface. The similar trend along soil depth was also reported by Sayam, 2016 and Rajput *et al*., 2016. In addition, previous studies also compared different labile carbon fractions for their sensitivity to management (Culman *et al.*, 2012; Dou *et al.*, 2008 and Geraei *et al.*, 2016).

Table 46: Soil physico-chemical properties under different forest classes in Khair working circle of Nurpur Forest Division of Himachal Pradesh

Forest classes	pH			Electrical conductivity (dSm^{-1})			Bulk density ($g\ cm^{-3}$)		
	0-20 cm	20-40 cm	Mean	0-20 cm	20-40 cm	Mean	0-20 cm	20-40 cm	Mean
RF	6.05	6.2	6.13	1.67	0.69	1.18	0.94	0.97	0.95
DPF	5.98	6.28	6.13	1.68	0.66	1.17	0.90	0.94	0.92
UPF	6.25	6.34	6.3	1.63	0.58	1.10	0.95	0.98	0.96
CFS	6.01	6.18	6.09	1.64	0.72	1.18	0.93	0.96	0.95
UF	5.98	6.3	6.14	1.7	0.6	1.15	0.92	0.95	0.94
Mean	6.05^{b}	6.26^{a}		1.66^{a}	0.65^{b}		0.93	0.96	
Forest classes (F) NS Depth (D) 0.11 F×D NS				Forest classes (F) 0.04 Depth (D) 0.02 F×D 0.05			Forest classes (F) NS Depth (D) 0.03 F×D NS		

Table 47: Fractions of soil carbon (%) under different forest classes in Khair working circle of Nurpur Forest Division of Himachal Pradesh

Forest classes	Organic carbon (%)			Labile carbon (%)			Non-labile carbon (%)		
	0-20 cm	20-40 cm	Mean	0-20 cm	20-40 cm	Mean	0-20 cm	20-40 cm	Mean
RF	1.44	1.3	1.37	0.35	0.28	0.31	0.42	0.32	0.37
DPF	1.6	1.35	1.48	0.32	0.29	0.3	0.46	0.3	0.38
UPF	1.26	1.15	1.20	0.3	0.27	0.29	0.37	0.25	0.31
CFSF	1.28	1.03	1.16	0.26	0.18	0.22	0.29	0.2	0.24
UF	1.3	1.03	1.17	0.3	0.26	0.28	0.38	0.27	0.33
Mean	1.38^{a}	1.17^{b}		0.30^{a}	0.26^{a}		0.38^{a}	0.27^{b}	
Forest classes (F): 0.17 Depth (D): 0.11 F×D: NS				Forest classes (F): NS Depth (D): 0.05 F××D: NS			Forest classes (F): 0.07 Depth (D): 0.04 F××D: NS		

4.9.3 Available Nitrogen ($kg\ ha^{-1}$), Phosphorus ($kg\ ha^{-1}$) and Potassium ($kg\ ha^{-1}$)

The available N, P and K show a significant decline with the increase in soil depth (Table 48). The available soil nitrogen shows a significant decrease in value along soil depth i.e., 222.91 at 0-20cm to 170.56 at 20-40 cm. In case of variation between the forest classes, DPF had the maximum value (311.68 $kg\ ha^{-1}$) which was at par with RF (309.42 $kg\ ha^{-1}$) and UF (299.80 $kg\ ha^{-1}$). However, the lowest value (278.49 $kg\ ha^{-1}$) was recorded in CFS which was also at par with UF and UPF (284.29 $kg\ ha^{-1}$). The symbiotic N_2 association with leguminous trees can contribute to elevate N-inputs below canopy (Vetaas, 1992). Nitrogen fixing species accumulate more carbon due to efficient system of fixation of nitrogen and carbon in their roots. Koutika *et al*. (2014) studied the impact of *Acacia mangium* in Eucalyptus stands and reported that C and N content of the soil were increased but the available P content decreases with the introduction of *Acacia mangium*.

Table 48: Soil macro nutrients under different forest classes in Khair working circle of Nurpur Forest Division of Himachal Pradesh

Forest classes	N (kg ha^{-1})			P (kg ha^{-1})			K (kg ha^{-1})		
	0-20 cm	20-40 cm	Mean	0-20 cm	20-40 Cm	Mean	0-20 Cm	20-40 cm	Mean
RF	344.34	274.50	309.42	48.46	30.44	39.45	73.25	59.47	66.36
DPF	346.97	276.39	311.68	43.15	25.35	34.25	76.25	59.25	67.75
UPF	303.87	264.71	284.29	38.67	24.08	31.37	63.29	56.02	59.65
CFS	298.25	258.72	278.49	33.46	21.68	27.57	61.28	54.28	57.78
UF	321.13	278.46	299.80	36.18	24.96	30.57	75.50	57.25	66.38
Mean	322.91	270.56		39.98^{a}	25.30^{b}		69.91^{a}	57.25^{b}	
Forest classes (F):15.75 Depth (D): 9.96 F××D: NS				Forest classes (F): NS Depth (D): 6.20 F××D: NS			Forest classes (F): 4.13 Depth (D): 2.61 F××D: 5.84		

The available phosphorus shows the significant variation only for soil depth where the value decrease from 39.98 kg ha^{-1} (0-20 cm) to 25.30 kg ha^{-1} (20-40 cm). The available potassium showed a significant decreasing trend along the soil depth i.e., 69.91 kg ha^{-1} at 0-20cm to 57.25 kg ha^{-1} at 20-40cm. The maximum value for available potassium was recorded in DPF (67.75 kg ha^{-1}) which was at par with RF (66.36 kg ha^{-1}) and UF (66.38 kg ha^{-1}), further, significantly followed by UPF (59.65 kg ha^{-1}) which was at par with CFS (57.78 kg ha^{-1}). Significant interaction between soil depth and forest class was observed only for available potassium where maximum value was recorded in DPF (76.25 kg ha^{-1}) at soil depth 0-20 cm which was at par with UF and RF at same depth, however the minimum value (54.28 kg ha^{-1}) for available potassium was recorded in CFS at soil depth 20-40cm. Similar findings have been reported by Baravaraja *et al*. (2010) and Noureen *et al*. (2008).

4.9.4 Soil micro nutrients (Zn, Fe, Mn and Cu)

The soil micro nutrients (Zn, Fe, Mn and Cu) decreased significantly along the soil depth (Table 49). The Zn decreased significantly from 5.70 (0-20 cm) to 5.14 (20-40 cm); Fe from 37.26 (0-20 cm) -32.87 (0-20 cm); Mn from 38.26 (0-20 cm) -33.37 (0-20 cm) and Cu from 1.22(0-20 cm) -0.95 (0-20 cm), respectively. Whereas, the variation was not significant between forest classes and the interaction between forest class and soil depth. Although decrease in micronutrients form forest under strict management regimes to CFS and decreased with increase in soil depth indicates the human interference on forest ecosystem and its effect on nutrient status of the soil (Norra *et al*., 2008 and Asinwa *et al*., 2018). The concentration of micronutrients (Zn, Fe and Mn) can be enhanced by decomposed organic materials on the soil surface (Chima *et al*., 2009, Toleti, 2011). Earlier works (Jiang *et al*., 2009 and Kumar and Babel, 2011) on the influence of land use management practices on available micronutrients have corroborated this finding

Available N, K and organic carbon were lower in CFS and the significantly higher values in DPF suggest that the change in forest management regimes from high protection to high anthropogenic pressure depletes the specific nutrients and organic matter. The soil physico-chemical nutrients showing higher range of soil pH, bulk density, organic carbon, EC, available nitrogen, phosphorus and potassium are in accordance with the findings of Kumar (1998) and concluded that the soil enrichment could be due to the difference in species-site interaction and differential nutrient uptake. Whereas, their gradual decline with soil depth could be due to more accumulation, mineralization and reduced root biomass in deeper soil layer. These results are also well supported by the findings of Malik (1992) in chir pine forest of Himachal Pradesh. Labile and non labile fractions of soil carbon in different forest classes varied in a range of 0.18–0.35% and 0.20–0.46%, respectively. Chen *et al.,* 2019 demonstrated that the carbon derived from understory vegetation is a major component of labile organic carbon in top soils, and it may be readily mineralized in the young plantation but accumulated as an important fraction of soil organic carbon in the mature plantation. The forest class with lesser number of trees and shrub density had significantly lower values of non labile carbon when compared to the forest classes with higher number of tree and shrub density in both soil layers. The higher value of non labile carbon than the labile carbon pool is a good indicator for carbon storage potential which is strongly bound to the soil mineral matrix to form mineral humus and act as a shielded from the microbial action and are least decomposed (Dwivedi *et al*., 2019). The dynamics of carbon stock can be significantly affected by various factors such as management regimes, climatic conditions and vegetation composition (Lal, 2008). Soil organic carbon (%) content under any land use type is the balance between carbon inputs and carbon losses which is determined by the residue turnover, their quality and decomposition rate (Ranch and Schlesinger, 1992). Further, the higher level of organic carbon, N, P and K in DPF, RF and UF in our present study could be

Table 49: Micro nutrients of soil under different forest classes in Khair working circle of Nurpur Forest Division of Himachal Pradesh

Forest classes	Zn ($kg\ ha^{-1}$)			Fe ($kg\ ha^{-1}$)			Mn ($kg\ ha^{-1}$)			Cu ($kg\ ha^{-1}$)		
	0-20 cm	20-40 cm	Mean	0-20 cm	20-40 cm	Mean	0-20 cm	20-40 cm	Mean	0-20 cm	20-40 cm	Mean
RF	5.88	5.25	5.56	39.5	37	38.25	42.25	35.25	38.75	1.28	1.03	1.15
DPF	5.71	5.18	5.44	38.69	34.07	36.38	39.48	35.08	37.28	1.34	1.07	1.21
UPF	5.75	5.2	5.48	37.25	32.5	34.88	37.23	34.1	35.66	1.23	1.05	1.14
CFS	5.58	5.05	5.31	35.38	30.25	32.81	34.18	31.67	32.92	1.01	0.71	0.86
UF	5.58	5.03	5.3	35.5	30.53	33.01	38.16	30.75	34.46	1.21	0.9	1.05
Mean	5.70^{a}	5.14^{b}		37.26^{a}	32.87^{b}		38.26^{a}	33.37^{b}		1.22^{a}	0.95^{b}	
Forest classes (F): NS Depth (D): 0.36 F×D: NS				Forest classes (F): NS Depth (D): 3.97 F×D: NS			Forest classes (F): NS Depth (D): 3.53 F×D: NS			Forest classes (F): NS Depth (D): 0.16 F×D: NS		

due to high level of inputs from the maximum number of tree and shrub as compare to the forest with low density of trees and shrubs (Nath *et al*., 2018). The understory vegetation also plays a vital role in regulating soil carbon and nitrogen characteristics due to differences in plant functional traits, due to this the understory vegetation might alter the litter decomposition rates and microbial activities by affecting soil moisture, temperature, and other environmental factors (Yildiz *et al*., 2011, Wang *et al*., 2014). The increase in anthropogenic pressure on forest could be the reason for lower value of soil nutrients in CFS which can further leads to substantial losses in soil nutrients (Singh *et al*., 2018). The disturbance in ecosystem may result in degradation of soil properties i.e., enhancement in soil compaction and decrease in soil macro porosity, infiltration etc and may cause a decrease in site productivity (Solgi, 2014).

4.10 Correlation studies

The establishment stocking index and regeneration success were shown to be highly and positively correlated (Table 50). Meanwhile, the establishment stocking index was substantially correlated with potassium and copper, whereas regeneration success was strongly correlated with Mn and copper. Among several soil parameters, soil organic carbon was shown to be significantly and positively connected to soil carbon density and nitrogen availability. The pH of the soil had a considerably negative relationship with the electrical conductivity. While, the available potassium had a significant positive association with available nitrogen. Phosphorus was significantly and negatively correlated with zinc and a positively related with Mn. Nitrogen availability had a substantial strong correlation with Cu.

4.11 Status and impact of *Lantana camara* infestation

The status of lantana infestation in Khair working circle of Nurpur forest division is shown in figure 3. The percentage of lantana infestation and basal area was calculated from the phyto-sociological studies under different compartments within different forest classes. The lantana infestation within RF ranged from 50 to 60 percent. 42.22 to 56.90 percent in DPF ranged from. 48.28 to 69.44 percent in UPF. 48.72 to 67.50 percent in CFS and 50 to 60.87 percent in UF, respectively.

Lantana infestation and basal area were shown to be adversely associated with tree density, vegetation diversity, and regeneration (Table 51 to 53). However, a negative association between lantana density and basal area with tree density, establishment stocking

Table 50: Relationship between regeneration status and soil physico-chemical properties

Particulars	Establishment	Regeneration success	OC	SCD	BD	pH	EC	K	P	N	Zn	Fe	Mn	Cu
Establishment	1													
Regeneration success	**0.94****	1												
OC	0.08	-0.02	1											
SCD	0.23	0.11	**.902****	1										
BD	0.33	0.28	-0.27	0.17	1									
pH	0.34	0.3	-0.31	-0.21	0.18	1								
EC	-0.06	0.02	0.07	-0.03	-0.21	**-0.45***	1							
K	**0.45***	0.41	0.3	0.26	-0.11	0	0.3	1						
P	0.35	0.37	0.15	0.26	0.23	0.22	0.03	0.35	1					
N	0.43	0.42	**0.47***	0.44	-0.08	-0.25	0.28	**0.62****	0.43	1				
Zn	-0.01	0.09	0.06	-0.08	-0.35	0.07	0.12	0.1	**-0.53***	-0.04	1			
Fe	0.34	0.43	-0.07	-0.16	-0.11	-0.2	0.18	0.26	-0.03	0.07	0.12	1		
Mn	0.38	**0.51***	-0.12	0	0.26	0.25	-0.03	0.19	**0.46***	0.04	0.05	0.16	1	
Cu	**0.702****	**0.70****	0.05	0.19	0.28	0.28	-0.16	0.39	0.44	**0.60****	0.11	-0.07	0.43	1

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

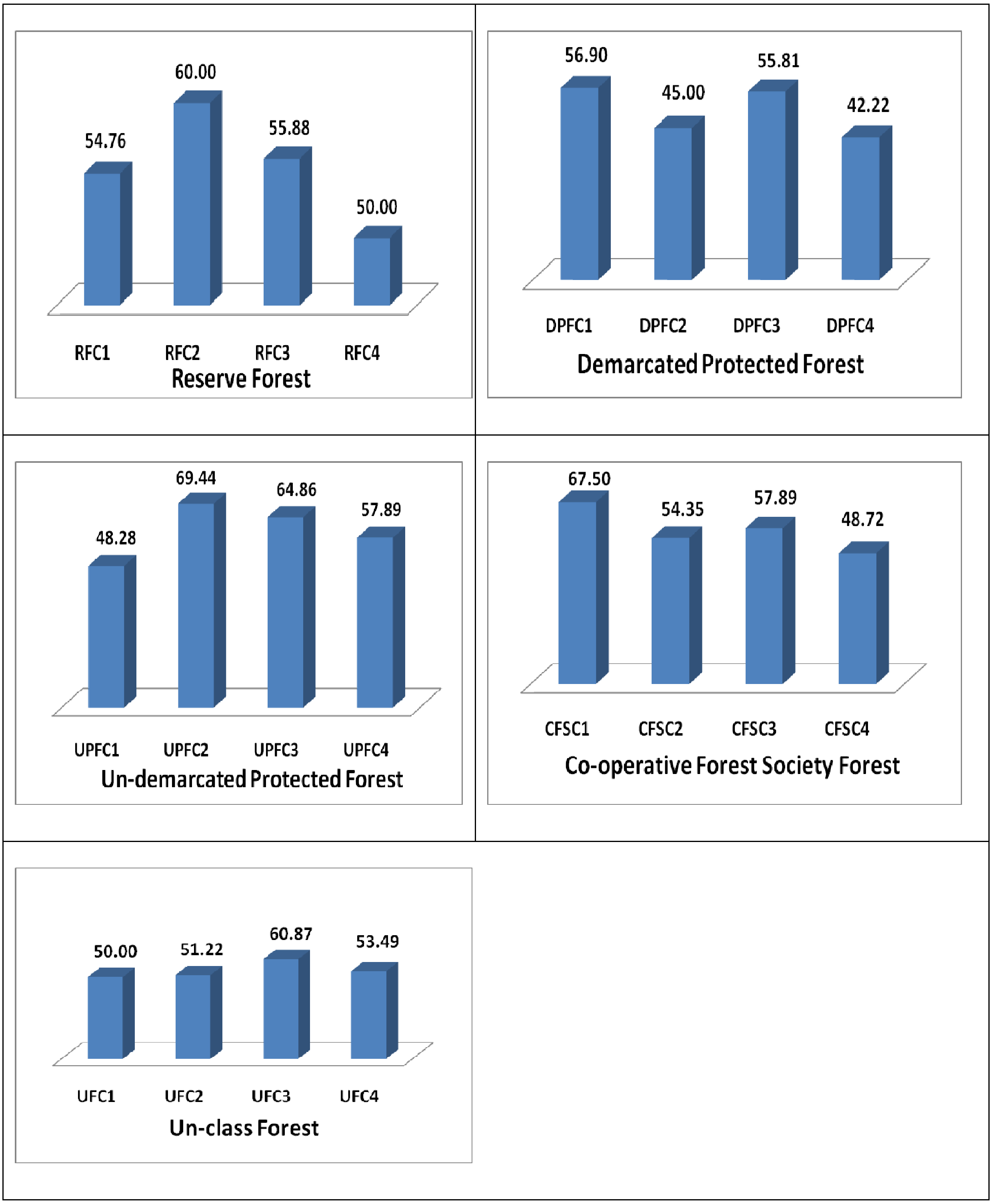


Figure 3: Lantana infestation (%) status under different compartment of Forest class in Khair working circle of Nurpur Forest Division, Himachal Pradesh

Table 51: Impact of lantana infestation on shrub, herbs diversity and richness and regeneration status

Particulars	Lantana density	Lantana basal area	Shrub diversity	Shrub richness	Herbs diversity	Herbs richness	Establishment Index	Regeneration success
Lantana density	1							
Lantana basal area	**0.93****	1						
Shrub diversity	-0.41	**-0.49***	1					
Shrub richness	-0.18	-0.3	**0.81****	1				
Herbs diversity	-0.14	-0.23	0.26	0.3	1			
Herbs richness	-0.03	-0.13	0.15	0.35	**0.91****	1		
Establishment Index	**-0.73****	**-0.64****	0.27	-0.05	-0.13	-0.22	1	
Regeneration success	**-0.69****	**-0.62****	0.17	-0.09	0	-0.11	**0.94*****	1

