Plant Community, Regeneration and Carbon Stock in Two Community Forests of Dang

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

BY

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I "Chiranjibi Dangi" therefore declares that the work enclosed here is totally original to me, unless otherwise indicated by reference or acknowledgement, and that it hasn't been published or submitted, in whole or in part, anywhere else in order to fulfill the requirements for any other degree or professional qualification. Every piece of writing, set of facts, or other work that is referenced in this thesis has been properly acknowledged and is included in the reference list.

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RECOMMENDATION

This is to recommended that the proposed research work entitled **"Plant community, regeneration and carbon stock in two community forest of Dang"** was conducted by "Chiranjibi Dangi", "TU Reg No. 5-2-1084-77-2014" under my guidance for the partial fulfillment of Master's Degree in Botany. The whole project work is based on his own scientific investigations. I hereby, suggest this work to be approved for Master's Degree in Botany.

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ABBREVIATIONS AND ACRONYMS

AGC	Aboveground carbon
BA	Basal area
BGC	Belowground carbon
C	Carbon
CF	Community forest
CMF	Collaborative managed forest
C-stock	Carbon stock
D	Density
DBH	Diameter at breast height
DS	Disturbed sites
F	Frequency
GIS	Geographical information system
GPS	Global positioning system
HDF	Highly disturbed forest
IVI	Important value index
K	Potassium
kg ha^{-1}	Kilogram per hectare
LDF	Less disturbed forest
m^2 ha^{-1}	Meter square per hectare
Mg ha^{-1}	Megagram per hectare
MS	Microsoft
N	Nitrogen
OM	Organic matter
P	Phosphorous
pl ha^{-1}	Plants per hectare

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ABSTRACT

Biotic and abiotic factors have led the Nepalese forest to the verge of degradation. The various disturbance factors, like grazing, human disturbance, forest fire, deforestation, construction activities, and habitat destruction, have deteriorated the quality of the forest. The present investigation aimed to study the effect of disturbances on carbon stock, regeneration and soil parameters in two community forests: Pathivara community forest and Janakalyan community forest regarded as highly disturbed forest (HDF) and less disturbed forest (LDF) in Dang, western Nepal. A total of 60 circular plots were laid (30 each on HDF and LDF). The depth of 30 cm was used for the analysis of soil sample. Collected soil samples will be tested for organic matter, nitrogen content, potassium content, phosphorous content and pH. In the present study, 18 tree species belonging to 15 genera and 10 families were recorded. The Shannon index for HDF and LDF was 0.447 and 0.764, respectively. In both the sites, *Shorea robusta* had the highest IVI, followed by *Terminalia alata.* In both the sites, highest number of tree species were found between 10 - 20 cm categories. However, no any tree species were recorded in 40 – 50 cm and 50 – 60 cm categories in HDF. The tree with DBH from 5 to 60 cm were recorded in LDF. The carbon stock in the study areas of the plots ranged from 18.2 t/ha to 180.6 t/ha. However, the mean carbon stock value in HDF and LDF was 46.48 and 72.72 t/ha respectively. *S. robusta* contributed most in the storage of tree carbon in the forests. The density of total seedlings and saplings were higher in LDF compared to HDF. Though the density of trees was higher in HDF, statistical significant difference (p= 0.37) was not seen. LDF had the highest content of organic matter (OM), nitrogen (N) and potassium (K) compared to HDF (Table 4). However, phosphorus (P) content was higher in HDF compared to LDF. The pH content was found more acidic in LDF compared to HDF, though both site had acidic. The density of seedling and sapling were higher in LDF compared to HDF. The natural regeneration was better in terms of seedlings, however, the status of saplings were worst in both the sites indicating the overall poor regeneration. A rigorous implementation of the policy of community forest user group must be practiced in both the forest, especially in HDF to maintain the sustainability of forest, improve the natural regeneration, and enhance the carbon storage capacity and conservation of biodiversity.

Keywords: Community forest, disturbance, carbon stock, regeneration, plant diversity

शोधसार

जैविक र अजैविक तत्वले नेपाली वनलाई विनाशको कगारमा पुऱ्याएको छ । चरन, मानव अस्तव्यस्तता, जंगलमा आगलागी, वन फँडानी, निर्माण गतिविधि र बासस्थान विनाश जस्ता विभिन्न विकृति कारकहरूले वनको गुणस्तर खस्किँदै गएको छ। हालको अनुसन्धानको उद्देश्य दुई सामुदायिक वनहरूमा कार्बन स्टक, पुन: उत्पादन र माटोको मापदण्डमा हुने असरको अध्ययन गर्ने उद्देश्य थियो: पाथीभरा सामुदायिक वन र जनकल्याण सामुदायिक वन, उच्च विक्षिप्त वन (HDF) र पश्चिम नेपालको दाङमा कम विक्षिप्त वन (LDF)। । कुल ६० गोलाकार प्लटहरू राखिएका थिए (प्रत्येक HDF र LDF मा ३०)। माटोको नमूनाको विश्लेषणका लागि ३० सेन्टीमिटरको गहिराइ प्रयोग गरिएको थियो। संकलित माटोको नमूना जैविक पदार्थ, नाइट्रोजन सामग्री, पोटासियम सामग्री, फस्फोरस सामग्री र पीएचको लागि परीक्षण गरिनेछ। हालको अध्ययनमा, 15 वंश र 10 परिवारहरूसँग सम्बन्धित 18 रूख प्रजातिहरू रेकर्ड गरिएको थियो। HDF र LDF को लागि श्यानन सूचकांक क्रमशः 0=447 र 0=764 थियो। दुबै साइटहरूमा, शोरिया रोबस्टाको उच्चतम IVI थियो, त्यसपछि टर्मिनलिया अलाटा। दुबै साइटहरूमा, 10 – 20 सेन्टिमिटर कोटिहरू बीचको रूख प्रजातिहरूको उच्चतम संख्या फेला पर्यो। यद्यपि, HDF मा 40 – 50 सेन्टिमिटर र 50 – 60 सेन्टिमिटर कोटिहरूमा कुनै पनि रूख प्रजातिहरू रेकर्ड गरिएको थिएन। 5 देखि 60 सेन्टिमिटर सम्मको DBH भएको रूख LDF मा रेकर्ड गरिएको थियो। प्लटहरूको अध्ययन क्षेत्रहरूमा कार्बन स्टक 18=2 टन / हेक्टर देखि 180=6 टन / हेक्टर सम्म थियो। यद्यपि, HDF र LDF मा औसत कार्बन स्टक मूल्य क्रमशः 46.48 र 72.72 t/ha थियो। एस रोबस्टाले वनमा रूख कार्बनको भण्डारणमा सबैभन्दा बढी योगदान पुऱ्यायो। कुल बिरुवा र बिरुवाको घनत्व HDF को तुलनामा LDF मा उच्च थियो। एचडीएफमा रूखहरूको घनत्व बढी भए तापनि, सांख्यिकीय महत्त्वपूर्ण भिन्नता ($p = 0.37$) देखिएन। HDF (तालिका ४) को तुलनामा LDF मा जैविक पदार्थ (OM), नाइट्रोजन (N) र पोटासियम (K) को उच्चतम सामग्री थियो। यद्यपि, LDF को तुलनामा HDF मा फस्फोरस (P) सामग्री उच्च थियो। HDF को तुलनामा LDF मा pH सामग्री बढी अम्लीय पाइयो, यद्यपि दुवै साइटमा अम्लीय थियो। बिरुवा र बिरुवाको घनत्व HDF को तुलनामा LDF मा उच्च थियो। प्राकृतिक पुनरुत्थान बिरुवाको सन्दर्भमा राम्रो थियो, तथापि, बिरुवाको स्थिति समग्र रूपमा कमजोर पुनर्जनन संकेत गर्ने दुवै साइटहरूमा खराब थियो। सामुदायिक वन प्रयोगकर्ता समूहको नीतिको कडा कार्यान्वयन दुवै वनमा, विशेष गरी एचडीएफमा वनको दिगोपन कायम गर्न, प्राकृतिक पुनरुत्थानमा सुधार गर्न, र कार्बन भण्डारण क्षमता र जैविक विविधताको संरक्षणमा वृद्धि गर्न अभ्यास गरिनुपर्छ।

1. INTRODUCTION

1.1. Background

Nepal has a high biodiversity because of the variations in altitude, climate, and physical topography. There are 35 different forest types in Nepal and play a significant role in the climate system (Sohel *et al*., 2009) and act as a carbon source and sink (*Liu et al*., 2019). Habitat destruction, grazing, deforestation, and fire have posed a great threat to the plant species diversity and carbon stock in Nepal (Ghimire *et al*., 1999). Because of the variation in altitude, climate, and physical geography, Nepal is rich in biodiversity. There are 35 different forest types in Nepal.

The main human activities (Ciais *et al*., 2013) contributing to the rise in CO2 include burning of fossil fuels, other land-use changes, and deforestation (Le-Quere *et al*., 2018). Moderate disturbances frequently increase diversity while causing only minor structural changes in the forest, but extreme disturbances significantly reduce plant diversity and vegetation structure (Upadhaya *et al*., 2008). So disturbance not only modifies the composition and structure of the stand but also causes a large loss of stand biomass and C stock (Yohannes *et al*., 2015). The community forests have been subjected to various human disturbances due to management techniques, which could potentially affect the species diversity, biomass, community structure, and carbon store of the woods. Numerous factors, including forest types, species richness (Liu *et al*., 1885; Hu *et al*. 2015; Gogoi *et al*., 2020) succession stage, specific disturbance (Gogoi *et al*., 2017) land use histories, management intervention, and soils (Masera *et al*., 2003; Usuga *et al*., 2010; McKinley *et al*., 2011) influence the C stock of forest ecosystems.

Through photosynthesis, plants naturally sequester carbon, which is then stored in soil, above-ground biomass, and below-ground biomass (Adam, 2001; Aryal *et al*., 2017). Thus, carbon sequestration by green plants is an effective means of lowering greenhouse gas emissions and assisting in the mitigation and adaptation of the effects of climate change (Jina *et al*., 2009). Through the process of photosynthesis, plants absorb certain quantity of carbon dioxide from the atmosphere naturally and sequester in the form of aboveground biomass, belowground biomass, and also store in the soil, termed as carbon sequestration (Watson *et al*., 2000; Adam, 2001; Aryal *et al*., 2017). Species diversity and soil nutrients are critical factors influencing the capacity to store carbon (Dixon *et al.*, 1994; Wang, 2015).

Anthropogenic disturbances have the power to alter a stand's successional pattern, subsequently the forest's biomass and diversity. Biomass quantification is necessary to assess the state and direction and the ecosystem of forest across a variety of environmental gradients, as well as to gain a deeper understanding of the ecosystem's structure and functions (Ovington, 1962; Brown *et al*., 1989). Protected forests in developing nations are highly disturbed by human activity as a result of chopping, fire, extraction of fuel wood, unwanted grazing, and haphazard collection of non-timber forest products for the benefit of communities that reside in the forests (Jhariya *et al*., 2014).

Regeneration preserves the stability or sustainability of the woods for future generations while illuminating the species composition and community's developmental trend (Napit, 2015; Bose *et al*., 2016). To identify and select species with high value carbon stocks, it is essential to examine the regeneration status of various species as well as the forest community (Gairhe, 2015). Regeneration is the process by which new plants are produced through their young, and it may be measured or counted how many seedlings, saplings, and trees there are in a given area (Koirala, 2004; Acharya & Acharya, 2011). In the ecology of forests, regeneration plays a critical role in maintaining the community. A healthy forest has enough seedlings, saplings, and trees to support the forest's vitality, increased productivity, and sustainability (Chauhan *et al*., 2008; Awasthi *et al.*, 2015). One of the most successful practise in Nepal is the community forest program to conserve biodiversity (Pathak & Baniya, 2016). There are a total of 17809 community forest user groups in Nepal and they cover an area of 1.665 million hectares out of 5.5 million hectares of forest in Nepal (Pathak & Baniya, 2016).

