Effect of Disturbance in Tree Diversity, Carbon Stock and Regeneration in the Community Forests of Dang, Nepal

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The tropical forests of Nepal face significant threats due to disturbances like grazing, human activities, forest fires, deforestation, and construction. This study aimed to assess the impact of disturbances on tree diversity, carbon stock, and regeneration and regeneration in two community forests in Dang, Western Nepal: Pathivara Community Forest (highly disturbed) and Janakalyan Community Forest (less disturbed). In the present study, data from 60 circular sample plots (30 in each forest) were analyzed. Soil samples, collected to a depth of 30 cm, were tested for organic matter, nitrogen, potassium, phosphorus, and pH content. Eighteen tree species across 15 genera and 10 families were recorded, where a higher diversity was observed in the less disturbed forest (LDF) compared to the highly disturbed forest (HDF). *Shorea robusta* was the dominant species in both forests, contributing significantly to carbon storage. The mean carbon stock in HDF and LDF was 46.48 Mg/ha and 72.72 Mg/ha, respectively. The overall regeneration was poor in both forests, particularly among saplings compared to standard community forest inventory guidelines. LDF showed higher organic matter, nitrogen, and potassium content, while HDF had greater phosphorus levels. The study highlighted the adverse effects of disturbances on forest quality and regeneration. The less disturbed forest (LDF) exhibits better carbon storage, soil fertility, and species diversity compared to the highly disturbed forest (HDF). To improve forest conditions, it is recommended to enhance conservation efforts, reduce anthropogenic pressures, and implement effective management practices to support natural regeneration, particularly for saplings.

Keywords: Anthropogenic disturbance; Carbon stock; Regeneration; Soil factors.

Nepal has a high biodiversity due to its variations in altitude, climate, and topography. There are 35 different forest types in Nepal, and they play a significant role in the climate system (Stainton, 1972), acting as a carbon source and sink (Liu et al., 2018). Due to increased human encroachment, deforestation, unsustainable harvesting, and the use of fodder, medicinal plants, and timber, as well as grazing pressures, many national forests in Nepal have been transferred to local communities and are now managed as community forests (Kanel et al., 2006). The implementation of community forestry was legally supported with the enactment of the Forest Act (1993) and the Forest Regulation (1995) (Kanal & Kandel, 2004). There are a total of 23026 community forest user groups in Nepal, managing an area of 2.42 million hectares of forests (FECOFUN, 2025). Though community forestry has set an example of high community-level participation to conserve the forest in Nepal (Shahi et al., 2022), some community forests have shown less active people's participation. Such community forests have been subjected to potentially affecting the species diversity, biomass, community structure, and carbon storage of the woods.

Plants naturally sequester carbon and store it in soil, above-ground biomass, and below-ground biomass (Aryal et al., 2017). It is an effective means of reducing greenhouse gas emissions and supporting

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the mitigation and adaptation to the effects of climate change (Jina et al., 2009). However, human activities such as burning of fossil fuels, other land-use changes, and deforestation are contributing to the rise in CO_2 levels (Ciais et al., 2013; Le Quéré et al., 2018). Moderate disturbances frequently increase plant diversity, causing only minor structural changes in the forest, while extreme disturbances significantly reduce plant diversity and vegetation structure (Upadhaya et al., 2008). The disturbance not only alters the composition and structure of the stand but also results in a substantial loss of stand biomass and carbon stock (Gautam & Mandal, 2016). Moreover, numerous factors, including forest types, species richness (Gogoi et al., 2020), succession stage, specific disturbance (Gogoi et al., 2017), land use histories (Mueller & Koegel-Knabner, 2009), management intervention (Chaudhary & Aryal, 2024), and edaphic factors (Chaudhary & Aryal, 2024), influence the carbon stock of forest ecosystems. Therefore, safeguarding the forest's ability to recover and persist - a process driven by effective regeneration - is critical for the long-term maintenance of this valuable carbon stock.