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Table 52: Relationship between lantana density with biomass and ecosystem carbon

Particulars	Lantana density	Tree density	Tree biomass	Shrub biomass	Herb biomass	Ecosystem carbon
Lantana density	1					
Tree density	**-0.74****	1				
tree biomass	0.02	0.35	1			
Shrub biomass	**0.46***	-0.17	0.41	1		
Herb biomass	-0.04	-0.29	-0.4	-0.12	1	
Ecosystem carbon	0.04	0.37	**0.99****	0.42	-0.4	1

**. Correlation is significant at the 0.01 level (2-tailed).

Table 53: Relationship between lantana density and soil physico-chemical properties

Particulars	Lantana density	OC	SCD	BD	pH	EC	K	P	N	Zn	Fe	Mn	Cu
Lantana density	1												
OC	0.35	1											
SCD	0.09	**0.90****	1										
BD	**-0.59****	-0.27	0.17	1									
pH	**-0.51***	-0.31	-0.21	0.18	1								
EC	0.25	0.07	-0.029	-0.21	**-0.45****	1							
K	-0.05	0.3	0.26	-0.12	0.02	0.3	1						
P	-0.11	0.15	0.26	0.23	0.22	0.026	0.35	1					
N	0.03	**0.47****	0.44	-0.08	-0.25	0.27	**0.62****	0.42	1				
Zn	-0.07	0.06	-0.08	-0.35	0.07	0.12	0.1	**-0.53****	-0.04	1			
Fe	-0.07	-0.07	-0.16	-0.11	-0.2	0.18	0.26	-0.025	0.07	0.11	1		
Mn	-0.43	-0.12	0.003	0.26	0.24	-0.03	0.19	**0.46****	0.04	0.05	0.16	1	
Cu	**-0.53****	0.045	0.19	0.28	0.28	-0.16	0.39	0.42	**0.60****	0.11	-0.07	0.43	1

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

index, and regeneration success was detected. Additionally, lantana's basal area demonstrated a significant adverse correlation with shrub diversity. However, the presence of lantana was associated with a strong positive relationship with shrub biomass. The current findings indicate that *Lantana camara* had a detrimental effect on native understory vegetation. The decline in shrub diversity was facilitated by the dominance of invasive species, which spread swiftly and outcompete native understory plants. Numerous additional studies found similar findings, with species numbers declining by 57 percent (Hartman and McCarthy, 2008), 28 percent (Dobhal *et al*., 2011), 48–52 percent (Sharma *et al*., 2017), 26 percent (Rusterholz *et. al*., 2018), and 42 percent (Rusterholz *et al*., 2018, Rivas-Torres *et al*., 2018). The decline in native flora is concerning because it had the potential to disturb the ecosystem's structure and processes by favouring one species over others (Vil'a *et al*., 2011). The extent to which an invasion had an effect is often determined by its degree of dominance (Pysek and Pysek, 1995). Duggin and Gentle (1998) demonstrated that *Lantana camara* is capable of interfering with native species' regeneration processes by lowering germination, reducing early growth rates, and increasing mortality. Gentle and Duggin (1997) discovered a considerable increase in seed germination and seedling biomass after the removal of *Lantana camara* thickets in three Australian forests. *Lantana camara* allelopathic effects result in significant decreases in seedling recruitment for practically all species that live under its cover (Sharma *et al*., 2005). The present findings corroborate those of Fensham *et al*. (1994), who reported a drop in plant species richness associated with rising levels of *Lantana camara* infestation in dry rainforest, as well as the buildup of substantial fuel loads resulting in severe canopy tree loss. Holmes *et al*. (2000) discovered considerably reduced indigenous plant cover and density in invaded regions compared to controls in South Africa's Western Cape Province. The loss in species diversity and richness observed in the present research is most likely due to *Lantana camara* effect on native species recruitment and establishment. It might also be attributable to the suppression of native species associated with the rising density of *Lantana camara*, as discovered by Thomas and Ellison discovered (2000).

Lantana infestation was shown to be negatively associated to bulk density, soil pH, K, P, Zn, Fe, Mn, and Cu, while the strongest negative association was being observed for bulk density, soil pH, and Cu (Table 52). Additionally, the infestation of lantana correlated positively with soil organic carbon, soil carbon density, electrical conductivity and nitrogen. Exotic plant species may influence soil fertility in a number of ways, including tissue type (herbaceous vs woody), root depth, and tissue chemistry (Ehrenfeld *et al*., 2001 and

Ehrenfeld, 2003). Lantana's deep root structure helps it to use nutrients in the deeper soil layer (Castillo *et al*., 2007), potentially increasing the amount of total nitrogen and phosphorus in surface soil. Additionally, Sharma and Raghubanshi (2011) assert that total nitrogen, organic carbon, and soil moisture all have an effect on the proliferation of invasive plants. The rise in nitrogen and phosphorus levels associated with increased *Lantana camara* intensity might be attributable to decreased nutrient sequestration as a result of native species displacement or decreased recruitment and growth rates of native species. *Lantana camara* produces a large amount of litter underneath it, which accounts for the higher nitrogen and phosphorus levels that result from the breakdown of the litter. These data corroborate Ehrenfeld's (2003) observations of an increase in soil nitrate after *Lantana camara* invasion, to the advantage of the *Lantana camara*, and a drop in other nutrients.

Chapter-5

SUMMERY AND CONCLUSION

The present investigation entitled "**Stand structure and site characteristics of Khair (*Acacia catechu* Willd.) working circle in Nurpur Forest Division of Himachal Pradesh"** encompasses two experiments, which exclusively dealt with floral diversity, stand structure, biomass and carbon stock, site characteristics, natural regeneration and impact of lantana infestation. Both experiments were carried out at different forest classes of Khair working circle in Nurpur Forest Division of Himachal Pradesh. A 31.62 m × 31.62 m plot for trees, 5m × 5m sub-plot for shrubs, 1m x1m sub-plot for herbs and 2m x 2m sub-plots for regeneration assessment were used. Data on phytosociology, stand structure and site characteristics and natural regeneration was collected, analyzed and interpreted based on standard laboratory and statistical procedure. The findings of these experiments are summarized as follows:

Floristic composition and phytosociology

The flora of various forest classifications included a total of 43 genera and 50 species belonging to 27 families. Among them, 29 tree species were from 14 families and 26 genera, 12 shrub species from 12 genera and 12 families. However, nine herbaceous species from 7 families and 9 genera were also identified.

In Reserve Forest (RF), 17 tree, 9 shrub and 5 herb species were identified. While in Demarcated protected Forest (DPF), 16 tree, 7 shrub and 3 herb species were present. In case of Un-demarcated Protected Forest (UPF) 11 tree, 7 shrubs and 5 herb species were available whereas, in Co-operative Forest (CF) Society 13 tree, 6 shrubs and 4 herb species were recorded. In Un-class Forest (UF), 11 tree, 6 shrub and 6 herb species were found.

In Reserve Forest, the compartment RFC3 had the maximum tree density (503.33 number ha^{-1}) and basal area (20.38 cm^{2} $^{1`}ha^{-1}$) whereas RFC2 had the minimum value. In compartment RFC1, RFC3 and RFC4 *Acacia catechu* was the most dominating species followed by *Lannea coromandelica*, *Cassia fistula* and *Mallotus phillippensis,* respectively. whereas, in compartment RFC2 *Pinus roxburghii* was the most contributing species followed by *Acacia catechu*. The maximum shrub density (3360.00 number ha^{-1}) was recorded in compartment RFC1 and RFC4 whereas, the maximum basal area (104192.36 cm^2 ha^{-1}) was found in RFC2 and minimum in RFC1. Athough, *Lantana camera* was the most dominating shrub in the Reserve Forest. Among herb species the maximum density (54400.00 number ha^{-1}) and basal area (945.42 cm^2 ha^{-1}) was recorded in RFC3 and minimum in RFC4. Further, *Ageratum conyzoides* occupy the majority of herb space in all the compartments of Reserve Forest.

Within Demarcated Protected Forest (DPF), the compartment DPFC2 had the maximum tree density (433.33 number ha^{-1}) and the minimum was recorded in DPFC1 (183.33 number ha^{-1}). The maximum basal area (18.82 m^2 ha^{-1}) was recorded in DPFC1 and minimum in DPFC4 (8.45 m^2 ha^{-1}). The compartment DPFC1 was mainly dominated by *Pinus roxburghii* followed by *Acacia catechu* whereas the compartment DPFC2 and DPFC4 were dominated by *Lannea coromandelica* followed by *Acacaia catechu*. In compartment DPFC3, *Mallotus phillippensis* and *Acacia catechu* were the main contributing species.

Among shrubs, the maximum density (4640.00 number ha^{-1}) and basal area (131626.20 cm^2 ha^{-1}) was recorded in compartment DPFC1. All the compartments within DPF were infested by *Lantana camara*. In case of herb species, the highest density (51600.00 number ha^{-1}) and basal area (810.57 cm^2 ha^{-1}) was recorded in DPFC3 whereas the minimum was recorded in DPFC4. Among them *Ageratum conyzoides* and *Parthenium hysterophorus* were reported as major herb species.

In Un-demarcated Protected Forest (UPF), the maximum tree density (506.67 number ha^{-1}) and basal area (10.36 m^2 ha^{-1}) was recorded in UPFC1. The major dominating species in UPFC1 was *Mallotus phillippensis* closely followed by *Lannea coromandelica* and *Acacia catechu.* In UPFC2, *Lannea coromandelica* and *Acacia catechu* were the main contributing species. In UPFC3 and UPFC4, *Acacia catechu* occupies the majority of share in IVI followed by *Lannea coromandelica*. The maximum shrub density (3040.00 number ha^{-1}) was reported in UPFC4 whereas, the basal area was maximum in compartment UPFC3 (97720.50 cm^2 ha^{-1}). All the compartments within Un-demarcated Protected Forest were greatly infested by *Lantana camara*. The herb density (43200.00 number ha^{-1}) and basal area (798.39 cm^2 ha^{-1}) was recorded maximum in compartment UPFC1 followed by UPFC2. The compartment UPFC1 and UPFC2 were dominated by *Parthenium hysterophorus* whereas, in compartment UPFc3 and UPFC4, *Ageratum conyzoides* was the dominating herb species.

In Co-operative Forest Society, the maximum tree density (356.6700 number ha^{-1}) and basal area (8.66 m^2 ha^{-1}) was recorded in compartment CFSC3. Whereas, the minimum density and basal area was found in CFSC2. The major dominating species in CFSC1, CFSC2, CFSC3 and CFSC4 was *Acacia catechu* with IVI value of 107.94, 103.98, 105.25 and 132.40, respectively.

The compartments of CFS were dominated by *Lantana camara*. However, the maximum shrub density (3680.0000 number ha^{-1}) and basal area (112377.20 cm^2 ha^{-1}) was found in compartment CFSC2. In case of herb species CFSC4 had the maximum herb density (42000.00 number ha^{-1}) and basal area (709.16 cm^2 ha^{-1}). The compartment CFSC1 and CFSC4 were dominated by *Ageratum conyzoides* whereas in compartment CFSC2, *Bidens pilosa* was the dominating herb. In compartment CFSC3, *Parthenium hysterophorus* and *Ageratum conyzoides* has the maximum IVI value.

In Un-class Forest, the maximum tree density was recorded in UFC2 (350.00 number ha^{-1}) followed by UFC4, UFC1 and UFC3, respectively. However, the maximum basal area was recorded in UFC4 (25.35 m^2 ha^{-1}) followed by UFC2, UFC1 and UFC3, respectively. The compartments within Un-class forest were mainly dominated by *Acacia catechu* followed by *Mallotus phillippensis, Cassia fistula* and *Lannea coromandelica*, respectively. In case of shrub species, the compartments were greatly infested by *Lantana camara* whereas the maximum shrub density (3680.00 number ha^{-1}) and basal area (111951.88 cm^2 ha^{-1}) was recorded in UFC3. The maximum herb density (45200.00 number ha^{-1}) and basal area (733.27 cm^2 ha^{-1}) was found in UFC2 whereas the minimum density and basal area was found in UFC4. The compartment UFC1 and UFC2, were dominated by *Parthenium hysterophorus* whereas, the compartment UFC3 and UFC4 were dominated by *Ageratum conyzoides*.

The Shannon Index of diversity (H') for trees ranged from 2.13 (DPF) to 1.24 (UF), for shrubs 1.48 (DPF) to 1.30 (CFS) and for herbs 1.29 (CFS, UF) to 0.85 (UF). The Simpson Index of diversity (D) for trees from 0.84 (DPF) to 0.56 (UF), for shrubs 0.69 (DPF) to 0.60 (UPF) and for herbs 0.70 (CFS) to 0.50 (DPF) and the Simpson Index of dominance (Cd) for trees ranged from 0.44 (UF) to 0.16 (DPF), for shrub 0.40 (UPF) to 0.31 (DPF) and for herbs 0.50 (DPF) to 0.30 (CFS). Pielou's Equitability (Eq) varied from 0.77 (DPF, UPF) to 0.52 (UF) for trees, 0.76 (DPF) to 0.66 (RF) for shrubs and 0.93 (CFS) to 0.72 (UF) for herbs, respectively. Margalef's Index of richness (MI) for trees ranged from 2.68 (RF) to 1.75 (UPF), for shrub 0.99 (RF) to 0.61 (UF) and for herbs 0.48 (UF) to 0.19 (DPF) and Species Heterogeneity (Hg) for trees ranged from 0.66 (UF) to 0.39 (DPF), for shrubs 0.63 (UPF) to 0.56 (DPF) and for herbs 0.71 (DPF) to 0.55 (CFS), respectively.

Stand structure

The maximum tree density (399.17 number ha^{-1}) was recorded in RF and minimum (2501.00 number ha^{-1}) was found in CFS. Further, the maximum number of trees in diameter class D1 (251.67 number ha^{-1}) and D2 (105.00 number ha^{-1}) was recorded in RF. However, the maximum number for D3 (49.17 number ha^{-1}) and minimum number in D1 (162.50 number ha^{-1}) diameter class was present in UF. The minimum number in D2 (44.17 number ha^{-1}) and D3 (8.33 number ha^{-1}) diameter class was recorded in CFS.

Within RF, the maximum average diameter (24.02 cm) was recorded in compartment RFC4 and the minimum (18.87 cm) was recorded in compartment RFC2. In DPF, maximum diameter was found in DPFC1 (24.62 cm) whereas, the minimum diameter was recorded in compartment DPFC2 (16.33 cm). In case of UPF, the highest value was found in compartment UPFC3 (21.53 cm) and, UPFC1 displayed the minimum average diameter (16.25). Within CFS, maximum (18.67 cm) was recorded in CFSC3 and minimum in CFSC4 (17.06 cm). In Un-class forest (UF), maximum average diameter (30.02 cm) was recorded in compartment UFC4 and the lowest was displayed by compartment UFC2 (20.10 cm). Overall, the trend followed by different forest was in the order: UF> RF≥ UPF≥ DPF> CFS.

The maximum tree height (8.50 m) within RF was recorded in compartment RFC2 whereas the minimum tree height (6.85 m) was recorded in RFC1. In DPF, maximum tree height (8.89m) was found in compartment DPFC1 and the minimum (6.03 m) was recorded in DPFC3. For compartment within UPF, the height parameter remains non-significant, however, the maximum value was recorded in UPFC2 (7.37m) and minimum in UPFC1 (6.21m), respectively. The compartment within CFS also remains statistically at par with each other. The maximum tree height was recorded in compartment CFSC1 (7.57m) whereas the minimum was found in compartment CFSC3 (6.58m). In UF, maximum tree height (8.95m) was recorded in compartment UFC4 whereas, the lowest value (6.79 m) was recorded in compartment UFC3. Among different forest classes, the maximum tree height (7.92m) was recorded in RF and the lowest value was found in UPF (6.92m).

The maximum volume (102.83 m^3 ha^{-1}) within RF was recorded in compartment RFC3 with lowest in RFC2 (54.72 m^3 ha^{-1}). In DPF the maximum volume was recorded in DPFC1 (139.46 m^3 ha^{-1}) whereas, the minimum was found in DPFC4 (42.48 m^3 ha^{-1}). In UPF, the highest volume was recorded in UPFC3 (48.20 m^3 ha^{-1}) and minimum was in UPFC4 (35.11 m^3 ha^{-1}). In CFS, the maximum volume was found in CFSC1 (37.39 m^3 ha^{-1})

and minimum was in CFSC4 (27.58m^3 ha^{-1}). In UF, compartment UFC4 (132.90 m^3 ha^{-1}) has the maximum volume whereas the minimum was recorded in UFC3 (25.56 m^3 ha^{-1}). Overall, the volume of trees between the forest classes followed the trend: RF≥ DPF> UF> UPF≥ CFS.

The maximum stem biomass within RF was recorded in compartment RFC3 (68.46 t ha^{-1}) whereas, the minimum was displayed by RFC2 (30.58 t ha^{-1}). The compartment DPFC1 under DPF displayed the maximum stem biomass (68.71 t ha^{-1}) whereas, the lowest stem biomass was recorded in DPFC4 (31.89 t ha^{-1}). In UPF and CFS, the stem biomass was arranged in following order: UPFC3 > UPFC1 > UPFC2 > UPFC4 and CFSC3 > CFSC1 > CFSC2 > CFSC4, respectively. In case of UF, maximum stem biomass (83.47 t ha^{-1}) was recorded in compartment UFC4 whereas, the lowest value (19.11 t ha^{-1}) was recorded for UFC3. The maximum stem biomass between different forest classes was recorded in RF (49.73 t ha^{-1}) and minimum was recorded in CFS (23.19 t ha^{-1}).

The maximum value for AGB (124.46 t ha^{-1}) within RF was recorded in compartment RFC3 whereas, RFC2 has the lowest value of 50.70 t ha^{-1}. In DPF, the highest value for AGB (133.53 t ha^{-1}) was recorded in compartment DPFC1 and the minimum (63.13 t ha^{-1}) was reported in compartment DPFC2. In UPF, the maximum AGB was found in UPFC3 (61.7913 t ha^{-1}) and minimum was in UPFC4 (46.2113 t ha^{-1}). In CFS, the maximum AGB was found in CFSC3 (52.50 t ha^{-1}) and minimum was recorded in CFSC2 (40.44 t ha^{-1}). In case of UF, maximum AGB (175.83 t ha^{-1}) was recorded in Compartment UFC4 whereas, the lowest value (41.90 t ha^{-1}) was found in UFC3. Overall, the AGB of forest classes followed the trend: UF≥ RF≥ DPF> UPF≥ CFS.