Moreover, the physico-chemical properties of the soil is not similar in all the environements. It varies according to the variation in space, biotic factors, topographic factors, microbial activities and vegetation (Bojko & Kabala, 2016). Temperature, precipitation, soil properties, and some other factors have a significant impact on vegetation in a given location. These parameters are influenced by altitude (Bhattarai & Mandal, 2018).

1.2 Rationale of the study

Nepal's forests are currently under great risk as a result of fast population increase, Unsustainable harvesting, overgrazing, illegal trading in forest resources, deforestation, careless gathering of forest products, and other human activities. Tarai forests, in particular, are under verge of threat as the people from the hills are migrating to Tarai for settlement, and playing the main role for the degradation of forest areas for their daily living. As a result, the Nepalese government has handed over the majority of its national forests to the people, converting them into community forests. This study will help to determine the amount of carbon stock and regeneration status of the community forest and help to implement forest management strategies.

1.3 Research questions

- What is the carbon stock in two study forests?
- What are the differences in soil parameters in two forests?
- What is the regeneration status in two study forests?
- Is there any difference in carbon stock and regeneration status in these relatively highly disturbed and low disturbed forests?

1.4 Research objectives

General objective

- To estimate carbon stock, regeneration patterns in both forest sites and observe differences in soil parameters

Specific objectives

- To study plant diversity in both study areas.
- To observe the difference between the carbon stock, regeneration, and soil parameters between highly disturbed and low disturbed forest.

2. LITERATURE REVIEW

2.1 Carbon sequestration by Sal forests of Nepal

The previous studies have reported the various estimations and quantities of carbon sequestered by the Nepalese Sal forest. Thapa-Magar and Shrestha (2015) studied in nine CFs of Dhading district to estimate the carbon stock where Sal was dominant in all forests. They study made an estimate of the carbon stock (70 to 183 T C/ha), with a average of 120 T C/ha. Dhakal *et al*. (2017) estimated 258.00 mg/ha average carbon stock in Kathmandu, central Nepal. Gairhe (2015) studied the carbon sequestered in the trees of community forests, Central Nepal. The study recorded that a Fulbari CF had tree carbon stock of 71.11 T C/ha, which was higher than the carbon stock of Taldanda CF (109.82 tons per ha). Pawar *et al* (2014) estimated 55.125 to 98.548 t C ha-1 in dry tropical forest in India. Pathak and Baniya (2016) reported 115.00 mg/ha average carbon stock in Nawalparasi, central Nepal. Ghimire, (2017) estimated 64.86 t/ha average carbon stock in Dang district, western Nepal. He also mentioned that the increase in carbon stock per year was 2.52 t/ha/year.

The study investigated an impact of disruption on biomass, productivity, and the flux of carbon (Gautam & Mandal, 2016). They have occupied both undisturbed and disturbed places in the forest. In contrast to disturbed sites, undisturbed sites had higher total standing biomass and C-stock.

Joshi *et al*. (2020) studied in disturbed and undisturbed community forest in the Terai region of Kanchanpur district, Nepal. They have estimated total carbon stock of 152.68 and 301.08 in disturbed and undisturbed.

2.2 Regeneration status of Sal forests in Nepal

Acharya and Acharya (2011) had observed the regeneration of the Sal forest in the Rupandehi, Central Nepal. From the 0.7 ha sampling area, the study had identified 125 plant species from 55 families, including 36 tree species, 50 shrub species, and 39 herb species. Total shrub/sapling density was 4708 pl/ha at SE slope and 4137 pl/ha at SW slope. Similarly, total herb/seedling density was 10.86 pl/m^2 at SE slope and 9.79 pl/m^2 at SW slope.

The previous study found higher density of seedling and sapling in the managed area as compared to the unmanaged area. Where the average seedling was 17,028 pl/ha and the average sapling was 2,038 pl/ha (Awasthi *et al*., 2015)

Basyal et al. (2011) had examined the regeneration of Sal forest in Palpa district. The overall density of saplings was recorded to be 3437.5 pl/ha. With 2250 pl/ha, Sal had the greatest density of saplings among them all.

Poudyal (2013) reported 6126 seedlings/ha of Sal in the forest of Kaski district, which was satisfactory.

Napit (2015) investigated species diversity, the structure of forest communities, and regeneration in western Nepal's Banke National Park. The study area has been divided into 17 equal grids by him. There were 38 species of seedlings and fifty-eight species of saplings identified. The maximum density of seedlings (27153.4 pl/ha) and saplings (200.49 pl/ha) was found in *Shorea robusta*.

Baral and Ghimire (2020) have studied the effect of the canopy on the regeneration of Sal in the Buddha-Shanti Collaborative Forest, Nawalparasi district. The forest was divided into four strata, viz. 0–25, 25–50, 50–75, and 75–100 percent crown cover. In comparison to the 50–75 and 75–100 percent crown cover respectively, the seedling density of Sal was observed to be higher in the 0–25 and 25–50 percent crown cover areas. Similarly, in the open canopy compared to the closed canopy, there was a larger density of saplings.

2.3 Soil Parameters

According to Gautam and Mandal (2016), nitrogen, phosphorus and potassium contained in undisturbed forest was higher than in compare to disturbed forest. Barbhaiya *et al*. (2004) have reported that the total organic carbon contained in winter and summer seasons in undistrubed forest is (1.65, 1.84) while the carbon contained in highly disturbed forest was (1.17, 1.42) at 0-15 cm soil depth. Similarly, total contained nitrogen (%) in winter and summer seasons in undistrubed forest was (0.63, 0.80) while nitrogen contained (%) in highly disturbed forest was (0.40, 0.27 in 0-15 cm soil depth.

Moreover, substantial negative correlations were found between silt and species richness and clay and sand, while substantial positive correlations were found between various edaphic factors. In a similar vein, there was a substantial positive link between sand percentage and nitrogen content, potassium and phosphorus content. However, the negative relationship was observed between species richness and humus content, WHC and pH value (Khatri, 2023).

Many studies have been conducted regarding the carbon stock and regeneration status of different types of forest in Nepal. However, very scarce studies have been conducted focusing the carbon stock and regeneration in high and less disturbed forest.

3. MATERIALS AND METHODS

3.1 Site description

3.1.1 Study area

The investigation was carried out in the Pathivara Community Forest and Janakalyan community forest of Dang, Lumbini Province (Figure 1), which was indicated as highly disturbed forest (HDF) and less disturbed forest (LDF) respectively, on the basis of selection criteria listed in 3.2. The area of HDF is 271 ha. It is located at 28°2ˈ N to 82°12ˈ E. It was established on 2048/03/12. The area of LDF is 1800 ha. It is located at 28°0ˈ N to 82°14ˈ E. It was established on 2056/01/15.

Dang is located in the inner terai and is the second largest valley in Asia. Due to the altitudinal variation from 218 to 2058m, Dang has various types of forest, viz. Sal forest, Khayar-Sissoo forest, mixed sal forest, mixed pine forest etc. There are a total of 365 community forests in the Dang district

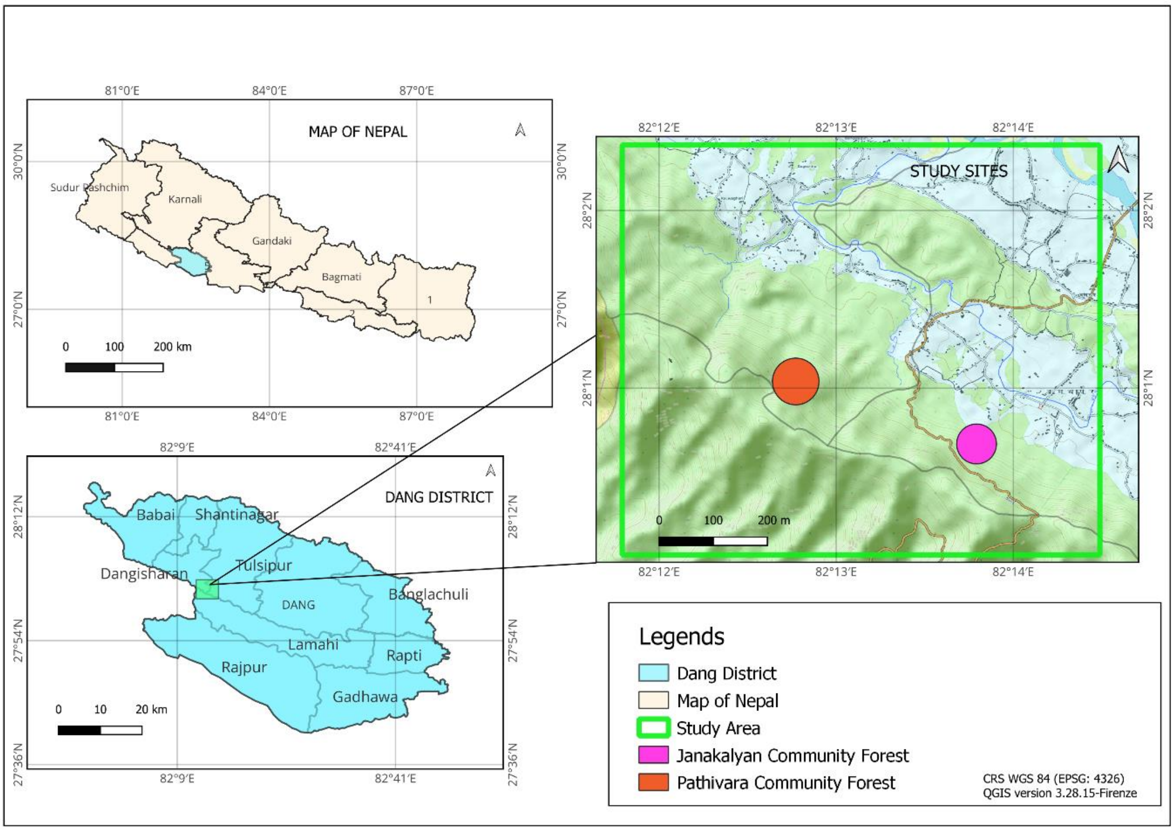


Figure 1: Map of the study area indicating the map of Nepal, Dang district and two study sites

3.1.2 Climate and vegetation

The climate is tropical and monsoon type with three distinct seasons: summer, rainy, and winter. The study areas receive about 1387 mm of average annual rainfall and the average lowest and highest temperature ranges between 20.5 °C and 28.9 °C respectively (Figure 2).

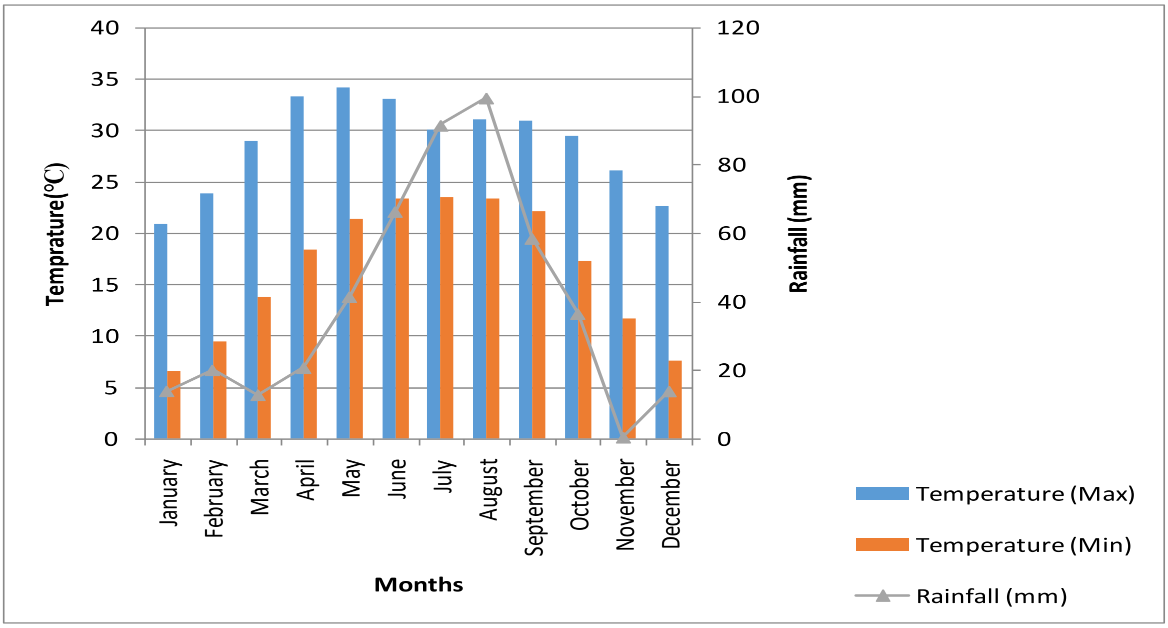


Figure 2: Climate summary of Dang (Ghorahi) with the 20 years average data of rainfall and temperature (Source:Department of Meteorology and Hydrology, Babarmahal, Kathmandu)

3.2 Selection criteria for highly disturbed and less disturbed community forests

The finalization of the study area was concluded after many visits to the different forest sites. The extent of high and low disturbances was crucial for the selection of the forest site. Therefore, the given criteria were taken as the references for the selection of the study areas.