Regeneration preserves the sustainability of the woods for future generations while illuminating the species composition and the community's developmental trend (Napit, 2016). The regeneration is the process by which new plants are produced through their young, and it can be measured or counted how many seedlings, saplings, and trees there are in a given area (Acharya & Shrestha, 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 (Awasthi et al., 2015). Moreover, the physio-chemical properties of the soil are not similar in all environments. It varies according to the variation in space, biotic factors, topographic factors, microbial activities, and vegetation (Bojko & Kabala, 2016; Shrestha et al., 2024).

While the strategy of Community Forest has led to forest conservation and an increase in forest cover, these systems still face some internal challenges. The community forests of Dang are significantly influenced by anthropogenic disturbances, livestock grazing, forest fire, unsustainable resource extraction, and management interventions. These disturbances do not always result in forest loss; however, they may cause crucial variation in forest structure, regeneration, and carbon storage. Therefore, this study is essential to provide current, site-specific data on the ecological status of Terai community forests in Dang. This study will help to determine the amount of carbon sequestration, regeneration status, and tree diversity of highly and less disturbed community forest and help to implement forest management strategies.

Materials and Methods

Study area

The study was carried out in the Pathivara Community Forest and Janakalyan Community Forest of Dang, Lumbini Province (Figure 1), which were indicated as a highly disturbed forest (HDF) and a less disturbed forest (LDF), respectively on the basis of selection criteria. The area of HDF and LDF is 271 ha and 100 ha, respectively. Dang is located in the inner terai and is the second largest valley in Asia. Due to the altitudinal variation from 218 to 2058 m, Dang has various types of forests, viz. Sal (*Shorea robusta*) Forest, Khayar (*Senegalia catechu*)-Sissoo (*Dalbergia sissoo*) Forest, mixed Sal Forest, mixed pine (*Pinus* sp.) Forest, etc.

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. The climate summary of the study area was the average data of 20 years (2000-2020 AD), extracted from the Department of Meteorology and Hydrology, Babarmahal, Kathmandu.

Selection criteria for highly disturbed and less disturbed community forests

The selection of highly disturbed and less disturbed forest was done by adopting the method followed by Jina et al. (2009) and Joshi et al. (2020).

- 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., 2009).
- Grazing: The presence of the hoofmarks and dung of livestock, broken tops of seedlings and saplings, signs of trampling, etc., was the criterion 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., 2009).