Within Reserve maximum, BGB (66.01 t ha^{-1}) was recorded in compartment RFC3 whereas, the lowest value (28.01 t ha^{-1}) was found in RFC2. The compartments within DPF, UPF and CFS followed the trend: DPFC1 > DPFC3 > DPFC4 > DPFC2; UPFC1 > UPFC3 > UPFC2 > UPFC4; CFSC3 > CFSC1 > CFSC4 > CFSC2 respectively. In UF the maximum BGB (84.03 t ha^{-1}) was recorded in Compartment UFC4 whereas, the minimum (21.93 t ha^{-1}) was displayed by UFC3. Overall, BGB of different forest classes was arranged in the following order of UF≥ RF> DPF> UPF> CFS, respectively.

The maximum value of total tree biomass (190.47 t ha^{-1}) within RF was recorded in compartment RFC3 whereas, lowest value (78.71 t ha^{-1}) was found in RFC2. In DPF, the compartment DPFC1 had maximum total tree biomass (173.25 t ha^{-1}) whereas, the lowest value was found in DPFC2 (98.71 t ha^{-1}). The compartments within UPF and CFS followed the trend: UPFC3> UPFC1> UPFC2> UPFC4 and CFSC3> CFSC1> CFSC4> CFSC2, respectively. In case of RF, the maximum total tree biomass (259.86 t ha^{-1}) was recorded in compartment UFC4, whereas the lowest value (63.83 t ha^{-1}) was recorded in UFC3. Overall, the total tree biomass for different forest classes has been arranged in following order: UF≥ RF≥ DPF> UPF≥ CFS, respectively.

The maximum value of tree carbon (90.47 t ha^{-1}) within RF was recorded in RFC3 and minimum (37.39 t ha^{-1}) was found in RFC2. Within DPF the maximum tree carbon (85.03 t ha^{-1}) was found in DPFC1 whereas, the lowest value was recorded in DPFC2 (46.91 t ha^{-1}). The value for tree carbon within UPF and CFS follows the following trend: UPFC3>UPFC1>UPFC2>UPFC4 and CFSC3>CFSC1>CFSC4>CFSC2 respectively. In case of UF the maximum tree carbon (123.43 t ha^{-1}) was recorded in UFC4 whereas, the lowest value (30.32 t ha^{-1}) was found in UFC3. Overall, the tree carbon accumulated in different forest classes are arranged in following order: UF≥ RF≥ DPF> UPF≥ CFS, respectively.

In RF, maximum above ground shrub biomass (0.52 t ha^{-1}) was recorded in compartment RFC4 and minimum in RFC2 (0.37 t ha^{-1}). Within DPF, maximum value for above ground biomass of shrubs (0.50 t ha^{-1}) was found in DPFC1 and the lowest value was found in DPFC2 (0.37 t ha^{-1}). In UPF maximum above ground shrub biomass was found in UPFC2 (0.37 t ha^{-1}) whereas, the lowest was recorded in UPFC1 (0.23 t ha^{-1}). Within CFS, the compartment CFSC2 had the maximum above ground shrub biomass (0.45 t ha^{-1}) whereas, the minimum (0.36 t ha^{-1}) was in CFSC4. In UPF, maximum above ground shrub biomass (0.44 t ha^{-1}) was present in UFC1 and minimum (0.38 t ha^{-1}) in UFC2. Overall, the above ground shrub biomass between forest classes was arranged in following order: RF= DPF> UF≥ CFS> UPF, respectively.

Within RF, maximum below ground shrub biomass (0.34 t ha^{-1}) was reported in compartment RFC4 whereas, the lowest (0.22 t ha^{-1}) was found in RFC2. In DPF, maximum below ground shrub biomass (0.32 t ha^{-1}) was found in DPFC1 and minimum was in DPFC2 (0.24 t ha^{-1}). In UPF, the maximum below ground shrub biomass was present in UPFC2 (0.24 t ha^{-1}) whereas, the lowest value was found in UPFC1 (0.15 t ha^{-1}). In CFS, compartment CFSC2 has the maximum below ground shrub biomass (0.29 t ha^{-1}), The lowest was recorded in compartments CFSC4. For UF, the maximum value (0.29 t ha^{-1}) was recorded in Compartment UFC1 whereas, UFC2 has lowest below ground shrub biomass (0.25 t ha^{-1}). Overall, the below ground shrub biomass between different forest class was arranged in following order: DPF≥ RF≥ UF≥ CFS> UPF.

Within RF, maximum total shrub biomass (0.85 t ha^{-1}) was recorded in compartment RFC4 and the minimum (0.61 t ha^{-1}) was found in RFC2. The compartment DPFC1 of DPF had the maximum value for total shrub biomass (0.82 t ha^{-1}). Whereas, the minimum value (0.61 t ha^{-1}) was found in DPFC2. In UPF, maximum total shrub biomass was recorded in UPFC2 (0.61 t ha^{-1}) and the minimum (0.38 t ha^{-1}) was present in UPFC1. Within CFS, the compartment CFSC2 has the maximum total shrub biomass (0.74 t ha^{-1}) whereas, CFSC4 has the lowest value of 0.60 t ha^{-1}. In UF, maximum value (0.73 t ha^{-1}) was recorded in Compartment UFC1 and minimum (0.63 t ha^{-1}) was found in compartment UFC2. Overall, the total shrub biomass between the forest classes was arranged in following order: RF= DPF> UF≥ CFS> UPF.

Within RF, the maximum value for above ground herb biomass was recorded in compartment RFC1, RFC2 and RFC3 with an identical value of 0.13 t ha^{-1}. However, the lowest value (0.06 t ha^{-1}) was found in RFC2. In DPF, the compartment DPFC1 had maximum above ground herb biomass (0.10 t ha^{-1}) whereas, DPFC1, DPFC2 and DPFC4 displayed the lowest identical value of 0.05 t ha^{-1}. In UPF, maximum above ground herb biomass was recorded in UPFC2 (0.14 t ha^{-1}) and the lowest value was found in UPFC1 (0.08 t ha^{-1}). In CFS, the maximum value (0.33 t ha^{-1}) was displayed by CFSC4 and the minimum was in CFSC1 (0.02 t ha^{-1}). In UF, maximum above ground herb biomass (0.14 t ha^{-1}) was in UFC3 and the lowest (0.05 t ha^{-1}) was recorded in UFC4. The above ground herb biomass recorded between the forest class was arranged in following order; CFS> UPF≥ RF> UF> DPF.

In RF, the compartments RFC1, RFC2 and RFC3 displayed the maximum (0.08 t ha^{-1}) below ground herb biomass whereas, the lowest value (0.04 t ha^{-1}) was recorded in compartment RFC2. The compartment DPFC3 within DPF has the maximum below ground herb biomass (0.06 t ha^{-1}) whereas, the compartment DPFC1, DPFC2 and DPFC4 displayed the lowest value (0.03 t ha^{-1}). In UPF, maximum below ground herb biomass was recorded in UPFC2 (0.08 t ha^{-1}) and the lowest value was recorded in UPFC1 (0.05 t ha^{-1}). In CFS, CFSC4 displayed the maximum value (0.19 t ha^{-1}) and minimum (0.01 t ha^{-1}) was found in

CFSC1. In UF, the maximum below ground herb biomass (0.08 t ha^{-1}) was recorded in UFC3 and the minimum was recorded in compartment UFC4. Overall, the below ground biomass between forest class was arranged in following order: CFSF> RF= UPF> UF≥ DPF.

Within Reserve Forest (RF), the compartments RFC1, RFC2 and RFC3 had the maximum total herb biomass (0.21 t ha^{-1}) whereas, the minimum (0.10 t ha^{-1}) was displayed by compartment RFC2. In DPF, DPFC3 has maximum total herb biomass (0.16 t ha^{-1}) whereas DPFC1, DPFC2 and DPFC4 had the lowest value (0.09 t ha^{-1}). In UPF, maximum value was recorded in UPFC2 (0.22 t ha^{-1}) and the minimum was found in UPFC1 (0.13 t ha^{-1}). In CFS, CFSC4 (65.07 t ha^{-1}) displayed the maximum total herb biomass whereas compartment CFSC1 has the minimum value (0.03 t ha^{-1}). In UF, the maximum total herb biomass (0.22 t ha^{-1}) was found in UFC3) whereas, the lowest value (0.09 t ha^{-1}) was recorded for UFC4 and UFC1. The total herb biomass between forest classes was maximum (0.28 t ha^{-1}) in CFS and minimum (0.11 t ha^{-1}) in DPF.

The under-storey carbon stock was recorded maximum in CFS and minimum in UPF. However, the soil carbon stock was found maximum in DPF. The maximum ecosystem carbon stock (85.50 t ha^{-1}) potential and CO_2 mitigated (313.79 t ha^{-1}) was recorded in UF whereas, it was minimum in CFS.

The maximum recruits (1187.50 recruits ha^{-1}) were recorded in RF and minimum were found in CFS (312.50 recruits ha^{-1}). The un-established regeneration ha^{-1} and established regeneration ha^{-1} between different forest classes was arranged in following order: RF> DPF> UPF> CFS> UF and RF> DPF> UPF> UF> CFS, respectively. Maximum establishment stocking percent and regeneration success was recorded in RF and minimum in CFSF.

The maximum value for soil pH (6.05) was recorded at 0-20 cm and minimum (6.26) at 20.40 cm soil depth. The maximum value for soil pH between the forest classes was recorded in UPF (6.30) and minimum was recorded in CFS (6.09). The soil electrical conductivity showed a decline in value along soil depth (1.66 dSm^{-2} at 0.20 cm and 0.65 dSm^{-2} at 20-40 cm). The variation between the forest classes was arranged in following order; RF= CFS≥ DPF≥ UF> UPF. The bulk density increases with the increase in soil depth from 0.93 to 0.96 g cm^{-3}. The maximum value was recorded in UPF and minimum in DPF.

The soil organic carbon and fractions of soil carbon showed a decreasing (soil carbon (1.38 % - 1.17 %), labile carbon (0.30 % - 0.26 %) and non labile carbon (0.38 % - 0.27 %) trend along soil depth. Soil organic carbon per cent was maximum (1.48 %) in DPF and was minimum in CFS (1.16 %). The non labile carbon was also found highest in DPF (0.38%) and minimum value was reported in CFS (0.24 %) which remained at par with UPF.

The available N, P and K showed a declining trend with the increase in soil depth. The available soil nitrogen was maximum in DPF and minimum (278.49 kg ha^{-1}) was recorded in CFS. The maximum value for available potassium was recorded in DPF (67.75 kg ha^{-1}) whereas, the minimum was found in CFS (57.78 kg ha^{-1}).

The soil micro nutrients viz, Zn, Fe, Mn and Cu decreased significantly along the soil depth. The Zn decreases from 5.70 (0-20 cm) to 5.14 (20-40 cm), Fe from 37.26 (0-20 cm) to 32.87 (0-20 cm), Mn from 38.26 (0-20 cm) to 33.37 (0-20 cm) and Cu from 1.22(0-20 cm) to 0.95 (0-20 cm).

The establishment stocking index was substantially correlated with K and Cu, whereas, regeneration success was strongly correlated with Mn and Cu.

The lantana infestation in RF ranged from 50 to 60 per cent, 42.22 to 56.90 per cent in DPF, 48.28 to 69.44 percent in UPF, 48.72 to 67.50 per cent in CFS, and 50 to 60.87 per cent in UF, respectively.

A negative relationship between lantana density and basal area with tree density, shrub diversity, establishment stocking index, and regeneration success was detected. The presence of lantana was associated with a strong positive relationship with shrub biomass.

Lantana infestation was significantly and negatively associated with bulk density, soil pH, and Cu. Whereas, it was positively correlated with soil organic carbon, soil carbon density, electrical conductivity, and nitrogen.

Conclusion

The forms of forest management regimes greatly influence species diversity, composition, structural attributes, and biomass carbon stocks. The study concluded that tree density, species diversity and composition were better off in DPF and RF. However, the herb diversity was maximum in CFS which may be due to disturbance factor which create the opening of canopy and allows the under-storey vegetation. The biomass and carbon stock were found better in UF and minimum in CFS which might be due to single species dominance and presence of higher number of bigger size trees in upper diameter class in UF as compare to other forest classes. Further, the overall regeneration success was fair in RF, DPF and UPF whereas, deficient regeneration success and establishment stocking index was recorded in CFS and UF. The soil properties varied significantly along soil depth. The maximum value for soil parameters was recorded in DPF and RF whereas, the low soil nutrients were recorded in CFS. Further, the impact of lantana infestation in different forest classes was significant which had negatively affected the shrub diversity and regeneration success. Therefore, the management practices that retain and enhances tree size inequalities, protects the diversity, stores larger quantities of biomass and carbon as live tree biomass and plays an important role in climate change mitigation while providing other key ecosystem services.

LITERATURE CITED

Act I F. 2016. The Indian Forest Act, 1927. *State Forest Acts*.

Adem M, Worku A, Lemenih M, Tadesse and Pretzsch J. 2014. Diversity, regeneration status and population structure of gum and resin bearing woody species in south Omo zone, southern Ethiopia. *Journal of Forestry Research* **25**: 319-328.

Aime C D V B T, Yves A Y C, Djaha K, Bruno K K, Bertin G B Z and Edouard N K. 2015. Trees species diversity and above ground biomass in three tropical forest types in Azaguie area, *Global Advanced Research Journal of Plant Science* **1**: 30-38.

Akash, Navneet, Bhandari B S and Bijalwan K. 2018. Phytodiversity, stand structure and biodiversity conservation in a tropical forest community under Rajaji Tiger Reserve, Uttarakhand, India. *Envis Bulletin Himalayan Ecology* **26**.

Akash, Navneet, Bhandari B S and Bjalwan K. 2018. Phytodiversity, stand structure and biodiversity conservation in a tropical forest community under Rajaji Tiger reserve, Uttarakhand, India. *ENVIS Bulletin Himalayan Ecology* **26**: 7-16.

Ali A, Lin, S L, He J K, Kong F M, Yu J H and Jiang H S. 2019. Big-sized trees overrule remaining trees attributes and species richness as determinants of aboveground biomass in tropical forests. *Global Change Biology* **127**. https://doi.org/10.1111/gcb.14707.

Ali A. 2019. Forest stand structure and functioning: Current knowledge and future challenges. *Ecol. Indication*https://doi.org/10.1016/j.ecolind.2018.11.017.

Ambika S R, Poornima S, Palaniraj R, Sati S C and Narwal S S. 2003. Allelopathic plants. 10. *Lantana camara* L. *Allelopathy Journal* **12:** 147-162.

Aponte C, Kasel S, Nitschke C R, Tanase M A, Vickers H, Parker L, Fedrigo M, Kohout M, Ruiz B P, Zavala M A and Bennett L T. 2020. Structural diversity underpins carbon storage in Australian temperate forests. *Global Ecology and Biogeography* **29**: 789-802. https://doi.org/10.1111/geb.13038.

Arasa-Gisbert R, Vayreda J, Roman C R M, Villela S A, Mayorga R, Retana J. 2018. Forest diversity plays a key role in determining the stand carbon stocks of Mexican forests. *Forest Ecology and Management* **415**: 160-171. https://doi.org/10.1016/j.foreco.2018.02.023.

Arora G, Chaturvedi S, Kaushal R, Nain A, Tewari S, Alam N M and Chaturvedi O P. 2014. Growth, biomass, carbon stocks, and sequestration in an age series of *Populusdeltoides* plantations in Tarai region of central Himalaya. *Turkish Journal of Agriculture and Forestry* **38**: 550-560.

Arora T H and Kohli R K. 1993. Autotoxic impact of essential oils extracted from *Lantana camara*L. *BiologiaPlantarum* **35**: 293-297.

Asinwa I O, Olajuyigbe S O and Adegeye A O. 2018. Tree Species Diversity, Composition and Structure in Ogun River Watershed, Southwestern Nigeria. *Journal of Forestry Research and Management* **15:** 114-134.

Aye Y Y, Pampasit S, Umponstira C, Thanacharoenchanaphas K and Sasaki N. 2014. Floristic composition, diversity and stand structure of tropical forests in Popamountainpark. *Journal of Environmental Protection* **5**: 1588-1602.

Bajpai O, Kumar A, Mishra A K, Sahu N, Pandey J, Behera S K and Chaudhary L B. 2012. Recongregation of tree species of Katerniaghat wildlife sanctuary, Uttar Pradesh, India. *Journal of Biodiversity and Environmental Sciences* **2**: 24-40.

Ballabha R, Gairola A, Tiwari J K and Tiwari P. 2014. Regeneration status of two forest types in Dhundsir Gad watershed of Garhwal Himalaya, Uttarakhand. *Journal of Ecology and Environmental Sciences* **2**: 11-16.

Baravaraja P K, Sharma S D, Dhananjaya B N, and Badrinath M S. 2010. Soil solution for changing work. 19th World Congress of Soil Science. Australia. **5:** 49-51.

Barker P C J and Patrik L B K. 1994. *Phyllocladus asplenifolius*: Variability in the population structure of the regeneration niche and dispersion pattern in Tasmanian forest. *Australian Journal of Botany* **42:** 163-90.

Barrett C B, Brandon K, Gibson C and Gjertsen H. 2001. Conserving tropical biodiversity amid weak institutions. *Bioscience* **51:** 497-502.

Becknell J M, Kucek L K and Powers J S. 2012. Aboveground biomass in mature and secondary seasonally dry tropical forests: a literature review and global synthesis. *Forest Ecology Management***276:** 88-95. doi:10.1016/j. foreco.2012.03.033.

Behera S K, Sahu N and Mishra A K. 2017. Aboveground biomass and carbon stock assessment in Indian tropical deciduous forest and relationship with stand structural attributes. *Ecological Engineering* **99:** 513-524. doi: 10.1016/j.ecoleng.2016.11.046.

Bhadouria R, Srivastava P, Singh S, Singh R, Raghubanshi A S and J S. 2018. Effects of light, nutrient and grass competition on growth of seedlings of four tropical tree species. *Forester* **144** : 54-65. http://www.Indianforester.co.in.

Bhola N. 1995. Studies on relative growth performance and soil enrichment potential of some nitrogen fixing trees. M.Sc. Thesis, Dr. Y. S. Parmar University of Horticulture and Forestry, Nauni, Soluan, H.P. India. 94p

Bhuyan P, Khan M L and Tripathi R S. 2003. Tree diversity and population structure in undisturbed and human-impacted stands of tropical wet evergreen forest in Arunachal Pradesh, Eastern Himalayas, India. *Biodiversity and Conservation* **12**: 1753−1773.