- **Presence or absence of regeneration:** The most important criteria for the selection of highly disturbed forest (HDF) and less disturbed forests (LDF) site was based on the presence or absence of regeneration (*Shorea robusta*) in different sites by surface view (Joshi *et al.*, 2020). The main reason behind choosing the regeneration of *S. robusta* is the dominancy of Sal in the forest.

- **Crown cover:** Plots having the cover percent less than 40 were classified as HDF, and those with more than 40% crown cover as LDF (Jina *et al.*, 2008).

- **Grazing:** The presence of the hoofmarks and dung's of livestock, broken tops of seedlings and saplings, signs of trampling, etc. was the criteria to determine the grazing pressure on community forests (Joshi *et al*., 2020).

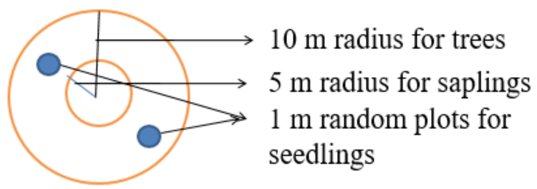
- **Fodder extraction:** locations inside community forests where access to fodder is restricted to a few weeks per year were classified as LDF, while locations with no restrictions on fodder extraction or consumption were classified as HDF (Jina *et al*., 2008).

- **The number of lopped branches per tree:** According to Jina *et al*. (2008), community forest sites with 50% or more lopped branches per tree were classified as HDF, whereas those with less than 20% lopped branches per tree were classified as LDF.

3.3 Experimental design

3.3.1 Sampling methods

A total of 60 circular plots were laid (30 each on disturbed and undisturbed sites) with the help of stratified random sampling. Circular plots of radius 10 m, 5 m, and 1 m (Aryal *et al*., 2017) were used for sampling trees (DBH > 5 cm), saplings (1–5 cm DBH and > 1 m height) and seedlings (< 1 m height) respectively (Timilsina *et al*., 2007).



The average value of two plots of one meter radius each was taken for the estimation of seedlings. A diameter of 1.37 meters was used to measure each tree's diameter at breast height (dbh) inside the plot, and a clinometer was used to measure each tree's height (Joshi *et al*., 2020). For DBH class distribution, DBH was categorized into five classes:

less than 10, 10 - 20 cm, 20 – 30 cm, 30 – 40 cm, 40 – 50 cm and 50 – 60 cm. A GPS tracker device was used to measure the study area's height and geographic coordinates. An IOS device's compass was utilized to determine the hill woods' aspect. The height of the tree was ultimately determined using the trigonometry tangent formula after a clinometer was used.

$$\tan \theta = p/b$$

where b = distance between the person holding clinometer; p = tree height, omitting the height of the person holding the clinometer. Thus, actual tree height equals p plus the height of the person holding the clinometer.

The soil samples from four quadrats (parts) of each sample plot was collected up to 30 cm depth and mixed readily to for a single sample for analyzing different soil parameters (Chaudhary and Aryal, 2023).

3.3.2 Data collection

The officials of each community forest and the local population assisted in the data collection. We were able to get the annual community forest progress reports from the Pathivara community forest and Janakalyan community forest subdivision offices. From October 08 to October 11, 2022 a preliminary investigation was carried out, during which time the nested layout was also laid. The main period of data collection was from October 16 to October 29, 2022.

3.4 Quantitative analysis

3.4.1 Community attributes

In accordance with Zobel *et al.* (1987), the ecological parameters density (pl ha–1), frequency (%), basal area (m2 ha–1), coverage (%), and their relative values were computed.

Frequency is the measure of how widely distributed a species is within a community. Frequency is the proportion of sample units that contain a species in a particular area.

$$\text{Frequency: } \frac{\text{Number of plots in which the species occured}}{\text{Total number of plots}} \times 100$$

The degree of a species' dispersion in a given area relative to the total number of species present is known as relative frequency, and it was calculated using the following formula:

$$\text{Relative frequency: } \frac{\text{Frequency of individual species}}{\text{Sum of frequency of all species}} \times 100$$

Density is the quantity of individuals per unit area. It displays the species' dominance in terms of numbers within the group. The density was calculated using the following equation:

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

The numerical strength of a species on the basis of total number of species is called relative density.

$$\text{Relative density: } \frac{\text{Density of individual species}}{\text{Sum of density of all species}} \times 100$$

The basal area of a species in each sample plot was determined by adding the BA of all the individuals in that species. The formula for converting BA to a percentage was as follows:

$$\text{Tree Basal area (BA): } \pi r^2$$

$$\text{Basal area (m}^2\text{/ha): } \frac{\pi r2}{\text{Area of quadrat}} \times 10000$$

Where r refers to the radius of a tree measured at breast height. Therefore, r = DBH/2

The basal area of certain tree species multiplied by the total basal area of all tree species results in the relative basal area.

$$\text{Relative basal area: } \frac{\text{Basal area of individual species}}{\text{Sum of Basal area of all species}} \times 100$$

Using the important value index (IVI), each species' overall relevance within the community structure is ascertained. To compute IVI, the following formula was used.

$$IVI = RF + RD + RB$$

In accordance with Nath *et al*. (2005), the Sorensen's species similarity index (SI) between the two sites was calculated:

$$SI = \left(\frac{2C}{a+b}\right) \times 100$$

Where, C is the number of species in sites a and b; a and b are the number of species in sites a and b.

3.4.2 Biomass and carbon estimation

3.4.2.1 Aboveground tree biomass (AGTB)

- Allometric equation was used to calculate above ground tree biomass (AGTB), AGTB = $0.0509 \times D^2 \times \rho \times H$ [where, D=Tree diameter at breast height (cm), ρ = Wood specific density (g cm^{-3}), H = Tree height (m)] for trees and poles (dbh $>$ 5 cm) (Chave *et al*. 2005). Belowground biomass (BGB) was estimated by multiplying the value of AGTB with the constant factor 0.15, prescribed by MacDicken (1997).

- The total carbon stock of tree was calculated by multiplying the default C fraction of 0.47 with the total dry vegetation mass (AGTB + BGB) (Eggleston *et al*., 2006).

- Finally, to determine the overall forest carbon stock, the carbon values for each forest carbon pool were added together.

3.5 Plant identification

Collected plants were dried and prepare for herbarium specimens in standard size (29 cm × 41 cm). Each specimen was assigned the collection, place name, latitude, longitude, and code. Further consultations with plant taxonomists were conducted to verify the nomenclature of collected plant species. Following plant identification, the most recent and widely recognized scientific names and families were verified using the websites; www.gbif.org.

3.6 Soil analysis

Soil samples at the depth of 30 cm were taken from all 60 plots of the study area. Hydrometric analysis of the soil texture was done. Walkley and Black (1934) suggested a titration method for determining soil organic matter. By dividing the soil organic matter (%) by the default proportion of 1.724, soil organic carbon (%) was obtained (Anderson and Ingram, 1993). Additionally, the soil organic carbon (%) was changed to soil organic carbon (t ha-1) using the Chhabra *et al*. (2003) literature in order to assess the soil carbon stock.

The micro-Kjeldal method was used to determine the total nitrogen content (Jackson, 1958). By using a modified Olsen and bicarbonate technique (Olsen and Sommers, 1982), the total phosphorus concentration was quantified. The flame photometer method was used to determine the total potassium concentration (Jackson, 1958). A digital pH meter was used to measure the pH of the soil using a 1:2.5 soil-water solution (Cottenie, 1980). The entire test for soil parameters were performed in Regional Agriculture Research Station, Nepalgunj, Banke, Nepal.

3.7 Data analysis

ArcGIS version 8.2 was used to make the map of the study area. With MS Excel 2007, all of the descriptive analysis was completed. One-way ANOVA and the Shapiro-Wilk test for correlation were used to determine the normality of data. Multiple correlation analysis was done between a few chosen forest parameters and the parameters of the soil. To find the significant variation in tree carbon stock throughout the altitudinal range, the Kruskal-Wallis test was used as the data were not distributed normally. The Wilcoxon pairwise test was utilized to determine the pairwise comparison of variables across different elevations. R software was used for the inferential analysis (R Core Team, 2023).

4. RESULTS

4.1 Community diversity and structure

In the present study, 18 tree species belonging to 15 genera and 10 families were recorded where, 14 tree species were recorded from HDF and LDF each (Table 1). According to Sorensen's similarity index, similarity between HDF and LDF was 71.4%.

Highest number of species was recorded from the family Combretaceae with 4 species, followed by Anacardiaceae and Fabaceae with 3 species each, Moraceae (2 species), Rutaceae, Phyllanthaceae, Ericaceae, Euphorbiaceae, Myrtaceae and Dipterocarpaceae with 1 species each. (Figure 3)

Table 1: Presence and absence of the tree species in LDF and HDF with their respective families

Tree species	**Family**	**LDF**	**HDF**
Aegle marmelos	Rutaceae	1	1
Anogeissus latifolia	Combretaceae	1	1
Buchanania conchinchensis	Anacardiaceae	1	1
Cassia fistula	Fabaceae	1	1
Dalbergia sissoo	Fabaceae	1	0
Ficus benghalensis	Moraceae	1	0
Ficus semicordata	Moraceae	0	1
Lannea coromandelica	Anacardiaceae	1	0
Lyonia ovalifolia	Ericaceae	1	0
Mallotus phillipensis	Euphorbiaceae	0	1
Phyllanthus emblica	Phyllanthaceae	0	1
Semecarpus anacardium	Anacardiaceae	1	1
Sengalia catechu	Fabaceae	1	1
Shorea robusta	Dipterocarpaceae	1	1
Syzgium cumini	Myrtaceae	1	1
Terminalia alata	Combretaceae	1	1
Terminalia bellerica	Combretaceae	1	1
Terminalia chebula	Combretaceae	0	1

Foot note: 1 = presence and 0 = absence

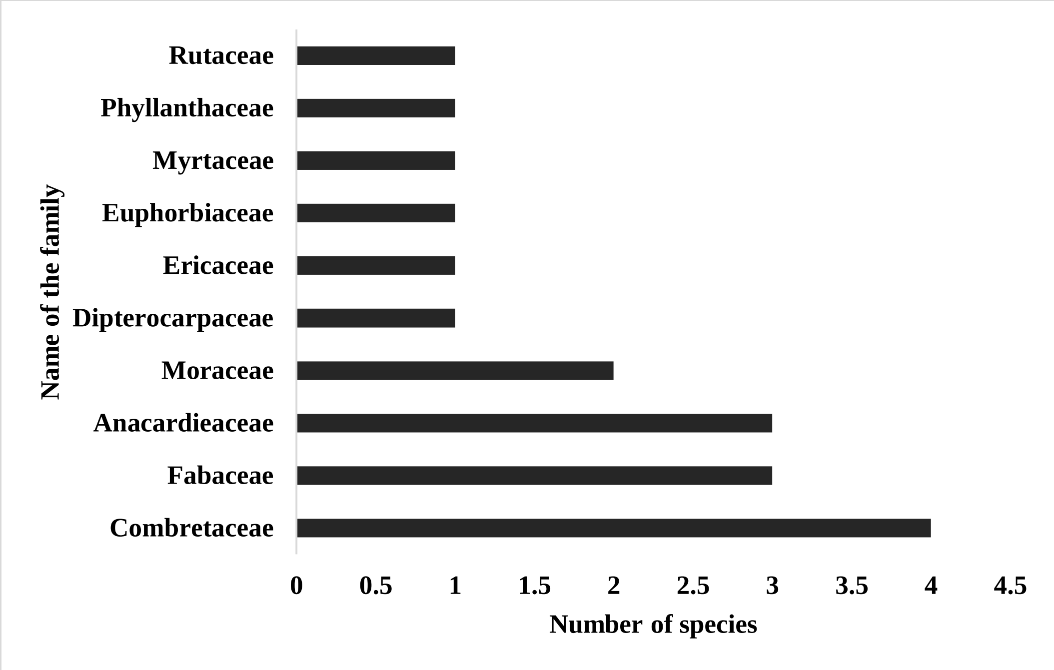


Figure 3: Name of the families with their respective number of species

The Shannon diversity indices (H) was calculated to determine the diversity of both forest in terms of tree species. The value of Shannon index for HDF and LDF was 0.447 and LDF 0.764 respectively (Figure 4). In order to observe the significant difference between the diversity index of HDF and LDF, one-way ANOVA was performed. There was significant difference (p value = 0.012) in diversity index between the study sites.

