TREE DIVERSITY, REGENERATION AND CARBON STOCK OF DIFFERENT AGED COMMUNITY MANAGED SAL FORESTS IN FAR-WESTERN NEPAL

A THESIS SUBMITTED FOR THE PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE MASTER'S DEGREE IN BOTANY

BY

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DECLARATION

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

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RECOMMENDATION

This is to recommend that the proposed research work entitled **"Tree Diversity, Regeneration and Carbon Stock of Different Aged Community Managed Sal Forests in Far-Western Nepal"** was carried out by **Mr. Nabin Singh Karki** "TU Reg. No. 5-2-554-99-2014" under my supervision for the partial fulfillment of Master's Degree in Botany. The entire work was based on original scientific investigation. I, therefore, recommend this thesis to be accepted for Master's of Science in Botany from Tribhuvan University, Nepal.

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APPROVAL

The M.Sc. dissertation presented by **"Nabin Singh Karki"** entitled **"Tree Diversity, Regeneration and Carbon Stock of Different Aged Community Managed Sal Forests in Far-Western Nepal"**, "T.U. Reg. No: 5-2-554-99-2014" has been accepted as a partial fulfillment of requirement for the completion of Master's Degree in Botany.

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ACRONYMS AND ABBREVIATIONS

AGC	Aboveground carbon
BA	Basal area
BGC	Belowground carbon
C	Carbon
CFs	Community forests
CFUGs	Community forestry user groups
CMF	Collaborative managed forest
C-stock	Carbon stock
D	Density
DBH	Diameter at breast height
F	Frequency
FAO	Food and agriculture organization of the United Nations
GIS	Geographical information system
GPS	Global positioning system
IVI	Important value index
ln	Natural logarithm
m^2 ha^{-1}	Meter square per hectare.
MS	Microsoft
pl ha^{-1}	Plants per hectare
RB	Relative basal area
RD	Relative density
RF	Relative frequency
SE	Southeast

SW	Southwest
t ha^{-1}	Tons per hectare
TSF	Terai Sal Forest
Yrs.	Years

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ABSTRACT

The study was conducted in Shree Samaichi community forest (managed for 25 yrs.), Manehara community forest (managed for 15 yrs.) and Mahalaxmi community forest (managed for 4 yrs.) of Kailali district. The community managed Sal Forest was based on their age (date since hand overed to community). The stratified random sampling method was used as sampling method. Altogether, 90 square plots (30 in each forest) for trees and saplings each and 180 square plots (60 in each forest) for seedlings were studied. The Dominance-Diversity curve (DD curve) showed the highest importance value index (IVI) of *Shorea robusta* in all three-community managed forest. The value of Shannon-Weiner Diversity index was found higher in the forests managed for 25 yrs. (1.869) followed by the forests managed for 4 yrs. (1.805) and the forests managed for 15 yrs. (1.455). Species richness was found higher in the forests managed for 25 yrs. than the forests managed for 15 yrs. and 4 yrs. However, there was little change in the carbon supply with increased species diversity. The total carbon stock of trees was highest in the forests managed for 25 yrs. (648.29 t ha^{-1}), followed by the forests managed for 15 yrs. (501.96) and in the forests managed for 4 yrs. (242.88 t ha^{-1}). Thus, the community managed forest was successful in storing high amount of tree carbon stock. The density of seedlings was higher in the forests managed for 25 yrs. (1, 02,500 pl ha^{-1}) followed by the forests managed for 15 yrs. (84,833.33 pl $ha^{-1)}$ and the forests managed for 4 yrs. (69,166.66 pl ha^{-1}). Similarly, the density of saplings was higher in the forests managed for 25 yrs. (3,426.66 pl ha^{-1}) followed by the forests managed for 15 yrs. (3,146.66 pl $ha^{-1)}$ and the forests managed for 4 yrs. (2,160 pl ha^{-1}). Thus, the community managed forests that have been managed for a longer period contain higher carbon stocks and regeneration status than those that have been managed for a shorter period. However, contrast results were obtained for tree diversity. According to the study, these forests have served as a carbon storage facility. Therefore, we may conclude that community management has benefited the growth of forests carbon stocks, seedlings, and saplings and consequently, the prevention of climate change.

Keywords: Diversity; sal forest; seedling; sapling; forest management duration.

CHAPTER 1: INTRODUCTION

1.1. Background

Shorea robusta (Sal) forest is rich in plant species diversity which stores a sufficient amount of carbon (Pathak and Baniya, 2016). The 60% of the world's terrestrial carbon (C) is stored in forest's plants and soil, forests are crucial in reducing the effects of climate change. This accounts for roughly 40% of all below-ground terrestrial C and over 80% of all above-ground terrestrial C (Dixon *et al.,* 1994). Globally, deforestation and forest degradation contribute about 12% of global greenhouse gas emissions (Van der Werf *et al.,* 2009). The concept of community forests (CFs) was introduced for the protection of forests in Nepal in 1978. By 17 July 2017, 1,813,478 ha of the total national forest had been handed to 19, 361 community forestry user groups (CFUGs) (DoF, 2017). There are 35 different forest types in Nepal. These forests are crucial to practices for conservation and participatory management of natural resources (Thapa-Magar and Shrestha, 2015).

The community forestry program in Nepal began in the late 1970s, and by 2018, a total of 22,266 community forest user's groups had received 2237670.5 ha of forestland (DoF/CFD, 2018). A source of carbon sink, community forests are said to hold 20% of Nepal's total carbon store. Forest carbon dynamics and sequestration are an increasing concern, particularly for developing nations like Nepal (Pokharel *et al.,* 2009). Nepal's forest contributes about 176.95 t/ha of carbon stock, with trees accounting for 61.53%, forest soil for 37.80%, and litter and debris for 0.67% (DFRS, 2015).

Community forestry program is considered as one of the most successful natural resource management programs in Nepal in terms of restoring degraded land and habitats, conserving biodiversity, increasing supply of forest products, empowering of women, poor and the disadvantaged groups, generating rural income, and developing human resources (Acharya, 2003; Springate-Baginski *et al.,* 2003). Although community forestry program has focused more on protection and production of forestry related needs for its user rather than conserving existing biodiversity (Belbase, 1999). It is perceived that it has contributed to biodiversity conservation (Adhikari *et al.,* 2004; Kijtewachakul *et al.,* 2004). Pokharel *et al.,* (2005) claimed

that community forests have improved overall forest conditions including biodiversity. Pandey, (2007) found comparatively higher tree species diversity on community-managed forest stands than the national parks and government managed forests.

Species richness and litter cover had no discernible effects on carbon stock, but management length typically causes it to rise (Thapa-Magar and Shrestha, 2015). Community forest management not only significantly reverses the rates of deforestation and forest degradation (Nagendra *et al.*, 2008) but also benefits the forest in terms of C-stock and C sequestration (Chhatre and Agrawal, 2009; Pandey *et al.*, 2014; Solomon *et al.*, 2017). Therefore, limiting the rates of deforestation and forest degradation through community forest management could help to mitigate the effects of climate change.

1.1.1. Carbon stock

The entire amount of carbon in a reservoir that can either accumulate or release carbon is known as the carbon stock (FAO, 2016). Forests store 20–100 times more carbon per unit area than croplands, and thus significantly contribute to lowering carbon dioxide levels (Brown *et al.*, 1994).

While C-stock is more prevalent in older, mature forests, it gets sequestered much more quickly in young, regenerating forests (Luyssaert *et al.*, 2008; Nair *et al.*, 2009). Approximately 40% of all below-ground carbon (soil, litter, and roots) and up to 80% of all above-ground carbon are found in the world's forests carbon from the earth (Dixon *et al.*, 1994).

The carbon stock of the forest and its capacity to store carbon are influenced by several variables, including the forest's age, species, size, density, biomass decomposition, stand health, degree of disturbance, and land management (Dixon *et al.*, 1994). Healthy, productive forests can store significant amounts of carbon (Pokharel *et al.*, 2007). In general, a forest's age increases its biomass and carbon stock (Baker *et al.*, 2004; Alexandrov, 2007). Several studies also demonstrated that C-stock in forests increased with age and that CFs effectively stored a large amount of C (Baral *et al.*, 2009; Bhattarai *et al.*, 2012; Pandey *et al.*, 2014; Thapa-Magar and Shrestha, 2015; Mandal *et al.*, 2016; Behera *et al.*, 2017; Dangal *et al.*, 2017).

1.1.2. Regeneration

Analyzing the current ratio of various age groups allows for the determination of the regeneration and productivity of forests (Chauhan *et al.*, 2008). Forest diversity and regeneration are impacted by a variety of natural and anthropogenic activities for a given ecosystem, including industrialization, grazing, fragmentation, overexploitation of resources, disease outbreaks, and forest fires (DFRS, 2014a; DFRS, 2014b). Currently, 2.3 million hectares of forest, or 38.5% of the country's total forest, are covered by CBFM, covering 44.74% of Nepal's land area (MoFSC, 2015; Pathak *et al.*, 2017) which demonstrates how Nepal is leading the way in CBFM, making it a success around the world (Ojha *et al.*, 2007).

The existence of various age groups of seedlings, saplings, and trees is indicative of a forest's capacity for regeneration and production (Chauhan *et al.*, 2008) which later makes it easier to apply conservation measures by comprehending the status of tree populations, regeneration, and diversity (Mishra *et al.*, 2013). A total of 2.54 million households in Nepal have organized into 19,916 Community Forest User Groups (CFUGs), which oversee administering the 18,79,998 hectares of National Forest that have been delegated to them (DOF, 2017). A small number of CFUGs have received funding for trial projects to increase carbon in their forests (Adhikari, 2016).

One of the world's most effective participatory resource management strategies, the community forestry program in Nepal has been credited with reversing the deforestation and forest degradation processes. The program was formally introduced in 1978 (Acharya, 2002), and as of September 19, 2013, the community forest user groups (CFUGs) had received about 29% of the nation's total forest for conservation and management (estimated from the database obtained from the Community Forestry Division, Department of Forest, Government of Nepal). Although the value of community forestry in preserving biodiversity has been contested (Shrestha *et al.*, 2010), it has considerably helped to stop deforestation and forest degradation. (Nagendra *et al.*, 2008).

According to a pilot study, these communally maintained forests have a significant capacity to store carbon (Banskota *et al.*, 2007). The research of community forests' capacity to store carbon has grown significantly in importance in Nepal because of the UNFCCC Parties' approval of the REDD+ plan in poor nations' carbon accounting.

However, there hasn't been a sufficient inventory, so we can't say whether community forests have a sustainable capacity to engage in REDD+.

As a result, this study calculates the carbon stock and pattern of regeneration in the live biomass of three Sal (*Shorea robusta*) forests managed by CFUGs in Dhangadhi, Kailali District (Far-Western, Nepal) during 4 to 25 years.

1.2. Rationale of the study

Currently, Nepal's community forests are crucial to practices of cooperative natural resource management and protection (Thapa-Magar and Shrestha, 2015). These community forests in Nepal have also played a major role in the conservation of forest diversity, storage of carbon and helped in the mitigation of impact of climate change. According to research by Nagendra *et al.,* (2008), community-based forest management not only significantly slows down deforestation and forest degradation rates but also has a positive effect on carbon stocks and carbon sequestration in the forest (Chhatre and Agrawal, 2009; Pandey *et al.,* 2014; Solomon *et al.,* 2017). Therefore, limiting the rates of deforestation and forest degradation through community forest management could help to mitigate the effects of climate change. The age, species, size, density, biomass decomposition, stand quality, amount and timing of disturbance, and land management all affect the forest's carbon stock and potential to store carbon (Dixon *et al.*, 1994). It is possible for productive, well-managed forests to sequester significant amounts of carbon (Pokharel *et al.*, 2007). As a forest gets older, its biomass and carbon stores often rise (Baker *et al.*, 2004; Alexandrov, 2007). Due to several factors such livestock grazing, lopping, burning of grasses, logging, forest fires, and more, the regeneration condition of Sal is poor in Nepal (Khumbongmayum *et al.,* 2006; Sapkota *et al.,* 2009). Since the date of hand over of the forest to any community, the responsibility of community forest user group is to enhance the quality and sustainability of the forest. Therefore, the age of the community managed Sal Forest may play an important role in the conservation of biodiversity, enhancement of quality and sustainability and increment of the carbon stock in forest. There is limited research work on tree diversity, carbon stock and regeneration pattern of Sal Forest in relation to different age parameters of CF in far-western Nepal. Therefore, it is important to research the Sal forest's tree diversity, carbon supply, and regeneration pattern. Similarly, this study will also help in

implementing the forest management and conservation strategies in the community managed forest.

1.3. Research questions

1. Does high tree diversity is found in an old age community managed forests?
2. Does high regeneration pattern is found in an old age community managed forests?
3. Does high carbon stock is found in an old age community managed forests?

1.4. Objectives

1.4.1. General objective

The general objective of the present study is to estimate the tree diversity, regeneration & carbon stock of *S. robusta* forests managed by CFUGs on the based on the age of the community forests in far-western Nepal.

1.4.2. Specific objectives

1. To determine tree diversity indices and Important Value Index (IVI) in the community managed forests on the basis of their age.
2. To study the regeneration pattern of *S. robusta* in the community managed forests on the basis of their age.
3. To estimate the tree carbon stock in the community managed forests on the basis of their age.

1.5. Limitations

1. The herbs and shrubs diversity were not studied.
2. The carbon stock of soil, shrubs, herbs, seedlings, saplings and litters were not estimated.
3. The regeneration of other tree species except *S. robusta* were not studied.

CHAPTER 2: LITERATURE REVIEW

2.1. Carbon stock by the age of community managed Sal forests of Nepal

Forests are important contributors to the global carbon cycle because they help carbon move from the land to the atmosphere and store 60% of the terrestrial carbon in the globe in their plants and soil (Dixon *et al.*, 1994; Pan *et al.*, 2011). The carbon stock in forests varies depending on factors including geographic location, forest type, forest structure, plant species, age of the stand, degree of disturbance, etc. (Brown *et al.*, 1989; Dixon *et al.*, 1994). According to Sedjo, (2001) and Luyssaert *et al.*, (2008) forests age, tree density, and area increase as well as their biomass and carbon stock. In young, regenerative forests, the rate of carbon sequestration is higher, but older, mature forests have higher carbon stocks (Luyssaert *et al.*, 2008). According to Kaul *et al.*, (2010) a forest's carbon stock fluctuates frequently because of plant growth, aging, and decomposition. In Nepal, distinct Sal forests that are managed by different communities for various purposes have varying amounts of carbon stock, according to different researchers.

According to Baral *et al.*, (2009) the C-stock in 75-year-old Sal stands in Nepal is higher than that in 18-, 25-, and 28-year-old *Alnus nepalensis*, tropical riverine, and *Pinus roxburghii* forests.

Thapa-Magar and Shrestha, (2015) studied in 9 community managed Sal Forest (managed for 4-29 yrs.) of Dhading district to estimate the carbon stock where Sal was dominant in all forests. They calculated the carbon stock to be between 70 and 183 Mg C/ha, with a mean value of 120 Mg C/ha. They discovered that forests managed for more than 20 years had much higher biomass and carbon stocks than forests managed for less than 20 years. The forests that have been managed by CFUGs for a longer time or for a shorter time have a higher carbon stock. They also found that the carbon stock increased with the management duration ($p < 0.05$) with sequestration rate of 2.6 Mg C ha^{-1} yr^{-1}.

Gairhe, (2015) investigated the tree carbon stock of two Sal forests in central Nepal's Tanahun district that are managed by the local community. He found Fulbari CF to have a lower value of tree carbon stock (71.11 per ha) than the carbon stock (109.82

tons per ha) of Taldanda CF. He concluded that carbon retention benefits biodiversity while disturbance levels had little bearing on total tree carbon and tree diversity.

Pathak and Baniya, (2016) reported 115.00 mg/ha average carbon stock of two community managed Sal Forest in Nawalparasi, central Nepal.

Pandey and Bhusal, (2016) conducted research in two cooperatively managed Sal forests in Chitwan (in the Terai) and Gorkha (in the Hills). They discovered that the total carbon stock in the CFs of the Hills and the Terai was found to be 234.54 t ha^{-1} and 479.29 t ha^{-1}, respectively. The Terai's CF was found to have a larger biomass carbon stock density (384.20 t ha^{-1}) than the Hills (123.15 t ha^{-1}).

According to Mandal *et al.,* (2016) conducted research in three community-managed Sal forests, the Chyandanda CF had a current annual carbon increment (CACI) of 2.85 t ha^{-1} and the Banke-Maraha CFM had a leakage of 1.68 t ha^{-1}.