Birben U. 2019. The effectiveness of protected areas in biodiversity conservation: the case of Turkey. *Cerne* **25**: 424–438.

Biswas S and Mukhopadhyay S C. 2016. Plant community structure and carbon stock assessment through phytosociological approach at dry tropics of Banka Forest Division, Bihar. *Indian Journal of Plant Sciences* **5**: 72-82. http://www.cibtech. org/jps.htm.

Borah M, Das D and Kalita J. et al. 2015. Tree species composition, biomass and carbon stocks in two tropical forest of Assam. *Biomass Bioenergy* **78:** 25-35. doi: 10.1016/j.biombioe.2015 .04.007.

Cairns M A, Brown S, Helmer E N and Baumgardener G A. 1997. Root biomass allocation in the world's upland forests. *Oecologia* **111:** 1-11.

Cairns M A, Olmsted I, Granados J and Argaez J. 2003. Composition and aboveground tree biomass of a dry semi-evergreen forest on Mexico's Yucatan Peninsula. *Forest Ecology and Management* **186**: 125-132.

Castillo J M, Leira-Doce P, Carrion-Tacuri J, Munoz-Guacho E, Arroyo-Solis A, Curado G, Doblas D, Rubio-Casal A E, Álvarez-Lopez A A, Redondo-Gomez S, Berjano R, Guerrero G, De Cires A, Figueroa E and Tye A. 2007. Contrasting strategies to cope with drought by invasive and endemic species of Lantana in Galapagos. *Biodiversity Conserv*ation **16:** 2123-2136.

Cazalis V, Princé K, Mihoub J B, Kelly J, Butchart S H and Rodrigues A S. 2020. Effectiveness of protected areas in conserving tropical forest birds. *Nature Commununications* **11**: 1–8.

Chacko V J. 1965. A manual of sampling techniques for forest surveys. Manager Publication, Delhi. 172p.

Champion H G and Seth S K. 1968. A revised survey of the forest types of India. Manager of Publications, Delhi, India. 404p.

Chandra R. 2009. Tree Species Composition, Regeneration and Diversity Status of Miscellaneous Forest in Tarai Region of Kumaon Himalaya. *Journal of Plant Development Sciences* **1**: 41-44.

Chatanga P. 2007. Impact of the invasive alien species, *Lantana camara* (L). on native vegetation in Northern Gonarezhou National Park, Zimbabwe. A thesis submitted in partial fulfilment of the requirements for the degree of Master of Science, Tropical Resource Ecology Programme, Department of Biological Sciences, Faculty of Science, University of Zimbabwe. 1-84pp.

Chaturvedi R K, Raghubanshi A S and Singh J S. 2011. Carbon density and accumulation in woody species of tropical dry forest in India. Forest Ecol Manage. *Carbon Management* **11:** 1576–1588. doi:10.1016/j.foreco.2011.07. 006.

Chaubey O P and Sharma A. 2013. Population structure and regeneration potential of Sal (*Shorearobusta*gaertn. f.) and its associates in sal bearing forests of Satpura Tiger Reserve. *International Journal of Bio-Science and Bio-Technology* **5**: 63-70.

Chauhan D S, Dhanai C S, Singh B, Chauhan S, Todaria N P and Khalid M A. 2008. Regeneration and tree diversity in natural and planted forests in a terai-bhabhar forest in Katarniaghat Wildlife Sanctuary, India. *Tropical Ecology* **49**: 53-67.

Chauhan N S. 1999. Medicinal and aromatic plants of Himachal Pradesh. Indus Publishing Company. New Delhi, India. 632p.

Chave J, Andalo C, Brown S, Cairns M A, Chambers J Q, Eamus D, Folster H, Fromard F, Higuchi N and Kira T. 2005. Tree allometry and improved estimation of carbon stocks and balance in tropical forests. *Oecologia* **145**: 87–99.

Chen L, Ren C, Zhang B, Wang Z and Wang Y. 2019. Mapping spatial variations of structure and function parameters for forest condition assessment of the Changbai Mountain National Nature Reserve. *Remote Sensing* **11**: 3004. doi:10.3390/rs 11243004.

Chen Y, Cao J, Zhao J, Wu J, Zou X, Fu S and Zhang W. 2019. Labile C dynamics reflect soil organic carbon sequestration capacity: understory plants drive topsoil C process in subtropical forests. *Ecosphere* **10:** 32-38 p.e02784.

Chhabra A, Palria S and Dadhwal V K. 2002. Growing stock-based forest biomass estimate for India. *Biomass Bioenergy* **22:** 187-194.

Chima U D, Ola-Adams B A, Adedire M O and Oyelowo O J. 2009. Impact of Land use Changes on Soil Quality of a Biosphere Reserve in South-Western Nigeria. *Journal of Research in Forestry, Wildlife and Environment*. **1:** 120-131.

Chittibabu C V and Parthasarathy N. 2000. Attenuated tree species diversity in human-impacted tropical evergreen forest sites at Kolli hills, Eastern Ghats, India. *Biodiversity Conservation* **9:** 1493–1519.

Collins M B and Mitchard E T A. 2017. A small subset of protected areas are a highly significant source of carbon emissions. *Scientific Report*s **7**. https://doi.org/10.1038/ srep41902.

Culman, S W, Snapp S S, Freeman M A, Schipanski M E, Beniston J, Lal R, Drinkwater L E, Franzluebbers A J, Glover J D, Stuart Grandy A, Lee J, Six J, Maul J E, Mirksy S B, Spargo J T and Wander M M. 2012. Permanganate oxidizable carbon reflects a processed soil fraction that is sensitive to management. *Soil Science. Society of America Journal* **76**: 494-504.

D F R S, 2015. Middle Mountains Forests of Nepal: Forest Resource Assessment (FRA).

Damptey F G, Birkhofer K, Nsiah P K and de la Riva E G. 2020. In: Soil Properties and Biomass Attributes in a Former Gravel Mine Area After Two Decades of Forest Restoration. *Land* **9**. 209p .

Dar J A and Sundarapandian S M. 2015. Variation of biomass and carbon pools with forest type in temperate forests of Kashmir Himalaya, India. *Environmental Monitoring an Assessment* **187:** 55-61. doi:10.100 7/s 0661-015-4299-7.

Devagiri G M, Money S, Singh S, Dadhawal V K, Patil P, Khaple A K, Devakumar A S and Hubballi S. 2013. Assessment of above ground biomass and carbon pool in different vegetation types of south western part of Karnataka, India using spectral modelling. *Tropical Ecology* **54**: 149-165.

Devi B, Bhardwaj D R, Panwar P, Pal S, Gupta N K and Thakur C L. 2013. Long term effects of natural and plantation forests on carbon sequestration and soil properties in mid hill sub humid condition of Himachal Pradesh, India. *Range Management and Agroforestry* **34**: 19-25.

Devi L S and Yadava P S. 2006. Floristic diversity assessment and vegetation analysis of tropical semievergreen forest of Manipur, north east India. *Tropical Ecology* **47**: 89–98.

Dobhal P K, Kohli R K and Batish D R. 2011. Impact of *Lantana camara* L. invasion on riparian vegetation of Nayar region in Garhwal Himalayas (Uttarakhand, India). *Journal of Ecology and the Natural Environment* **3:** 11-22.

Dobhal P K, Kohli R K and Batish D R. 2011. Impact of *Lantana camara* L. Invasion on riparian vegetation of Nayar region in garhwal Himalayas (Uttarakhand, India). *Journal of Ecology and Natural Environment* **3:** 11-22.

Dobhal P K. 2010. Ecological Audit of Invasive Weed *Lantana camara* L. along an Altitudinal Gradient in PauriGarhwal (Uttranchal). Ph.D. Thesis Submitted in Faculty of Sciences, Panjab University Chandigarh (India).

Dogra K S, Kohli R K and Sood S K**.** 2009. An assessment and impact of three invasive species in the Shivalik hills of Himachal Pradesh, India. *International Journal of Biodiversity Conservation* **1**: 4-10.

Duggin J A and Gentle C B. 1998. Experimental Evidence on the Importance of Disturbance Intensity for Invasion of *L. camara* L. in Dry Rainforest Ecotones in North-eastern NSW, Australia. *Forest Ecology Management* **109:** 279-292.

Dutta G and Devi A. 2013. Inventory of floristic diversity in protected area of tropical forests of Assam, northeast India. *Indian Biodiversity Congress* 305-313.

Dutta G and Devi A. 2013. Plant diversity, population structure, and regeneration status in disturbed tropical forests in Assam, northeast India. *Journal of Forestry Research* **24**: 715–720. doi 10.1007/s11676-013-0409-y.

Dutta R K and Agrawal M. 2002. Effect of tree plantations on the soil characteristics and microbial activity of coal mine spoil land. *Tropical ecology* **43**: 315-324.

Dwivedi D, Tang J, Bouskill N, Georgiou K, Chacon S S and Riley W J. 2019. Abiotic and biotic controls on soil organo-mineral interactions: developing model structures to analyze why soil organic matter persists. *Reviews in Mineralogy and Geochemistry 85: 329-348.*

Ehrenfeld J G. 2003. Effects of exotic plant invasions on soil nutrient cycling processes. Ecosystems **6:** 503-523

Eltahir M E S and Wagner S. 2012. Assessment of regeneration situation in natural and in plantation parts of Elsareef reserved forest, Kordofan region, Sudan. Conference on International Research on Food Security, Natural Resource Management and Rural Development. Gottingen, Germany.

Fan L, Chen Y, Yuan J G and Yang Z Y. 2010. The effect of Lantana camara Linn. invasion on soil chemical and microbiological properties and plant biomass accumulation in southern China. *Geoderma* **154**: 370-378.

FAO, UNEP, 2020. The State of the World's Forests 2020, The State of the World's Forests 2020. https://doi.org/10.4060/ca8642en.

Fayiah M, Swarray M K, Otesile A and Chen B. 2018. Comparative study of the regeneration potential of Kasewe and Taia Riverine Forests, Moyamba District, Sierra Leone," presented at the 40th Annual Conference of Forestry Association of Nigeria (FAN) March 12-16, 2018 Edo State Nigeria, 2018b.

Fensham R J, Fairfax R J and Cannell R J. 1994. The Invasion of *L. camara* L. in Forty Mile scrub National Park, north Queensland. *Australian Journal of Ecology* **19**: 297-305.

Forest Survey of India. 2019. State of forest report. Forest Survey of India, Ministry of Environment and Forests, Government of India, India.

FRA. 2011. Global forest resources assessment 2010. Progress towards sustainable forest management. FAO forestry paper, Rome. 147p.

Gandhi D S and Sundarapandian S. 2017. Large-scale carbon stock assessment of woody vegetation in tropical dry deciduous forest of Sathanur reserve forest, Eastern Ghats, India. *Environmental Monitoring and Assessment* **4:** 187-189. doi:10.1007/s10661-017-5899-1.

Gebeyaw T Y. 2015. Assessment of Micronutrient Status in Different Land Use Soils in Maybar Lake Watershed of Albuko District, South Wello Zone, North Ethiopia *American Journal of Environmental Protection* **3:** 30-36.

Geldmann J, Manica A, Burgess N D, Coad L and Balmford A. 2019. A global-level assessment of the effectiveness of protected areas at resisting anthropogenic pressures. *Proceedings of Natural Academy of Sciences* **116:** 23209-23215.

Gentle C B and Duggin J A. 1997. *L. camara* L. Invasion in Dry Rainforest-Open Forest Ecotones: The Role of Disturbance Associated with Fire and Cattle Grazing. *Australian Journal of Ecology* **22:** 296-304.

Geraei D S, Hojati S, Landi A, Cano A F. 2016. Total and labile forms of soil organic carbon as affected by land use change in southwestern Iran. *Geoderma Regional* **7:** 29-37.

Giril A, Arya B, Ghimire S K, Shrestha K K and Jha P K. 2001. Vegetation Composition and Biomass Production in Riverine Forest of the Royal Bardia National Park, Nepal. *Nepal Journal of Science and Technology* **3**: 33-40.

Gogoi A, Sahoo U K and Singh S L. 2017. Assessment of biomass and total carbon stock in a tropical wet evergreen rainforest of Eastern Himalaya along a disturbance gradient. *Journal of Plant Biology and Soil Health* **4**:1-8.

Grace M, Menas W and George N. 2017. Effects of different disturbance regimes on grass and herbaceous plant diversity and biomass in Zimbabwean dambo systems. *International Journal of Biodiversity Science, Ecosystem Services and Management* **13:** 181-190. doi: 10.1080/21513732.2017.1299222.

Grote R. 2002. Foliage and branch biomass estimation of coniferous and deciduous tree species. *Silva Fennica* **36**: 779-788.

Grunow J O, Groeneveld H T and DuToit S H C.1980. Above ground dry matter dynamics of the grass layer of a South African tree Savanna. *Journal of Ecology* **68:** 877–889.

Gupta M K, Panwar V P and Kumar M. 2015. Carbon Sequestration in the soils under similar vegetation growing in Uttarakhand and Haryana states of India. *Octa Journal of Environmental Research* **3**: 41-49.

Hailemariam M B and Temam T D. 2018. The vegetation composition, structure and regeneration status of Gole natural forest, West Arsi Zone, Oromia regional state. *Ethiopian Journal of Agricultural Science and Botany* **2:** 10–21.

Hartman K M, McCarthy B C. 2008. Changes in forest structure and species composition following invasion by a non-indigenous shrub, Amur honeysuckle (*Lonicera maackii*). *Journal of Torrey Botanical. Society* **7:** 245-259. https://doi.org/10.3159/TORREY-D-15-00036.1.

Hashmat M A, Hussain R. 2013. A review on *Acacia catechu* wild. *Interdisciplinary Journal of Contemporary Research in Business* **5**: 593-600.

Hoffmann S, Beierkuhnlein C, Field R, Provenzale A and Chiarucci A. 2018. Uniqueness of protected areas for conservation strategies in the European Union. *Scientific Reports* **8**: 1–14.

Holmes P M, Richardson D M, Van-Wilgen B W and Gelderblom C. 2000. Recovery of South African Fynbos Vegetation Following Alien Woody Plant Clearing and Fire: Implications for Restoration. *Austral Ecology* **25**: 631-639.

Ingram J C, Whittaker R J and Dawson T P. 2005. Tree structure and diversity in human-impacted littoral forest, Madagascar. *Environmental Management* **35**: 779−798.

International Energy Agency. 2017. WEO-2017 Special Report: Energy Access Outlook. https://www.iea.org/reports/energy-access-outlook-2017.

IPCC. 1996. Climate change 1995- impacts, adaptations and mitigation of climate: scientific technical analyses. In: contribution of II to the second assessment report of the Intergovernmental Panel on Climate Change. Cambridge University.

Jackson M L. 1973. *Soil chemical analysis*. Prentice hall of India Private Limited, New Delhi. 498p.

Jones C G, Lawton J H and Shachak M. 1994. Organisms as ecosystem engineers. *Oikos* **69:** 373-386. Doi : 10.2307/3545850.

Kadavul K and Parthasarathy N. 1999. Plant biodiversity and conservation of tropical semi-evergreen forest in the Shervarayan hills of Eastern Ghats, India. *Biodiversity Conservation* **8:** 419–437.

Kandel P N, Awasthi K D, Kauranne T, Gautam B, Gunia K and Baral S. 2014. Estimation of above ground Forest biomass and Carbon stock by Integrating LiDAR, satellite image and field measurement in Nepal. *Research Journal of Agriculture and Forestry Sciences* **2**: 1-6.

Karki D. 2002. Economic Assessment of Community Forestry in Inner Terai of Nepal: A Case Study from Chitwan District, Asian Institute of Technology, Thailand.

Khaine I, Woo S Y, Kwak M, Lee S H, Sun M J, You H and H C Cheng. 2018. Factors affecting natural regeneration of tropical forests across a precipitation gradient in Myanmar. *Forests* **9:** 143-145. https://doi.org/10.3390/f9030143.

Khali M and Bhatt V P. 2014. Community structure of montane forest along the altitudinal gradient in Garhwal Himalaya, India. *Journal of Ecology and the Natural Environment* **6**: 206-214.

Khanal K P. 2001. Economic Evaluation of Community Forestry in Nepal and its Equity Distribution Effect, The Royal Veterinary and Agricultural University, Denmark.

Khanna L S. 1996. Principle and practice of Silviculture. International Book. Distributor, Dehradun. 473p.

Khurana P. 2009. Tree layer analysis and regeneration in tropical dry deciduous forest of Hastinapur, Uttar Pradesh. *Indian Journal of Tropical Biodiversity* **16**: 43-50.

Kimble J M, Lal R and Follett R R. 2002. Agricultural practices and policy options for carbon sequestration: what we know and where we need to go. In: Kimbel J M, Lal R and Follett R.R (eds.). Agricultural practices and policies for carbon sequestration in soil. New York, Lewis Publishers. 512p.

Koutika l S, Epron D, Bouillet J P and Mareschal L. 2014. Change in N and C concentrations, soil acidity and P availability in tropical mixed acacia and eucalyptus plantations on a nutrient-poor sandy soils. *Plant soil* **379:** 205-216.

Kozlowski T T. 1979. Wisconsin woodlands-how trees grow. University of Wisconsin Extension.7p.

Kukshal S, Nautiyal B P, Anthwal A, Sharma A and Bhatt A B. 2009. Phytosociological investigation and life form pattern of grazinglands under pine canopy in temperate zone, Northwest Himalaya, India. *Research Journal of Botany* **4:** 55-69.

Kumar M, Sharma C M and Rajwar G S. 2004. A study on community structure and diversity of a sub-tropical forest of Garhwal Himalayas. *Indian Forester* **130:** 207-214.

Kumar M, Verma A K and Garkoti S C. 2020. *Lantana camara* and *Ageratina adenophora* invasion alter the understory species composition and diversity of Chir pine forest in central Himalaya, India. *Acta Oecologica* **109**: 1036-42.

Kumar S. 1998. Above ground biomass production and its estimation in *Acacia mollissima* through prediction model. M.Sc. Thesis, Dr. Y. S. Parmar University of Horticulture and Forestry, Nauni, Solan, HP. India. 120p.

Lal C, Singh L and Bhardwaj D R. 2015. Regeneration status and floristic composition of natural and plantation forest ecosystems of Barnawapara Wildlife Sanctuary, Chhattisgarh, India. *Indian Forester* **141**: 848-853. http://www.indianforester.co.in.