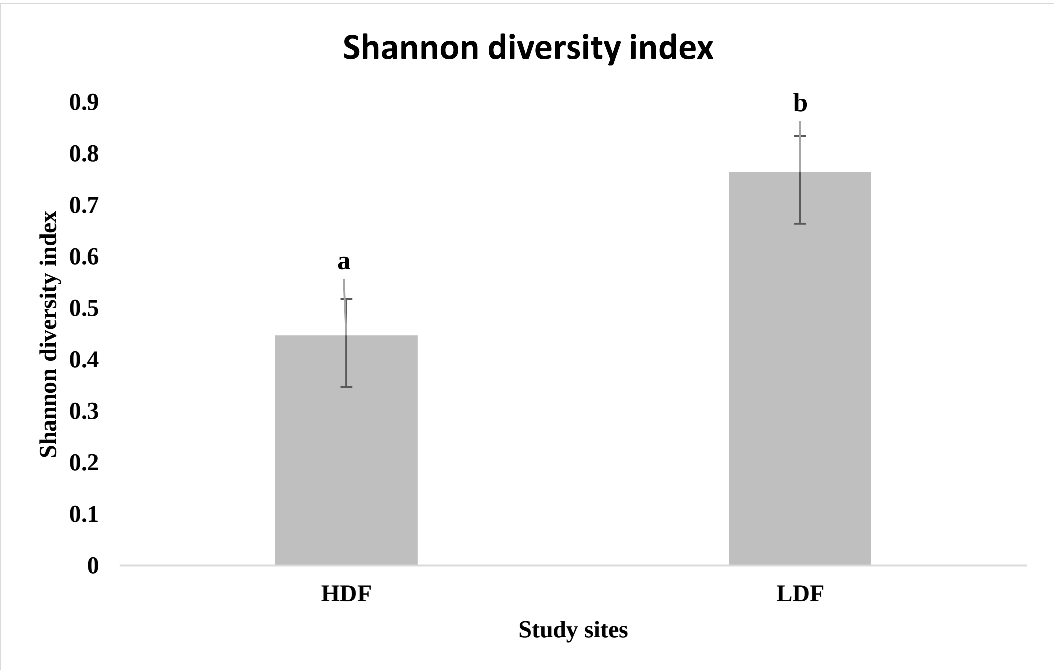


Figure 4: Shannon diversity index of LDF and HDF with standard error bar. The superscript “a” and “b” above the bar graph represent the significant difference between the values of diversity index.

4.2 Community attributes

4.2.1 Importance value index (IVI)

The important value index (IVI) was calculated to observe the spatial value index of single particular species and which species has the dominant presence in the given forest area. In HDF, *Shorea robusta* had the highest IVI value (207.32), followed by *Terminalia alata* (44.30), *Senegalia catechu* (18.51) and *Buchanania conchinchensis* (6.77). However, *Anogeissus latifolia* had the lowest IVI value with 1.59 (Figure 5).

In LDF, *Shorea robusta* had the highest IVI value (204.24), followed by *Terminalia alata* (28.15), *Senegalia catechu* (19.06) and *Aegle marmelos* (14.04). However, *Ficus benghalensis* had the lowest IVI value with 1.66 (Figure 6).

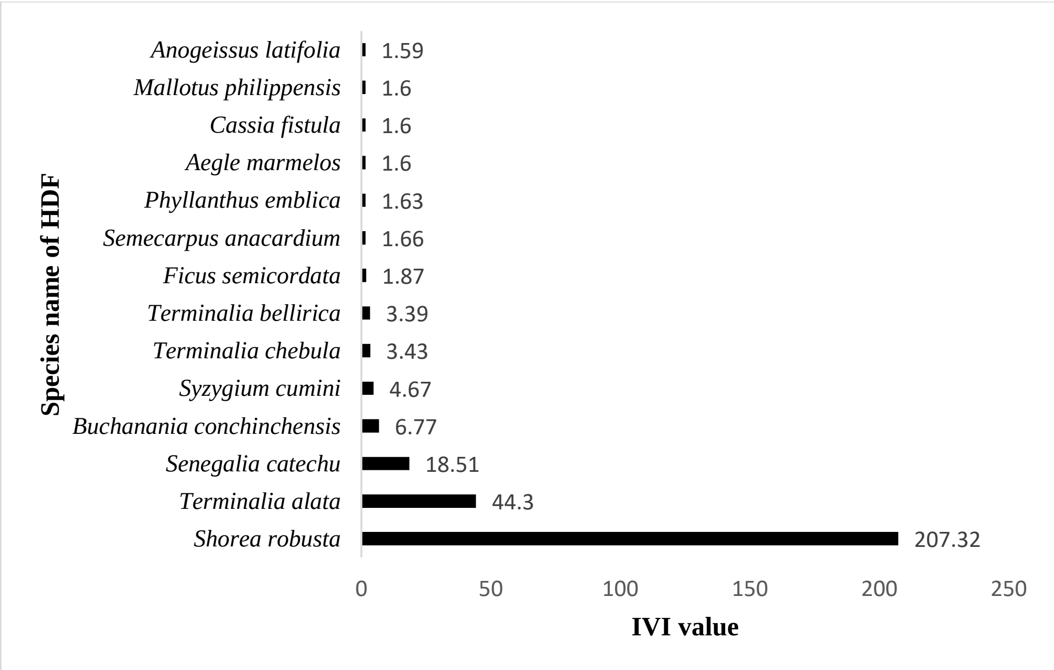


Figure 5: IVI value of the given tree species in HDF

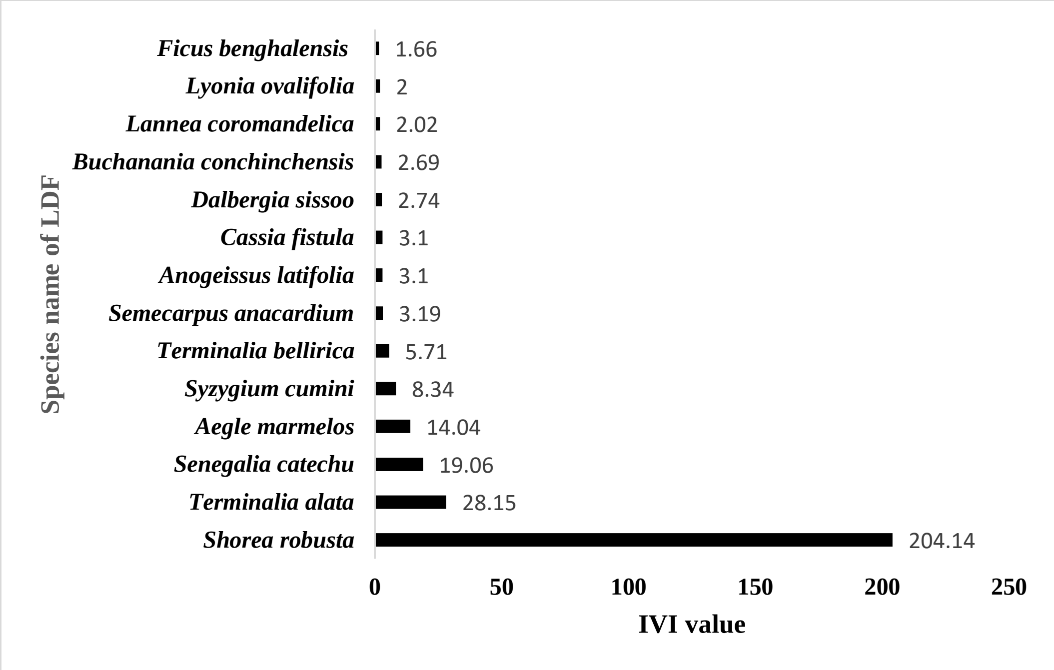


Figure 6: IVI value of the given tree species in HDF

4.2.2 Size-class distribution

Five different classes were categorized to observe the size class distribution in both the forest sites. In HDF, highest number of tree species (n = 373 pl/ha) was found between 10 -19 cm category, followed by 20 – 29 cm (211 pl/ha), 30 – 39 (15 pl/ha) and less than 10 cm (2.12 pl/ha). However, no any tree species were recorded above 40 cm category (Figure 7).

In LDF, highest number of tree species (n = 284 pl/ha) was found between 10 -19 cm category, followed by 20 – 29 cm (200 pl/ha), 30 – 39 (62 pl/ha), 40 -49 cm (13 pl/ha) and above 50 cm category (9 pl/ha) (Figure 7).

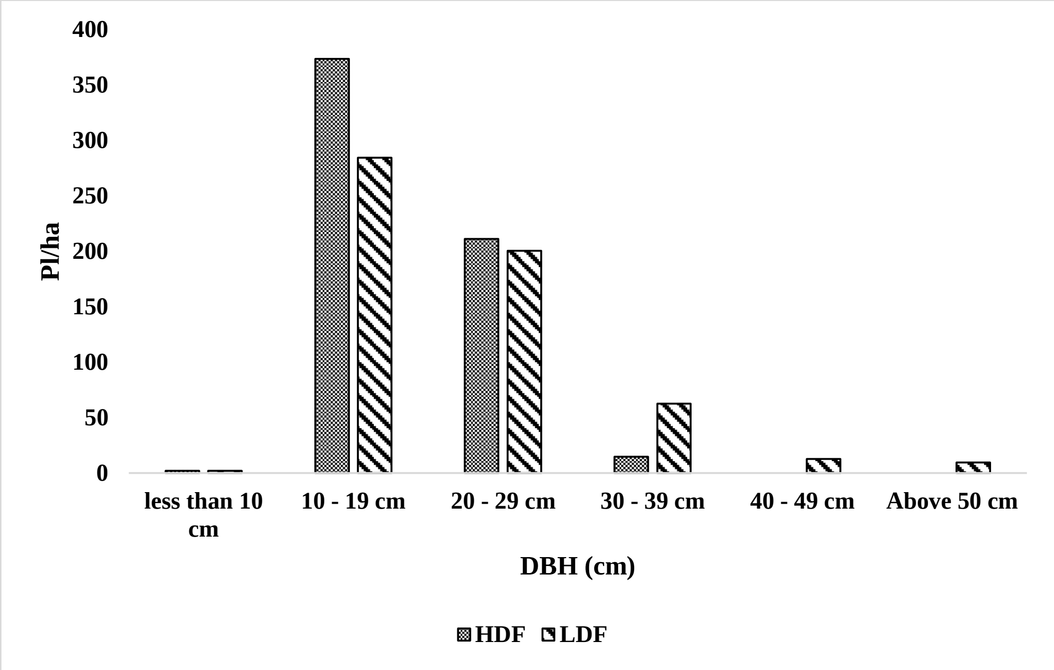


Figure 7: Size-class distribution or density diameter graph of the tree species in HDF and LDF

4.3 Carbon stock

The carbon stock in the study areas of the plots ranged from 18.2 t/ha to 180.6 t/ha. However, the mean carbon stock value in HDF and LDF was 46.48 and 72.72 t/ha respectively. The highest tree carbon stock was observed in LDF. There was a significant difference (p value = 0.002) in the carbon stock between the study areas (Figure 8).