Bhatta and Devkota, (2020) assessed the carbon stock in Dadeldhura community forests, dividing the CFs into two groups based on the length of management (11 and 20 yrs.). The average carbon stock of the analyzed forest's living biomass ranged from 148 to 202 Mg ha^{-1}, with the forest managed for about 20 years having a greater carbon stock than the forest managed for about 11 years (199 Mg ha^{-1}). They discovered that community forests managed for longer periods of time contain higher carbon stocks than those managed for shorter periods.

Joshi *et al.,* (2021) estimated the carbon stock in two community managed Sal Forest of Kailali district. They have estimated the carbon stock ranging from 92.99 to 51.94 t/ha.

Tesfaye, (2021) studied the Gojjamdur community managed Sal Forest and found the stored carbon ranging from 109.84 to 987.81 t/ha.

Joshi *et al.,* (2021) investigated the tropical Sal (*Shorea robusta*) forest in Nepal's Kanchanpur area for its potential to store carbon. Ganesh CF and Ramnagar CF both had carbon stocks valued at 76.6416.34 t ha^{-1} and 163.120.23 t ha^{-1}, respectively. Due to the presence of large-sized trees with higher biomass values, Ramnagar CF has a bigger carbon stock than Ganesh CF. The biggest contributor to the carbon stock was

Shorea robusta, which contributed 143.10 t ha^{-1} (87.73%) and 38.45 t ha^{-1} (50.17%) in Ramnagar CF, respectively.

Similarly, Regmi *et al.,* (2021) estimated 99.02 t ha^{-1} carbon stock in the Sal (*Shorea robusta*) forest in Bagdaila Chisapani community forest of Dang district, Nepal.

2.2 Regeneration status of community managed Sal forests in Nepal

Giri *et al.,* (1999) recorded 11185 pl ha^{-1} seedling and 321 pl ha^{-1} sapling density of Sal higher than other associated species in Terai Sal Forest of Bardia National Park.

Bashyal, (2005) reported 1375 pl ha^{-1} seedling and 562.5 pl ha^{-1} sapling for 209.37 pl ha^{-1} tree of *Shorea robusta* in tropical forests of Palpa district.

In central Nepal's Sal-dominated Inner Terai woods, which are community managed, Kandel, (2007) also noted the similar tendency of greater Sal density. He recorded 43000 pl ha^{-1} seedling and 2974 pl ha^{-1} sapling density of Sal.

In Sal-dominated forests of Nepal's Western Terai, Timilsina *et al.,* (2007) observed 1431 pl ha^{-1} sapling and 70462 pl ha^{-1} seedling density of Sal higher than other related species.

Shrestha, (2009) recorded 6758 pl ha^{-1} seedling, 4484 pl ha^{-1} sapling, and 962 pl ha^{-1} tree density of Sal higher than other associated species in CF of Surkhet district.

Sapkota *et al.,* (2009) studied the regeneration status of two community managed Sal Forest in central Nepal and reported the 17 families, 19 genera and 21 species in the Bhabar lowland (LEF). There were 13, 18, and 21, respectively, families, genera, and species found in the Hill (HEF). According to the data, *Shorea robusta* was the most prevalent species in both the LEF (IVI=174.4%) and HEF (IVI=206.9%).

Acharya and Shrestha, (2011) studied the regeneration of the community managed Sal Forest in Rupandehi district, central Nepal. In the 0.7-hectare sampling area, he recorded 125 plant species from 55 families, including 36 tree species, 50 shrubs, and 39 herbs. Where the average seedling was 15,208 Pl/ha and the average sapling 1,228 pl/ha.

Basyal *et al.,* (2011) has studied the regeneration of Sal in tropical forest of Palpa district and recorded 4375 seedling, 2562.5 sapling and 209.37 adults pl ha^{-1} of Sal.

In the jointly managed hill Sal Forest in the Kaski district, Paudyal, (2013) found that the Sal seedling density was 6,126 pl ha^{-1}, which was higher than that of other associated species.

According to Pandey *et al.,* (2012) a good regeneration status for replacing old Sal trees is defined as having more than 5000 seedlings and 2000 saplings per hectare. According to numerous research conducted in Nepal, Sal has a higher rate of regeneration in Sal forests than the other species that are related to it (Bhatta, 2016).

In the Lumbini collaborative forests of Rupandehi, Awasthi *et al.,* (2015) discovered that Sal had better regeneration rates than other related species. The seedling density of Sal was found to be higher in the managed area (13,977 pl ha^{-1} and 9,311 pl ha^{-1}) than unmanaged area (6445 pl ha^{-1}).

In Banke National Park, western Nepal, Napit, (2015) investigated species diversity, forest community structure, and regeneration. Sal had the highest density of seedlings (27153.4 pl ha^{-1}) and saplings (200.49 pl ha^{-1}) according to him.

Chand *et al.,* (2018) reported altogether 10 species and 144 trees of community managed forest of Kanchanpur district. *Shorea robusta,* with a basal area of 9.73 m2 per hectare and an IVI of 75.33, was the dominant species in the community forest.

In the Buddha Shanti Collaborative Forest in the Nawalparasi district, Baral and Ghimire, (2020) investigated the role of canopy in the regeneration of Sal. They separated the forest into four groups, with a percentage crown cover of 0–25, 25–50, 50–75, and 75–100. Sal had seedling densities of 22,167 pl ha^{-1} and 13,667 pl ha^{-1} in the 0-25 and 25-50 percentage crown cover areas, respectively. Like this, Sal had seedling densities of 11,667 pl ha^{-1} and 11,000 pl ha^{-1} in the 50-75 and 75-100 percentage crown cover areas, respectively.

Sal was the dominating species and Dipterocarpaceae was the dominant family, according to Sharma *et al.,* (2020) study of the regeneration condition of a community-managed hill Sal Forest in Baglung district, central Nepal. They recorded total number of sal seedlings 8,352 pl ha^{-1}, 4,384 pl ha^{-1}, saplings 1,876 pl ha^{-1}, 1,043 pl ha^{-1} and trees 1,320 pl ha^{-1}, 804 pl ha^{-1} respectively.

Joshi *et al.,* (2021) reported 100 plant species from the two-community managed Sal Forests of Kailali district. They recorded 1, 69,000 pl ha^{-1} and 68,250 pl ha^{-1} seedling density and 13,090 pl ha^{-1} and 5,520 pl ha^{-1} sapling density respectively.

According to Joshi *et al.,* (2021) there are an estimated 8591 ± 288 and 25000 ± 1663 seedlings per hectare in the Ganesh and Ramnagar CFs, respectively. Like this, it was discovered that Ramnagar CF had more saplings overall than Ganesh CF, accounting for 928 and 381 saplings pl ha^{-1}. They recorded 15 seedlings and 17 saplings from the community-managed Sal Forest of Kanchanpur district.

When Poudel and Devkota, (2021) examined the state of the regeneration in the Tanahun district's community-managed Sal Forest, they discovered that the MCF forest's total tree density-1230 plants per ha was lower than the LCF forest's total tree density-1314 plants per ha.

2.3. Community forest in Nepal

The community forestry program is one of Nepal's most effective and successful natural resource management techniques for rehabilitating damaged habitats, protecting biodiversity, utilizing forest products sustainably, producing income in rural areas, and developing human resources (Acharya, 2004). Deforestation, forest degradation, and biodiversity loss were not halted by the forest management program in 1978 (Shrestha *et al.,* 2010) the community forestry initiative was established. 5.96 million hectares of land are covered by forests in Nepal (DFRS, 2014), and according to DFSC's 2018 report, 19.361 community forestry users' organizations (CFUGs) in Nepal now own about 1,813,478 hectares of the country's total national forest.

According to Pokharel *et al.,* 2007; Pandey *et al.,* 2014; Solomon *et al.,* 2017) a well-managed CF has a huge potential to sequester a significant amount of carbon that can help mitigate climate change. The community forestry program plays several significant roles, including biodiversity preservation, the provision of various ecosystem services, and the sustainable development of the local population. With a sequestration rate of 1 to 5 Mg ha^{-1} yr^{-1}, these forests store around 20% of the total carbon stock (Pokharel *et al.,* 2007). The age or length of management of the forest increases the carbon stock in the CFs. Thapa-Magar and Shrestha, (2015) and Bhatta

and Devkota, (2020) found that CFs managed for a longer period had higher C-stock than CFs handled for a shorter period.

In various regions of Nepal, there have been numerous studies on C-stock estimation and forest regeneration. However, little research has been done on the Sal forest's ability to regenerate in western Nepal. To analyze the age-based patterns of Sal Forest regeneration in far-western Nepal, a knowledge gap will be filled by this research. Additionally, factors influencing the carbon supply and regeneration pattern in Sal forests will be investigated, including disturbance, crown coverage, and litter depth. To determine the Sal forest's species diversity, carbon stock, and regeneration status based on their age, this study will be useful.

CHAPTER 3: MATERIALS AND METHODS

3.1. Study Area

The present study was carried out in the Sal forests of Dhangadhi sub-metropolitan city of Kailali district in Province-7, Nepal. The district covers an area of 3, 23,500 ha with an altitude ranging from 109 to 1950 m (DFO, 2021/2022). Around 2, 05,724 hectares of land is covered by forest and 43.38% has been referred to as community forest (DFO, 2021/2022). There are 637 community forests in Kailali district which covers an area of 58,020.37 hectares (DFO, 2021/2022). In Division Forest Office of Dhangadhi, Kailali there are total 316 community forest which were managed by hand overed to the community (DFO, 2021/2022). The study was conducted in Shree Samaichi community forest (SSCF) CFs managed for 25 yrs., Manehara community forest (MCF) CFs managed for 15 yrs. and Mahalaxmi community forest (MLCF) CFs managed for 4 yrs. which were handed over to the community in 1998, 2007 and 2019 AD respectively. SSCF is divided into five blocks, to stop forest fires, MLCF is separated into two blocks while MCF is divided into three blocks. In 1998 AD, SSCF was distributed to the 1057 user groups, MCF was distributed to the 893 users, and MLCF was distributed to the 915 users in 2019. (Figure 3.1).

SSCF covers an area of 332.45 hectares. It lies at 28°42' N and 80°37' E with altitude 190 to 250 m. This forest is categorized as a low altitudinal range forest that comes under Terai Sal Forest (TSF). MCF has an area of 285.05 hectares with an altitude ranging from 190 to 200 m. It lies at 28°41' N and 80°35' E. MLCF is situated at 28°43' N and 80°44' E covering an area of 200.89 hectares. It lies at an altitudinal range between 180 to 210 m (Figure 3.1).

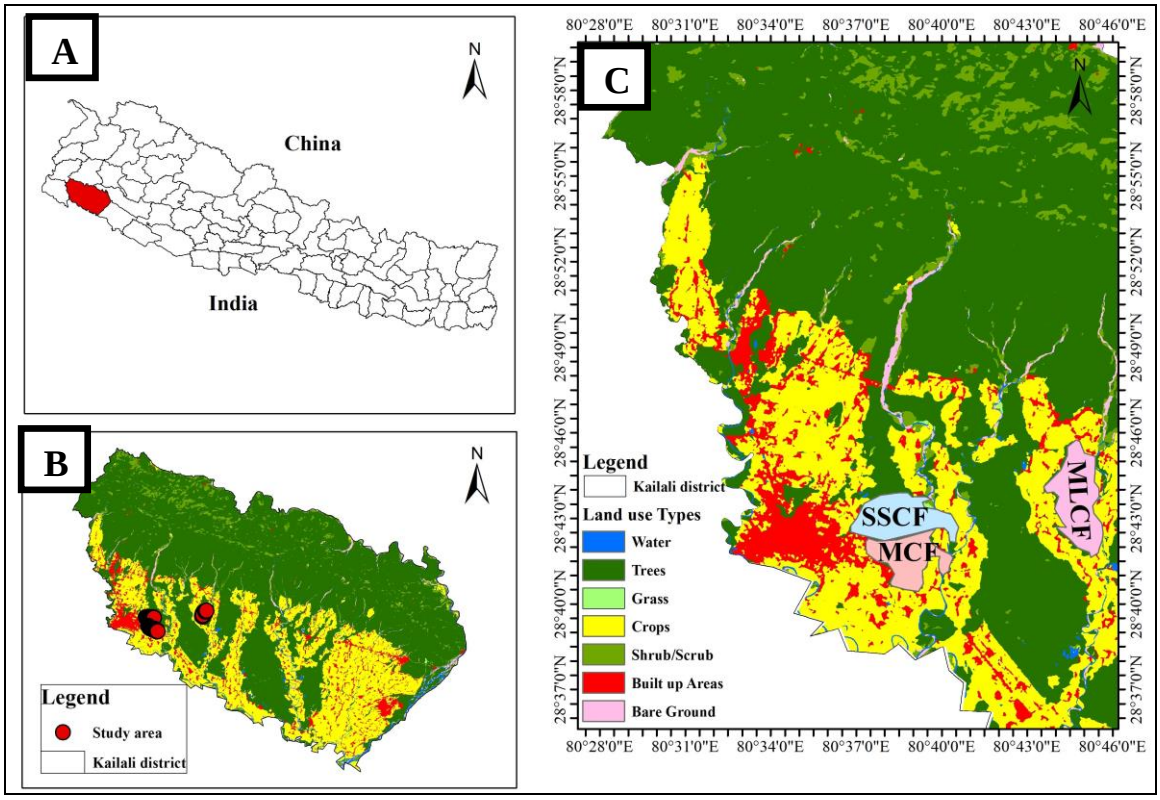

Figure 3.1 Map of the study area; Map of Nepal with provinces and districts (A), Kailali district with local administrative units (B), Location of community forests (SSCF, MCF and MLCF) in Dhangadhi sub-metropolitan city (C).

3.2. Climate

The monthly average maximum and minimum temperature of Dhangadhi were 30.60°C and 13.75°C respectively (average data of 22 years) (Figure 3.2). The highest monthly rainfall was in July (537.24 mm), and the lowest was in November (1.9 mm), with a mean annual rainfall of 1892.88 mm. The climate is very warm in summer and very cold in winter whereas rainfall is high in summer and very low in winter.

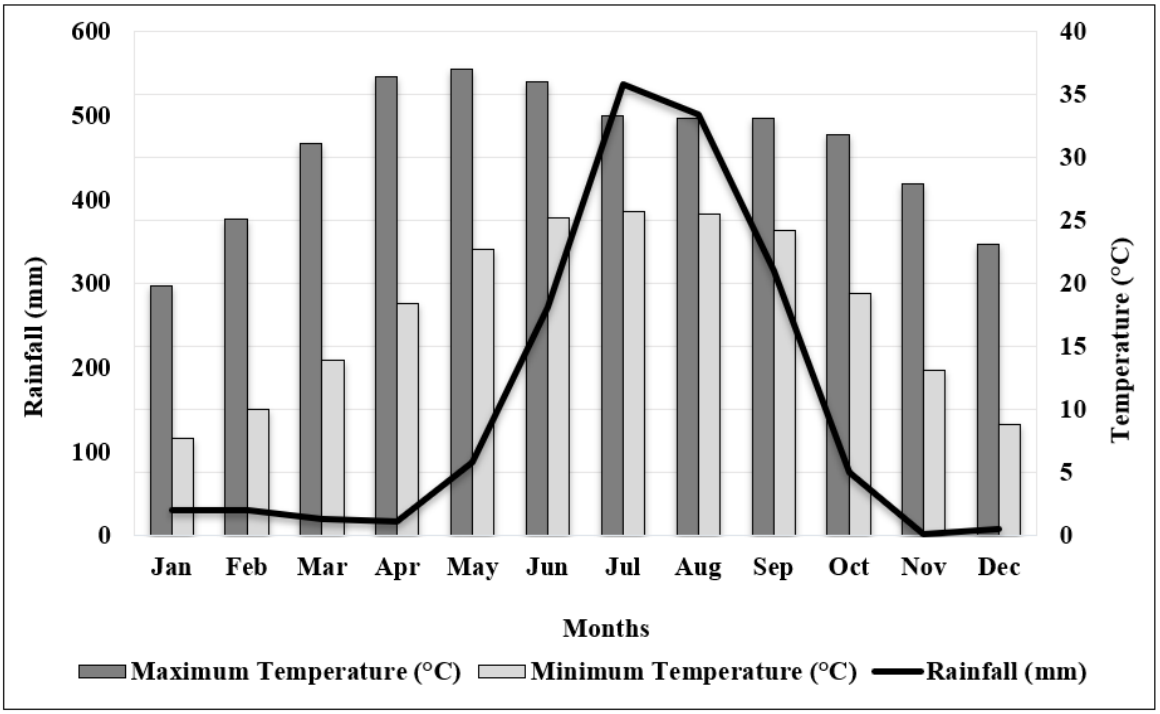

Figure 3.2 Twenty-two years (2000-2022) monthly average data of average temperature and rainfall recorded at Attariya Station of Kailali district for SSCF, MCF and MLCF respectively. (Source: Department of Hydrology & Meteorological, Kathmandu).