Lal R. 2008. Sequestration of Atmospheric CO_2 in Global Carbon Pools. *Energy and Environmental Science* **1:** 86-100. https://doi.org/10.1039/b809492f .

Lecina-Diaz J, Alvarez A, Regos A, Drapeau P, Paquette A, Messier C and Retana J. 2018. The positive carbon stocks-biodiversity relationship in forests: co-occurrence and drivers across five subclimates. *Ecological Applications* https://doi.org/10.1002/eap.1749.

Lewis S L, Sonke B and Sunderland T. 2013. Above-ground biomass and structure of 260 African tropical forests. *Philosophical Transaction of the Royal Society* **368**: 1-17.

Li Y, Bao W, Bongers F, Chen B, Chen G, Guo K, Jiang M, Lai J, Lin D, Liu C, Liu X, Liu Y, Mi X, Tian X, Wang X, Xu W, Yan J, Yang B, Zheng Y and Ma K. 2019. Drivers of tree carbon storage in subtropical forests. *Science of Total Environment* **654**: 684-693. https://doi.org/10.1016/j.scitotenv.2018.11.024.

Liu X, Trogisch, S, He J S, Niklaus P A, Bruelheide H, Tang Z, Erfmeier A, Scherer-Lorenzen M, Pietsch K A, Yang B, Kuhn P, Scholten T, Huang Y, Wang C, Staab M, Leppert K N, Wirth C, Schmid B, Ma K. 2018. Tree species richness increases ecosystem carbon storage in subtropical forests. *Proceedings of The Royal Society B: Biological Sciences* **285**. https://doi.org/10.1098/rspb.2018.1240.

Lone P A, Dar J A, Kothandaraman S and Khan M L. 2021. An invasive shrub *Lantana camara* L. alters the flora and soils in tropical dry deciduous forests of Central India. Research square. 1-25. https://doi.org/10.21203/rs.3.rs-223195/v1

Lu Y, Yang Y, Sun B, Yuan J, Yu M, Stenseth N C and Obersteiner M. 2020. Spatial variation in biodiversity loss across China under multiple environmental stressors. *Scientific Advances* **6**. DOI: eabd0952.10.1126/sciadv.abd0952.

Luck G W, Ricketts T H, Daily G C and Imhoff M. 2004. Alleviating spatial conflict between people and biodiversity. *Proceedings of the National Academy of Sciences, USA* **101:**182-186.

Luna R K. 1995. Plantation trees. International Book Distributors, New Delhi, India. 975p.

Luna-Kamyshev N M, Lopez-Martınez J O, Vargas-Larreta B, Islebe G A, Villalobos-Guerrero T F, Va´zquez de la Rosa A, Reyes-Mendoza O F and Trevino-Garza E. 2020. Floristic Composition, Diversity, and Biomass of a Protected Tropical Evergreen Forest Belize. *Tropical Conservation Science Volume* **13**: 1–13.

Lung M and Espira A. 2015. The influence of stand variables and human use on biomass and carbon stocks of a transitional African forest: implications for forest carbon projects. *Forest Ecology Management* **351**: 36–46.

Lutz J A, Furniss T J, Johnson D J, Davies S J, Allen D, Alonso A, Anderson- Teixeira K J, Andrade A, Baltzer J, Becker K M L, Blomdahl E M, Bourg N A, Bunyavejchewin S, Burslem D F R P, Cansler C A, Cao K, Cao M, Cardenas D, Chang L W, Chao K J, Chao W C, Chiang J M, Chu C, Chuyong G B, Clay K, Condit R, Cordell S, Dattaraja H S, Duque A, Ewango C E N, Fischer G A, Fletcher C, Freund J A, Giardina C, Germain S J, Gilbert G S, Hao Z, Hart T, Hau B C H, He F, Hector A, Howe R W, Hsieh C F, Hu Y H, Hubbell S P, and Zimmerman J K. 2018. Global importance of large-diameter trees. *Global Ecology and Biogeography* **27**: 849-864.

Magurran A E. 1988. Ecological Diversity and its Measurement. Princeton, New Jersey: Princeton University Press.

Majumdar K, Choudhary B K and Datta B K. Aboveground woody biomass, carbon stocks potential in selected tropical forest patches of Tripura, Northeast India. *Open Journal Ecology* **6:** 598-612. doi:10.4236/oje. 2016.610057.

Malik P C. 1992. Studies on relationship of soil physic- chemical properties with Chirpine association. M.Sc. Thesis, Dr. Y. S. Parmar University of Horticulture and Forestry, Nauni, Solan, HP. India. 74p.

Malik Z A and Bhatt A B. 2016. Regeneration status of tree species and survival of their seedlings in Kedarnath Wildlife Sanctuary and its adjoining areas in Western Himalaya, India. *Tropical Ecology* **57:** 677-690.

Malik ZA. 2014. Phytosociological Behaviour, Anthropogenic Disturbances and Regeneration Status Along an Altitudinal Gradient in Kedarnath Wildlife Sanctuary (KWLS) and its Adjoining Areas. Ph.D Thesis HNB Garhwal University, Srinagar Uttarakhand. 154p.

Mamun A, Hossain M A, Hossain M K and Alam S. 2015. Quantifying diversity and composition of tree species in secondary hill forests of Chunati forest, Chittagong, Bangladesh. *Indian Forester* **141:** 566-572.

Mandal R A, Jha P K, Dutta I C, Thapa U and Karmacharya S B. 2016. Carbon Sequestration in Tropical and Subtropical Plant Species in Collaborative and Community Forests of Nepal. *Advances in Ecology* 1529703: 7. http://dx.doi.org/10.1155/2016/1529703.

Margalef D R. 1958. Information theory in ecology. *General Systems* **3:** 36-71.

Martinez R M, Ortiz R I A, Pinero D, Dirzo R and Sarukhan J. 2016. Anthropogenic disturbances jeopardize biodiversity conservation within tropical rain- forest reserves. *Proceedings of Natural Academy of Sciences* **113:** 5323-5328.

Masum K M, Islam M S, Parvej M, Abdullah-Al- Mamun M M and Arfin-Khan M A S. 2020. Biodiversity comparison between forest-protected and forest-reserved areas in Bangladesh in context of co-management for conservation. *Forestist* doi:20.10.5152/ forestist.2020.20023.

Meena A, Bidalia A, Hanief M, Dinakaran J and Rao K S. 2019. Assessment of above-and belowground carbon pools in a semi-arid forest ecosystem of Delhi, India. *Ecological Processes* **8:** 1-11.

Meena A, Bidalia A, Hanief M, Dinakaran J and Rao K S. 2019. Assessment of above- and belowground carbon pools in a semi-arid forest ecosystem of Delhi, India. Ecological Processes 8:8 https://doi.org/10.1186/s13717-019-0163-y.

Merwin H D and Peach P M. 1951. Exchangeability of soil potassium in the sand, silt and clay fractions as influenced by nature of complementary exchangeable cations. *Proceeding Soil Science Society of America* 15:125-128.

Meyer V, Saatchi S, Clark D B, Keller M, Vincent G, Ferraz A, Espirito-Santo F, D'Oliveira M V N, Kaki D and Chave J. 2018. Canopy area of large trees explains aboveground biomass variations across Neotropical forest landscapes. *Biogeosciences***15:** 3377-3390.

Mishra B P, Tripathi O P, Tripathi R S and Pandey H N. 2004. Effect of anthropogenic disturbance on plant diversity and community structure of a sacred grove in Meghalaya, northeast India. *Biodiversity and Conservation* **13**: 421−436.

Morris R J. 2010. Anthropogenic impacts on tropical forest biodiversity: a network struc- ture and ecosystem functioning perspective. *Philosophical Transactions of Royal Society B: Biological Sciences* **365**: 3709-3718.

Morton J F. 1994. Lantana or red sage (*Lantana camara* L., Verbenaceae). Notorious weed and popular garden flower: Some cases of poisoning in Florida. *Econ. Bot* **48:** 259-270.

Murphy P G and Lugo A E. 1986. Structure and biomass of a subtropical dry forest in Puerto Rico. *Biotropica* 1**8:** 8996. doi:10.2307/2388750.

Nagamastu D, Seiwa K and Sakai A. 2002. Seedling establishment of deciduous trees in various topographic positions. *Journal of Vegetation Science* **13:** 35-44.

Nagaraja B C, Maskey N and Somashekara R K. 2011. Regeneration of native woody species under plantations in Kudremukh national park, Western ghats of south India. *International Journal of Biodiversity Science, Ecosystem Services and Management* **7:** 77-83.

Naidu M T and Kumar O A. 2016. Tree diversity, stand structure, and community composition of tropical forests in Eastern Ghats of Andhra Pradesh, India. *Journal of Asia Pacific Biodiversity* **9**: 328–334.

Nath A J, Brahma B, Sileshi G W and Das A K. 2018. Impact of land use changes on storage of soil organic carbon in active and recalcitrant pools in a humid tropical region of India. *Science of the Total Environment* **624:** 908-917. https://doi.org/10.1016/j.scitotenv.2017.12.199PMID: 29275253.

Nayak B K. 1996. Studies on biomass productivity and nutrient content in *Eucalyptus tereticornis*, *Leucaena leucocephala* and *Melia azedarach* under high density plantation. M.Sc. Thesis, Dr. Y. S. Parmar University of Horticulture and Forestry, Nauni, Soluan, H.P. India. 88p

Neelo J, Teketey D, Kashey K and Masamba W. 2015. Stand structure, diversity and regeneration status of woody species in open and enclosed dry woodland sites around Molapo farming areas of the Okavango delta, northeastern Botswana. *Open Journal of Forestry* **5:** 313-328.

Nelson D W and Sommers L E. 1996. Total carbon, organic matter. In: Method of soil analysis. Part 3. Chemical methods (DL Sparks eds). *Soil Science Society of America*, Madison, Wisconsin. 961-1010pp.

Nirola R and Jha P K. 2011. Phytodiversity and soil study of Shiwalik hills of Ilam, Nepal: an ecological perspective. *Ecoprint* **18**: 77-83.

Norra S, Fjer N, Li F, Chu X, Xie X and Stüben D. 2008. The influence of different land uses on mineralogical and chemical composition and horizonation of urban soil profiles in Qindao, China.Journal of Soils and Sediments 8: 4-16. doi:10.1065/jss2007.08.250.

Noureen S, Muhhamad A, Karamat M and Yasin A M. 2008. Improvement in fertility of nutritionally poor sand soil of Cholistan desert, Pakistan by *Calligonum polygonoides* Linn. *Pakistan Journal of Botany* **40:** 265-274.

Oladoye A O, Ola A B A, Adedire M A and Agboola D A. 2008. Nutrient dynamics and litter decomposition in *Leucaenaleucocephala* (Lam.) de wit plantation in Nigerian derived savanna. *West African Journal of Applied Ecology* **13**: 96-103.

Olsen S R, Cole W, Watanable F S and Dean L A. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. *USDA Circular* **939**: 1-19.

Oo M Z, Shin T, Yasao O and Yoshiyuki K. 2006. Biomass of palnted forests and biotic climax of shrub and grass communities in the central dry zone of Myanmar. *Bulletin of FFPRI* **5:** 271-288.

Padmakumar B, Sreekanth N P, Shanthiprabha V, Paul J, Sreedharan K, Augustine T and Thomas A P. 2018. Tree biomass and carbon density estimation in the tropi- cal dry forest of Southern Western Ghats, India. *iForest - Biogeosciences and Forestry* **11**: 534p.

Pala N A, Negi A K, Gokhale Y and Todaria N P. 2013. Tree Regeneration Status of Sacred and Protected Landscapes in Garhwal Himalaya, India. *Journal of Sustainable Forestry* **32:** 230-246. doi: 10.1080/10549811.2013.762492.

Pan Y, Birdsey R A, Fang J, Houghton R, Kauppi P E, Kurz W A, Phillips O L, Shvidenko, A, Lewis, S L, Canadell J G, Ciais P, Jackson R B, Pacala S W, McGuire A D, Piao S, Rautiainen A, Sitch S and Hayes D. 2011. A large and persistent carbon sink in the world's forests. *Science***333**: 988-993. https://doi.org/10.1126/ science.1201609.

Panda P C, Mahapatra A K, Acharya P K and Debata A K. 2013. Plant diversity in tropical deciduous forests of Eastern Ghats, India: a landscape level assessment. *International Journal of Biodiversity Conservation* **5:** 625–639.

Pande P K. 2005. Biomass and productivity in some disturbed tropical dry deciduous teak forests of Satpura plateau, Madhya Pradesh. *Tropical Ecology* **46:** 229-240.

Pandey C B, Pandya K S, Pandey D and Sharma R B. 2000. Growth and productivity of rice (*Oryzasativa*) as affected by *Acacia nilotica*in a traditional agroforestry system. *Tropical Ecology* **40:** 109-117.

Panzou G J L, Fayolle A and Feldpausch T R. et al. 2018. What controls local-scale aboveground biomass variation in central Africa? Testing structural, composition and architectural attributes. *Forest Ecology Management* **429:** 570–578. doi:10.1016/j.foreco.2018.07.056.

Pearson T R H, Brown S, Murray L, Sidman G. 2017. Greenhouse gas emissions from tropical forest degradation: An underestimated source. *Carbon Balance and Management* **12:** 1-11. https://doi.org/10.1186/s13021-017-0072-2.

Philip O and Gentry A H. 1993. The Useful Plants of Tambopata, Peru: Statistical Hypothesis Tests with a new Quantitative Technique. *Economic Botany* **47:** 15-32.

Phillips E A. 1959. Methods of Vegetation Study. New York: Henry Holt and Co. Inc, 107.

Pielou E C. 1966. The measurement of diversity in different types of biological collections. Journal of Theoretical Biology **13:**131-144.

Pilania P K, Gujar R V and Panchal N S. 2014. Species diversity and phytosociological analysis of important plants of Tropical Dry deciduous forest of Dahod district of Gujarat, India. *International Journal of Science & Medical Research* **1**: 37-46.

Pokhriyal P, Uniyal P, Chauhan D S and Todaria N P. 2010. Regeneration status of tree species in forest of Phakot and Pathri Rao watersheds in Garhwal Himalaya. *Current Science* **98**: 171-175.

Pokhriyal P, Uniyal P, Chauhan D S and Todaria N P. 2010. Regeneration status of tree species in forest of Phakot and Pathri Rao watersheds in Garhwal Himalaya. *Current Science* **98**: 171-175.

Poorter L, Bongers F, Rompaey R S V, and de Klerk M. 1996. Regeneration of canopy tree species at five sites in West African moist forest. *Forest Ecology and Management* **84:** 61-69. Available at: https://doi.org/10.1016/0378-1127(96)03736-x.

Pradhan A, Ormsby A A and Behera N. 2019. A comparative assessment of tree diversity, biomass and biomass carbon stock between a protected area and a sacred forest of Western Odisha, India. *Écoscience* doi: 10.1080/11956860.2019.1586118.

Prado-Junior J A, Schiavini I and Vale V S, et al. 2016. Conservative species drive biomass productivity in tropical dry forests. *Journal Ecology* **104**: 817-827. doi: 10.1111/1365-2745.12543.

Puri S, Singh S and Khara A. 1992. Effect of wind break on the yield of cotton crop in semiarid region of Haryana. *Agroforestry Systems* **18:** 183–195.

Pysek P, Pysek A. 1995. Invasion by *Heracleum mantegazzianum* in different habitats in the Czech Republic. *Journal of Vegetable Science* **6:** 711–718. https://doi.org/10.2307/3236442.

Raghubanshi A S. 1991. Dynamics of soil biomass C, N, and P in a dry tropical forest in India. *Biology and Fertility of Soils* **12**: 55-59.

Raha D, Dar J A, Pandey P K, Lone P A, Verma S, Khare P K and Khan M L. 2020. Variation in tree biomass and carbon stocks in three tropical dry deciduous forest types of Madhya Pradesh, India. *Carbon Management* **11:** 109-120.

Rai P and Gupta B. 2018. Estimation of biomass and carbon stock variations in vegetation of differently managed *Quercus leucotrichophora* forests along an elevation gradient in Western Himalaya, India. *Indian Journal of Ecology* **45**: 100-106.

Raizada A and Juyal G P. 2012. Tree species diversity, species regeneration and biological productivity of seeded *Acacia catechu* Willd. in rehabilitated limestone mines in the north west Himalayas. *Land Degradation and Development* **23**: 167-174.

Rajput B S, Bhardwaj D R., Dwivedi K P and Kumar D 2016. Soil organic carbon stock under different land use systems in mountainous ecosystem. *Indian Journal of Ecology* **43:** 93-97.

Ranch J W and Schlesinger W H. 1992. The global carbon dioxide flux in soil respiration and its relationship to climate. *Tellus* **44:** 81-99.

Rao P, Barik S K, Pandey H N and Tripathi R S. 1990. Community composition and tree population structure in a sub-tropical broad-leaved forest along a disturbance gradient. *Vegetation* **88**: 151−162.

Rao V S and Rao B R P. 2015. Carbon sequestration potential of tropical deciduous forests of Nallamalais, India. *Asian Journal of Plant Science and Research* **5:** 24-33.

Ravindranath N H, Somasekhar B S and Gadgil M. 1997. Carbon flows in Indian forest. *Climate Change* **35**: 297-320.

Rawat D S, Dash S S, Sinha B K, Kumar V, Banerjee A and Singh P. 2018. Community structure and regeneration status of tree species in Eastern Himalaya: A case study from Neora Valley National Park, West Bengal, India. *Taiwania* **63:** 16-24.

Rawat L, Luna R K, Kholiya D and Kamboj S K. 2008. Biomass, productivity and nutrient retention in *Acacia catechu* Willd. plantations in Shiwalik hills of Punjab. *Indian Forester* **134**: 212-225.

Reddy C S and Ugle P. 2008 Survival threat to the flora of Mudumalai Wildlife Sanctuary, India: an assessment based on regeneration status. *Nature and Science* **6**: 42-54.

Reddy C S, Babar S, Amarnath G, and Pattanaik C. 2011. Structure and floristic composition of tree stand in tropical forest in the Eastern Ghats of northern Andhra Pradesh. *Indian Journal of Forest Research* **22**:491.

Report, 2019. Parliament of India RajyaSabha Department-Related Parliamentary Standing Committee On Science & Technology, *Environment & Forests* 2019. 1-46pp.

Richardson D M, Pysek P, Rejmanek M, Barbour M G, Panetta F D and West C J. 2000. Naturalization and invasion of alien plants: concepts and definitions. *Diversity and Distributions* **6**: 93-107.