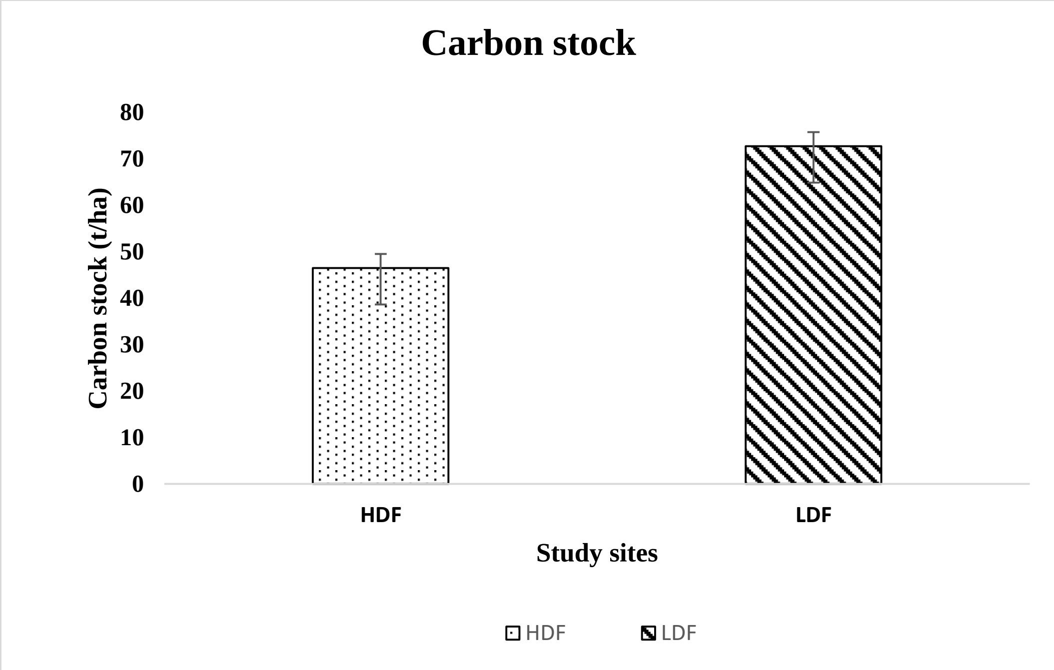


Figure 8: Carbon stock (t/ha) of LDF and HDF with standard error bar

Shorea robusta contributed the most (77.37%) in the total tree carbon stock of LDF, followed by *Terminalia alata* (8.9%), *Senegalia catechu* (6.9%), *Terminalia bellirica* (2.9%), *Dalbergia sissoo* (1.67%) and *Syzygium cumini* (1.14%). However, the lowest contributors of tree carbon stock in LDF were *Ficus benghalensis* (0.005%), *Anogeissus latofolius* (0.03%), *Lannea coromandelica* (0.06%) and *Buchanania conchinchensis* (0.09%) (Figure 9).

S. robusta was the highest contributor (84.04%) in the total tree carbon stock of HDF, followed by *Terminalia alata* (11.03%), *Senegalia catechu* (3.48%) and *Terminalia chebula* (0.52%). However, the lowest contributors of tree carbon stock in HDF were *Semecarpus anacardium* (0.012%), *Anogeissus latofolius* (0.036%), *Aegle marmelos* (0.036%) and *Phyllantbus emblica* (0.04%) (Figure 10).

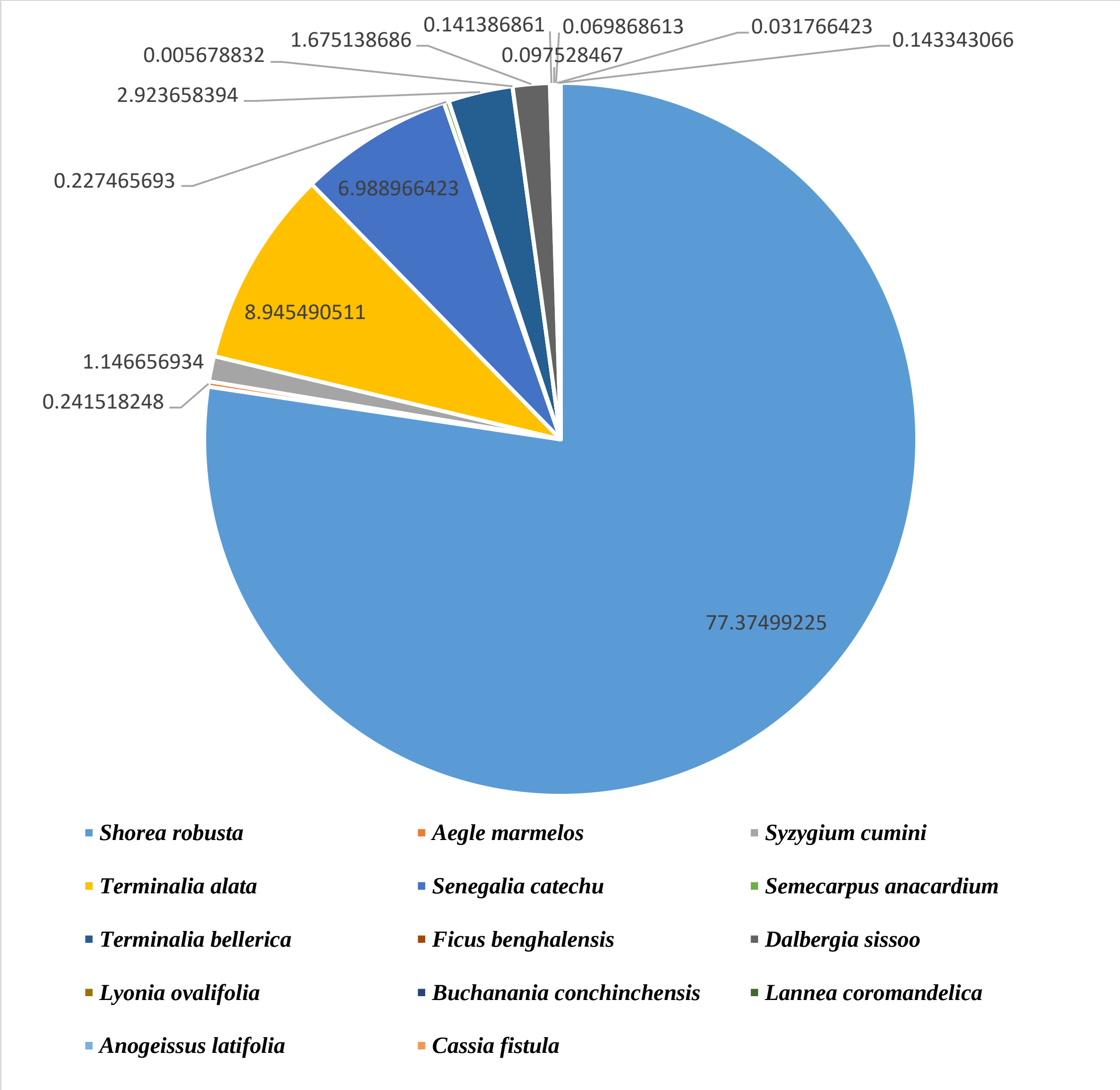


Figure: 9: Contribution of the species in carbon stock in LDF (convert this into simple table)

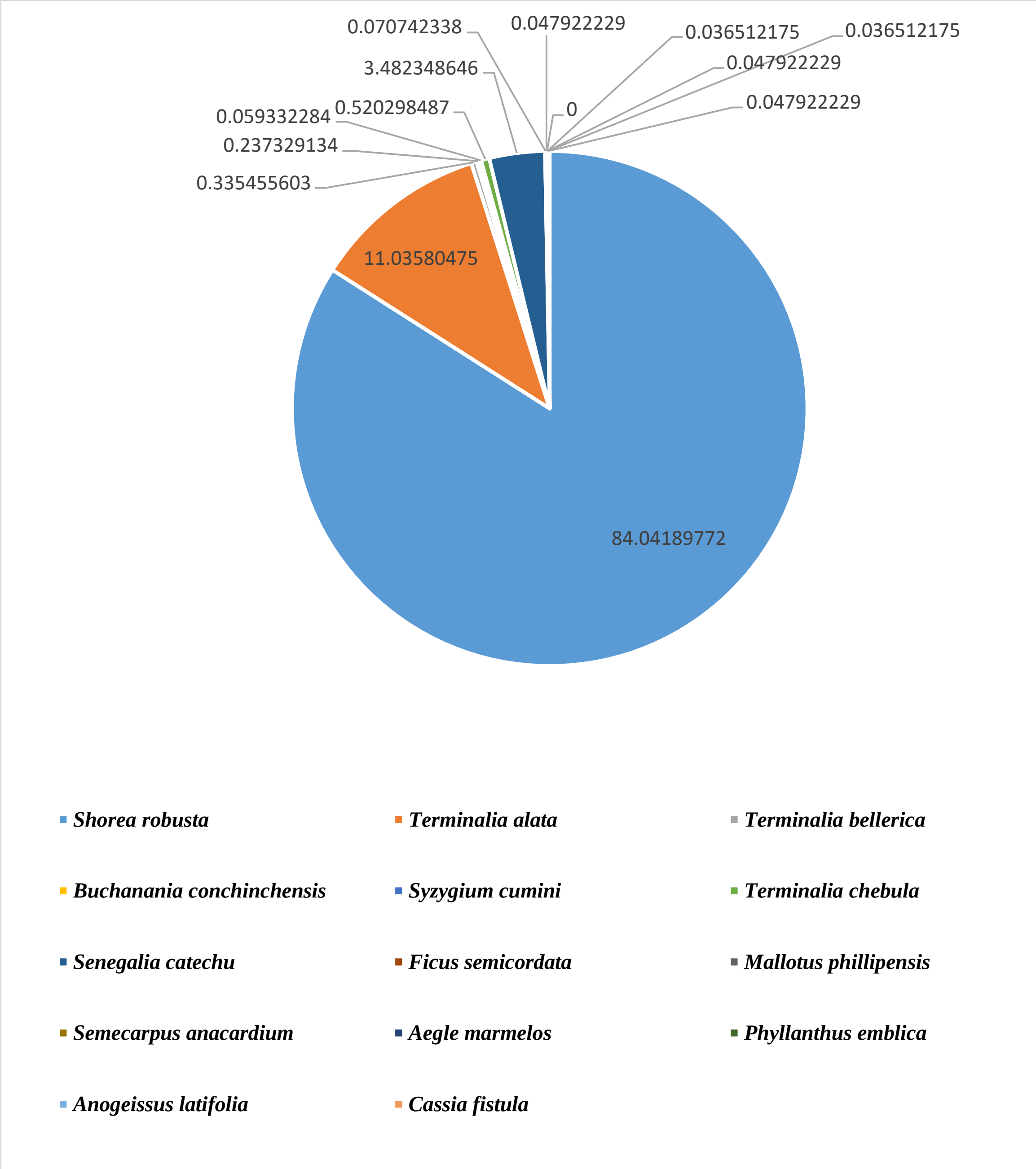


Figure 10: Contribution of the species in carbon stock in HDF

4.4 Regeneration and Edaphic Factor

The density of total seedlings was higher (51474 pl/ha) in LDF compared to HDF (20316 pl/ha). There was significant difference (p value = 0.001) in the total seedlings between the study areas (Table 2). Similarly, the density of total saplings was also higher (1167 pl/ha) in LDF compared to HDF (598 pl/ha) and significant difference (p value = 0.001) was seen in the total saplings between the study areas. However, there was no any significant difference (p value = 0.37) in the density of trees between the study areas.