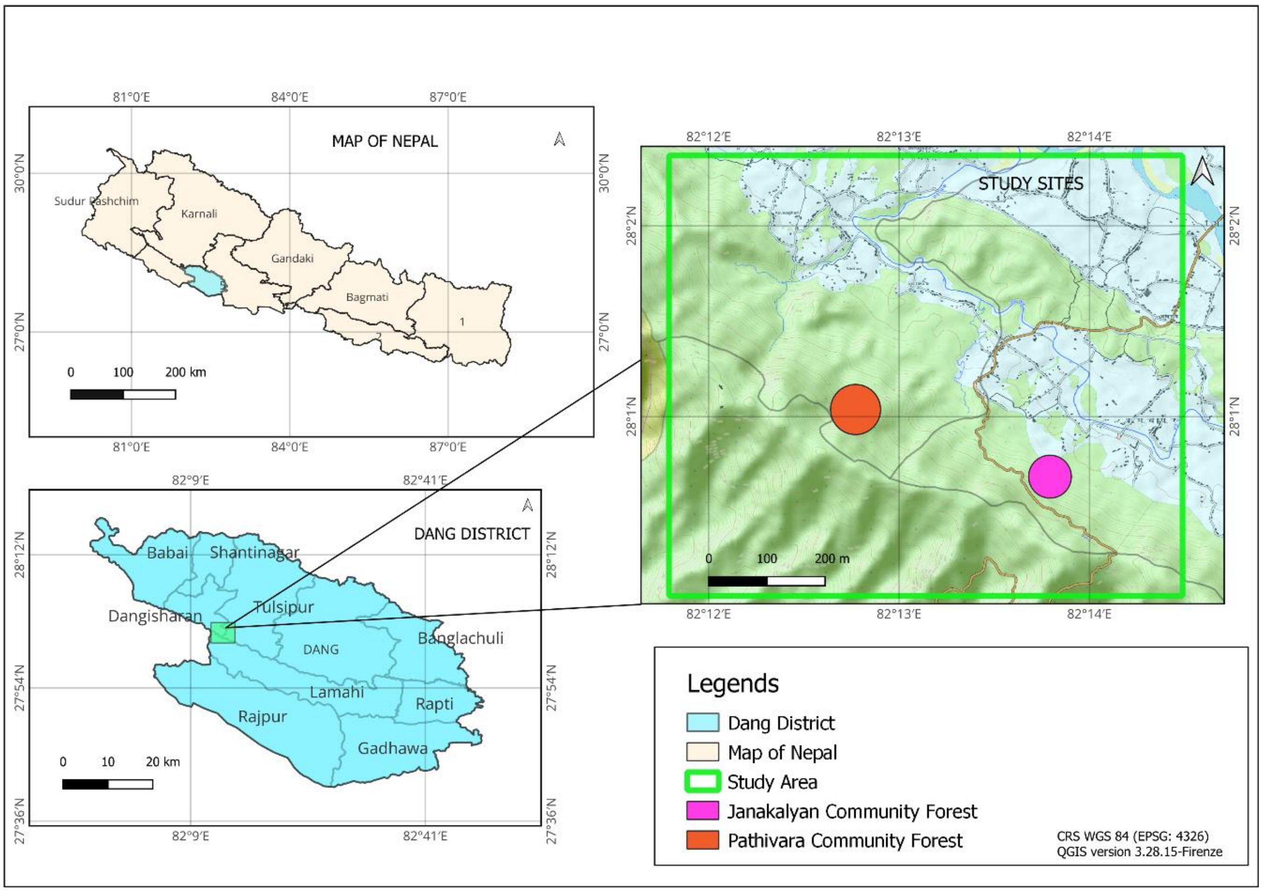

Figure 1: Map of the study area indicating the map of Nepal, Dang district and two study sites

- The number of lopped branches per tree: 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 (Jina et al., 2009).

Sampling design

A stratified random sampling design was employed to lay a total of 60 circular plots, distributed equally with 30 plots in each highly disturbed forest stratum and less disturbed forest stratum. All the study areas were differentiated into three blocks based on species composition, different age blocks, and geographical locations by the authors and forest authorities. The random sampling was then used in the different blocks. To minimize the impact of edge effects and human-induced boundary disturbances, sampling plots were established at least 200 m from the forest periphery.

Data collection

The local communities and officials from each community forest were involvedin the data collection process. We obtained the annual progress reports from the subdivision offices of the Pathivara community forest and Janakalyan community forest. A preliminary investigation, including the establishment of the nested plot layout, was conducted from October 08 to October 11, 2022. The primary phase of field data collection was conducted over two weeks, from October 16 to October 29, 2022. The circular plots of radius 10 m, 5 m, and 1 m were used for sampling trees (DBH > 5 cm), saplings (DBH 1 to 5 cm), and seedlings, respectively. The average value of two plots for seedling was taken for the estimation of seedling density. The diameter at breast height (dbh) of all trees was measured inside the plot at 1.3 m tree height from the ground, and a clinometer was used to measure each tree's height. For DBH class distribution, DBH was categorized into five classes: less than 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 elevation and spatial location. 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 (equation *I*).

$$\text{Tan}\ \theta = p/b \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (I)$$

where b = distance between the person holding clinometer; p = tree height, omitting the height of the person holding the clinometer; θ = angle of elevation recorded by clinometer

To find the Total Tree Height (H), the height of the observer at eye level (h) must be added to the calculated value (equation *II*):

$$H = (b.\tan\theta) + h \ldots\ldots\ldots\ldots\ldots\ldots\ldots..(II)$$

The soil samples from our quadrats 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 & Aryal, 2024).