Rivas-Torres G, Flory S L and Loiselle B. 2018. Plant community composition and structural characteristics of an invaded forest in the *Galapagos. Biodivers. Conserv*. **27:** 329-344. https://doi.org/10.1007/s10531-017-1437-2.

Rocky J and Mligo C. 2012. Regeneration pattern and size-class distribution of indigenous woody species in exotic plantation in Pugu Forest Reserve, Tanzania. *International Journal of Biodiversity and Conservation* **4:** 1-14.

Rusterholz H P, Schneuwly J and Baur B. 2018. Invasion of the alien shrub Prunus laurocerasus in suburban deciduous forests: effects on native vegetation and soil properties. *Acta Oecologica* **92:** 44-51. https://doi.org/10.1016/j.actao.2018.08.004.

Sagar R, Raghubanshi A S and Singh J S. 2003. Tree species composition, dispersion and diversity along a disturbance gradient in a dry tropical forest region of India. *Forest Ecology Management* **186**: 61-71. doi:10. 1016/S0378-1127(03)00235-4.

Salunkhe O, Khare P K and Sahu T R, et al. 2014. Aboveground biomass and carbon stocking in tropical deciduous forests of state of Madhya Pradesh, India. *Taiwania* **59:** 353-359.

Sandford W W, Usman S, Obot S E, Isichei A O and Wari. 1982. Relationship of woody plants to herbaceous production in Nigerian savanna. *Tropical Agriculture* **59:** 315-318.

Sanyam. 2016. Studies on growth potential biomass production and nutrient status of *Acacia catechu* Wild. under low hill condition of Himachal Pradesh. PhD. Thesis, Dr. Y. S. Parmar University of Horticulture and Forestry, Nauni, Solan, HP. India. 116p.

Sapkota R P, Stahl P D, Hengaju K and Rijal K. 2018. Changes in the ecological parameters of mixed forests of sal (shorearobustagaertn.) are a function of distance from the human settlements. *International Journal of Ecology*. https://doi.org/10.1155/2018/1394814.

Sarlach H S. 1994. Nutrient dynamics and biomass production of *Eucalyptus tereticornis* Smith, in high density short rotation system. M.Sc. Thesis, Dr. Y. S. Parmar University of Horticulture and Forestry, Nauni, Solan, H.P. India. 99p

Saxena A K and Singh J S. 1984. Tree population structure of certain Himalayan forest associations and implications concerning their future composition. *Vegetation* **58:** 61-69.

Scrub National Park, north Queensland. *Australian Journal of Ecology* **19:** 297-305.

Seddon N, Chausson A, Berry P, Girardin C A J, Smith A and Turner B. 2020. Understanding the value and limits of nature-based solutions to climate change and other global challenges. *Philosophical Transactions of Royal Society B: Biological Sciences* **375**: 20190120. https://doi.org/10.1098/ rstb.2019.0120.

Shahid M and Joshi S P. 2018. Carbon stock variation in different forest types of Western Himalaya, Uttarakhand. *Journal of Forest and Environmental Science* **34**: 145-152. https://doi.org/10.7747/JFES.2018.34.2.145 .

Shannon C E, Weaver W. 1963. The mathematical theory of communication. University Illinois Press. Urbana, USA. 117p.

Sharma A, Batish D R, Singh H P, Jaryan V and Kohli R K. 2017. The impact of invasive *Hyptis suaveolens* on the floristic composition of the periurban ecosystems of Chandigarh, northwestern India. *Flora* **233**: 156-162. https://doi.org/10.1016/j. flora.2017.04.008.

Sharma G P and Raghubanshi A S. 2006. Tree population structure, regeneration and expected future composition at different levels of *Lantana camara* L. invasion in the Vindhyan tropical dry deciduous forest of India. *Lyonia* **11:** 27-39.

Sharma G P and Raghubanshi A S. 2007. Effect of *Lantana camara* L. cover on local depletion of tree population in the Vindhyan tropical dry deciduous forest of India. *Applied Ecology and Environmental. Research* **5:** 109-121.

Sharma G P, Raghubanshi A S. 2011. *Lantana camara* L. invasion and impact on herb layer diversity and soil properties in a dry deciduous forest of India. *Applied Ecological. Environmental Research* **9:** 253-264. https://doi.org/10.15666/aeer/0903_253264.

Sharma G P, Raghubashi A S and Singh J S. 2005. *L. camara* Invasion: An Overview. *Weed Biology and Management* **5:** 157-165.

Sharma N and Kant S. 2014. Vegetation structure, floristic composition and species diversity of woody plant communities in sub-tropical KandiSiwaliks of Jammu, J & K, India. *International Journal of Basic and Applied Sciences* **3**: 382.

Sheikh M A and Kumar M. 2010. Nutrient status and economic analysis of soils in oak and pine forests in Garhwal Himalaya. *Journal of American Science* **6**: 117-122.

Shen Y, Yu S, Lian J, Shen H, Cao H, Lu H and Ye W. 2016. Tree aboveground carbon storage correlates with environmental gradients and functional diversity in a tropical forest. *Scientific Reports* **6**, 25304. https://doi.org/10.1038/srep25304.

Shinwari M I and Khan M A. 2000. Folk use of medicinal herbs of Margalla Hills National Park, Islamabad. *Journal of Ethnopharmacolgy* **69:** 45-56.

Simpson E H. 1949. Measurement of diversity. *Nature* **163**: 688.

Singh S and Verma A K. 2018. Biomass and carbon stocks in different forest types of Western Himalaya. *Tropical Ecology* **59:** 647-658.

Singh S L, Sahoo U K, Kenye A and Gogoi A. 2018. Assessment of growth, carbon stock and sequestration potential of oil palm plantations in Mizoram, Northeast India. *Journal of Environ Protection* **9:** 912-931.

Singh S, Chand H B, Khatri P K, Kumar D, Kewat A K, Kumar A and Singh K P. 2021. Phytosociology and regeneration status in different permanent preservation plots across different forest types in Madhya Pradesh, Central India. *Grassroots Journal of Natural Resources* **4**: 179-198. doi: https://doi.org/10.33002/nr2581.6853.040213.

Singh V, Gupta S R and Singh N. 2016. Carbon sequestration potential of tropical dry deciduous forests in Southern Haryana, India. *International Journal of Ecology and Environmental Science***42:** 51-64.

Singh V, Tewari A, Kushwaha S P and Dadhwal V K. 2011. Formulating allometric equations for estimating biomass and carbon stock in small diameter trees. *Forest Ecology and Management* **261**: 1945-1949.

Slik J W F, Aiba S I and Brearley F Q. 2010. Environmental correlates of tree biomass, basal area, wood specific gravity and stem density gradients in Borneo's tropical forests. *Global Ecology and Biogeography***19:** 50-60. doi: 10.1111/j.1466-8238.2009.00489.x.

Slik J W F, Paoli G and McGuire K. 2013. Large trees drive forest aboveground biomass variation in moist lowland forests across the tropics. *Global Ecology and Biogeography***22**: 1261–1271. doi:10.1111/geb.12092.

Srinivas K and Sundarapandian S. 2019. Biomass and carbon stocks of trees in tropical dry forest of East Godavari region, Andhra Pradesh, India. *Geology Ecology and Landscapes***3**: 114–122.

Stephenson N L, Das A J, Condit R, Russo S E, Baker P J, Beckman N G, Lines E R, Morris W K, Ruger N, ´Alvarez E, Blundo C, Bunyavejchewin S, Chuyong G, Davies S J, Duque A, Ewango C N, Flores O, Franklin J F, Grau H R, Hao Z, Harmon M E, Hubbell S P, Kenfack D, Lin Y, Makana J R, Malizia A, Malizia L R, Pabst R J, Pongpattananurak N, Su S H, Sun I F, Tan S, Thomas D, Mantgem P J, Wang X, Wiser S K and Zavala M A. 2014. Rate of tree carbon accumulation increases continuously with tree size. *Nature* **507**: 90-93. https://doi.org/10.1038/nature12914.

Subbiah B V and Asija G S. 1956. Rapid procedure for estimation of available nitrogen in soil. *Current Sciences* **25**: 259-260.

Sundarapandian S M, Dar J A and Gandhi D S. 2013. Estimation of biomass and carbon stocks in tropical dry forests in Sivagangai district, Tamil Nadu, India. *International Journal of Environmental Science and Engineering Research* **4**: 66-76.

Tangki H and Chappell N A. 2008. Biomass variation across selectively logged forest within a 225-km^2 region of Borneo and its prediction by Landsat TM. *Forest Ecology and Management* **256**: 1960–1970.

Terakunpisut J, Gajaseni N and Ruankawe N. 2007. Carbon sequestration potential in aboveground biomass of Thong PhaPhum national forest, Thailand. *Applied Ecology and Environment Research* **5:** 93–102. doi:10.15666/aeer/0502_ 093102.

Thomas S E and Ellison C A. 2000. A Century of Classical Biological Control of *L. camara*: can pathogens make a significant difference." In *Proceedings of the X international symposium on biological control of weeds,* Montana State USDA-ARS Bozeman, Montana 4: 97-104.

Toky O P and Bisht R P. 1993. Above-ground and below-ground biomass allocation in important fuel wood trees from arid north-western India. *Journal of Arid Environments* **25**: 315-320.

Toleti B. 2011. Urban forest soil characteristics: a geostatistical analysis of Allan Gardens Park, Toronto, Canada. In: Slope stability: natural and manmade slope (eds T.N. Singh, Y.C. Sharma), New Delhi348-386pp.

Traore S, Kabore O, Rasolodimby J M, Thiombiano L and Guinko S. 2008. Impact of protected areas and land use on regeneration of Acacia woodlands in eastern Burkina Faso. *Flora etVegetatioSudano-Sambesica* **11**: 17-24.

Troup R S. 1921. The Silviculture of Indian trees. Vol II. Clarendon Press, Oxford.

U N. 2015. United Nations Transforming Our World: the 2030 Agenda for Sustainable Development. A/RES/70/1, United Nations.

Vaidyanathan S, Krishnaswamy J, Samba Kumar N, Dhanwatey H, Dhanwatey P and Karanth K U. 2010. Patterns of tropical forest dynamics and human impacts: Views from above and below the canopy. *Biological Conservation* **143**: 2881-2890. https://doi.org/10.1016/j.biocon.2010.04.027.

Van De Perre F, Willig M R, Presley S J, Andemwana F B, Beeckman H, Boeckx P, Cooleman S, De Haan M, De Kesel A, Dessein S, Grootaert P, Huygens D, Janssens S B, Kearsley E, Kabeya P M, Leponce M, Van Den Broeck D, Verbeeck H, Würsten B, Leirs H and Verheyen E. 2018. Reconciling biodiversity and carbon stock conservation in an Afrotropical forest landscape. *Science Advances*. https:// doi.org/10.1126/sciadv.aar6603.

Van Der Werf G R, Morton D C, Defries R S, Olivier J G J, Kasibhatla P S, Jackson R B, Collatz G J and Randerson J T. 2009. CO_2 emissions from forest loss. *Nature Geoscience* **2**: 737-38. https://doi.org/10.1038/ngeo671.

Vetaas O R. 2000. The effect of environmental factors on the regeneration of *Quercus semecarpifolia* Sm. in Central Himalaya, Nepal. *Plant Ecology* **146:** 137-144.

Vila M, Espinar J L, Hejda M, Hulme P E, Jarosík V, Maron J L and Pysek P. 2011. Ecological impacts of invasive alien plants: a meta-analysis of their effects on species, communities and ecosystems. *Ecology Letter* **14:** 702–708. https://doi.org/ 10.1111/j.1461-0248.2011.01628.x.

Vitousek P M, Mooney H A and Labcheneco J. 1997. Human domination of the earth's ecosystem. *Science* **277**: 494-499.

Wang F, Zou B, Li H and Li Z. 2014. The effect of understory removal on microclimate and soil properties in two subtropical lumber plantations. *Journal of Forest Research* **19**: 238-243.

Wang R, Quan G, Kang X, Zhang J and Qin Z. 2015. Influence of *Lantana camara* on soil I. Effects on soil chemical properties, enzymes and microorganisms. *Allelopathy Journal* **35**: 197-206.

Wang Y, Yu J, Xiao L, Zhong Z, Wang Q and Wang W. 2020. Dominant species abundance, vertical structure and plant diversity response to nature forest protection in Northeastern China: conservation effects and implications. *Forests* 1**1:** 295-298.

White R J and Razgour O. 2020. Emerging zoonotic diseases originating in mammals: a systematic review of effects of anthropogenic land-use change. *Mammal Review* **50**: 336-352. https:// doi.org/10.1111/mam.12201.

Whitmore T C. 1975. Tropical rain forests of the far East. Oxford, UK: Clarendon Press, 1975.

Whittaker R H. 1972. Evolution and measurement of species diversity. *Taxon* **21**: 213-215

Whittaker R H. 1977. Evolution of species diversity in land plant communities. *Evolutionary Biology* **10**: 1- 67.

Xu Y, Franklin S B, Wang Q, Shi Z, Luo Y, Lu Z, Zhang J, Qiao X and Jiang M. 2015. Topographic and biotic factors determine forest biomass spatial distribution in a subtropical mountain moist forest. *Forest Ecology and Management*. https://doi.org/10.1016/j. foreco.2015.08.010.

Yildiz O, Cromack K, Radosevich S R, Martinezghersa M A and Baham J E. 2011. Comparison of 5th- and 14thyear Douglas-fir and understory vegetation responses to selective vegetation removal. *Forest Ecology and Management* **262:** 586-597.

Yuan Z, Wang S, Ali A, Gazol A, Ruiz-Benito P, Wang X, Lin F, Ye J, Hao Z and Loreau M. 2018. Aboveground carbon storage is driven by functional trait composition and stand structural attributes rather than biodiversity in temperate mixed forests recovering from disturbances. *Annals of Forest Science* **75**: 67-71. https://doi.org/ 10.1007/s13595-018-0745-3.

Zalucki M P, Day M D and Playford J. 2007. Will biological control of *Lantana camara* ever succeed? Patterns, processes and prospects. *Biological Control* **42**: 251-261.

Zhang Y, Chen H Y H, Taylor A R. 2017. Positive species diversity and above-ground biomass relationships are ubiquitous across forest strata despite interference from overstorey trees. *Functional Ecology* **31**: 419-426. https://doi.org/10.1111/1365-2435.12699.

APPENDIX I

Volumetric equations, wood density and biomass expansion factor of different forest tree species (FSI,1996)

Sr. No.	Scientific name	Volumetric Equation	Wood density	Biomass Expansion Factor
1	*Acacia catechu*	$V = 0.048535-0.183567*SQRT*D+3.787825*D^2$	0.875	2.52
2	*Aegle marmelos*	$V= D^2*(0.0697/D^2-1.4597/F16+11.79933-2.35397*D)$	0.754	1.5
3	*Albizia lebbeck*	$V= 0.27-2.953*D+12.336*D^2$	0.66	1.5
4	*Bombax ceiba*	$V= D^2*(0.18573/D^2-2.8541/D+15.03576)$	0.329	1.4
5	*Broussonetia papyrifera*	V = SQRT(-0.10185087+3.07466775*D)	0.619	1.5
6	*Butea monosperma*	$V = D^2*(0.0697/D^2-1.4597/D+11.79933-2.35397*D)$	0.465	1.5
7	*Casearia tomentosa*	$V = 0.066+0.287*D^2*H$	0.746	1.5
8	*Cassia festula*	$V = 0.066+0.287*D^2*H$	0.746	1.5
9	*Dalbergia sissoo*	$V = -0.013703+3.943499*D^2$	0.669	1.5
10	*Eucalyptus globulus*	$V = -0.0015+0.2401*D^2*H$	0.619	1.5
11	*Ficus benghalensis*	V = SQRT(0.03629+3.95389*D-0.84421*SQRT(D))	0.385	1.5
12	*Ficus glomerata*	V = SQRT(0.3629+3.95389*D-0.84421*SQRT(D))	0.619	1.5
13	*Ficus palmata*	V = SQRT(0.3629+3.95389*D-0.84421*SQRT(D))	0.619	1.5
14	*Flacourtia indica*	$V = D^2*(0.0697*D^2-1.4597/D+11.79933-2.35397*D)$	0.619	1.5
15	*Lannea coromandelica*	$V = -0.004511+0.377131*D^2*H$	0.513	1.5
16	*Leucaena leucocephala*	$V = D^2*(-0.00342/D^2-0.0922/D+2.28178+9.46641*D)$	0.55	1.5
17	*Mallotus phillippensis*	$V = 0.14749-2.87503*D+19.61977*D^2-19.1163*D^3$	0.64	1.5
18	*Morus alba*	$V = 0.167174-1.735312*D+12.039017*D^2$	0.622	1.3
19	*Ougeinia oojeinensis*	$V = D^2*(0.0697/D^2-1.4597/D+11.79933-2.35397*D)$	0.704	1.5
20	*Phyllanthus embelica*	$V = -0.406+3.54*D-2.31*D^2$	0.619	1.5
21	*Pinus roxburghii*	$V = D^2*(0.167095/D^2-2.085944/D+9.929936)$	0.47	1.5
22	*Pistacia integerrima*	$V = D^2*(0.0697/D2-1.4597/D+11.79933-2.35397*D)$	0.619	1.5
23	*Pyrus pashia*	$V = D^2*(0.0697/D^2-1.4597/D+11.79933-2.35397*D)$	0.754	1.5
24	*Stephegyne parvifolia*	V = D2*(0.0697/D2-1.4597/F30+11.79933-2.35397*D)	0.619	1.5
25	*Syzygium cumini*	$V = D^2*(0.09809/D^2-1.94468/D+13.36728-6.33263*D)$	0.647	1.5
26	*Terminalia arjuna*	V = SQRT(-0.14017+3.36423*D)	0.628	1.56
27	*Terminalia bellirica*	V = SQRT(-0.14017+3.36423*D)	0.628	1.56
28	*Wendlandia exserta*	$V = D^2*(0.0697/D^2-1.4597/D+11.79933-2.35397*D)$	0.704	1.51
29	*Xylosma longifolium*	$V = D^2*(0.0697/D^2-1.4597/D+11.79933-2.35397*D)$	0.619	1.5

APPENDIX II

Density (Number ha^{-1}), Frequency (%) and Basal area (m^2) of different tree species under Reserve Forest (RF) of Khair Working Circle in Nurpur Forest Division of Himachal Pradesh