In HDF and LDF, *S. robusta* had the highest density of seedlings, saplings and trees (Table 3). In HDF, the density of seedlings of *S. robusta* was followed by *S. catechu* and *T. alata*. However, In LDF, the density of seedlings of *S. robusta* was followed by *T. alata* and *S. cumini*. *T. alata* and *S. catechu* were the most frequently observed associate tree species with *S. robusta* in both the forest.

Table 2: Average number of seedlings, saplings and trees of Sal and total tree species in HDF and LDF with standard error (Mean ± standard error)

		Average pl/ha (HDF)	**Average pl/ha (LDF)**	**p-value**
Shorea robusta	Seedlings	17929.1 ± 3798.84	45798.8 ± 7470.31	0.001
Shorea robusta	Saplings	445.5 ± 117.2	607.2 ± 77.66	0.256
Shorea robusta	Trees	525 ± 42.68	458.1 ± 41.03	0.264
Total	Seedlings	20316.14 ± 3749.29	51474.64 ± 7639.23	0.001
Total	Saplings	598.3 ± 126.3	1167.7 ± 114.6	0.001
Total	Trees	607.73 ± 42.67	557.88 ± 35.04	0.37

Table 3: Seedling, sapling and trees of highest three species

Plot	**Seedling**	**Pl/ha**	**Sapling**	**Pl/ha**	**Tree**	**Pl/ha**
HDF	*Shorea robusta*	17929	*Shorea robusta*	445	*Shorea robusta*	525
	Senegalia catechu	848	*Buchanania conchinchensis*	29	*Terminalia alata*	45
	Terminalia alata	742	*Terminalia alata*	25	*Senegalia catechu*	15
LDF	*Shorea robusta*	45798	*Shorea robusta*	606	*Shorea robusta*	458
	Senegalia catechu	2546	*Syzygium cumini*	173	*Senegalia catechu*	41
	Syzygium cumini	1538	*Casearia graveolens*	67	*Terminalia alata*	24

LDF had the highest content of organic matter (OM), nitrogen (N) and potassium (K) compared to HDF (Table 4). However, phosphorus (P) content was higher in HDF compared to LDF. The pH content was found more acidic in LDF compared to HDF, though both site had acidic soil (Table 4). There was a significant difference in OM (p <

0.001), N ($p < 0.001$) and pH ($p = 0.019$) between HDF and LDF. However, there was no any differences in P and K content in the soil of HDF and LDF.

The density of seedlings and saplings was affected positively by OM content (Table 5). Nitrogen content also had the positive relationship with the density of seedlings. The Spearman correlation value was also weakly supported by multiple regression analysis. Multiple regression value for seedling ($R = 0.178$ and $p = 0.045$) and sapling ($R = 0.125$ and $p = 0.047$) reported that 17.8% and 12.5% factors among the total factors has some effects on seedling and sapling of the community forests respectively.

Table 4: Edaphic factors of the study area written as mean ± standard error

	OM (%)	N (%)	P (kg/ha)	K (kg/ha)	pH
HDF	0.606 ± 0.037	0.030 ± 0.002	76.457 ± 3.227	78.74 ± 11.970	4.913 ± 0.093
LDF	1.047 ± 0.048	0.050 ± 0.003	73.688 ± 5.831	114.748 ± 19.251	4.676 ± 0.735
P value	< 0.001	< 0.001	0.734	0.117	0.019

note: OM = Organic matter; N = Nitrogen; P = Phosphorus; K = Potassium

Table 5: Spearman correlation of seedling and sapling with the selected edaphic factors

	Seedling		Sapling	
	rho (ρ) value	p value	rho (ρ) value	p value
OM	0.249	0.050*	0.272	0.035*
N	0.349	0.006**	0.216	0.096
P	0.12	0.36	0.099	0.45
K	0.095	0.468	-0.123	0.348
pH	0.077	0.556	0.155	0.234

5. DISCUSSION

5.1 Community diversity and structure

In the current study, 18 tree species from 15 genera and 10 families were identified, of which 14 species were identified from each of the HDF and LDF. According to Sorensen's similarity index, the similarity between HDF and LDF was 71.4%. The high similarity between both the study sites may be by the virtue of presence of the forests in the similar topographical area and experiencing similar climatic condition.

The Shannon diversity indices (H) were calculated to determine the diversity of both forest in terms of tree species. The value of Shannon index for HDF and LDF was 0.447 and LDF 0.764 respectively. Kunwar and Sharma (2004) had reported the Shannon diversity of two forests in Dolpa district as 2.36 and 3.02, which is much higher than our results. Dhakal *et al*. (2021) had also reported higher tree diversity index (2.49) compared to our study. According to Ortiz-Burgos (2016), the ideal Shannon diversity value falls between 1.5 and 3.5, seldom rising above 4.5. Plant diversity increases with the H value. But none of the diversity indices fall between 1.5 and 3.5, which means that there is less tree diversity across both the sites. The degradation of forests due to haphazard collection of fodder and firewood, high intensity of grazing may have reduced the number of saplings and may have resulted in the degredation of the diversity of trees, which was also reported by Chaudhary and Aryal (2024).

5.2 Community attributes

In both the sites *Shorea robusta* had the highest IVI value. In order to determine which species is more prevalent in a specific forest region and to monitor the spatial value index of a single species, the important value index (IVI) was computed. The primary elements influencing Sal's growth and development include the age of the forest, disturbances, community group management techniques, resources available, and related species (Mandal & Joshi, 2014). A high IVI value for a species of plant indicates that species' dominance in the forest, growth success, ecological adaptability to the specific habitat, and potential for regeneration are all present (Shameem & Kangroo, 2011). The forest of low altitudinal range exhibited the second greatest IVI for *T. alata*. Similar findings were made by Chaudhary and Aryal (2024) and DFRS (2014), which conducted the Tarai Forest Inventory and found that *S. robusta* had the highest IVI, followed by *T. alata*.

The greatest number of tree species in HDF was discovered in the categories of 10 - 20 cm, followed by 20–30 cm, and 30–40 cm. Nevertheless, no tree species were found in the 40–50 cm and 50–60 cm ranges. The group with the greatest number of tree species in LDF was between 10 - 20 cm, followed by 20–30 cm, 30–40 cm, 40–50 cm, and 50–60 cm. The Density-Diameter graph showed an inverse J shaped curve representing healthy regenerating forest (Timilsina *et al*., 2007). Nonetheless, there had been some natural disasters, disturbances, or human activity in HDF, and the forest had begun to regenerate. As a result, no trees having a DBH greater than 40 cm have been observed.

5.3 Tree carbon stock

The plots in the study areas had carbon stocks ranging from 18.2 t/ha to 180.6 t/ha. In HDF and LDF, on the other hand, the mean carbon stock value was 46.48 and 72.72 t/ha, respectively. The ABG carbon stock in the study area is lower compared to previous literatures (Baral et al., 2009; Thapa-Magar and Shrestha, 2015; Pandey & Bhusal, 2016; Banik *et al.*, 2018; Bhatta & Devkota, 2020; Chaudhary & Aryal, 2024). However, the tree carbon stock in the current investigation was higher compared to Poudyal *et al*. (2022). Several parameters, such as DBH measurement, plot size, methodology of estimating the biomass and carbon stock, comparison of the sites, sampling and overall assessment of the entire carbon store in trees like leaves, twigs, poles, branches and roots may alter the carbon stock of the tree and forest (Saner *et al*., 2012). Illegal logging, livestock grazing, fire, leaf gathering, human encroachment, and other disturbances could all contribute to the low value of tree carbon stocks in our both the study area. However, if we compare HDF and LDF, the density of trees, DBH classes, and basal area may have affected. The relationship between tree species' carbon stock, DBH, and basal area suggests that increased stand structure leads to higher forest production (Ogawa *et al.*, 1965).

5.4 Regeneration and edaphic factor

In LDF as opposed to HDF, there was a higher overall seedling density. The total number of seedlings varied significantly amongst the research areas. *Shorea robusta* exhibited the maximum density of seedlings, saplings, and trees in both HDF and LDF. A healthy forest's nature and sustainability are demonstrated by the abundance of seedlings and saplings in the forest (Chaudhary, 2023). It is thought that having more than 5000 seedlings and 2000 saplings per hectare is a very good quantity for replacing older *S. robusta* trees with new ones (DoF, 2004). Comparing the CI Inventory guideline of DoF (2004), the status of sapling in both the sites are very poor and can affect the healthy and sustainable growth of forest. A sufficient quantity of saplings guarantees the future vegetation's composition (Swaine & Hall, 1988). Moreover, poor number of saplings in both the sites may be caused by looping, cattle grazing at higher intensities, gathering fodder and firewood, and being close to a settlement.

LDF had the highest content of organic matter (OM), nitrogen (N) and potassium (K) compared to HDF. A higher number of seedlings and saplings in LDF compared to LDF might be due to the result of more nutrients (organic matter and nitrogen content) being supplied to the plants. As the total content of OM and N in the study areas are significantly high in the LDF, and positive correlation was also observed between the number of seedlings and saplings with OM and N.

6. CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The forests were dominated by the *Shorea robusta*, with other associated tree species like *Senegalia catechu, Terminalia alata, Syzygium cumini* etc. There was a high significant difference in tree diversity, carbon stock, and regeneration of forest between LDF and HDF. HDF was highly degraded in terms of diversity, carbon stock and regeneration compared to LDF. Though, the regeneration of LDF was better compared to HDF, the number of saplings in both the forest was worst. Therefore, the overall regeneration of the forest was not satisfactory in both the forest.

6.2 Recommendation

In both the sites, regeneration of *Shorea robusta* is essential for both a high potential carbon stock and a sustainable way of life. The failure of CFUGs to produce saplings from seedlings, which is crucial for a sustainable forest, appears to a significant issue in both the forest. Though, the number of seedlings was good, the saplings in proportion to them were very poor. Therefore, CFUGs pay their attention to conserve and develop saplings to tree phase.

REFERENCES

Acharya, R., & Shrestha, B. B. (2011). Vegetation structure, natural regeneration and management of Parroha community forest in Rupandehi district, Nepal. *Scientific World*, *9*(9), 70-81.

Adam, D. (2001). Royal society disputes value of carbon sinks. *Nature*, *412*(6843), 108-108.

Anderson, J. M., & Ingram, J. S. I. (1993). A handbook of methods. *CAB International, Wallingford, Oxfordshire*, *221*, 62-65.

Aryal, B., Bhattarai, B. P., Pandey, M., & Giri, A. (2017). Carbon sequestration and CO2 mitigation in a burned ecosystem of Pinus roxburghii forest in Langtang National Park, Nepal. *Tropical Plant Research*, *4*(2), 297-306.

Awasthi, N., Bhandari, S. K., & Khanal, Y. (2015). Does scientific forest management promote plant species diversity and regeneration in Sal (Shorea robusta) forest? A case study from Lumbini collaborative forest, Rupandehi, Nepal. *Banko Janakari*, *25*(1), 20-29.

Bajpai, O., Dutta, V., Chaudhary, L. B., & Pandey, J. (2018). Key issues and management strategies for the conservation of the Himalayan Terai forests of India. *International Journal of Conservation Science*, *9*(4).

Baral, S. K., Malla, R., & Ranabhat, S. (2009). Above-ground carbon stock assessment in different forest types of Nepal. *Banko Janakari*, *19*(2), 10-14.

Baral, S., & Ghimire, P. (2020). Effect of tree canopy opening in the regeneration layer of Terai Sal (*Shorea robusta* Gaertn.) forest in Western Nepal: A case study. *Tropical Plant Research*, *7*(2), 502-507.

Barbhuiya, A. R., Arunachalam, A., Pandey, H. N., Arunachalam, K., Khan, M. L., & Nath, P. C. (2004). Dynamics of soil microbial biomass C, N and P in disturbed and undisturbed stands of a tropical wet-evergreen forest. *European Journal of Soil Biology*, *40*(3-4), 113-121.

Basyal, S., Lekhak, H. D., & Devkota, A. (2011). Regeneration of Shorea robusta. Gaertn in tropical forest of Palpa district, Central Nepal. *Scientific world*, *9*(9), 53-56.

Bhatta, S. P., & Devkota, A. (2020). Carbon stock in the community managed Sal (*Shorea robusta*) forests of Dadeldhura district, western Nepal.