3.3. Vegetation

The tropical type of vegetation was found in SSCF (25 yrs.) with dominance of *Shorea robusta* species. Other associated species were *Terminalia alata* (Saj/Asna), *Mallotus philippensis* (Sindure/Ruhina), *Syzygium cumini* (Jamun), *Syzygium nervosum* (Camun), *Dalbergia sissoo* (Sisam), Senegalia *catechu* (Khair) and *Schleichera oleosa* (Kusum) etc. (DFO, 2021/2022).

The tree vegetation in MCF (15 yrs.) was dominated by *S. robusta* with the associated tree species like *Mallotus philippensis* (Sindure/Ruhina), *Grewia optiva* (Vimal), *Terminalia alata* (Saj/Asna), *Lagerstroemia parviflora* (Bot dhagero/Asiddha), *Syzygium cumini* (Jamun) etc. (DFO, 2021/2022).

Similarly, the tree vegetation in MLCF (4 yrs.) was also dominated by *S. robusta* with the associated tree species like *Mallotus philippensis* (Sindure/Ruhina), *Diospyros melanoxylon* (Tendu), *Lagerstroemia parviflora* (Bot dhagero/Asiddha), *Syzygium cumini* (Jamun), and *Senegalia catechu* (Khair) etc. (DFO, 2021/2022).

3.4. Selection of the community forests

To get sufficient information about the community forest of the Kailali district, the Division Forest Office of Dhangadhi, Kailali, was first visited. The CFs were visited in August and September 2022 for preliminary studies on the forest type and the management duration. Out of 637 CFs in the district, 316 CFs lie in Dhangadhi sub-metropolitan city which were managed by hand overed to the community (DFO, 2021/2022). However, three community forests were selected on the basis following criterias;

1. The forest vegetation must have included *Shorea robusta* as a part of it.
2. The communiy managed forest must be based on their management duration (date since handed over to community.
3. The study area must be a community managed forest.

Table 3.1 Community forests selected for the study (data were taken in August 2022).

Name of municipality	**Area (ha)**	**Elevation(m)**	**Year of handover (AD)**	**Management duration (yrs.)**	**No. of plots (N)**	**Category of CF based on management duration**
Dhangadhi	332.45	190-250	1998	25	30	CF managed for > 20 yrs.
Dhangadhi	285.05	190-200	2007	15	30	CF managed for 10-20 yrs.
Dhangadhi	200.89	180-210	2019	4	30	CF managed for < 10 yrs.

3.5. Experimental design

3.5.1. Sampling methods

The sampling in the study areas was done using the stratified random sampling approach. All the study areas were differentiated into different blocks or strata based on species composition, different age blocks and geographical locations by the forest

authorities (Gairhe, 2015). The random sampling was then used in the different strata. The square plot in each site was studied randomly at the minimal distance of 50 m. Altogether 90 plots were laid (30 plots in each on the forest based on their age) for trees and saplings and 180 plots (60 in each on the forest based on their age) for seedlings were studied.

3.5.2. Sampling techniques inside the plot

A square plot of 10 × 10 meters plot was divided into 4 sub-plots of 5 × 5 meters, and one of them was selected randomly, and 1 × 1 meter was employed in each square plot to sample trees (DBH ≥ 5 cm), saplings (DBH < 15 cm, height > 1 m), and seedlings (DBH < 1 cm, height < 1 m), respectively (Thapa-Magar and Shrestha, 2015). To study the regeneration status of *S. robusta*, density of trees, saplings and seedlings were studied from the square plots and two square plots were selected randomly inside the plot for seedling.

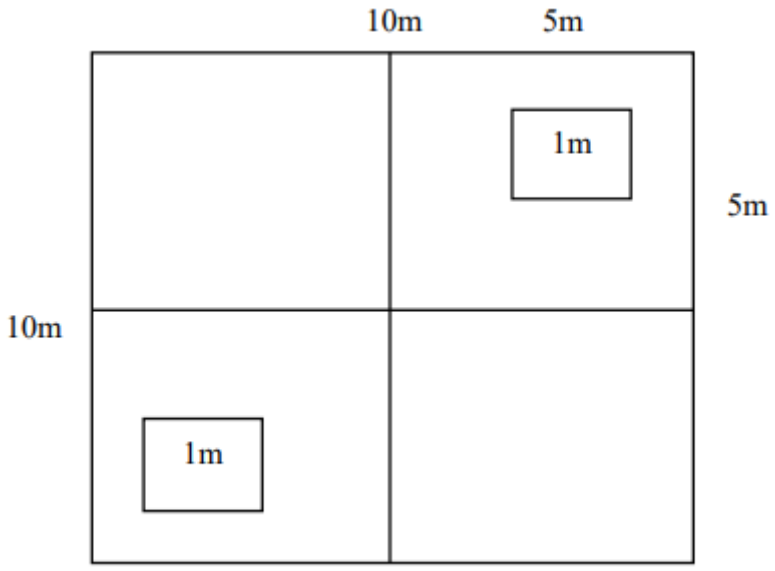

Figure 3.3. Square plot design for sampling.

The diameter of each tree was measured at breast height (DBH=1.37 m) with DBH tape, and its height was determined using a clinometer. Each kind of tree and sapling rooted inside the plots was identified. Trees near the boundary were additionally counted if at least 50% of their basal area fell inside the plot (Bhatta, 2016). Plants having DBH less than 5 cm were excluded for the estimation carbon stock (Chave *et al.*, 2005). A common forestry practice from MacDicken, (1997) was used to measure

the DBH of trees with a typical shape (such as trees with forked stems, trees with bulged or curved stems at 137 cm, trees inclined in ground, etc.).

A GPS tracker was placed in the middle of each plot to record its latitude, longitude, and elevation. Each plot also had a disturbance level recorded, which was graded as 0 (undisturbed), 1 (slightly disturbed), 2 (moderately disturbed), and 3 (very disturbed) based on factors such grazing, cut trees, seedling and sapling density, crown cover, ground vegetation, branch dropping, etc. Each plot's canopy cover was calculated using a visual estimation method starting at the plot's center. Additionally, visual records of ground vegetation, ground litter, grazing, and forestry practices were made.

3.5.3. Data collection

The data collection was done with the help of local people and the authorities of the community forests in each forest. The annual progress reports of community forests were obtained from the Sub-division offices of SSCF (25 yrs.), MCF (15 yrs.) and MLCF (4 yrs.). The preliminary study was conducted from August 5 to 15, 2022 where the square plot was also laid. The primary data were collected from October 12 to November 10, 2022.

3.6. Quantitative analysis

3.6.1. Community attributes

The ecological characteristics, such as density (pl ha^{-1}), frequency (%), basal area (m2 ha-1), with their relative values, and importance value index (IVI), were quantified in accordance with Zobel *et al.*, (1987).

The density (D) is the number of distinct species in each area. It displays the species' relative population size within the community. It is calculated by the following formula:

$$\text{Density (pl ha}^{-1}) = \frac{\text{Total number of plants in all the studied plots}}{\text{Number of plots studied} \times \text{Area of plot (m2)}} \times 10000$$

Relative density (RD) is the study of numerical strength of a species in relation to the total number of individuals of all the species and it was calculated using the following formula:

$$\text{Relative density (\%)} = \frac{\text{Density of individual species}}{\text{Sum of densities of all species}} \times 100$$

Frequency (F) describes the degree of dispersion of a specific species within a community. It is the percentage of sampling units in a specific area that contains a species. It is also used to describe how species are distributed throughout a community. It was calculated by the following formula:

$$\text{Frequency (\%)} = \frac{\text{Number of plots in which the species occured}}{\text{Total number of plots studied}} \times 100$$

The term "relative frequency" (RF) describes the degree of dispersion of a specific species in a given area in relation to the overall number of species that occurred, and it was calculated using the following formula:

$$\text{Relative frequency (\%)} = \frac{\text{Frequency of individual species}}{\text{Sum of frequencies of all species}} \times 100$$

The cross-sectional size of a tree species' basal area (BA) is measured at 137 cm above the ground. It is measured in square meters per hectare of land. It was calculated from the following formula:

$$\text{Basal area } (m^2) = \pi r^2$$

where, r = radius of tree trunk measured at breast height

$$\text{Basal area } (m^2\, ha^{-1}) = \frac{\pi r2}{\text{Area of quadrat}} \times 10000$$

The total basal area of a species relative to the total basal area of all species is known as the relative basal area (RB) and is expressed in percentage by using the following formula:

$$\text{Relative basal area (\%)} = \frac{\text{Basal area of individual species}}{\text{Sum of basal areas of all species}} \times 100$$

The importance value index (IVI) is the total of the relative values of the density, frequency, and basal area (for tree species only) or coverage (for shrubs and herbs). It is used to determine the overall importance of each species in the community structure. IVI of tree species was calculated by using the following formula:

IVI = RD + RF + RB

3.6.2. Species diversity

Shannon's diversity index (H) was used to calculate the diversity of tree species (Shannon and Weaver, 1949). The diversity includes both richness and evenness of tree species in the community. The higher value of Shannon's diversity index (H) represents higher diversity. Shannon's diversity index were calculated by using the following formula:

$$\text{Shannon's diversity index (H)} = -\sum \text{pi}(\ln \text{pi})$$

Where, pi = Species proportion (total number of species divide by total number of all the species)

ln = Natural logarithm

The higher value of H represents higher diversity.

3.6.3. Estimation of biomass and carbon stock

3.6.3.1. Estimation of above-ground biomass

The aboveground biomass (AGB) will be calculated by using allometric equation, $AGB=0.0509\times\rho\times D^2\times H$ [where, ρ =Wood specific density (g/cm^{-3}), D=Tree diameter at breast height (cm), H=Tree height (m)] for trees and poles (DBH $>$ 5 cm) (Chave *et al.,* 2005). This method was followed by Aryal *et al.,* (2017). Specific wood density of tree species was used from Reyes *et al.,* (1992); Jackson *et al.,* (1994); Zanne *et al.,* (2009) and Karki *et al.,* (2016) (Appendix II).

3.6.3.2. Estimation of below-ground biomass

The below ground biomass (root system) was calculated by multiplying the default factor of 0.15 with the biomass of bole (MacDicken, 1997).

3.6.3.3. Estimation of carbon stock

The total tree biomass was obtained by adding the above-ground and below-ground biomass. When both the biomass was multiplied separately by default carbon fraction 0.47 (Eggleston *et al*., 2006), gave total C-stock in kg.

3.7. Plant identification and Herbarium preparation

Most of the plants were identified with their local name at the time of field sampling with the help of field members of CFs and local experts. However, unidentified plants were gathered, tagged, and compressed with the use of newspaper. Herbarium was prepared for unidentified species following Lawrence (1951) and were identified with the help of book "Plant Resources of Kailali, West Nepal" (DPR, 2016) and using references such as Rajbhandari and Rai, (2017) and also with the help of taxonomic experts. After the identification of plants, confirmation of latest and accepted scientific names and families were done with the help of websites; www.gbif.org, www.theplantlist.org and www.efloras.org (Annotated Checklist of Flowering Plants of Nepal) (Press *et al.*, 2000). The herbarium specimens were also tallied with the specimens of National Herbarium and Plant Laboratories, Godawari (KATH). Herbarium specimens were deposited in Ascol herbarium, Kathmandu, Nepal.

3.8. Data analysis

The map of the study area was prepared using ArcGIS version 8.2. All the ecological parameters were quantitatively analyzed in Microsoft Office Excel program 2013. All the statistical analysis was performed in R software version 4.0.3. However, some descriptive analyses were performed in MS Excel 2017.

Normality of the data was tested by Shapiro-Wilk test for One-way ANOVA. One-way analysis of variance (ANOVA), followed by multiple comparisons using Tukey's test, revealed a significant difference in tree species richness and tree carbon stock among the three categories of CFs depending on the length of management. One-way ANOVA was performed to observe the significant difference of the carbon stock and regeneration of CFs classified based on the management duration.

CHAPTER 4: RESULTS

4.1. Tree diversity

Altogether 23 tree species were recorded in the study areas. The CFs managed for 25 yrs. (Shree Samaichi CFs), 15 yrs. (Manehara CFs) and 4 yrs. (Mahalaxmi CFs) had 15, 12 and 12 tree species respectively. Here, CFs managed for 25 yrs. had the highest number of tree species (Figure 4.1). There was significant difference ($P < 0.01$) in tree species richness among CFs managed for 25 yrs., 15 yrs. and 4 yrs. analyzed by Tukey's test.

The Shannon-Weiner Diversity index (H) value was highest in CFs managed for 25 yrs. (1.869) followed by CFs managed for 4 yrs. (1.805) and CFs managed for 15 yrs. (1.455) (Figure 4.2).

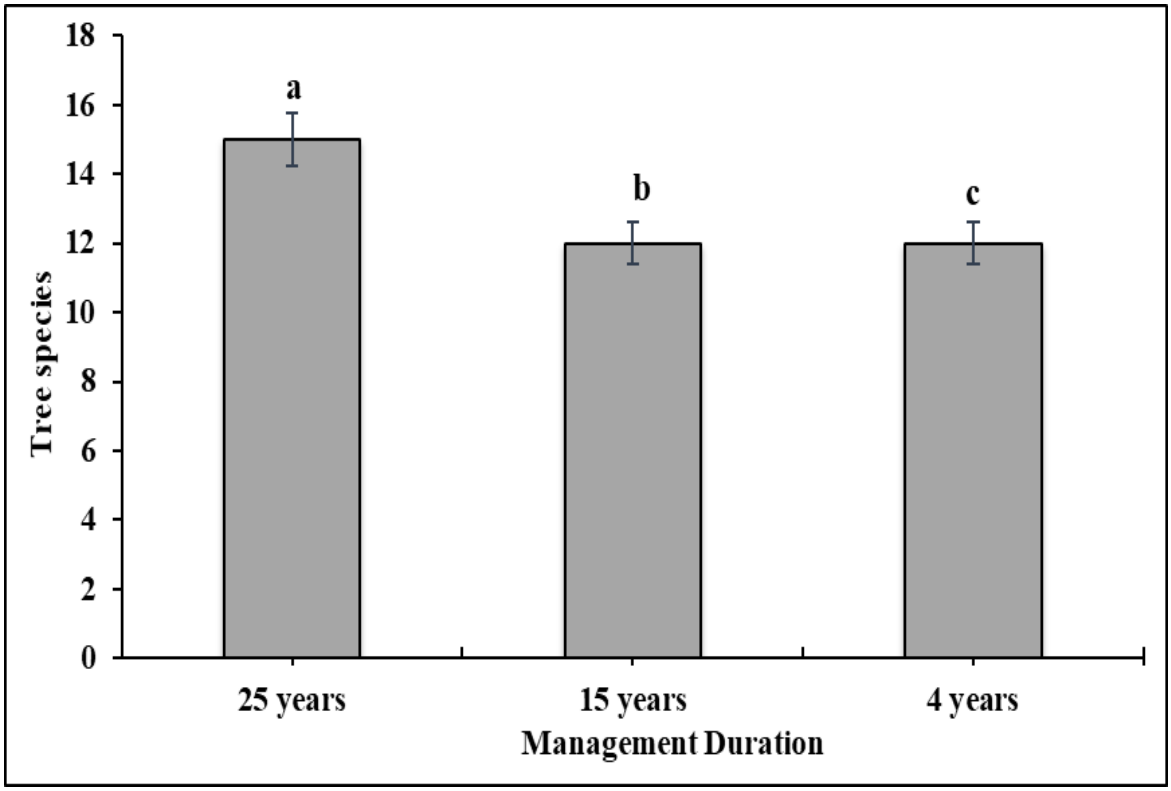

Figure 4.1 Tree species richness in CFs managed for 25 yrs., 15 yrs. and 4 yrs. Different superscript indicated significant difference ($P < 0.01$) of tree species richness analyzed by Tukey's test.