Data analysis

The map of the study area was generated using ArcGIS version 8.2. For all descriptive and inferential statistical analyses, R software was employed (R Core Team, 2023). Data normality was assessed using the Shapiro-Wilk test. An independent t-test was used to find out the significant difference between the study sites for diversity index. One-way ANOVA was used to find the significant difference between the sites for edaphic parameters and regeneration status. To determine the significant variation in tree carbon stock between the disturbed sites, the Mann-Whitney U Test was used because the data was not distributed normally. A Spearman correlation test was used to find out the relationship of number of seedlings and saplings with edaphic factors.

Community attributes:

Zobel et al. (1987) described the ecological parameters density (plha^{-1}), frequency (%), basal area (m^2ha^{-1}), coverage (%), their relative values and important value index (IVI) were computed. The Shannon diversity index of trees in both forests was calculated directly using R software. The Sorensen's species similarity index (SI) between the two sites was calculated with the given literature (Nath et al., 2005) (Equation *III*):

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

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

Biomass and carbon estimation

Aboveground tree biomass (AGTB):

Allometric equation was used to calculate above ground tree biomass (AGTB) (Equation *IV*),

$$AGTB = 0.0509 \times D2 \times r \times H \ldots.(IV)$$

[where, D=Tree diameter at breast height (cm), r = Wood specific density (kg m^{-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) (Van Amstel, 2006).
- Finally, to determine the overall forest carbon stock, the carbon values for each forest carbon pool were added together.

Plant identification and nomenclature

Collected plant specimens were pressed, dried, and mounted to prepare the standard herbarium specimens (Lawrence, 1951). Initial identification was made using established taxonomic keys and identification tools, followed by consultation with botanical experts. Following successful identification, the most recent and widely recognized scientific names and family classifications were systematically verified using the reliable online databases, specifically the Annonated Floralist of Nepal (www.efloras.org) and the Global Biodiversity Information Facility (www.gbif.org). The finalized herbarium specimens are permanently housed in Ascol Herbarium, Kathmandu, Nepal.

Soil analysis

Soil samples were collected from a depth of 30 cm across all 60 study plots. The collected samples were then analyzed, where hydrometric analysis was employed to determine the soil texture. Soil organic matter (SOM) was quantified using the technique developed by Walkey and Black (1934), and the resulting SOM% was converted to soil organic carbon (SOC%) by dividing it by the default conversion factor of 1.724 (Baillie et al., 1990). To assess the carbon stock, the SOC% was subsequently converted to soil organic carbon (t ha^{-1}) using the literature outlined by Chhabra et al. (2003). For nutrient analysis, the micro-Kjeldal method was used to determine the total nitrogen (N) content (Jackson, 1958), while total phosphorus (P) content was quantified using a modified Olsen and bicarbonate technique (Olsen & Sommers, 1982). The flame photometer method was used to determine the total potassium concentration (Jackson, 1958) and a digital pH meter was used to measure the pH of the soil using a 1:2.5 soil-water solution (Cottenie et al., 1980).

Results

Community diversity and structure

In the study, 18 tree species belonging to 15 genera and 10 families were recorded where 14 tree species were recorded from HDF and LDF each (Figure 2). According to Sorensen's similarity index, similarity between HDF and LDF was 71.4%. The 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).