Bhattarai, K. P., & Mandal, T. N. (2018). Variation in carbon stock in litterfall, fine root and soil in Sal (Shorea robusta Gaertn.) forests of eastern Nepal. *Our Nature*, *16*(1).

Bojko, O., & Kabala, C. (2016). Transformation of physicochemical soil properties along a mountain slope due to land management and climate changes—A case study from the Karkonosze Mountains, SW Poland. *Catena*, *140*, 43-54.

Bose, A. K., Weiskittel, A., Wagner, R. G., & Kuehne, C. (2016). Assessing the factors influencing natural regeneration patterns in the diverse, multi-cohort, and managed forests of Maine, USA. *Journal of Vegetation Science*, *27*(6), 1140-1150.

Brown, S., Gillespie, A. J., and Lugo, A. E. (1989). Biomass estimation methods for tropical forests with applications to forest inventory data. *Forest science*, *35*(4), 881-902.

Chaudhary, S. (2023). TREE DIVERSITY, CARBON STOCK AND REGENERATION PATTERN IN SHOREA ROBUSTA GAERTN. FORESTS ALONG THE ALTITUDINAL GRADIENT IN EASTERN NEPAL (Master dissertation, Amrit Campus).

Chaudhary, S., & Aryal, B. (2023). Factors affecting the tree and soil carbon stock in Shorea robusta Gaertn. forests along the elevational gradient in Eastern Nepal. *Acta Ecologica Sinica*.

Chaudhary, S., & Aryal, B. (2024). Diversity and distribution of tree species with respect to edaphic and physical factors in Shorea robusta Gaertn. forests along the altitudinal gradient. *Vegetos*, 1-12.

Chauhan, P. S., Negi, J. D. S., Singh, L. O. K. E. N. D. E. R., & Manhas, R. K. (2008). Regeneration status of Sal forests of Doon Valley. *Annals of Forestry*, *16*(2), 178-182.

Chave, J., Andalo, C., Brown, S., Cairns, M. A., Chambers, J. Q., Eamus, D. Folster, H., Fromard, F., Higuchi, N., Kira, T., Lescure, J. P., Nelson, B. W., Ogawa, H., Puig, H., Riera, B., & Yamakura, T. (2005). Tree allometry and improved estimation of carbon stocks and balance in tropical forests. Oecologia, 145(1), pp. 87–99.

Chhabra, A., Palria, S., & Dadhwal, V. K. (2003). Soil organic carbon pool in Indian forests. *Forest ecology and management*, *173*(1-3), 187-199.

Ciais, P., Dolman, A. J., Bombelli, A., Duren, R., Peregon, A., Rayner, P. J., ... & Zehner, C. (2013). Current systematic carbon cycle observations and needs for implementing a policy-relevant carbon observing system, Biogeosciences Discuss., 10, 11447–11581.

Cottenie, A. (1980). Soil and plant testing as a basis of fertilizer recommendations (No. 38/2).

DFRS. (2014). *Terai Forests of Nepal*. Forest Resource Assessment Nepal Project/ Department of Forest Research and Survey, Kathmandu, Nepal.

Dhakal, S., Maharjan, S. R., & Aryal, P. C. (2017). Assessment of Carbon Stock in Gokarna Forest, Kathmandu, Nepal. *Golden Gate Journal of Science & Technology*, *3*, 42-45.

Dhakal, S., Mohanty, A., & Rijal, K. P. (2021). Assessment of Carbon Sequestration and Tree Diversity in Gokarna Forest, Kathmandu, Nepal. In *Sustainable Climate Action and Water Management* (pp. 167-180). Singapore: Springer Singapore.

Dixon, R. K., Solomon, A. M., Brown, S., Houghton, R. A., Trexier, M. C., and Wisniewski, J. (1994). Carbon pools and flux of global forest ecosystems. *Science*, *263*(5144), 185-190.

DOF (2004). Community Forest Inventory Guidelines. Department of Forests, Kathmandu, Nepal.

Eggleston, H. S., Buendia, L., Miwa, K., Ngara, T., & Tanabe, K. (2006). 2006 IPCC guidelines for national greenhouse gas inventories.

Gairhe, P. (2015). *Tree regeneration, diversity and carbon stock in two community managed forests of Tanahun district, Nepal* (Doctoral dissertation, Department of Botany).

Gautam, T. P., & Mandal, T. N. (2016). Effect of disturbance on biomass, production and carbon dynamics in moist tropical forest of eastern Nepal. *Forest Ecosystems*, *3*, 1-10.

Ghimire, P. (2017). *Plant Species Diversity and Tree Carbon Stock in Danphe community Forest, Kuirepani, Dang, Nepal* (Doctoral dissertation, Central Department of Botany Tribhuvan University Kirtipur, Kathmandu, Nepal).

Ghimire, S. K., Sah, J. P., Shrestha, K. K., & Bajracharya, D. (1999). Ecological study of some high altitude medicinal and aromatic plants in the Gyasumdo valley, Manang, Nepal. *Ecoprint*, *6*(1), 17-25.

Gogoi A, Sahoo UK, Singh SL. Assessment of biomass and total carbon stock in a tropical wet evergreen rainforest of Eastern Himalaya along a disturbance gradient. Journal of Plant & Biological Soil Health. 2017; 4(1):1–8. 37.

Gogoi, R. R., Adhikari, D., Upadhaya, K., & Barik, S. K. (2020). Tree diversity and carbon stock in a subtropical broadleaved forest are greater than a subtropical pine forest occurring in similar elevation of Meghalaya, north-eastern India. *Tropical Ecology*, *61*, 142-149.

Gupta, P. K., Gupta, P. K., & Gupta, P. K. (2007). *Methods in environmental analysis: water, soil and air* (pp. 5-127). Jodhpur, India: Agrobios.

Hara, H., Stearn, W. T., & Williams, L. H. J. (1978). *An enumeration of the flowering plants of Nepal. Volume one* (pp. 154-pp).

Hooker, J.D. (1872-1897). *Flora British India*, 1. L, Reeve, London.

Hu Y, Su Z, Li W. (2018). Influence of tree species composition and community structure on carbon density in a subtropical forest. PLoS One. 2015; *10*(8), e0136984 34.

Jhariya, M. K. (2014). Effect of Forest Fire on Microbial Biomass, Storage and Sequesrration of Carbaon in a Tropical Deciduous Forest of Chhattisgarh (Doctoral dissertation, Indira Gandhi Krishi Vishwavidyalaya, Raipur).

Jhariya, M. K., Bargali, S. S., Swamy, S. L., Kittur, B., Bargali, K., & Pawar, G. V. (2014). Impact of forest fire on biomass and Carbon storage pattern of Tropical

Deciduous Forests in Bhoramdeo Wildlife Sanctuary, Chhattisgarh. *International Journal of Ecology and Environmental Sciences*, *40*(1), 57-74.

Jina, B. S., Sah, P., Bhatt, M. D., & Rawat, Y. S. (2008). Estimating carbon sequestration rates and total carbon stockpile in degraded and non-degraded sites of Oak and Pine forest of Kumaun Central Himalaya. *Ecoprint: An International Journal of Ecology*, *15*, 75-81.

Jina, B. S., Sah, P., Bhatt, M. D., & Rawat, Y. S. (2008). Estimating carbon sequestration rates and total carbon stockpile in degraded and non-degraded sites of Oak and Pine forest of Kumaun Central Himalaya. *Ecoprint: An International Journal of Ecology*, *15*, 75-81.

Joshi, R., Singh, H., Chhetri, R., & Yadav, K. (2020). Assessment of Carbon Sequestration Potential in Degraded and Non-Degraded Community Forests in Terai Region of Nepal. *Journal of Forest and Environmental Sciences, 36*(2), 113-121.

Joshi, R., & Singh, H. (2020). Carbon sequestration potential of disturbed and non-disturbed forest ecosystem: A tool for mitigating climate change. *African Journal of Environmental Science and Technology*, *14*(11), 385-393.

Koirala, M. (2004). Vegetation composition and diversity of Piluwa micro-watershed in Tinjure-Milke region, east Nepal. *Himalayan journal of Sciences*, *2*(3), 29-32.

Kunwar, R. M., & Sharma, S. P. (2004). Quantitative analysis of tree species in two community forests of Dolpa district, mid-west Nepal. *Himalayan Journal of Sciences*, *2*(3), 23-28.

Lawrence, G. (1951) Taxonomy of Vascular plants. New York: Macmillan

Le Quéré, C., Andrew, R. M., Friedlingstein, P., Sitch, S., Pongratz, J., Manning, A. C., ... & Zhu, D. (2018). Global carbon budget 2017. *Earth System Science Data*, *10*(1), 405-448.

Liu X, Trogisch S, He J.S. (2018). Tree species richness increases ecosystem carbon storage in subtropical forests. Proc R Soc B. 2018; *285* (1885), 20181240.

Liu, S., Shen, H., Zhao, X., Zhou, L., Li, H., Xu, L., ... & Fang, J. (2019). Estimation of plot-level soil carbon stocks in China's forests using intensive soil sampling. *Geoderma*, *348*, 107-114.

MacDicken, K. G. (1997). A guide to monitoring carbon storage in forestry and agroforestry projects.

Mandal, G., & Joshi, S. P. (2014). Analysis of vegetation dynamics and phytodiversity from three dry deciduous forests of Doon Valley, Western Himalaya, India. *Journal of Asia-Pacific Biodiversity*, *7*(3), 292-304.

Masera, O. R., Garza-Caligaris, J. F., Kanninen, M., Karjalainen, T., Liski, J., Nabuurs, G. J., ... & Mohren, G. M. J. (2003). Modeling carbon sequestration in afforestation, agroforestry and forest management projects: the CO2FIX V. 2 approach. *Ecological Modelling*, *164*(2-3), 177-199.

McKinley, D. C., Ryan, M. G., Birdsey, R. A., Giardina, C. P., Harmon, M. E., Heath, L. S., ... & Skog, K. E. (2011). A synthesis of current knowledge on forests and carbon storage in the United States. *Ecological applications*, *21*(6), 1902-1924.

Nath, P. C., Arunachalam, A., Khan, M. L., Arunachalam, K., & Barbhuiya, A. R. (2005). Vegetation analysis and tree population structure of tropical wet evergreen forests in and around Namdapha National Park, northeast India. *Biodiversity & Conservation*, *14*, 2109-2135.

Ogawa, H. (1965). Comparative ecological studies on three main types of forest vegetation in Thailand II. *Structure and floristic composition.: nature & Life in SE Asia*, *4*, 49-80.

Ortiz-Burgos, S. (2016). Shannon-weaver diversity index. *Encyclopedia of estuaries*, 572-573.

Ovington, J. D. (1962). Quantitative ecology and the woodland ecosystem concept. In *Advances in ecological research* (Vol. 1, pp. 103-192). Academic Press.

Pandey, H. P., & Bhusal, M. (2016). A comparative study on carbon stock in Sal (Shorea robusta) forest in two different ecological regions of Nepal. *Banko Janakari*, *26*(1), 24-31.

Pathak, R. P., & Baniya, C. B. (2017). Species diversity and tree carbon stock pattern in a community-managed tropical Shorea forest in Nawalparasi, Nepal. *International Journal of Ecology and Environmental Sciences*, *42*(5), 3-17.

Paudyal, A., Chettri, M. K., Subedi, B., & Khanal, R. P. (2022). Tree Species Diversity and Carbon Stock in Community and Religious Forests of Rupandehi, Nepal. *Journal of Plant Resources*, *20*(1), 64-72.

Paudyal, B. K. (2013). Regeneration, growth of hill sal and plant diversity in community forest: A case study from Pragatisil community forest in Kaski district, Western Nepal. *Banko Janakari*, *23*(2), 37-43.

Pawar, G. V., Singh, L., Jhariya, M. K., & Sahu, K. P. (2014). Effect of anthropogenic disturbances on biomass and carbon storage potential of a dry tropical forest in India. *Journal of Applied and Natural Science*, *6*(2), 383-392.