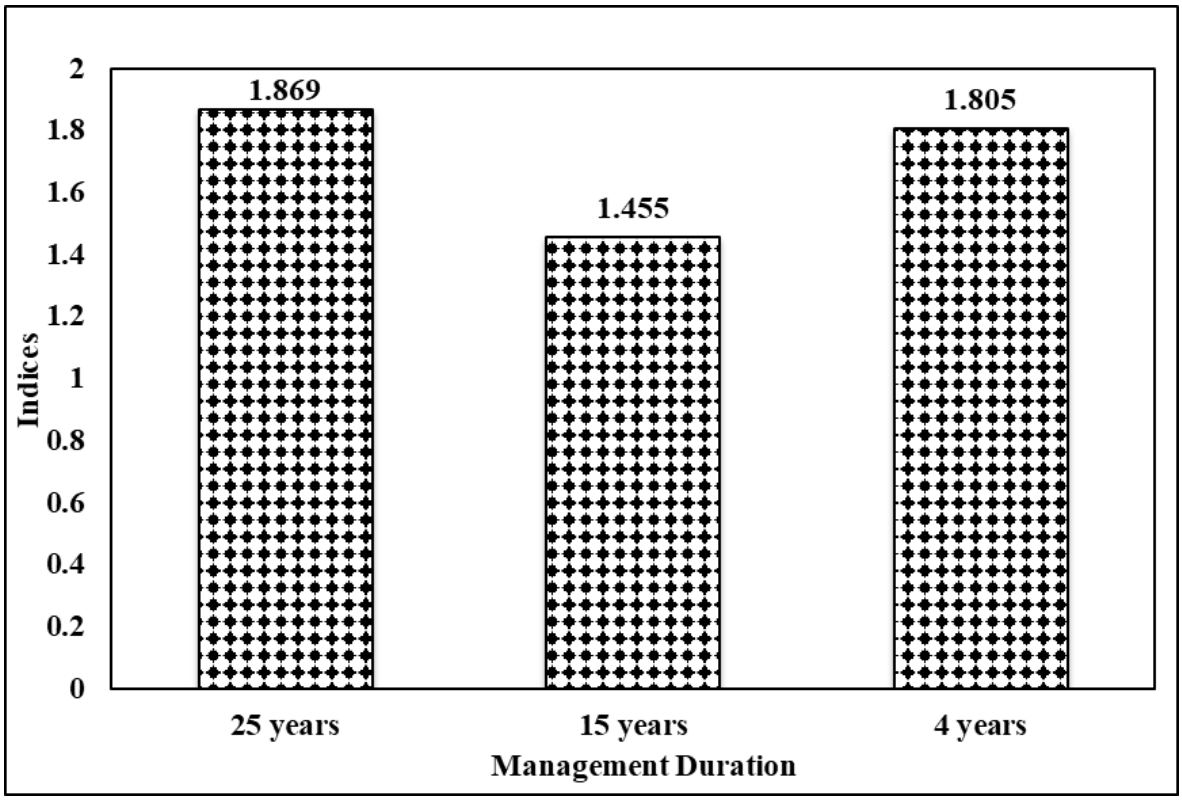

Figure 4.2 Shannon-Weiner Diversity index (H) of the tree species in CFs managed for 25 yrs., 15 yrs. and 4 yrs.

4.2. Community attributes

In all three community-managed forests, the *S. robusta* Importance Value Index (IVI) was greatest, according to the Dominance-Diversity curve (DD curve). According to DD curve *S. robusta* was highly dominated in all three community managed forests. (Appendix 3-5). In CFs managed for 25 yrs., IVI of *S. robusta* (103.92) was also highest followed by *T. alata* (45.07) and *S. catechu* (18.10) (Figure 4.6). Similarly, in CFs managed for 15 yrs., IVI of *S. robusta* (128.47) was highest followed by *S. cumini* (33.47) and *T. alata* (31) (Figure 4.7). And, in CFs managed for 4 yrs., IVI of *S. robusta* (75.61) was highest followed by *T. alata* (50.06), *M. phillipensis* (44.14) and *A. cordifolia* (24.74) (Figure 4.8).

The highest tree density (1063.33 pl ha^{-1}) was found in CFs managed for 25 yrs. followed by CFs managed for 4 yrs. (1020 pl ha^{-1}) and CFs managed for 15 yrs. (586.66 pl ha^{-1}). *S. robusta* had the highest tree density of all three community managed forests. The density of *S. robusta* (440 pl ha^{-1}) was highest followed by *T. alata* (243 pl ha^{-1}) and *M. phillipensis* (80 pl ha^{-1}) in CFs managed for 25 yrs. (Figure

4.9). Similarly, the density of *S. robusta* (337 pl ha^{-1}) was also highest followed by *M. phillipensis* (293 pl ha^{-1}) and *T. alata* (150 pl ha^{-1}) in CFs managed for 4 yrs. (Figure 4.11). And the density of *S. robusta* (317 pl ha^{-1}) was highest followed by *S. cumini* (117 pl ha^{-1}) and *M. phillipensis* (67 pl ha^{-1}) in CFs managed for 15 yrs. (Figure 4.10). Moreover, the canopy cover of 25 yrs, 15 yrs and 4 yrs managed community forest was 40.44%, 51.23% and 55.23% respectively.

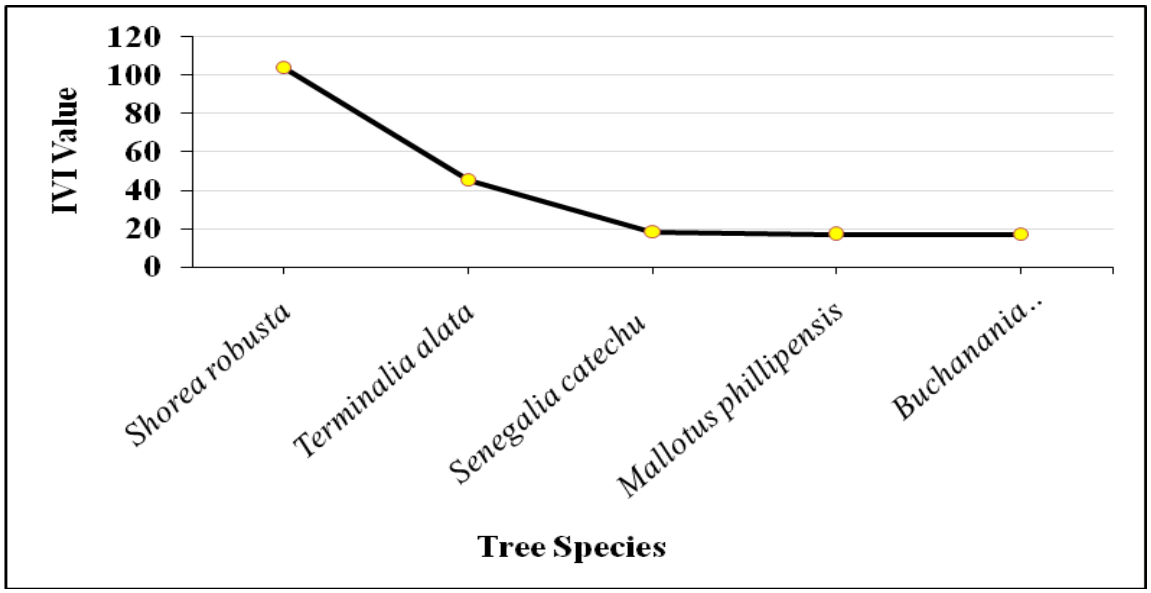

Figure 4.3 Dominance-Diversity (DD) curve of five dominant trees in CFs managed for 25 yrs.

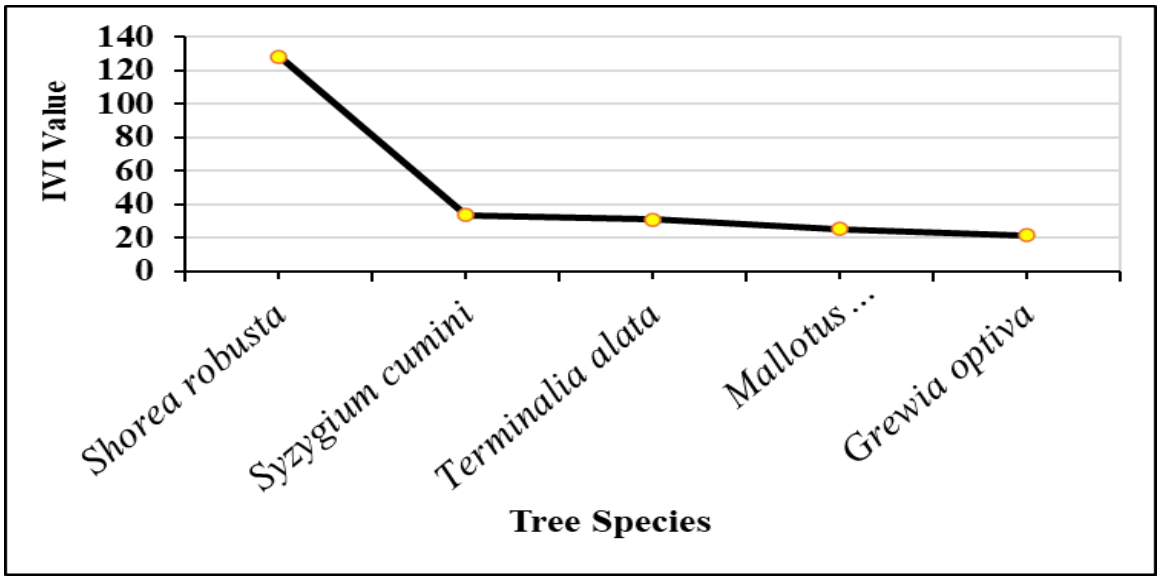

Figure 4.4 Dominance-Diversity (DD) curve of five dominant trees in CFs managed for 15 yrs.

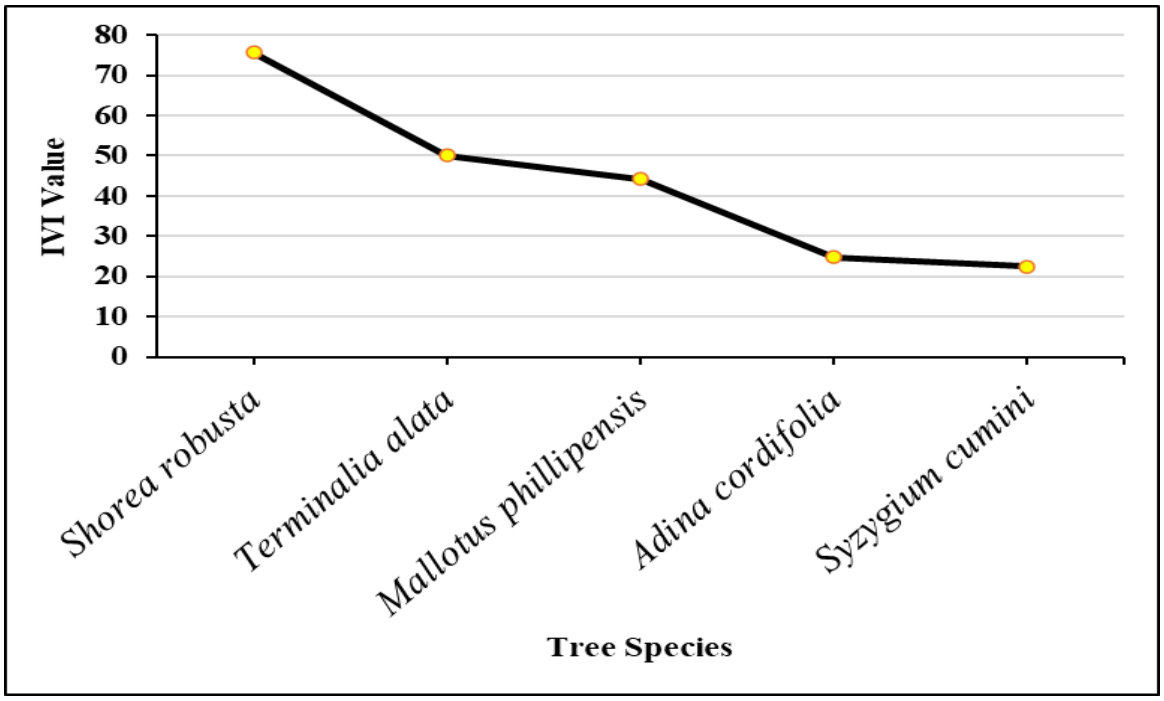

Figure 4.5 Dominance-Diversity (DD) curve of five dominant trees in CFs managed for 4 yrs.

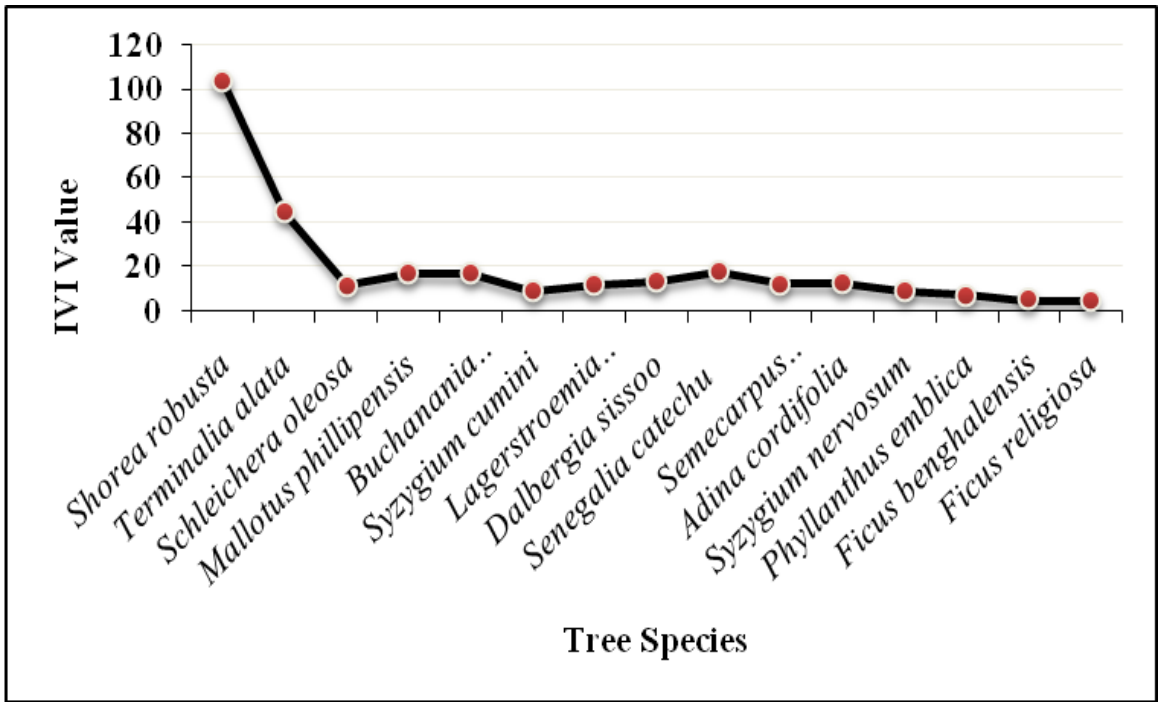

Figure 4.6 Dominance-Diversity (DD) curve of trees in CFs managed for 25 yrs.

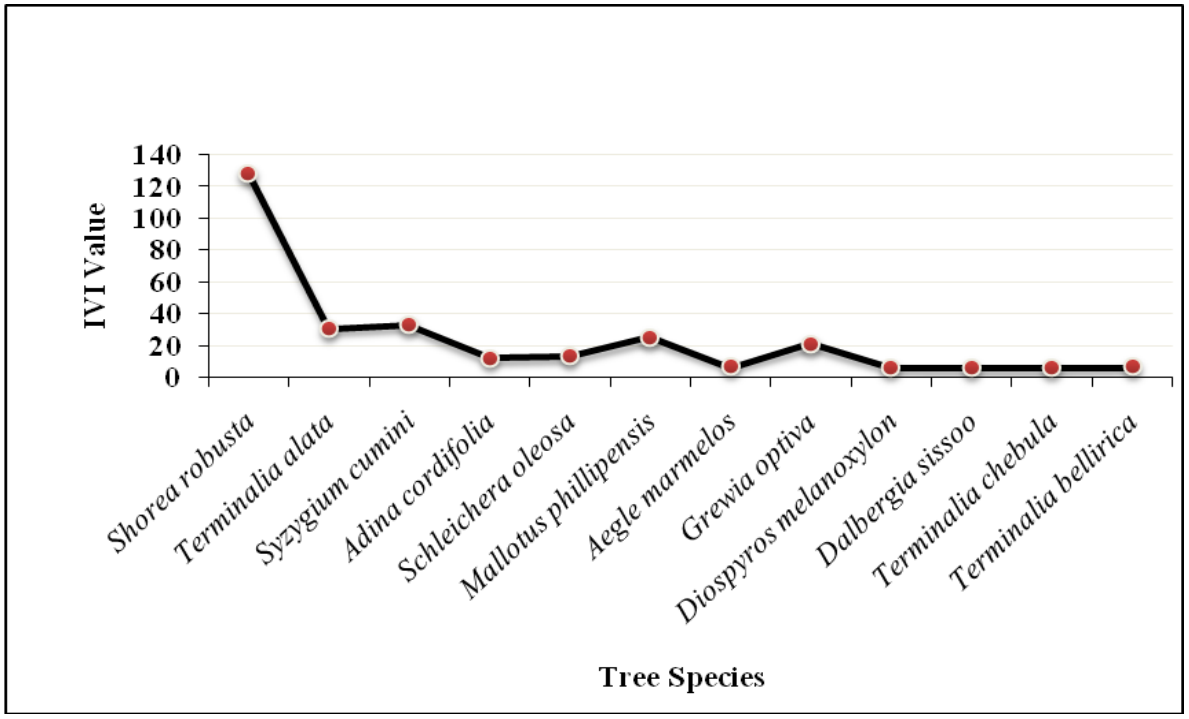

Figure 4.7 Dominance-Diversity (DD) curve of trees in CFs managed for 15 yrs.