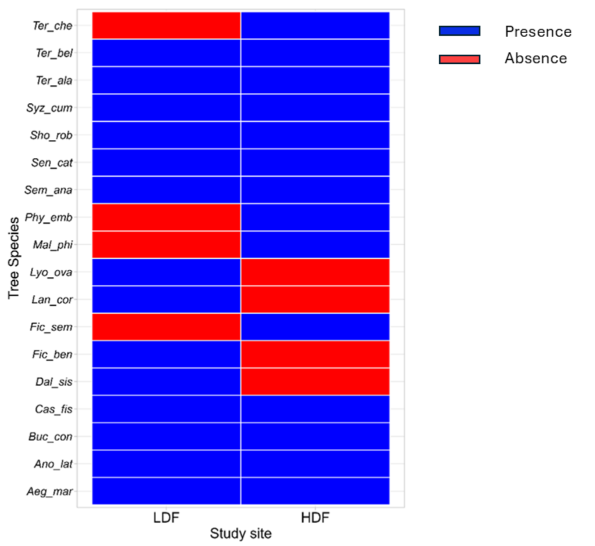

Figure 2: Presence and absence of the tree species in LDF and HDF with their respective families

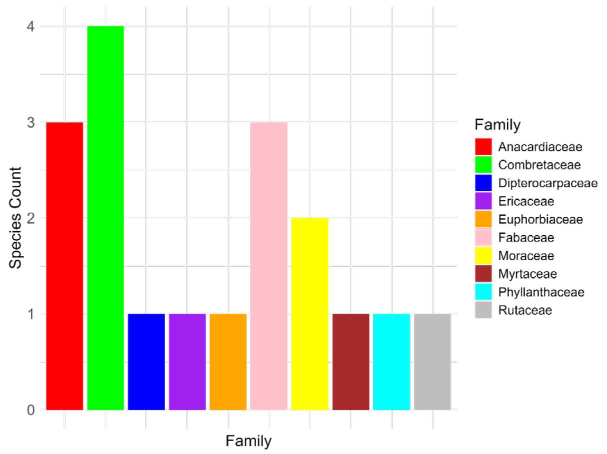

Figure 3: Name of families with their respective number of species

The Shannon diversity indices (H) were calculated to determine the diversity of both forests in terms of tree species. The value of the 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, an independent t-test was performed. There was a significant difference (p-value = 0.012) in the diversity index between the study sites.

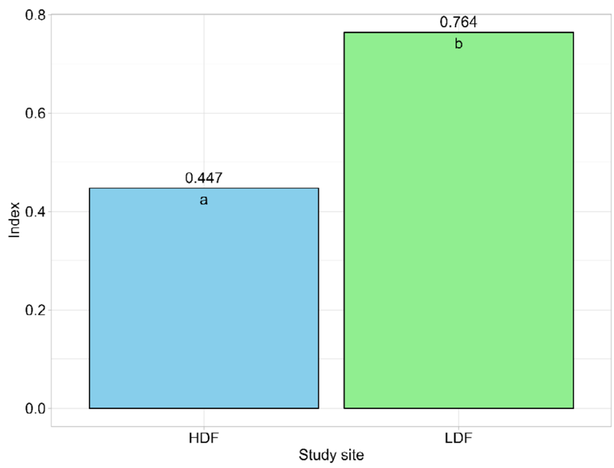

Figure 4: Shannon diversity index of LDF and HDF with standard error bar. The superscript "a" and "b" above the bar graph represent the significant difference between the values of diversity index

Community attributes

Important value index (IVI):

The important value index (IVI) was calculated to determine the spatial ecological importance of individual species. This index effectively identifies which species holds the dominant presence within a given forest area, providing a quantitative measure of its contribution to the community structure. 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), while *Anogeissus latifolia* had the lowest IVI value with 1.59 (Figure 5).