Pearson, T. R. (2007). *Measurement guidelines for the sequestration of forest carbon* (Vol. 18). US Department of Agriculture, Forest Service, Northern Research Station.

Rautiainen, O. 1994. Natural Regeneration Potential of Mixed Shorea robusta Forest. Working Paper 10, 2-3, Forest management and utilization Development Project, HMG/ FINNIDA, Kathmandu.

R Core Team. (2023). A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.

Saner, P., Loh, Y. Y., Ong, R. C., & Hector, A. (2012). Carbon stocks and fluxes in tropical lowland dipterocarp rainforests in Sabah, Malaysian Borneo. PloS one, 7(1).

Shameem, S. A., & Kangroo, I. N. (2011). Comparative assessment of edaphic features and phytodiversity in lower Dachigam National Park, Kashmir Himalaya, India. *African Journal of Environmental Science and Technology*, *5*(11), 972-984.

Siwakoti, M., & Varma, S. K. (1999). *Plant diversity of eastern Nepal*.???? Incomplete citation

Sohel, M. S. I., Rana, M. P., Alam, M., Akhter, S., & Alamgir, M. (2009). The carbon sequestration potential of forestry sector: Bangladesh context. *Journal of forest and environmental science*, *25*(3), 157-165.

Swaine, M. D., and Hall, J. B. (1988). The mosaic theory of forest regeneration and the determination of forest composition in Ghana. Journal of Tropical Ecology, 4(3), 253- 269.

Thapa-Magar, K. B., & Shrestha, B. B. (2015). Carbon stock in community managed hill sal (Shorea robusta) forests of central Nepal. *Journal of Sustainable forestry*, *34*(5), 483-501.

Timilsina, N., Ross, M. S., & Heinen, J. T. (2007). A community analysis of sal (Shorea robusta) forests in the western Terai of Nepal. *Forest ecology and management*, *241*(1-3), 223-234.

Upadhaya, K., Barik, S. K., Pandey, H. N., & Tripathi, O. P. (2008). Response of woody species to anthropogenic disturbances in sacred forests of northeast India. *International Journal of Ecology and Environmental Sciences*, *34*(1), 00-00.

Usuga, J. C. L., Toro, J. A. R., Alzate, M. V. R., & Tapias, Á. D. J. L. (2010). Estimation of biomass and carbon stocks in plants, soil and forest floor in different tropical forests. *Forest Ecology and Management*, *260*(10), 1906-1913.

Walkley, A., & Black, I. A. (1934). An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil science*, *37*(1), 29-38.

Wang, Y. C., Liu, W. Y., Ko, S. H., & Lin, J. C. (2015). Tree species diversity and carbon storage in air quality enhancement zones in Taiwan. *Aerosol and Air Quality Research*, *15*(4), 1291-1299.

Watson, R. T., Noble, I. R., Bolin, B., Ravindranath, N. H., Verardo, D. J., & Dokken, D. J. (2000). *Land use, land-use change and forestry: a special report of the Intergovernmental Panel on Climate Change*. Cambridge University Press.

Yohannes, H., Soromessa, T., & Argaw, M. (2015). Carbon stock analysis along forest disturbance gradient in gedo forest: Implications of managing forest for climate change mitigation. *Journal of Ecosystem and Ecography, 5*, 1-5.

Zobel, D. B., Jha, P. K., Behan, M. J., & Yadav, U. K. R. (1987). A practical manual for ecology. *Ratna Book Distributors, Kathmandu, Nepal*, *149*(7), 75-83.

APPENDICES

Appendix 1. Community attributes of HDF

Tree species	B (m2/ha	RB	F (%)	RF	D (pl/ha)	RD	IVI
Aegle marmelos	0.490006	0.097669	3.33	1.33328	1.060895	0.174521	1.60547
Anogeissus latifolia	0.422502	0.084214	3.33	1.33328	1.060895	0.174521	1.592015
Buchanania conchinchensis	1.967791	0.392225	13.33	5.337124	6.365372	1.047126	6.776474
Cassia fistula	0.490006	0.097669	3.33	1.33328	1.060895	0.174521	1.60547
Ficus semicordata	1.822502	0.363265	3.33	1.33328	1.060895	0.174521	1.871066
Mallotus philippensis	0.490006	0.097669	3.33	1.33328	1.060895	0.174521	1.60547
Phyllanthus emblica	0.640006	0.127568	3.33	1.33328	1.060895	0.174521	1.635368
Semecarpus anacardium	0.809994	0.16145	3.33	1.33328	1.060895	0.174521	1.669251
Senegalia catechu	32.92	6.56169	23.31	9.33296	15.91343	2.617814	18.51246
Shorea robusta	412.7833	82.27692	96.57	38.66512	525.1432	86.38787	207.3299
Syzygium cumini	0.75	0.149492	9.99	3.99984	3.182686	0.523563	4.672894
Terminalia alata	44.15528	8.801133	69.93	27.99888	45.6185	7.504401	44.30441
Terminalia bellirica	1.912508	0.381205	6.66	2.66656	2.121791	0.349042	3.396807
Terminalia chebula	2.125016	0.423563	6.66	2.66656	2.121791	0.349042	3.439165

Appendix 2. Community attributes of LDF

Tree species	**B (m2/ha**	**RB**	**F (%)**	**RF**	**D (pl/ha)**	**RD**	**IVI**
Aegle marmelos	4.296626	0.618166	29.97	12.85163	3.182686	0.570343	14.04014
Anogeissus latifolia	0.413749	0.059527	6.66	2.855918	1.060895	0.190114	3.105559
Buchanania conchinchensis	2.22788	0.320531	3.33	1.427959	5.304477	0.950572	2.699061
Cassia fistula	0.413749	0.059527	6.66	2.855918	1.060895	0.190114	3.105559
Dalbergia sissoo	7.829408	1.126436	3.33	1.427959	1.060895	0.190114	2.74451
Ficus benghalensis	0.318269	0.04579	3.33	1.427959	1.060895	0.190114	1.663863
Lannea coromandelica	1.527689	0.219792	3.33	1.427959	2.121791	0.380229	2.02798
Lyonia ovalifolia	1.368555	0.196897	3.33	1.427959	2.121791	0.380229	2.005085
Semecarpus anacardium	3.055379	0.439585	3.33	1.427959	7.426268	1.330801	3.198345
Senegalia catechu	61.10757	8.791698	6.66	2.855918	41.37492	7.414462	19.06208
Shorea robusta	550	79.12986	100	42.88165	458.3068	82.12942	204.1409
Syzygium cumini	10.34373	1.488178	13.32	5.711835	6.365372	1.140686	8.3407
Terminalia alata	36.28262	5.220071	43.29	18.56346	24.40059	4.372631	28.15617
Terminalia bellirica	15.8816	2.284926	6.66	2.855918	3.182686	0.570343	5.711187

Appendix 3. Basal area of tree species in HDF

Tree species	**m2/ha**
Aegle marmelos	0.490006
Anogeissus latifolia	0.422502
Buchanania conchinchensis	1.967791
Cassia fistula	0.490006
Ficus semicordata	1.822502
Mallotus phillipensis	0.490006
Phyllanthus emblica	0.640006
Semecarpus anacardium	0.809994
Senegalia catechu	32.92
Shorea robusta	412.7833
Syzygium cumini	0.75
Terminalia alata	44.15528
Terminalia bellerica	1.912508
Terminalia chebula	2.125016

Appendix 4. Basal area of tree species in HDF merge table 3 and 4

Tree species	m2/ha
Aegle marmelos	4.296626
Anogeissus latifolia	0.413749
Buchanania conchinchensis	2.22788
Cassia fistula	0.413749
Dalbergia sissoo	7.829408
Ficus benghalensis	0.318269
Lannea coromandelica	1.527689
Lyonia ovalifolia	1.368555
Semecarpus anacardium	3.055379
Senegalia catechu	61.10757
Shorea robusta	550
Syzgium cumini	10.34373
Terminalia alata	36.28262
Terminalia bellerica	15.8816

Appendix 5. Seedling density of different plants in HDF and LDF

Plot	HDF	LDF
Aegle marmelos	0	53.04477
Anogeissus latifolia	53.04477	0
Bauhinia sp.	53.04477	0
Buchanania conchinchensis	106.0895	106.0895
Casearia graveolens	53.04477	0
Mallotus phillipensis	0	53.04477
Mangifera indica	53.04477	106.0895
Psidium guajava	0	53.04477
Semecarpus anacardium	0	371.3134
Senegalia catechu	848.7163	2546.149
Shorea robusta	17929.13	45798.85
Syzygium cumini	424.3582	1538.298
Terminalia alata	742.6268	848.7163
Unknown 1 (Tilko)	53.04477	0

Appendix 6. Sapling density of different plants in HDF and LDF

Plot	HDF	LDF
Adina cordifolia	0	4.243582
Aegle marmelos	12.73074	4.243582
Anogeissus latifolia	4.243582	0
Bauhinia sp.	8.487163	0
Buchanania conchinchensis	29.70507	25.46149
Lagerstroemia parviflora	0	8.487163
Casearia graveolens	25.46149	67.89731
Falconeria insignis	0	4.243582
Ficus benghalensis	0	4.243582
Ficus religiosa	0	4.243582
Ficus semicodata	4.243582	0
Lannea coromandelica	0	8.487163
Mallotus philippensis	16.97433	12.73074
Phyllanthus emblica	8.487163	0
Santat	0	4.243582
Semecarpus anacardium	4.243582	59.41014
Senegalia catechu	0	21.21791
Shorea robusta	445.5761	606.8322
Syzygium cumini	12.73074	173.9868
Syzygium nervosum	0	4.243582
Terminalia alata	25.46149	0

Appendix 7. Tree density of different plants in HDF and LDF

Plot	HDF	LDF
Acacia catechu	0	41.37492
Aegle.marmelos	1.060895	3.182686
Anogeissus latifolia	1.060895	1.060895
Buchanania.conchinchensis	6.365372	5.304477
Cassia fistula	1.060895	1.060895
Dalbergia sissoo	0	1.060895
Ficus benghalensis	0	1.060895
Lannea coromandelica	0	2.121791
Lyonia ovalifolia	0	2.121791
Ficus semicordata	1.060895	0
Mallotus philippensis	1.060895	0
Phyllanthus emblica	1.060895	0
Semecarpus anacardium	1.060895	7.426268
Senegalia catechu	15.91343	0
Shorea robusta	525.1432	458.3068
Syzygium cumini	3.182686	6.365372
Terminalia alata	45.6185	24.40059
Terminalia bellirica	2.121791	3.182686
Terminalia chebula	2.121791	0

Appendix 8. Standard wood density data of all tree species with the references

Tree species	Wood density	Reference
Aegle marmelos	0.72	https://www.fao.org/3/w4095e/w4095e0c.htm
Anogeissus latifolia	0.79	Karki et al. (2016)
Buchanania conchinchensis	0.45	Karki et al. (2016)
Cassia fistula	0.97	Jackson (1994)
Dalbergia sissoo	0.7	Agroforest data base
Ficus benghalensis	0.39	Reyes *et al*. (1992)
Ficus semicordata	0.39	Reyes *et al*. (1992)
Lannea coromandelica	0.54	Reyes *et al*. (1992)
Lyonia ovalifolia	0.59	Karki *et al*. (2016)
Mallotus phillipensis	0.64	Reyes *et al*. (1992)
Phyllanthus emblica	0.84	Jackson (1994)
Semecarpus anacardium	0.64	Reyes *et al*. (1992)
Sengalia catechu	0.88	Reyes *et al*. (1992)
Shorea robusta	0.88	Jackson (1994)
Syzgium cumini	0.7	Reyes *et al*. (1992)
Terminalia alata	0.95	Jackson (1994)
Terminalia bellerica	0.77	Jackson (1994)
Terminalia chebula	0.92	Jackson (1994)

PHOTO PLATES

***Plate 1*: Picture with one of the authorities of Pathivara community forest

***Plate 2*: Picture with fodder and firewood collectors in Pathivara community forest

***Plate 3*: Measuring DBH of tree

***Plate 4*:** Collecting soil sample

Plate 5: Janakalyan community forest (LDF)

***Plate 6*:** Grazing in HDF