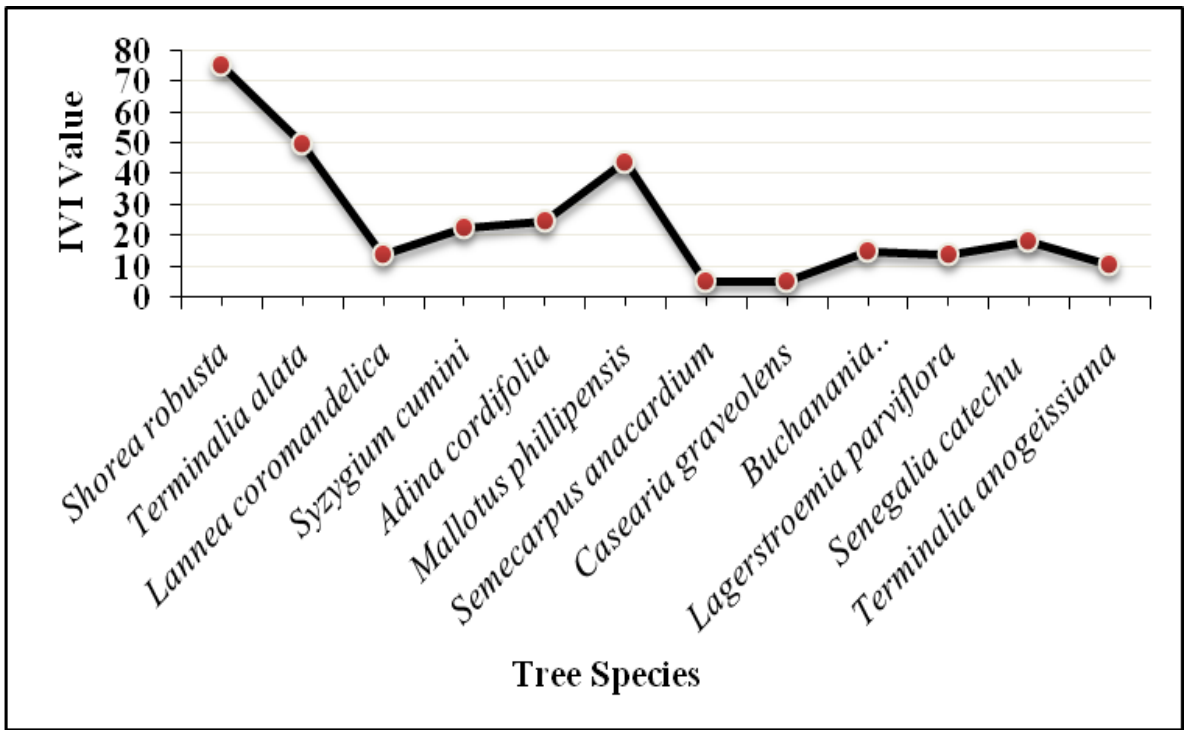

Figure 4.8 Dominance-Diversity (DD) curve of trees in CFs managed for 4 yrs.

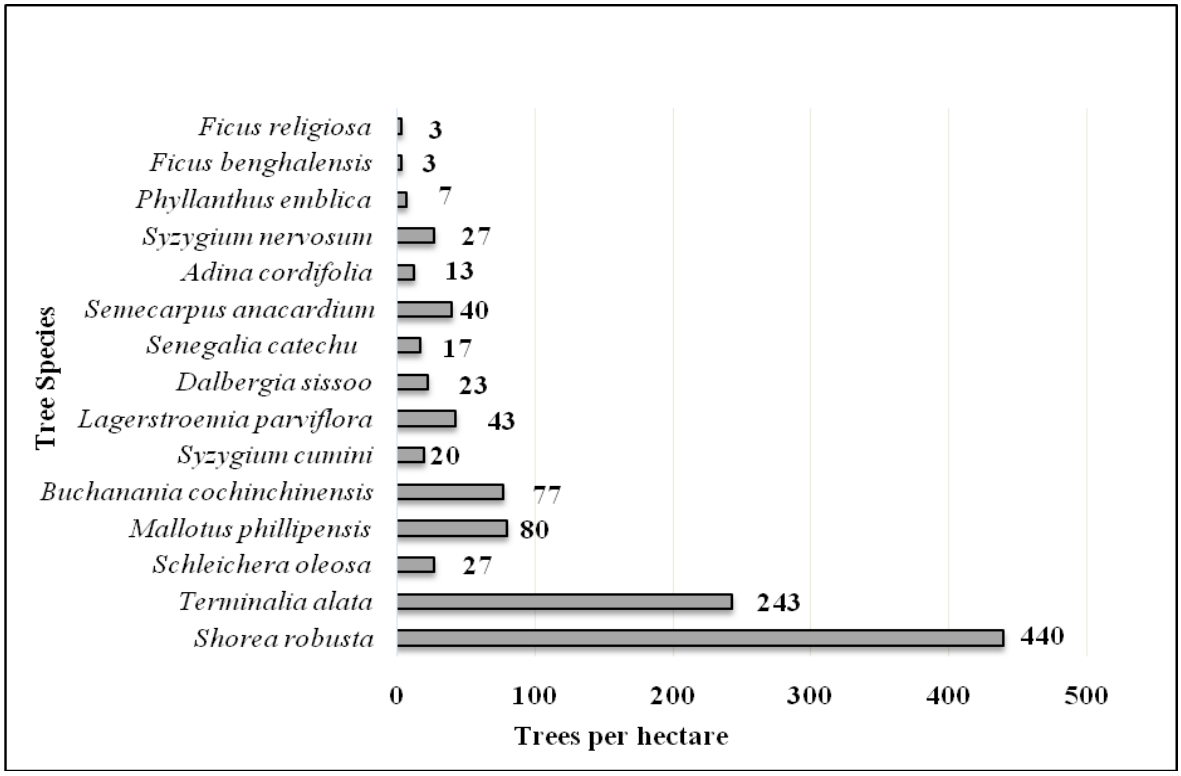

Figure 4.9 Tree species density in CFs managed for 25 yrs.

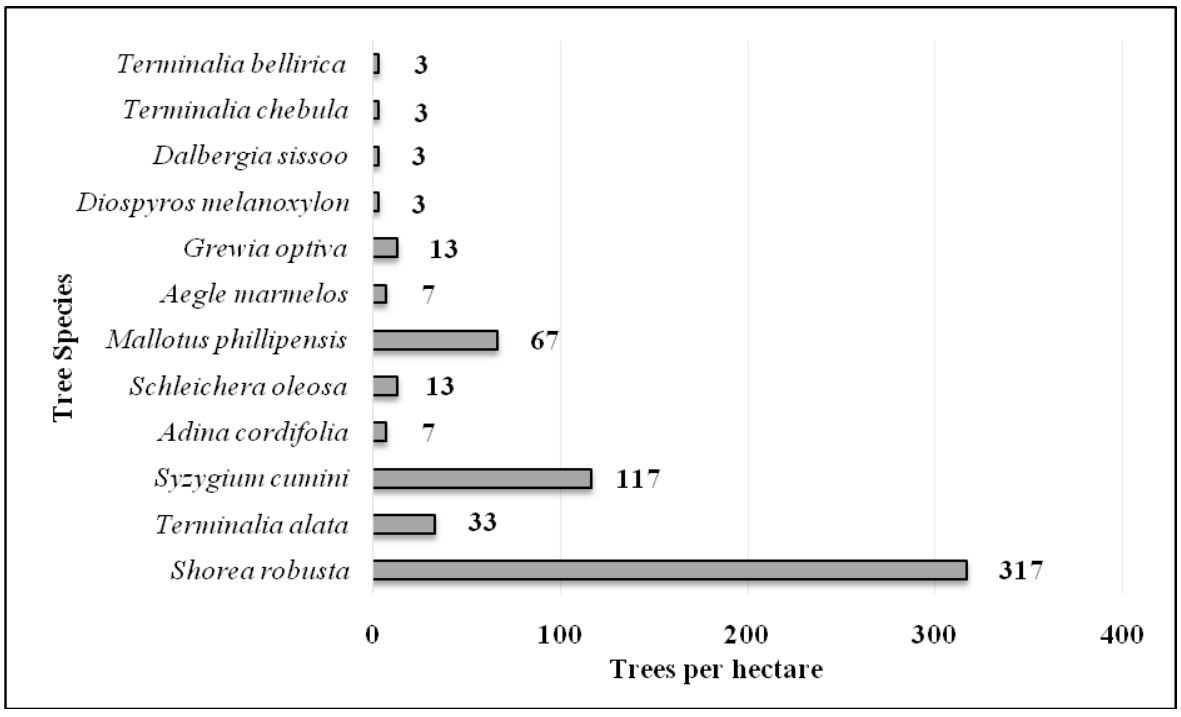

Figure 4.10 Tree species density in CFs managed for 15 yrs.

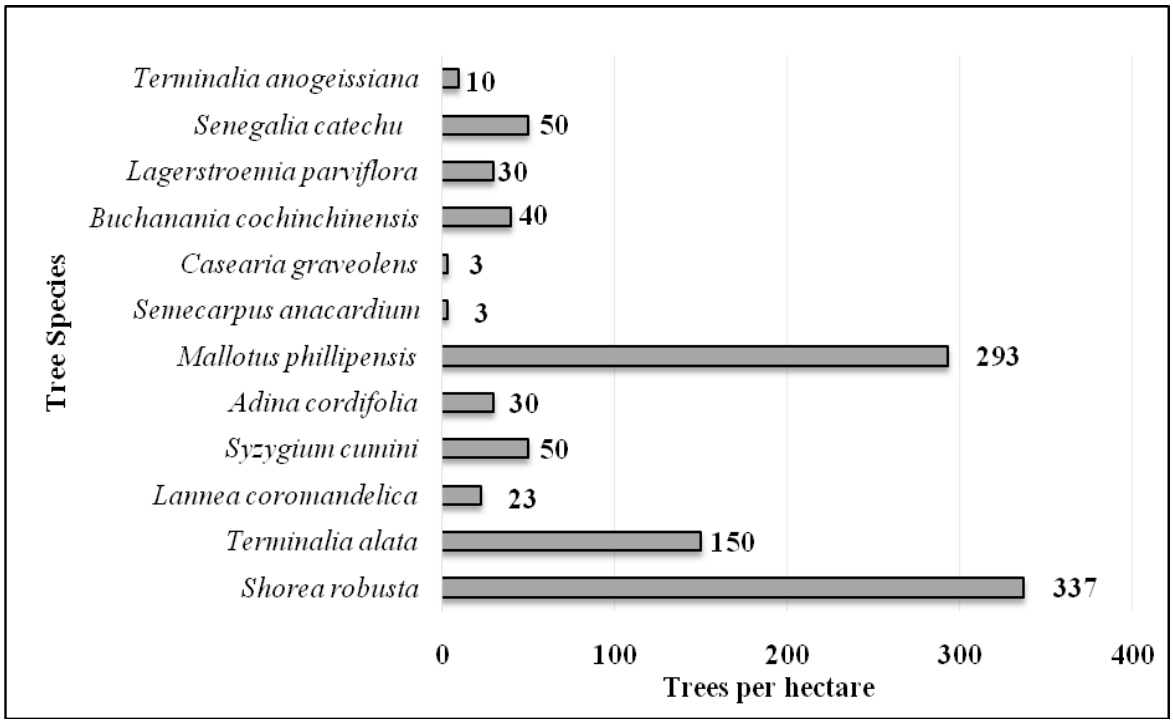

Figure 4.11 Tree species density in CFs managed for 4 yrs. Higher density of Sal than 15 yrs.

4.3. Size-class distribution

Firstly, different DBH sizes of trees were categorized into 15 groups starting from 5-10 cm to >150 cm. In CFs managed for 25 yrs., the density of trees was higher in 5-10 cm (438.60 tree ha^{-1}) DBH category followed by 10-20 cm (353.60 tree ha^{-1}), 20-30 cm (88.40 tree ha^{-1}), 60-70 cm (47.60 tree ha^{-1}) and 50-60 cm (40.80 tree ha^{-1}) (Figure 4.15). Nevertheless, 6.80 tree ha^{-1} was recorded in 90-100 cm, 105-110 cm, and 120-130 cm DBH category.

In CFs managed for 15 yrs., the higher density of trees was also found in 5-10 cm (224.40 tree ha^{-1}) DBH category followed by 10-20 cm (159.80 tree ha^{-1}), 70-80 cm (37.40 tree ha^{-1}), 60-70 cm (34 tree ha^{-1}) and 20-30 cm, 40-50 cm, 50-60 cm (23.80 tree ha^{-1}) (Figure 4.15). However, 3.40 tree ha^{-1} and 6.80 tree ha^{-1} was recorded in 110-120 cm, 120-130 cm, >150 cm and 105-110 cm DBH category respectively.

Moreover, the density of trees in CFs managed for 4 yrs., was highest in 5-10 cm (482.80 tree ha^{-1}) DBH category followed by 10-20 cm (353.60 tree ha^{-1}), 20-30 cm (88.40 tree ha^{-1}), 40-50 cm (37.40 tree ha^{-1}) and 30-40 cm (17 tree ha^{-1}) (Figure 4.15). However, the lowest tree density was in 70-80 cm and 80-90 cm (6.80 tree ha^{-}

[1]) DBH category. The size class distribution diagram of the total number of individual trees in the three community managed forests displayed an interrupted curve. The density of the trees with larger girth size was higher than that of the smaller girth size.

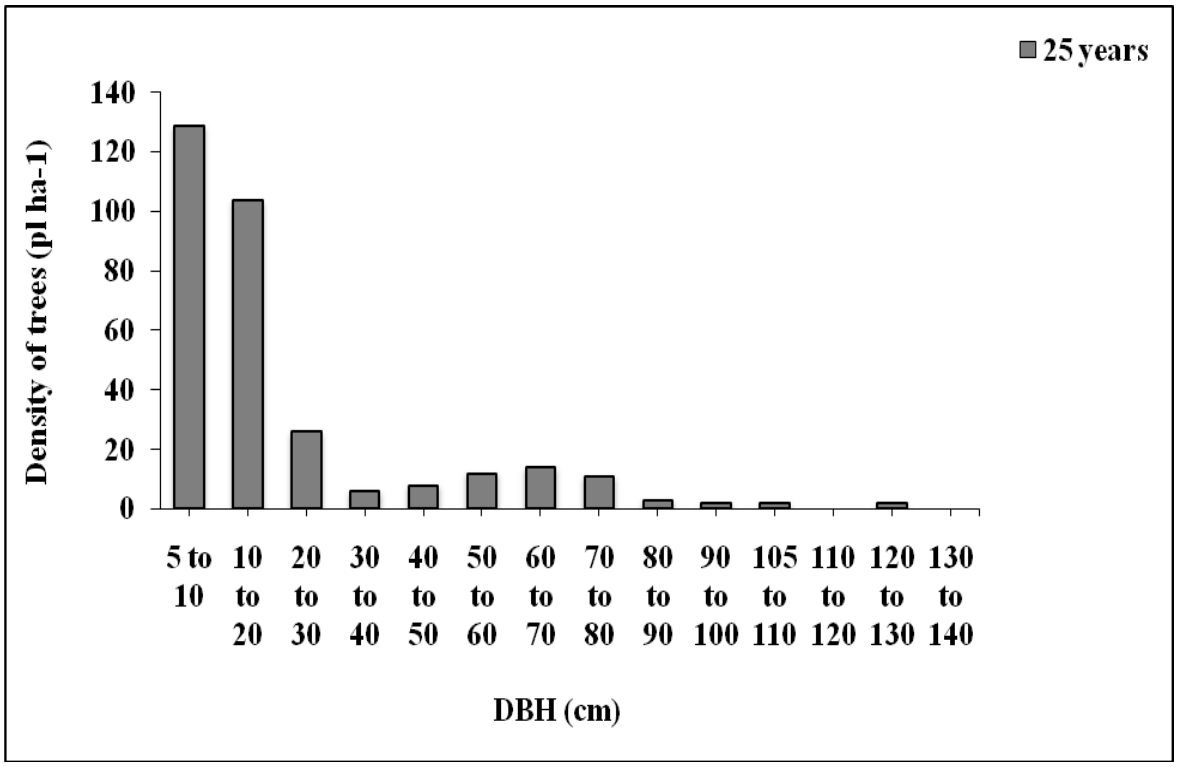

Figure 4.12 Size-class distribution of the tree species in CFs managed for 25 yrs.