Sr. No.	Species	Density (Number ha^{-1})				Frequency (%)				Basal area (m^2)			
		RFC1	RFC2	RFC3	RFC4	RFC1	RFC2	RFC3	RFC4	RFC1	RFC2	RFC3	RFC4
1	*Acacia catechu*	146.67	86.67	120.00	150.00	100.00	100.00	100.00	100.00	3.90	1.44	5.73	5.05
2	*Aeglemarmelos*	-	-	6.67	-	-	-	33.33	-	-	-	0.10	-
3	*Bombexceiba*	-	10.00	-	-	-	33.33	-	-	-	0.18	-	-
4	*Caseariatomentosa*	3.33	3.33	-	-	33.33	100.00	-	-	0.06	0.06	-	-
5	*Cassia fistula*	16.67	66.67	140.00	83.33	66.67	100.00	100.00	100.00	0.61	0.92	3.48	1.44
6	*Ficusbenghalensis*	-	3.33	-	-	-	100.00	-	-	-	0.33	-	-
7	*Flacourtiaindica*	10.00	-	-	-	33.33	-	-	-	0.27	-	-	-
8	*Lanneacoromandelica*	83.33	56.67	106.67	56.67	100.00	66.67	100.00	100.00	3.97	1.79	5.62	1.49
9	*Mallotusphillippensis*	50.00	30.00	76.67	83.33	100.00	100.00	100.00	100.00	0.83	0.43	1.66	1.51
10	*Ougeiniaoojeinensis*	6.67	-	-	-	33.33	-	-	-	0.23	-	-	-
11	*Phyllanthusembelica*	13.33	16.67		3.33	33.33	33.33		33.33	0.25	0.24	-	0.07
12	*Pinusroxburghii*	-	43.33	16.67	30.00	-	33.33	33.33	100.00	-	3.44	1.51	3.51
13	*Pyruspashia*	-	-	13.33	-	-	-	33.33	-	-		0.29	-
14	*Syzygiumcumini*	-	6.67	16.67	-	-	666.67	33.33	-	-	0.38	0.72	-
15	*Terminaliaarjuna*	-		6.67	-	-		33.33	-	-	-	0.15	-
16	*Terminaliabellirica*	26.67	-	-	-	66.67	-	-	-	1.08	-	-	-
17	*Wendlandiaexserta*	6.67	-	-	-	33.33	-	-	-	0.26	-	-	-
	Total	**363.33**	**323.33**	**503.33**	**406.67**	**600.00**	**1333.33**	**566.67**	**533.33**	**11.46**	**9.21**	**19.25**	**13.08**

APPENDIX III

Density (Number ha^{-1}), Frequency (%) and Basal area (m^2) of different tree species under Demarcated Protected Forest (DPF) of Khair Working Circle in Nurpur Forest Division of Himachal Pradesh

Sr. No.	Species	Density (Number ha^{-1})				Frequency (%)				Basal area (m^2)			
		DPFC1	DPFC2	DPFC3	DPFC4	DPFC1	DPFC2	DPFC3	DPFC4	DPFC1	DPFC2	DPFC3	DPFC4
1	*Acacia catechu*	40.00	133.33	100.00	80.00	100.00	100.00	100.00	100.00	1.50	3.46	3.22	2.46
2	*Albizialebbeck*	-	16.67	-	-		33.33	-	-	-	0.31	-	-
3	*Bombexceiba*	3.33	6.67	30.00	-	33.33	33.33	66.67	-	0.13	0.14	0.67	-
4	*Buteamonosperma*	3.33	-	-	-	33.33	-	-	-	0.05	-	-	-
5	*Caseariatomentosa*	-	-	10.00	-	-	-	33.33	-	-	-	0.24	-
6	*Cassia fistula*	16.67	83.33	-	50.00	100.00	100.00		100.00	0.37	1.32		0.91
7	*Dalbergiasissoo*	-	10.00	40.00	-	-	33.33	100.00	-	-	0.23	1.01	
8	*Lanneacoromandelica*	-	163.33	-	116.67	-	100.00		100.00	-	4.70		3.21
9	*Mallotusphillippensis*	10.00	-	136.67	63.33	66.67	-	100.00	100.00	0.20		2.73	1.13
10	*Ougeiniaoojeinensis*	-	20.00	43.33	-	-	66.67	100.00	-	-	0.28	0.72	-
11	*Phyllanthusembelica*	-	-	10.00	-	-	-	33.33	-	-	-	0.21	-
12	*Pinusroxburghii*	110.00	-	-	-	100.00	-	-	-	15.63	-	-	-
13	*Pistaciainterrima*	-	-	-	6.67	-	-	-	33.33	-	-	-	0.18
14	*Syzygiumcumini*	-	-	-	16.67	-	-	-	66.67	-	-	-	0.45
15	*Terminaliabellirica*	-	-	3.33	-	-	-	33.33	-	-	-	0.21	-
16	*Wendlandiaexserta*	-	-	36.67	-	-	-	66.67	-	-	-	0.98	-
	Total	**183.33**	**433.33**	**410.00**	**333.33**	**433.33**	**466.67**	**633.33**	**500.00**	**17.88**	**10.43**	**9.98**	**8.34**

APPENDIX IV

Density (Number ha^{-1}), Frequency (%) and Basal area (m^2) of different tree species under Un-demarcated Protected Forest (UPF) of Khair Working Circle in Nurpur Forest Division of Himachal Pradesh

Sr. No.	Species	Density (Number ha^{-1})				Frequency (%)				Basal area (m^2)			
		UPFC1	UPFC2	UPFC3	UPFC4	UPFC1	UPFC2	UPFC3	UPFC4	UPFC1	UPFC2	UPFC3	UPFC4
1	*Acacia catechu*	100.00	80.00	90.00	96.67	100.00	100.00	100.00	100.00	2.39	2.57	3.65	2.83
2	*Aegle marmelos*	-	-	10.00	-	-	-	33.33	-	-	-	0.20	
3	*Albizia lebbeck*	-	-	56.67	50.00	-	-	100.00	100.00	-	-	2.17	1.62
4	*Cassia fistula*	73.33	46.67	-	-	100.00	100.00	-	-	1.41	0.85	-	-
5	*Dalbergia sissoo*	46.67	-	-	-	100.00	-	-	-	0.81	-	-	-
7	*Ficus benghalensis*	-	-	3.33	-	-	-	33.33	-	-	-	0.04	-
8	*Flacourtia indica*	-	-	13.33	-	-	-	33.33	-	-	-	0.34	-
9	*Lannea coromandelica*	106.67	73.33	60.00	70.00	100.00	100.00	100.00	100.00	2.49	2.81	3.00	2.62
10	*Mallotus phillippensis*	156.67	33.33	-	13.33	100.00	66.67	-	33.33	2.58	0.61	-	0.27
11	*Phyllanthus embelica*	-	-	6.67	6.67	-	-	33.33	33.33	-	-	0.13	0.15
12	*Pinus roxburghii*	23.33	16.67	-	-	66.67	66.67	-	-	0.63	1.26	-	-
	Total	**506.67**	**250.00**	**240.00**	**236.67**	**566.67**	**433.33**	**433.33**	**366.67**	**10.32**	**8.10**	**9.53**	**7.48**

APPENDIX V

Density (Number ha^{-1}), Frequency (%) and Basal area (m^2) of different tree species under Co-operative Forest Society (CFS) of Khair Working Circle in Nurpur Forest Division of Himachal Pradesh

Sr. No.	Species	Density (Number ha^{-1})				Frequency (%)				Basal area (m^2)			
		CFSC1	**CFSC2**	**CFSC3**	**CFSC4**	**CFSC1**	**CFSC2**	**CFSC3**	**CFSC4**	**CFSC1**	**CFSC2**	**CFSC3**	**CFSC4**
1	*Acacia catechu*	90.00	80.00	143.33	120.00	100.00	100.00	100.00	100.00	2.70	2.21	3.51	3.12
2	*Aegle marmelos*	-	-	6.67	-	-		33.33	-	-		0.10	-
3	*Broussonetia papyrifera*	-	10.00	-	-	-	66.67	-	-	-	0.22	-	-
4	*Cassia fistula*	-	26.67	83.33	-	-	100.00	100.00	-	-	0.41	1.54	-
5	*Dalbergia sissoo*	-	26.67	-	73.33		100.00	-	100.00		0.49	-	1.14
6	*Ficus glomerata*	10.00	3.33	-	-	66.67	33.33	-	-	0.35	0.07	-	-
7	*Ficus palmata*	-	-	-	6.67	-	-	-	33.33	-	-	-	0.16
8	*Lannea coromandelica*	50.00	36.67	23.33	46.67	100.00	100.00	100.00	100.00	2.00	1.40	1.64	1.39
9	*Leucaena leucocephala*	23.33	-	-	-	66.67	-	-	-	0.52	-	-	-
10	*Mallotus phillippensis*	13.33	-	100.00	-	33.33	-	100.00	-	0.19	-	1.56	-
11	*Morus alba*	3.33	-	-	-	33.33	-	-	-	0.03		-	-
12	*Syzygium cumini*	-	6.67	-	-		33.33	-	-		0.31	-	-
13	*Xylosma longifolium*	16.67	-	-	-	100.00	-	-	-	0.29		-	-
	Total	**206.67**	**190.00**	**356.67**	**246.67**	**500.00**	**533.33**	**433.33**	**333.33**	**6.07**	**5.12**	**8.35**	**5.81**

APPENDIX VI

Density (Number ha^{-1}), Frequency (%) and Basal area (m^2) of different tree species under Un-class Forest (UF) of Khair Working Circle in Nurpur Forest Division of Himachal Pradesh

Sr. No.	Species	Density (Number ha^{-1})				Frequency (%)				Basal area (m^2)			
		UFC1	UFC2	UFC3	UFC4	UFC1	UFC2	UFC3	UFC4	UFC1	UFC2	UFC3	UFC4
1	*Acacia catechu*	236.67	133.33	176.67	220.00	100.00	100.00	100.00	100.00	7.93	5.53	4.07	9.22
2	*Cassia fistula*	-	86.67	10.00	46.67	-	100.00	33.33	100.00	-	2.79	0.39	2.31
3	*Eucalyptus globulus*	-	10.00	-	-	-	33.33	-	-	-	0.73	-	-
4	*Ficusbenghalensis*	-	-	-	3.33	-	-	-	33.33	-	-	-	0.04
5	*Lannea coromandelica*	-	13.33	10.00	23.33	-	66.67	33.33	66.67	-	0.52	1.52	2.50
6	*Mallotus phillippensis*	40.00	93.33	10.00	3.33	66.67	100.00	33.33	33.33	1.31	1.68	0.27	0.03
7	*Pinus roxburghii*	-		-	40.00	-	-	-	100.00	-	-	-	7.47
8	*Pyruspashia*	-	6.67	-	-	-	33.33	-	-	-	0.10	-	-
9	*Stephegyne parvifolia*	-	3.33	-	-	-	33.33	-	-	-	0.04	-	-
10	*Terminalia bellirica*	3.33		-	-	33.33		-	-	0.30	-	-	-
11	*Xylosma longifolium*	-	3.33	-	3.33	-	33.33	-	33.33	-	0.07	-	0.05
	Total	**280.00**	**350.00**	**206.67**	**340.00**	**200.00**	**500.00**	**200.00**	**466.67**	**9.54**	**11.45**	**6.25**	**21.61**

APPENDIX VII

Analysis of variance for tree density

Source of variance	Number of Observation	df	SSR	MSS	F_{cal}	F_{tab}
Replication	3	2	1363.33	681.67	0.51	3.24
Compartments (C)	20	19	608006.67	32000.35	24.08	1.86
Between Forest type	5	4	157723.33	39430.83	29.67	2.62
C within RF	4	3	53825.00	17941.67	13.50	2.85
C within DPF	4	3	114600.00	38200.00	28.74	2.85
C within UPF	4	3	157633.33	52544.44	39.54	2.85
C within CFSF	4	3	50600.00	16866.67	12.69	2.85
C within UF	4	3	73625.00	24541.67	18.47	2.85
Error		38	50503.33	1329.04		
Total	60	59	659873.33			

Analysis of variance for tree basal area

Source of variance	Number of Observation	df	SSR	MSS	F_{cal}	F_{tab}
Replication	3	2	0.59	0.30	0.13	3.24
Compartments [C]	20	19	1559.22	82.06	35.61	1.87
Between Forest type	5	4	513.46	128.36	55.70	2.62
C within RF	4	3	213.01	71.00	30.81	2.85
C within DPF	4	3	187.09	62.36	27.06	2.85
C within UPF	4	3	12.27	4.09	1.77	2.85
C within CFSF	4	3	18.47	6.16	2.67	2.85
C within UF	4	3	614.92	204.97	88.95	2.85
Error		38	87.57	2.30		
Total	60	59	1647.38			

Analysis of variance for shrub density

Source of variance	Number of Observation	df	SSR	MSS	F_{cal}	F_{tab}
Replication	3	2	71652.10	35826.05	0.56	3.24
Compartments [C]	20	19	12315360.00	648176.84	10.05	1.87
Between Forest type	5	4	5917560.00	1479390.00	22.95	2.62
C within RF	4	3	825600.00	275200.00	4.27	2.85
C within DPF	4	3	3567300.00	1189100.00	18.44	2.85
C within UPF	4	3	992100.00	330700.00	5.13	2.85
C within CFSF	4	3	744000.00	248000.00	3.85	2.85
C within UF	4	3	268800.00	89600.00	1.39	2.85
Error		38	2449775.90	64467.79		
Total	60	59	14836788.00			

Analysis of variance for shrub basal area

Source of variance	Number of Observation	df	SSR	MSS	F_{cal}	F_{tab}
Replication	3	2	114379240.00	57189620.00	46.16	3.24
Compartments [C]	20	19	13021563085.20	685345425.54	553.13	1.87
Between Forest type	5	4	2670608881.87	667652220.47	538.85	2.62
C within RF	4	3	722996355.22	240998785.07	194.51	2.85
C within DPF	4	3	3757124566.86	1252374855.62	1010.77	2.85
C within UPF	4	3	2728248962.66	909416320.89	733.97	2.85
C within CFSF	4	3	2316551459.60	772183819.87	623.22	2.85
C within UF	4	3	826032858.99	275344286.33	222.23	2.85
Error		38	47083160.00	1239030.53		
Total	60	59	13183025485.20			

Analysis of variance for herb density

Source of variance	Number of Observation	df	SSR	MSS	F_{cal}	F_{tab}
Replication	3	2	34480030.00	17240015.00	1.80	3.24
Compartments [C]	20	19	7435426260.00	391338224.21	40.83	1.87
Between Forest type	5	4	1866674160.00	466668540.00	48.68	2.62
C within RF	4	3	1292520000.00	430840000.00	44.95	2.85
C within DPF	4	3	1263872100.00	421290700.00	43.95	2.85
C within UPF	4	3	616800000.00	205600000.00	21.45	2.85
C within CFSF	4	3	1789440000.00	596480000.00	62.23	2.85
C within UF	4	3	606120000.00	202040000.00	21.08	2.85
Error		38	364248170.00	9585478.16		
Total	60	59	7834154460.00			

Analysis of variance for herb basal area

Source of variance	Number of Observation	df	SSR	MSS	F_{cal}	F_{tab}
Replication	3	2	253446.40	126723.20	9.10	3.24
Compartments [C]	20	19	1897380.84	99862.15	7.17	1.87
Between Forest type	5	4	450278.10	112569.52	8.08	2.62
C within RF	4	3	335398.66	111799.55	8.03	2.85
C within DPF	4	3	344703.87	114901.29	8.25	2.85
C within UPF	4	3	275870.95	91956.98	6.60	2.85
C within CFSF	4	3	419573.54	139857.85	10.04	2.85
C within UF	4	3	71555.74	23851.91	1.71	2.85
Error		38	529377.60	13930.99		
Total	60	59	2680204.84			

Analysis of variance for tree diameter

Source of variance	Number of Observation	df	SSR	MSS	F_{cal}	F_{tab}
Replication	3	2	5.13	2.56	0.60	3.24
Compartments [C]	20	19	625.76	32.93	7.73	1.87
Between Forest class	5	4	216.97	54.24	12.73	2.62
C within RF	4	3	47.73	15.91	3.73	2.85
C within DPF	4	3	128.78	42.93	10.08	2.85
C within UPF	4	3	46.76	15.59	3.66	2.85
C within CFSF	4	3	4.02	1.34	0.31	2.85
C within UF	4	3	181.49	60.50	14.20	2.85
Error		38	161.88	4.26		
Total	60	59	792.76			

Analysis of variance for tree height

Source of variance	Number of Observation	df	SSR	MSS	F_{cal}	F_{tab}
Replication	3	2	3.12	1.56	3.09	3.24
Compartments [C]	20	19	41.16	2.17	4.29	1.87
Between Forest class	5	4	8.09	2.02	4.00	2.62
C within RF	4	3	5.32	1.77	3.51	2.85
C within DPF	4	3	14.55	4.85	9.60	2.85
C within UPF	4	3	2.23	0.74	1.47	2.85
C within CFSF	4	3	1.85	0.62	1.22	2.85
C within UF	4	3	9.12	3.04	6.02	2.85
Error		38	19.21	0.51		
Total	60	59	63.49			

Analysis of variance for tree Volume

Source of variance	Number of Observation	df	SSR	MSS	F_{cal}	F_{tab}
Replication	3	2	552.00	276.00	2.13	3.24
Compartments [C]	20	19	62585.24	3293.96	25.37	1.87
Between Forest class	5	4	19138.45	4784.61	36.85	2.62
C within RF	4	3	4469.04	1489.68	11.47	2.85
C within DPF	4	3	18421.12	6140.37	47.29	2.85
C within UPF	4	3	291.58	97.19	0.75	2.85
C within CFSF	4	3	181.37	60.46	0.47	2.85
C within UF	4	3	20083.67	6694.56	51.56	2.85
Error		38	4934.23	129.85		
Total	60	59	68071.47			

Analysis of variance for Stem biomass

Source of variance	Number of Observation	df	SSR	MSS	F_{cal}	F_{tab}
Replication	3	2	294.01	147.00	2.65	3.24
Compartments [C]	20	19	18315.22	963.96	17.37	1.87
Between Forest class	5	4	6275.47	1568.87	28.27	2.62
C within RF	4	3	2409.11	803.04	14.47	2.85
C within DPF	4	3	2707.98	902.66	16.27	2.85
C within UPF	4	3	146.08	48.69	0.88	2.85
C within CFSF	4	3	76.47	25.49	0.46	2.85
C within UF	4	3	6700.12	2233.37	40.25	2.85
Error		38	2108.74	55.49		
Total	60	59	20717.97			