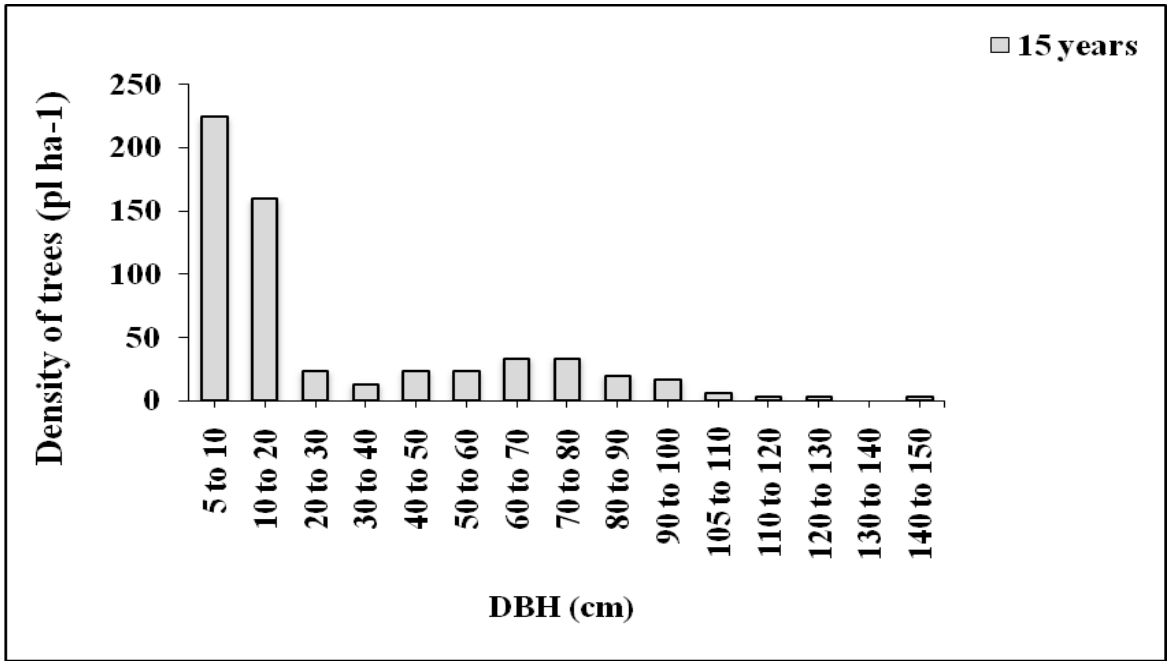

Figure 4.13 Size-class distribution of the tree species in CFs managed for 15 yrs.

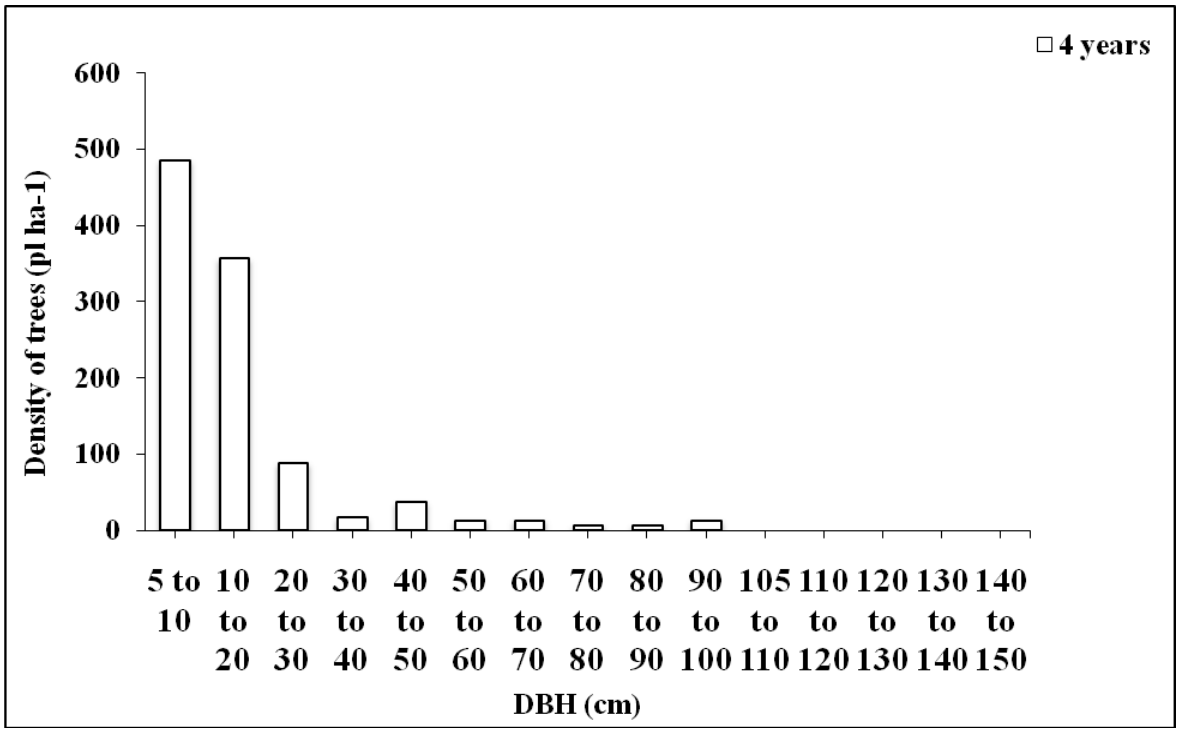

Figure 4.14 Size-class distribution of the tree species in CFs managed for 4 yrs.

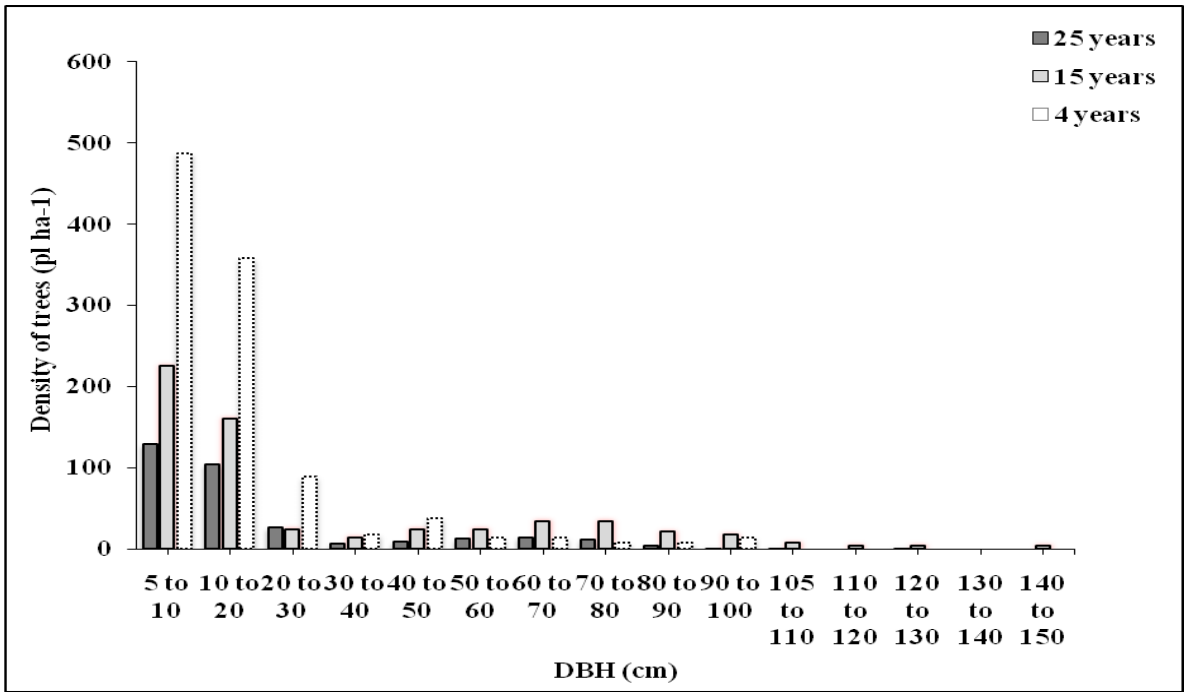

Figure 4.15 Size-class distribution of the trees with the density of trees species in each DBH class category in all study sites.

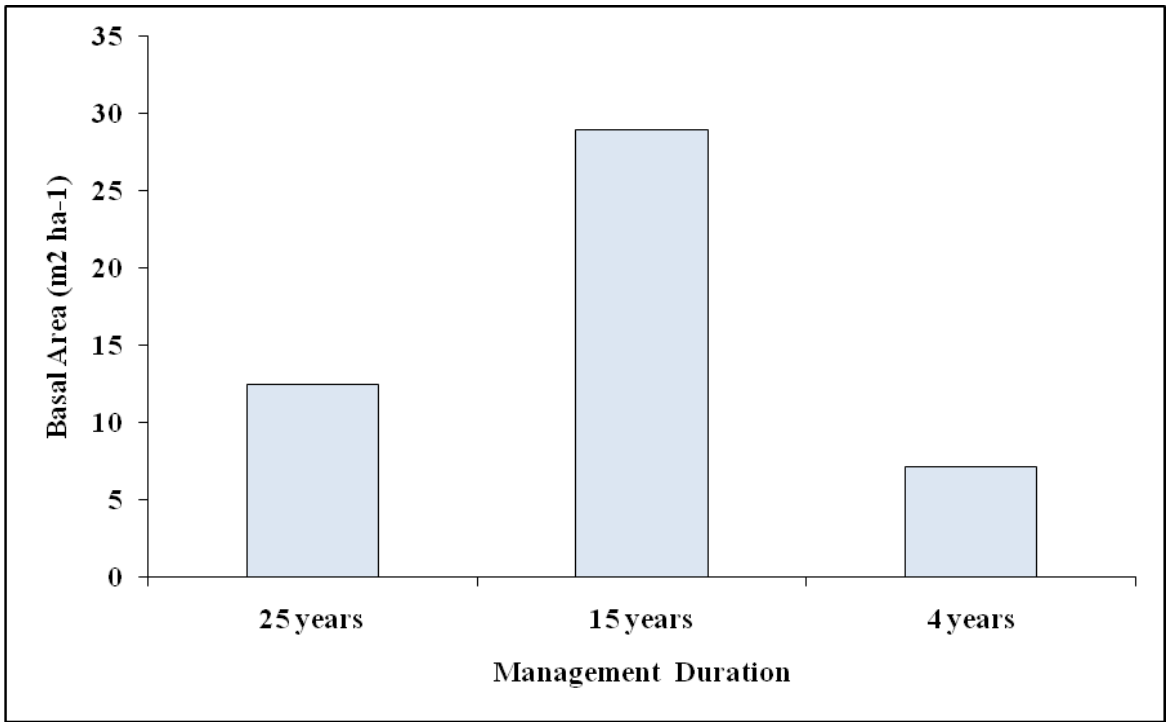

Figure 4.16 Total basal area of tree species of CFs managed for 25 yrs., 15 yrs. & 4 yrs.

The total basal area of tree species of CFs managed for 25 yrs., 15 yrs. and 4 yrs. was 12.64 m^2 ha^{-1}, 28.96 m^2 ha^{-1} and 7.15 m^2 ha^{-1} respectively.

4.4. Tree carbon stock

The total mean tree C-stock was highest in CFs managed for 25 yrs. (648.29 t ha^{-1}) followed by CFs managed for 15 yrs. (501.96 t ha^{-1}) and CFs managed for 4 yrs. (242.88 t ha^{-1}) (Figure 4.17). There was a significant difference ($P < 0.01$) between the estimated mean total trees C-stock among all three community forests tested by Tukey's test (Figure 4.17). However, there was no significant difference between the estimated mean total tree carbon stock among CFs managed for 25 yrs., 15 yrs. & 4 yrs.

S. robusta had the highest carbon stock value in all three community managed forests. The mean total carbon stock of *S. robusta* (483.74 t ha^{-1}) was highest followed by *T. alata (*95.46 t ha^{-1}), *A. cordifolia* (31.73 t ha^{-1}) and *S. oleosa* (14.42 t ha^{-1}) in CFs managed for 25 yrs. (Table 4.1). Similarly, the mean total C-stock of *S. robusta* (359.17 t ha^{-1}) was also highest followed by *T. alata* (92.26 t ha^{-1}) and *S. oleosa* (17.72 t ha^{-1}) and *A. cordifolia* (17.35 t ha^{-1}) in CFs managed for 15 yrs. (Table 4.2).

And the mean total C-stock of *S. robusta* (101.45 t ha^{-1}) was highest followed by *T. alata* (71.59 t ha^{-1}), *A. cordifolia* (28.75 t ha^{-1}) and *S. cumini* (19.26 t ha^{-1}) in CFs managed for 4 yrs. (Table 4.3).

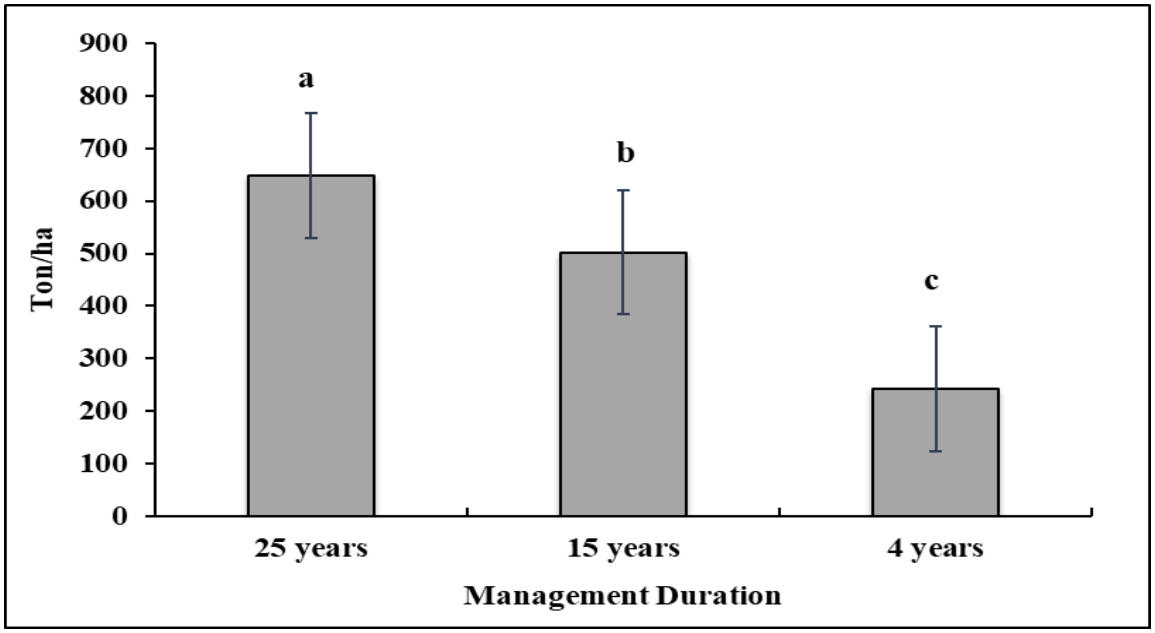

Figure 4.17 The mean total tree carbon stock in CFs managed for 25 yrs., 15 yrs. and 4 yrs. Different lowercase letters above the bar graph shows the significant difference at $P < 0.01$ level.

Table 4.1 Tree carbon stock (t ha^{-1}) and its percentage in CFs managed for 25 yrs.

Name of species	**Carbon stock (t ha^{-1})**	**Carbon stock (%)**
Shorea robusta	483.74	74.61
Terminalia alata	95.46	14.72
Schleichera oleosa	14.42	2.22
Mallotus phillipensis	1.05	0.16
Buchanania cochinchinensis	0.88	0.13
Syzygium cumini	6.37	0.98
Lagerstroemia parviflora	1.34	0.20
Dalbergia sissoo	1.11	0.17
Senegalia catechu	4.78	0.73
Semecarpus anacardium	1.61	0.24
Adina cordifolia	31.73	4.89
Syzygium nervosum	0.24	0.03

Phyllanthus emblica	0.26	0.04
Ficus benghalensis	3.03	0.46
Ficus religiosa	2.22	0.34

Table 4.2 Tree carbon stock (t ha^{-1}) and its percentage in CFs managed for 15 yrs.

Name of species	**Carbon stock (t ha^{-1})**	**Carbon stock (%)**
Shorea robusta	359.17	54.69
Terminalia alata	92.26	14.05
Syzygium cumini	5.69	0.86
Adina cordifolia	17.35	2.64
Schleichera oleosa	17.72	2.69
Mallotus phillipensis	0.53	0.08
Aegle marmelos	0.09	0.01
Grewia optiva	1.25	0.19
Diospyros melanoxylon	1.44	0.21
Dalbergia sissoo	0.08	0.01
Terminalia chebula	0.15	0.02
Terminalia bellirica	6.21	0.94

Table 4.3 Tree carbon stock (t ha^{-1}) and its percentage in CFs managed for 4 yrs.

Name of species	**Carbon stock (t ha^{-1})**	**Carbon stock (%)**
Shorea robusta	101.45	41.77
Terminalia alata	71.59	29.47
Lannea coromandelica	3.81	1.56
Syzygium cumini	19.26	7.92
Adina cordifolia	28.75	11.83
Mallotus phillipensis	4.75	1.95
Semecarpus anacardium	0.19	0.07
Casearia graveolens	0.04	0.01
Buchanania cochinchinensis	1.57	0.64

Lagerstroemia parviflora	2.64	1.08
Senegalia catechu	2.28	0.94
Terminalia anogeissiana	6.53	2.69

4. 5. Regeneration status of *S. robusta*

To investigate *S. robusta's* pattern of regeneration in the study areas, the densities of seedlings, saplings, and trees were estimated. In the present study, the density of seedlings was higher in CFs managed for 25 yrs. (102500 pl ha^{-1}) followed by CFs managed for 15 yrs. (84833.33 pl ha^{-1}) and CFs managed for 4 yrs. (69166.66 pl ha^{-1}) (Figure 4.21). Similarly, the density of saplings was higher in CFs managed for 25 yrs. (3426.66 pl ha^{-1}) followed by CFs managed for 15 yrs. (3146.66 pl ha^{-1}) and CFs managed for 4 yrs. (2160 pl ha^{-1}) (Figure 4.21). However, the density of *S. robusta* tree was higher in CFs managed for 25 yrs. (440 pl ha^{-1}) followed by CFs managed for 4 yrs. (336.66 pl ha^{-1}) and CFs managed for 15 yrs. (316.66 pl ha^{-1}). (Figure 4.21). As a result, CFs managed for 25 yrs. had higher tree, sapling, and seedling densities followed by CFs managed for 15 yrs. & CFs managed for 4 yrs. Statistically the density of seedlings, saplings and trees were significantly different in all forests performed in One-way ANOVA (Table 4.4).

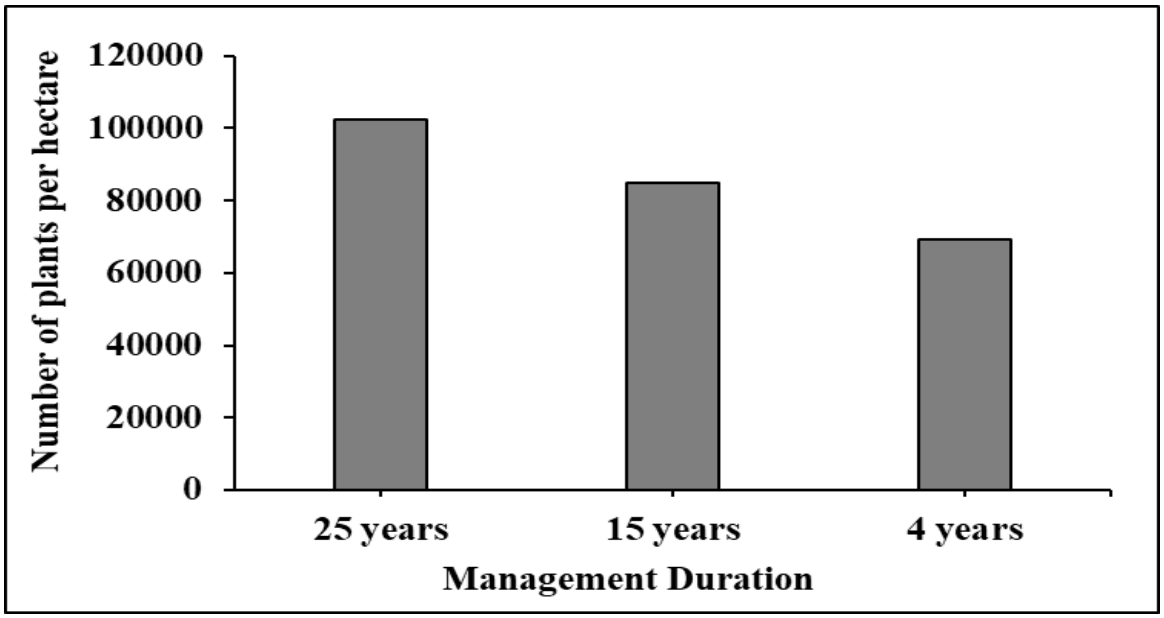

Figure 4.18 Regeneration status of seedlings of *S. robusta* in CFs managed for 25 yrs., 15 yrs. & 4 yrs.

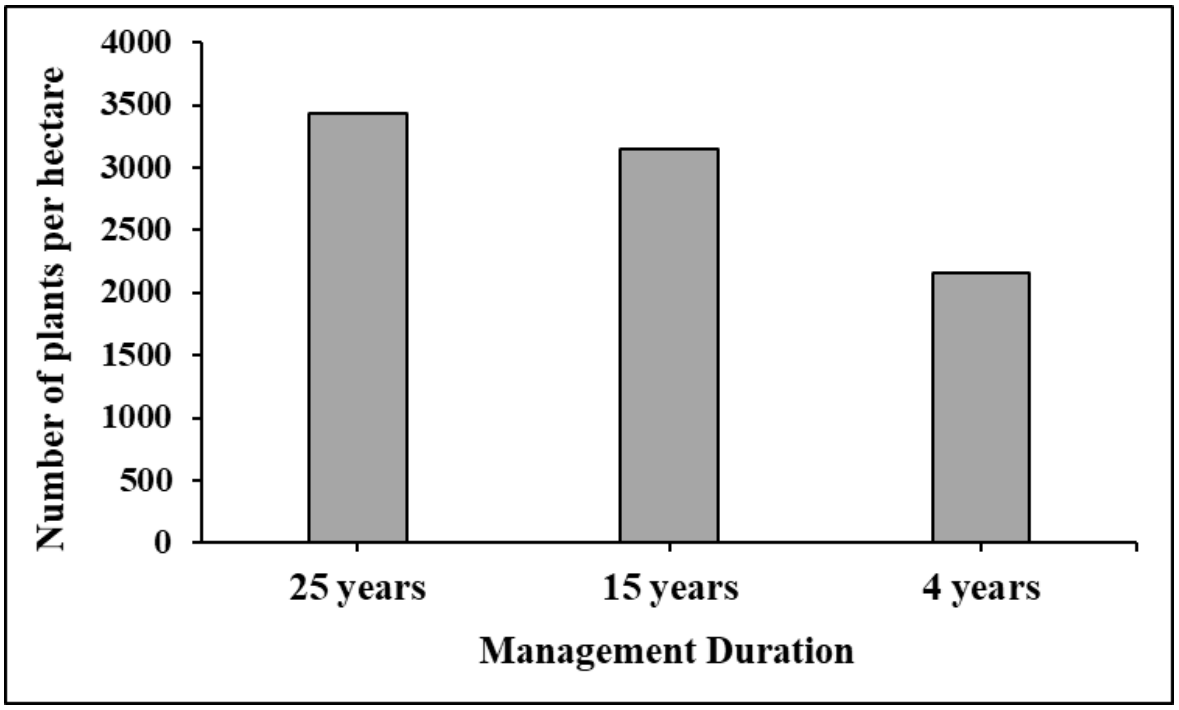

Figure 4.19 Regeneration status of saplings of *S. robusta* in CFs managed for 25 yrs., 15 yrs. & 4 yrs.

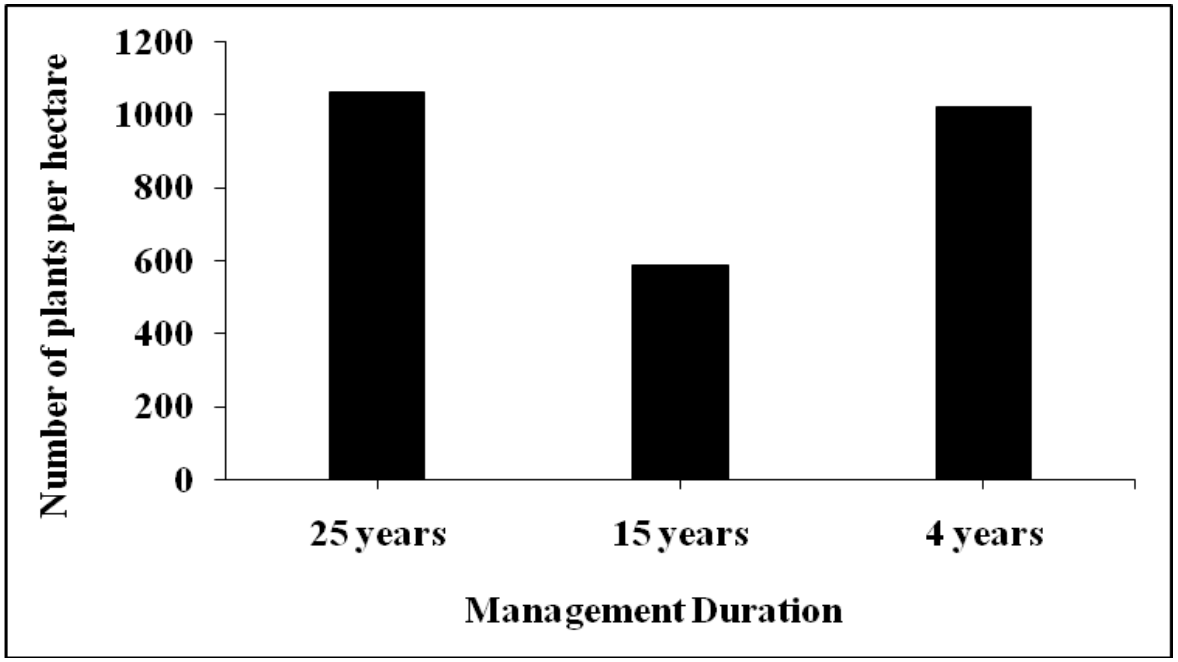

Figure 4.20 Regeneration status of trees of *S. robusta* in CFs managed for 25 yrs., 15 yrs. & 4 yrs.

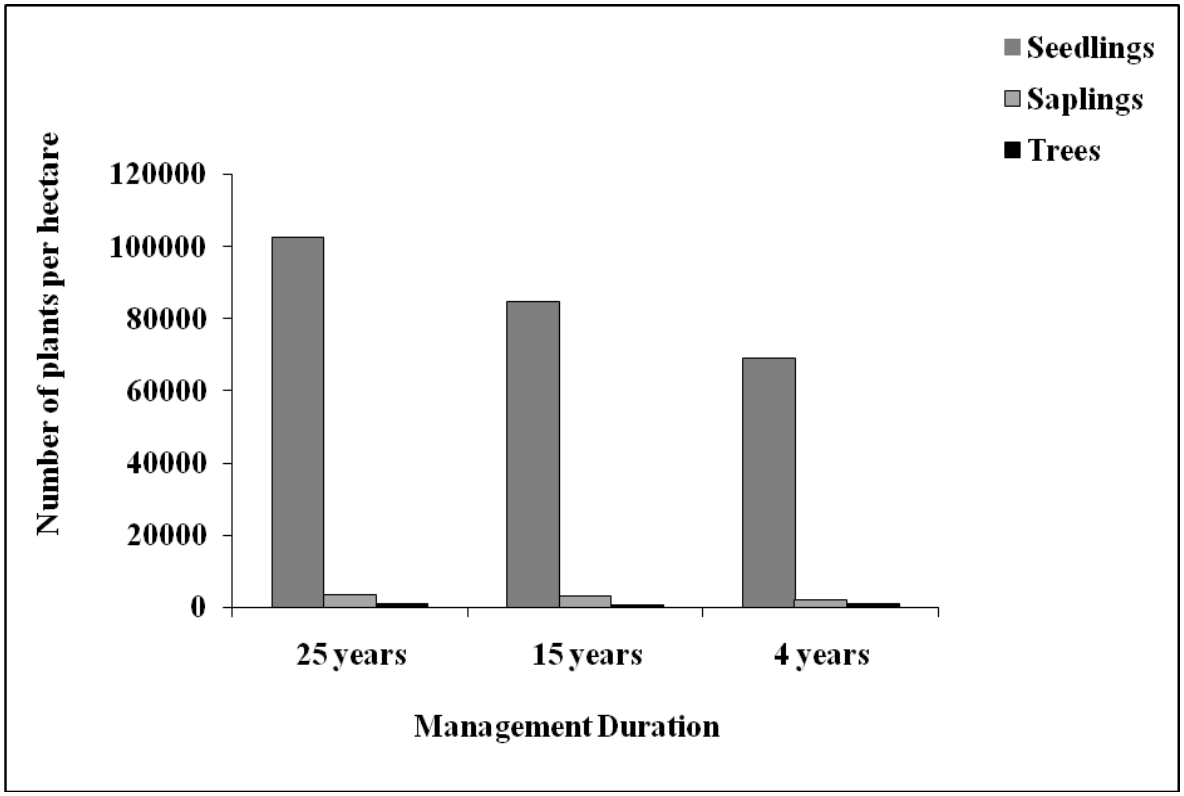

Figure 4.21 Regeneration status of seedlings, saplings & trees of *S. robusta* in CFs managed for 25 yrs., 15 yrs. and 4 yrs.

Table 4.4 The density of seedlings, saplings, and trees of Sal in CFs managed for 25 yrs., 15 yrs. & 4 yrs. with the significant difference (p-value) of variables performed by One-way ANOVA.

Management duration	**Seedlings (pl ha^{-1})**	**Saplings (pl ha^{-1})**	**Trees (pl ha^{-1})**	**p-value**
25 yrs.	102500	3426.67	440	< 0.001
15 yrs.	84833.34	3146.67	316.67	< 0.001
4 yrs.	69166.67	2160	336.67	< 0.001

CHAPTER 5: DISCUSSION

5.1. Tree diversity

Species diversity is a measurement of a region's evenness and species richness (Awasthi *et al.,* 2015). The Shannon-Weiner Diversity Index (H) is frequently used to describe species diversity in a community. The value of Shannon-Weiner Diversity index (H) was highest in the CFs managed for 25 yrs. (1.869) followed by CFs managed for 4 yrs. (1.805) and lowest in the CFs managed for 15 yrs. (1.455). All three CFs used silvicultural techniques such thinning, pruning, selective cutting, clearing shrubs, etc. however the CFs managed for 15 yrs. used more of these techniques than the CFs managed for 25 yrs. or the CFs managed for 4 yrs. This might be one of the reasons for the high diversity in the CFs managed for 25 yrs. Management techniques can have an impact on plant diversity (Awasthi *et al.,* 2015) and changes in habitat, soil, climate, location, and disturbance can have a significant impact on tree species diversity (Ram *et al.,* 2004).

Similarly, species richness was found highest in the CFs managed for 25 yrs., followed by CFs managed for 15 yrs. & 4 yrs. in *S. robusta* forest. The return of formerly extinct understory species into forest gaps may be the cause of the CFs managed for 25 yrs. high species richness (Waring and Running, 2007).

5.2. Community attributes

Shameem and Kangroo, (2011) state that a species with a high IVI is more dominant, capable of vigorous regeneration, and has a bigger ecological amplitude. All community managed forests have the highest *S. robusta* Importance Value Index (IVI). Similar conditions have also been recorded in inner terai Sal forests (Acharya *et al.,* 2006; Kandel, 2007) and mid hill Sal forests (Shrestha, 2005). Generally, *S. robusta* is the dominant tree species in the forests where it occurs (Tripathi and Shankar, 2014). The dominance of *S. robusta* is influenced by successional changes, age, associated species and the availability of resources (Mandal and Joshi, 2014). The superior seed distribution abilities and pollen grains of some species may be the cause of their dominance (Rahman *et al.,* 2011).

The highest tree density (1063.33 pl ha^{-1}) was found in CFs managed for 25 yrs. followed by CFs managed for 4 yrs. (1020 pl ha^{-1}) and CFs managed for 15 yrs. (586.66 pl ha^{-1}). The values reported by present work were higher than the values

reported for Sal Forest by Giri, (1999) and Acharya, (2007). According to Saxena, (1979) tropical forests typically have tree densities between 550 and 1100 pl ha^{-1}. The soil characteristics, natural disasters, and human activity can all have an impact on the variation in tree density (Naidu and Kumar, 2016).

5.3. Size-class distribution

The three community-managed woodlands' size class distribution diagrams showed an interrupted curve for the total number of individual trees. Sharma *et al.,* (2020) found a similar tendency in Sal Forest. The density of the trees with larger girth sizes was greater than that of the trees with smaller girth sizes, which represented the forest's maturity. However, the density of the tree was higher in DBH ranging 5-30 cm in 25 yrs. community managed forests indicating regenerating forest. Forest regeneration may have been triggered by anthropogenic and natural disturbances (Timilsina *et al.,* 2007; Sharma *et al.,* 2020).