Analysis of variance for above ground biomass

Source of variance	Number of Observation	df	SSR	MSS	F_{cal}	F_{tab}
Replication	3	2	826.91	413.45	1.82	3.24
Compartments [C]	20	19	73956.44	3892.44	17.17	1.87
Between Forest class	5	4	24924.27	6231.07	27.48	2.62
C within RF	4	3	9148.21	3049.40	13.45	2.85
C within DPF	4	3	10547.15	3515.72	15.51	2.85
C within UPF	4	3	436.33	145.44	0.64	2.85
C within CFSF	4	3	275.41	91.80	0.40	2.85
C within UF	4	3	28625.05	9541.68	42.09	2.85
Error		38	8615.52	226.72		
Total	60	59	83398.86			

Analysis of variance for below ground biomass

Source of variance	Number of Observation	df	SSR	MSS	F_{cal}	F_{tab}
Replication	3	2	405.02	202.51	3.24	3.24
Compartments [C]	20	19	14060.66	740.03	11.84	1.87
Between Forest class	5	4	5401.18	1350.29	21.61	2.62
C within RF	4	3	2366.90	788.97	12.63	2.85
C within DPF	4	3	30.65	10.22	0.16	2.85
C within UPF	4	3	144.98	48.33	0.77	2.85
C within CFSF	4	3	110.06	36.69	0.59	2.85
C within UF	4	3	6006.89	2002.30	32.04	2.85
Error		38	2374.66	62.49		
Total	60	59	16840.33			

Analysis of variance for total biomass

Source of variance	Number of Observation	df	SSR	MSS	F_{cal}	F_{tab}
Replication	3	2	2370.04	1185.02	2.43	3.24
Compartments [C]	20	19	147813.07	7779.64	15.95	1.87
Between Forest class	5	4	52783.02	13195.75	27.05	2.62
C within RF	4	3	20812.74	6937.58	14.22	2.85
C within DPF	4	3	11638.19	3879.40	7.95	2.85
C within UPF	4	3	1034.50	344.83	0.71	2.85
C within CFSF	4	3	728.75	242.92	0.50	2.85
C within UF	4	3	60815.87	20271.96	41.56	2.85
Error		38	18534.07	487.74		
Total	60	59	168717.18			

Analysis of variance for tree carbon

Source of variance	Number of Observation	df	SSR	MSS	F_{cal}	F_{tab}
Replication	3	2	502.49	251.25	2.28	3.24
Compartments [C]	20	19	33854.06	1781.79	16.18	1.87
Between Forest class	5	4	11978.23	2994.56	27.19	2.62
C within RF	4	3	4695.87	1565.29	14.21	2.85
C within DPF	4	3	3060.54	1020.18	9.26	2.85
C within UPF	4	3	233.41	77.80	0.71	2.85
C within CFSF	4	3	164.43	54.81	0.50	2.85
C within UF	4	3	13721.58	4573.86	41.53	2.85
Error		38	4184.60	110.12		
Total	60	59	38541.16			

Analysis of variance for shrub above ground biomass

Source of variance	Number of Observation	df	SSR	MSS	F_{cal}	F_{tab}
Replication	3	2	0.00	0.00	4.18	3.24
Compartments [C]	20	19	0.24	0.01	72.53	1.87
Between Forest class	5	4	0.13	0.03	180.10	2.62
C within RF	4	3	0.03	0.01	65.88	2.85
C within DPF	4	3	0.03	0.01	57.27	2.85
C within UPF	4	3	0.03	0.01	64.37	2.85
C within CFSF	4	3	0.01	0.00	21.40	2.85
C within UF	4	3	0.01	0.00	10.29	2.85
Error		38	0.01	0.00		
Total	60	59	0.25			

Analysis of variance for shrub below ground biomass

Source of variance	Number of Observation	df	SSR	MSS	F_{cal}	F_{tab}
Replication	3	2	0.00	0.00	4.58	3.24
Compartments [C]	20	19	0.11	0.01	80.16	1.87
Between Forest class	5	4	0.05	0.01	177.76	2.62
C within RF	4	3	0.02	0.01	108.69	2.85
C within DPF	4	3	0.01	0.00	60.50	2.85
C within UPF	4	3	0.01	0.00	68.00	2.85
C within CFSF	4	3	0.00	0.00	22.61	2.85
C within UF	4	3	0.00	0.00	10.87	2.85
Error		38	0.00	0.00		
Total	60	59	0.11			

Analysis of variance for total shrub biomass

Source of variance	Number of Observation	df	SSR	MSS	F_{cal}	F_{tab}
Replication	3	2	0.00	0.00	4.13	3.24
Compartments [C]	20	19	0.66	0.03	72.33	1.87
Between Forest class	5	4	0.34	0.09	179.56	2.62
C within RF	4	3	0.09	0.03	65.67	2.85
C within DPF	4	3	0.08	0.03	57.14	2.85
C within UPF	4	3	0.09	0.03	64.23	2.85
C within CFSF	4	3	0.03	0.01	21.35	2.85
C within UF	4	3	0.01	0.00	10.27	2.85
Error		38	0.02	0.00		
Total	60	59	0.68			

Analysis of variance for herb above ground biomass

Source of variance	Number of Observation	df	SSR	MSS	F_{cal}	F_{tab}
Replication	3	2	0.00	0.00	1.36	3.24
Compartments [C]	20	19	0.34	0.02	79.70	1.87
Between Forest class	5	4	0.08	0.02	92.35	2.62
C within RF	4	3	0.01	0.00	15.74	2.85
C within DPF	4	3	0.01	0.00	8.27	2.85
C within UPF	4	3	0.01	0.00	8.72	2.85
C within CFSF	4	3	0.22	0.07	329.18	2.85
C within UF	4	3	0.01	0.00	19.74	2.85
Error		38	0.01	0.00		
Total	60	59	0.35			

Analysis of variance for herb below ground biomass

Source of variance	Number of Observation	df	SSR	MSS	F_{cal}	F_{tab}
Replication	3	2	0.00	0.00	1.36	3.24
Compartments [C]	20	19	0.11	0.01	79.59	1.87
Between Forest class	5	4	0.03	0.01	91.93	2.62
C within RF	4	3	0.00	0.00	15.74	2.85
C within DPF	4	3	0.00	0.00	8.12	2.85
C within UPF	4	3	0.00	0.00	8.72	2.85
C within CFSF	4	3	0.07	0.02	329.18	2.85
C within UF	4	3	0.00	0.00	19.74	2.85
Error		38	0.00	0.00		
Total	60	59	0.12			

Analysis of variance for total herb biomass

Source of variance	Number of Observation	df	SSR	MSS	F_{cal}	F_{tab}
Replication	3	2	0.00	0.00	1.36	3.24
Compartments [C]	20	19	0.84	0.04	79.66	1.87
Between Forest class	5	4	0.21	0.05	92.19	2.62
C within RF	4	3	0.03	0.01	15.74	2.85
C within DPF	4	3	0.01	0.00	8.22	2.85
C within UPF	4	3	0.01	0.00	8.72	2.85
C within CFSF	4	3	0.55	0.18	329.18	2.85
C within UF	4	3	0.03	0.01	19.74	2.85
Error		38	0.02	0.00		
Total	60	59	0.87			

Analysis of variance for total ecosystem biomass

Source of variance	Number of Observation	df	SSR	MSS	F_{cal}	F_{tab}
Replication	3	2	2375.67	1187.83	2.44	3.24
Compartments [C]	20	19	147986.02	7788.74	15.97	1.87
Between Forest class	5	4	52972.88	13243.22	27.15	2.62
C within RF	4	3	20867.78	6955.93	14.26	2.85
C within DPF	4	3	11675.44	3891.81	7.98	2.85
C within UPF	4	3	1018.40	339.47	0.70	2.85
C within CFSF	4	3	716.00	238.67	0.49	2.85
C within UF	4	3	60735.52	20245.17	41.50	2.85
Error		38	18535.54	487.78		
Total	60	59	168897.23			

Analysis of variance for total vegetation carbon stock

Source of variance	Number of Observation	df	SSR	MSS	F_{cal}	F_{tab}
Replication	3	2	503.72	251.86	2.29	3.24
Compartments [C]	20	19	33849.35	1781.54	16.18	1.87
Between Forest class	5	4	11981.12	2995.28	27.20	2.62
C within RF	4	3	4707.80	1569.27	14.25	2.85
C within DPF	4	3	3068.88	1022.96	9.29	2.85
C within UPF	4	3	229.97	76.66	0.70	2.85
C within CFSF	4	3	157.18	52.39	0.48	2.85
C within UF	4	3	13704.41	4568.14	41.48	2.85
Error		38	4185.33	110.14		
Total	60	59	38538.40			

Analysis of variance for soil + vegetation carbon stock

Source of variance	Number of Observation	df	SSR	MSS	F_{cal}	F_{tab}
Replication	3	2	503.72	251.86	2.29	3.24
Compartments [C]	20	19	34474.98	1814.47	16.47	1.87
Between Forest class	5	4	13094.12	3273.53	29.72	2.62
C within RF	4	3	4251.35	1417.12	12.87	2.85
C within DPF	4	3	3522.54	1174.18	10.66	2.85
C within UPF	4	3	418.29	139.43	1.27	2.85
C within CFSF	4	3	129.64	43.21	0.39	2.85
C within UF	4	3	13059.04	4353.01	39.52	2.85
Error		38	4185.33	110.14		
Total	60	59	39164.03			

Analysis of variance for CO_2 mitigated

Source of variance	Number of Observation	df	SSR	MSS	F_{cal}	F_{tab}
Replication	3	2	6784.59	3392.29	2.29	3.24
Compartments [C]	20	19	464340.12	24438.95	16.47	1.86
Between Forest class	5	4	176363.44	44090.86	29.72	2.61
C within RF	4	3	57261.04	19087.01	12.87	2.85
C within DPF	4	3	47444.72	15814.91	10.66	2.85
C within UPF	4	3	5633.90	1877.97	1.27	2.85
C within CFSF	4	3	1746.14	582.05	0.39	2.85
C within UF	4	3	175890.88	58630.29	39.52	2.85
Error		38	56371.75	1483.47		
Total	60	59	527496.45			

Analysis of variance for soil organic carbon

Source of variance	df	SS	MSE	F_{cal}	F_{tab}
Replication	3	0.096994	0.032331	1.206944	2.960351
Forest class (F)	4	0.652955	0.163239	6.093756	2.727765
Soil depth (D)	1	0.419226	0.419226	15.64983	4.210008
F*D	4	0.040518	0.010129	0.378135	2.727765
Error	27	0.723273	0.026788		
Total	39	1.932965			

Analysis of variance for non labile carbon

Source of variance	df	SS	MSE	F_{cal}	F_{tab}
Replication	3.0000	0.0279	0.0093	2.2707	2.9604
Forest class (F)	4.0000	0.0946	0.0237	5.7826	2.7278
Soil depth (D)	1.0000	0.1351	0.1351	33.0292	4.2100
F*D	4.0000	0.0072	0.0018	0.4369	2.7278
Error	27.0000	0.1105	0.0041		
Total	39.0000	0.3753			

Analysis of variance for labile carbon

Source of variance	df	SS	MSE	F_{cal}	F_{tab}
Replication	3	0.043697	0.014566	2.819469	2.960351
Forest class (F)	4	0.044685	0.011171	2.16242	2.727765
Soil depth (D)	1	0.023281	0.023281	4.506432	4.210008
F*D	4	0.003323	0.000831	0.160784	2.727765
Error	27	0.139484	0.005166		
Total	39	0.254469			

Analysis of variance for soil pH

Source of variance	df	SS	MSE	F_{cal}	F_{tab}
Replication	3	0.130652	0.043551	1.586174	2.960351
Forest class (F)	4	0.20876	0.05219	1.900831	2.727765
Soil depth (D)	1	0.426422	0.426422	15.53089	4.210008
F*D	4	0.080918	0.020229	0.736784	2.727765
Error	27	0.741323	0.027456		
Total	39	1.588075			

Analysis of variance for soil electrical conductivity

Source of variance	df	SS	MSE	F_{cal}	F_{tab}
Replication	3	0.00069	0.00023	0.188984	2.960351
Forest class (F)	4	0.037115	0.009279	7.624049	2.727765
Soil depth (D)	1	10.28196	10.28196	8448.354	4.210008
F*D	4	0.038565	0.009641	7.921904	2.727765
Error	27	0.03286	0.001217		
Total	39	10.39119			

Analysis of variance for available K

Source of variance	df	SS	MSE	F_{cal}	F_{tab}
Replication	3	39.11918	13.03973	0.804653	2.960351
Forest class (F)	4	656.0423	164.0106	10.12074	2.727765
Soil depth (D)	1	1602.359	1602.359	98.87811	4.210008
F*D	4	224.9212	56.23029	3.469849	2.727765
Error	27	437.5458	16.2054		
Total	39	2959.988			

Analysis of variance for available P

Source of variance	df	SS	MSE	F_{cal}	F_{tab}
Replication	3	39.11918	13.03973	0.804653	2.960351
Forest class (F)	4	656.0423	164.0106	10.12074	2.727765
Soil depth (D)	1	1602.359	1602.359	98.87811	4.210008
F*D	4	224.9212	56.23029	3.469849	2.727765
Error	27	437.5458	16.2054		
Total	39	2959.988			

Analysis of variance for available N

Source of variance	df	SS	MSE	F_{cal}	F_{tab}
Replication	3	5327.564	1775.855	7.538198	2.960351
Forest class (F)	4	7051.769	1762.942	7.483388	2.727765
Soil depth (D)	1	27409.45	27409.45	116.3484	4.210008
F*D	4	2139.674	534.9185	2.270637	2.727765
Error	27	6360.681	235.5808		
Total	39	48289.13			

Analysis of variance for Zn

Source of variance	df	SS	MSE	F_{cal}	F_{tab}
Replication	3	1.928528	0.642843	2.036663	2.960351
Forest class (F)	4	0.399093	0.099773	0.316103	2.727765
Soil depth (D)	1	3.104718	3.104718	9.836412	4.210008
F*D	4	0.012613	0.003153	0.00999	2.727765
Error	27	8.522152	0.315635		
Total	39	13.9671			

Analysis of variance for Fe

Source of variance	df	SS	MSE	F_{cal}	F_{tab}
Replication	3	101.2182	33.73938	0.903173	2.960351
Forest class (F)	4	169.6176	42.40439	1.135127	2.727765
Soil depth (D)	1	192.9962	192.9962	5.166334	4.210008
F*D	4	9.270053	2.317513	0.062038	2.727765
Error	27	1008.626	37.35651		
Total	39	1481.728			

Analysis of variance for Mn

Source of variance	df	SS	MSE	F_{cal}	F_{tab}
Replication	3	155.5731	51.85769	1.755868	2.960351
Forest class (F)	4	167.7478	41.93694	1.419958	2.727765
Soil depth (D)	1	239.0819	239.0819	8.09516	4.210008
F*D	4	39.69267	9.923167	0.335992	2.727765
Error	27	797.4161	29.53393		
Total	39	1399.511			

Analysis of variance for Cu

Source of variance	df	SS	MSE	F_{cal}	F_{tab}
Replication	3	0.199763	0.066588	1.112505	2.960351
Forest class (F)	4	0.596849	0.149212	2.492949	2.727765
Soil depth (D)	1	0.710116	0.710116	11.86419	4.210008
F*D	4	0.019826	0.004957	0.082812	2.727765
Error	27	1.616051	0.059854		
Total	39	3.142605			

Analysis of variance for soil bulk density

Source of variance	df	SS	MSE	F_{cal}	F_{tab}
Replication	3	0.014368	0.004789	1.962762	2.960351
Forest class (F)	4	0.007201	0.0018	0.737812	2.727765
Soil depth (D)	1	0.010476	0.010476	4.293395	4.210008
F*D	4	0.000207	5.17E-05	0.021176	2.727765
Error	27	0.065881	0.00244		
Total	39	0.098132			

Analysis of variance for available soil carbon density

Source of variance	df	SS	MSE	F_{cal}	F_{tab}
Replication	3	12.86855	4.289515	0.786621	2.960351
Forest class (F)	4	101.0619	25.26548	4.633241	2.727765
Soil depth (D)	1	40.74988	40.74988	7.472804	4.210008
F*D	4	6.038285	1.509571	0.276829	2.727765
Error	27	147.2335	5.453091		
Total	39	307.9521			

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Title of the Thesis	**:**	**"Stand structure and site characteristics if Khair (*Acacia catechu* Willd.) working circle in Nurpur Forest Division of Himachal Pradesh"**
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ABSTRACT

The study entitled "**Stand structure and site characteristics of Khair (*Acacia catechu* Willd.) working circle in Nurpur Forest Division of Himachal Pradesh"** was carried out in differently managed forest classes to access the floral diversity, stand structures, biomass and carbon stock, site characteristics natural regeneration and impact of lantana infestation. The Shannon Index of diversity (H') for trees ranged from 2.13 (DPF) to 1.24 (UF), for shrubs 1.48 (DPF) to 1.30 (CFS) and for herbs 1.29 (CFS, UF) to 0.85 (UF), respectively. The maximum number of trees under diameter class D1 (251.67 number ha^{-1}) and D2 (105.00 number ha^{-1}) were recorded in RF however, the maximum number for D3 (49.17 number ha^{-1}) were present in UF. The minimum number in D2 (44.17 number ha^{-1}) and D3 (8.33 number ha^{-1}) diameter class were recorded in CFS. The maximum tree carbon accumulated in different forest classes was found maximum in UF whereas, the minimum was recorded in CFS. The under storey carbon stock was recorded maximum in CFS and minimum in UPF. However, the soil carbon stock was found maximum in DPF. The maximum ecosystem carbon stock (85.50 t ha^{-1}) potential and Co_2 mitigated (313.79 t ha^{-1}) was recorded in UF whereas, it was minimum in CFS. Further the overall regeneration success was fair in RF, DPF and UPF whereas, deficient regeneration success and establishment stocking index was recorded in CFS and UF. The soil properties vary significantly along soil depth. The maximum value for soil parameters was recorded in DPF and RF whereas, the low soil nutrients were recorded in CFS. Further the impact of lantana infestation in different forest classes was significant which have negatively affected the shrub diversity and regeneration success. We reiterate that the management that retains and enhances tree size inequalities and protects the diversity can help and store larger quantities of biomass and carbon as live tree biomass and play an important role in climate mitigation while providing other key ecosystem services.

Signature of Major Advisor **Signature of student**

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