5.4. Carbon stock

5.4.1. Tree carbon stock in *S. robusta* forests

The mean total tree C-stock of the present study was highest in CFs managed for 25 yrs. (648.29 t ha^{-1}) and lowest in CFs managed for 4 yrs. (242.88 t ha^{-1}). The C-stock of CFs managed for 15 yrs. was very different from the CFs managed for 25 yrs. i.e., 501.96 t ha^{-1}. The C-stock of the current study was higher than the C-stock estimated by numerous researchers in *S. robusta* forests under various management styles from Nepal and India. Baral *et al.,* (2009); Shrestha, (2009); Pandey *et al*., (2012); Mbaabu *et al*., (2014); Neupane and Sharma, (2014); Thapa-Magar and Shrestha, (2015); Pathak, (2015); Mandal *et al.,* (2016); Bhatta and Devkota, (2020); Joshi *et al.,* (2021) and Regmi *et al.,* (2021) reported lower value of tree carbon stock from different parts of Nepal compared to present study. Similarly, in comparison to earlier studies conducted in *S. robusta* forests in various parts of India (Baishya *et al.,* 2009; Singh, 2010; Shahid and Joshi, 2015), the C-stock of the current study was also greater. However, Pandey and Bhusal, (2016) reported substantial carbon stock in communally managed forest from Gorkha and Chitwan district, and they also achieved comparable results.

Higher carbon stock in 25 yrs managed forest may be due to the higher tree density in the forest compared to other forests. Forest C-stock fluctuation and sequestration capacity carbon depends on a number of variables, including the type of forest, the age of the forest, the size and density of trees, biomass decomposition, stand condition, the local climate (temperature, rainfall, etc.), the degree and history of disturbance, land management activities, and other human-induced disturbances (Dixon *et al.*, 1994; Pandit, 2014; Thapa-Magar and Shrestha, 2015). According to time, space, and other aspects including plot size, tree height and DBH measurements, biomass estimation, and carbon estimation using various methodologies, the assessment of carbon stock in each forest may vary (Saner *et al.,* 2012). The forests with higher tree DBH and height had higher biomass and C-stock, but these factors don't always become a variation factor for biomass and C-stock as C-stock of the forest does not always increase with an increase in the size of the individual tree (Baral *et al*., 2009; Thapa-Magar and Shrestha, 2015). Tree density also has a significant effect on biomass and C-stock as shown in the results of various researchers (Baral *et al.,* 2009; Mbaabu *et al.,* 2014; Behera *et al.,* 2017; Dangal *et al.,* 2017).

When a forest gets older, its biomass and carbon stores typically rise (Baker *et al.*, 2004; Alexandrov, 2007) due to the difference in the age of the forests. This finding supports the claim that CF management has a favorable effect on the forest in terms of C-stock (Chhatre and Agrawal, 2009; Pandey *et al.,* 2014; Solomon *et al.,* 2017). Several earlier studies had demonstrated an increase in C-stock of the forests with an increase in forest age (Pandey *et al.,* 2014; Thapa-Magar and Shrestha, 2015; Mandal *et al.,* 2016; Behera *et al.,* 2017; Dangal *et al.,* 2017). The potential to sequester carbon and store it as biomass increases with the age of forest (Bhatta, 2016) and the young, aged forest store less carbon in compared to mature forest (Behera *et al.,* 2017). The present investigation reported the higher carbon stock with the increase in basal area and decrease in density. The present study reported higher number of mature trees and non-degraded forests in CFs managed for 25 yrs. in comparison to CFs managed for 15 yrs. & CFs managed for 4 yrs. This might be the reason for higher carbon stock in CFs managed for 25 yrs.

5.5. Regeneration of *S. robusta*

5.5.1. Regeneration status of *S. robusta*

The key component that determines a forest's sustainability is regeneration. According to Pandey *et al.,* (2012) a healthy regenerating forest has more than 5000 seedlings and more than 2000 saplings per hectare. *S. robusta* seedling and sapling densities in CFs managed for 25 years are 1, 02,500 per ha^{-1} and 3,426.66 per ha^{-1}, respectively, in the current study. In CFs managed for 15 years, the densities are 84,833.33 per ha^{-1} and 3,146.66 per ha^{-1}, respectively. In CFs managed for 4 years, the density of seedlings and saplings 69,166.66 per ha^{-1} and 2,160 pl ha^{-1}, respectively. According to other related research, this suggests good generation (Pandey *et al.,* 2012). In comparison to values published from other regions of Nepal (Giri *et al*., 1999; Shrestha, 2009; Acharya and Shrestha, 2011; Basyal *et al*., 2011; Poudyal, 2013; Awasthi *et al.,* 2015; Napit, 2015), the density of seedling in CFs managed for 25 yrs, 15 yrs and 4 yrs was greater. In contrast to the current study, Suoheimo, (1999) and Joshi *et al.,* (2021) have reported greater value of seedling density. In comparison to the current study, Joshi *et al.,* 2021; Shrestha, 2009; Aryal *et al.,* 2021; and Poudel *et al.,* 2021 have reported greater values of sapling density. A healthy forest regeneration stage is indicated by a higher tree density and smaller girth size (Basyal *et al.,* 2011). Similarly, the density of *S. robusta* tree was highest in 5-30 cm DBH category in CFs managed for 25 yrs., 15 yrs. and 4 yrs. indicating good regeneration. In comparison to 15 years and 4 years of managed forest, the 25 yrs managed forest may have a lower canopy percentage, which could account for the higher density of Sal seedlings. Sal is a light-demanding species, and in most circumstances, full overhead light is required from the very beginning of development (Champion and Seth, 1968). The growth of understory seedlings and saplings is encouraged by the opening of the canopy in the forest stand (Troup, 1986). As a result, it was discovered that *S. robusta* regeneration in CFs controlled for 25 yrs was greater than that in CFs managed for 4 yrs.

Regeneration is affected by a variety of factors, including soil nutrients, sunlight, temperature, rainfall, canopy cover, and human pressure (Shrestha *et al.,* 2007; Bhatta and Devkota, 2020). It is possible that some of the seedlings were unable to withstand the severe environmental conditions and effectively compete with the herbaceous flora (Basyal *et al.,* 2011). The differences between the current study's regeneration pattern and the findings of other studies conducted in various regions of the nation could be caused by differences in a number of variables, including the study site's topography, climate, stand, soil nutrients, management techniques, and disturbances (both natural and man-made) (Gautam and Devoe, 2006). The density of the trees indicates that the community played a significant part in preserving the forests after they were turned up to it. They have prevented the cutting of forest trees as well as any unlawful commerce. However, they were unable to transition the seedlings to the sapling phase.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

6.1. Conclusion

The CFs managed for 25 yrs had the highest tree carbon stock, tree diversity, and density of seedlings and saplings; however, the CFs managed for 4 yrs had the lowest tree carbon stock, tree diversity and poor regeneration. With a mean value of 464.37 t ha^{-1}, the carbon stock varied from 242.88 to 648.29 t ha^{-1}. The length of forest management determined the increase in carbon stock; forests under care for 25 yrs had the highest carbon stock. The findings unequivocally demonstrated that community management has potential to sequester the high amount of carbon. As a result, by reducing deforestation and degradation and sequestering atmospheric CO2 into forest biomass, CFs have the ability to mitigate climate change. As a result, the community forests in the current study area qualify for the REDD+ program's carbon accounting program. The regeneration status of seedlings, and saplings of *S. robusta* were highest in CFs managed for 25 yrs. followed by 15 yrs. & 4 yrs. All three CFs, however, had acceptable regeneration status and were appropriately regenerating, which is a sign of a healthy forest.

6.2. Recommendations

1. Even though the density of saplings met the standards and was in acceptable shape, it was nevertheless slightly above the lower bounds. In order to maintain the continuity and general health of the forest, it is imperative that sufficient care be paid to protecting its saplings. Strict prohibitions must be placed on the grazing of cattle and the unsustainable harvesting of firewood and fodder.
2. Community forest user groups should manage anthropogenically induced disturbances and create suitable management strategies to establish seedling to sapling phase, which ensures the tree density and contribute in considerable stock of carbon.
3. The free grazing should also be outright restricted to promote greater forest regeneration.

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APPENDICES

Appendix I. Data sheets used during field sampling.

Data sheet for tree species

Size of plot for tree: Establish 10m × 10m Square plot.

Date: ……Transect No: ……. Plot No: ….....Plot size: …….

Locality: ……Forest Type: ……...Aspect: …… Slope: ……....

Latitude: ……..... Longitude: …… Elevation: ……....

Tree canopy (%): ……..... Ground vegetation cover (%): ……....

Disturbance: ……..……...

SN	Scientific name of Tree species	Local name	DBH (cm)	Estimated height (m)	Remarks
1					
2					
3					
4					

Data sheet for sapling

Size of plot for sapling: Establish 4 sub-plots of 5m × 5m Square plot inside the main plot.

Transect No: .....Plot No: ….....Plot size: .....

Quadrat no: .....Altitude: ..... Site: .....

SN	Scientific name of Tree species	Local name	DBH (cm)	Estimated height (m)	Remarks
1					
2					
3					
4					

Data sheet for seedling

Size of plot for seedling: Establish two 1m × 1m Square plots inside the main plot.

Transect No: .....Plot No: ….....Plot size: .....

Quadrat no: .....Altitude: ..... Site: .....

S N	**Sub-plot 1**			**Sub-plot 2**		
	Scientific name of Tree species	**Number**	**Cover (%)**	**Scientific name of Tree species**	**Number**	**Cover (%)**
1						
2						
3						
4						

Appendix II. Referenced literatures used for the standard tree density of the tree species.

S. N	**Name of species**	**References**
1	*Adina cordifolia* (Roxb.) Brandis	Jackson (1994)
2	*Aegle marmelos* L. Correa	Jackson (1994)
3	*Buchanania cochinchinensis* (Lour.)	Jackson (1994)
4	*Casearia graveolens* Dalzell	Reyes *et al*. (1992)
5	*Dalbergia sissoo* Roxb. ex-DC.	Jackson (1994)
6	*Diospyros melanoxylon Roxb.*	Jackson (1994)
7	*Ficus benghalensis* L.	Reyes *et al*. (1992)
8	*Ficus religiosa* L.	Jackson (1994)
9	*Grewia optiva* J.R Drumm. ex Burret	Jackson (1994)
10	*Lagerstroemia parviflora* Roxb.	Jackson (1994)
11	*Lannea coromandelica* (Houtt.) Merr.	Reyes et al. (1992)
12	*Mallotus philippensis* (Lam.) Mull.Arg	Reyes *et al*. (1992)
13	*Phyllanthus emblica* L.	Jackson (1994)
14	*Schleichera oleosa* (Lour.) Oken	Reyes *et al*. (1992)

15	*Semecarpus anacardium* L.fil.	Reyes *et al*. (1992)
16	*Senegalia catechu* (L.f.) Willd.	Jackson (1994)
17	*Shorea robusta* Gaertn. f.	Jackson (1994)
18	*Syzygium cumini* (L.) Skeels	Jackson (1994)
19	*Syzygium nervosum* DC.	Reyes *et al*. (1992)
20	*Terminalia alata* B.Heyne ex Roth	Jackson (1994)
21	*Terminalia anogeissiana* Gere & Boatwr	Jackson (1994)
22	*Terminalia bellirica* (Gaertn.) Roxb.	Jackson (1994)
23	*Terminalia chebula* Retz.	Jackson (1994)

Appendix III. Density (D), relative density (RD), frequency (F), relative frequency (RF), basal area (BA), relative basal area (RB) and important value index (IVI) of tree species of CFs managed for 25 yrs.

S. N	**Name of species**	**D (pl ha^{-1})**	**RD**	**F (%)**	**RF**	**BA (m^2 ha^{-1})**	**RBA**	**IVI**
1	*Shorea robusta*	455.17	14.78	96.66	22.13	5399.10	67	103.92
2	*Terminalia alata*	251.72	8.17	96.66	22.13	1189	14.75	45.07
3	*Schleichera oleosa*	100	3.24	26.66	6.10	195.33	2.42	11.77
4	*Mallotus phillipensis*	171.42	5.56	46.66	10.68	69.63	0.86	17.11
5	*Buchanania cochinchinensis*	164.28	5.33	46.66	10.68	74.16	0.92	16.94
6	*Syzygium cumini*	120	3.89	16.66	3.81	116.26	1.44	9.15
7	*Lagerstroemia parviflora*	162.5	5.27	26.66	6.10	55.8	0.69	12.07
8	*Dalbergia sissoo*	350	11.36	6.66	1.52	42.83	0.53	13.42
9	*Senegalia catechu*	500	16.23	3.33	0.76	89.43	1.10	18.10
10	*Semecarpus anacardium*	144.44	4.69	30	6.87	73.26	0.90	12.47

11	*Adina cordifolia*	100	3.24	13.33	3.05	516.76	6.41	12.71
12	*Syzygium nervosum*	160	5.19	16.66	3.81	15.63	0.19	9.20
13	*Phyllanthus emblica*	200	6.49	3.33	0.76	7.53	0.09	7.35
14	*Ficus benghalensis*	100	3.24	3.33	0.76	116.73	1.44	5.45
15	*Ficus religiosa*	100	3.24	3.33	0.76	95.76	1.18	5.19

Appendix IV. Density (D), relative density (RD), frequency (F), relative frequency (RF), basal area (BA), relative basal area (RB) and important value index (IVI) of tree species of CFs managed for 15 yrs.

S. N	**Name of species**	**D (pl ha^{-1})**	**RD**	**F (%)**	**RF**	**BA (m^2 ha^{-1})**	**RBA**	**IVI**
1	*Shorea robusta*	327.58	15.88	96.66	40.28	6014.53	72.30	128.47
2	*Terminalia alata*	142.85	6.92	23.33	9.72	1193.93	14.35	31
3	*Syzygium cumini*	291.66	14.14	40	16.66	221.23	2.65	33.47
4	*Adina cordifolia*	100	4.84	6.66	2.77	407.63	4.90	12.52
5	*Schleichera oleosa*	133.33	6.46	10	4.16	256.63	3.08	13.71
6	*Mallotus phillipensis*	166.66	8.08	40	16.66	48.06	0.57	25.32
7	*Aegle marmelos*	100	4.84	6.66	2.77	7	0.08	7.70
8	*Grewia optiva*	400	19.39	3.33	1.38	38.2	0.45	21.24
9	*Diospyros melanoxylon*	100	4.84	3.33	1.38	40.8	0.49	6.72
10	*Dalbergia*	100	4.84	3.33	1.38	5.36	0.06	6.30

	sissoo							
11	*Terminalia chebula*	100	4.84	3.33	1.38	8	0.09	6.33
12	*Terminalia bellirica*	100	4.84	3.33	1.38	76.66	0.92	7.15

Appendix V. Density (D), relative density (RD), frequency (F), relative frequency (RF), basal area (BA), relative basal area (RB) and important value index (IVI) of tree species of CFs managed for 4 yrs.

S. N	**Name of species**	**D (pl ha^{-1})**	**RD**	**F (%)**	**RF**	**BA (m^2 ha^{-1})**	**RBA**	**IVI**
1	*Shorea robusta*	408	18.31	83.33	20.66	1569.13	36.63	75.61
2	*Terminalia alata*	200	8.97	73.33	18.18	981.26	22.90	50.06
3	*Lannea coromadelica*	116.66	5.23	20	4.95	156.43	3.65	13.84
4	*Syzygium cumini*	136.36	6.12	36.66	9.09	313.53	7.31	22.53
5	*Adina cordifolia*	128.57	5.77	23.33	5.78	565.03	13.19	24.74
6	*Mallotus phillipensis*	366.66	16.45	80	19.83	336.12	7.84	44.14
7	*Semecarpus anacardium*	100	4.48	3.33	0.82	9.53	0.22	5.53
8	*Casearia graveolens*	100	4.48	3.33	0.82	2.86	0.06	5.38
9	*Buchanania cochinchinensis*	171.42	7.69	23.33	5.78	74.03	1.72	15.20
10	*Lagerstroemia parviflora*	100	4.48	30	7.43	89.30	2.08	14.01
11	*Senegalia catechu*	250	11.22	20	4.95	83.56	1.95	18.13
12	*Terminalia anogeissiana*	150	6.73	6.66	1.65	102.56	2.39	10.77

Appendix VI. Selected photo plates.

S. robusta sapling

Measuring tree DBH

Quadrat of sampling

Using clinometer to measure angle of inclination for tree height

S. robusta seedling

S. robusta canopy cover

Field teams and members of Shree Samaichi and Mahehara CF