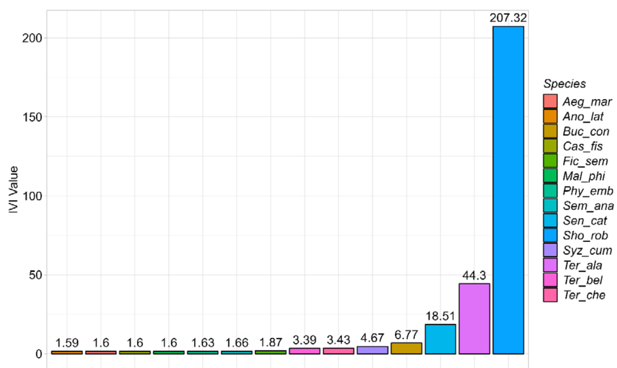

Figure 5: IVI value of the given tree species in HDF

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

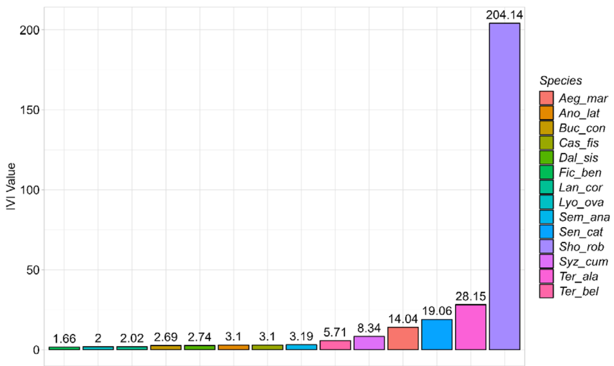

Figure 6: IVI value of the given tree species in LDF

Size-class distribution:

Five different classes were categorized to observe the size class distribution in both forest sites. In HDF, the highest number of tree species (n = 419/ ha) was found under less than 20 cm category, followed by 20-30 cm (170 pl/ha) and 30-40 (25 pl/ha). However, no tree species were recorded in the 40-50 cm and 50-60 cm categories (Figure 7). In LDF, highest number of tree species (n = 309/ ha) was found under less than 20 cm category, followed by 20-30 cm (187 pl/ha), 30-40 (49 pl/ha), 40-50 cm (13 pl/ha) and 50-60 cm (12 pl/ha) (Figure 7).

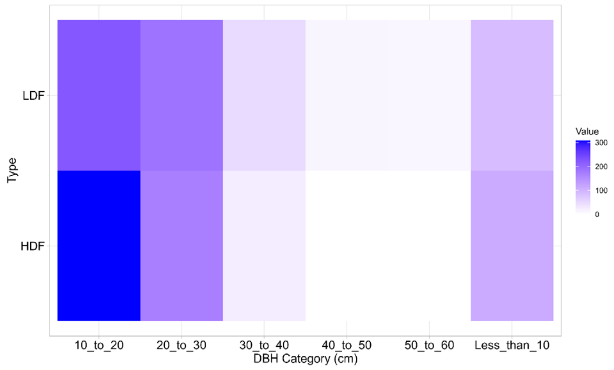

Figure 7: The heat map of size-class distribution or density diameter of the tree species in HDF and LDF

Carbon stock:

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

S. robusta contributed the most (77.37%) in the total tree carbon stock of LDF, followed by *Terminalia*

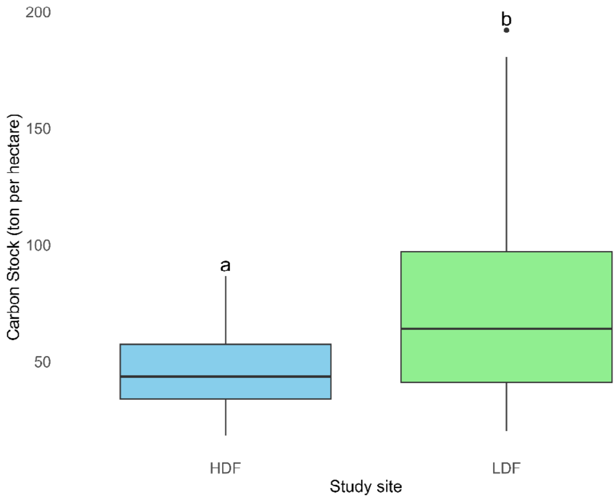

Figure 8: A boxplot representing the mean carbon stock (Mg/ha) of LDF and HDF

(Note: Different superscripts highlight the significant difference in the mean carbon stock)

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).

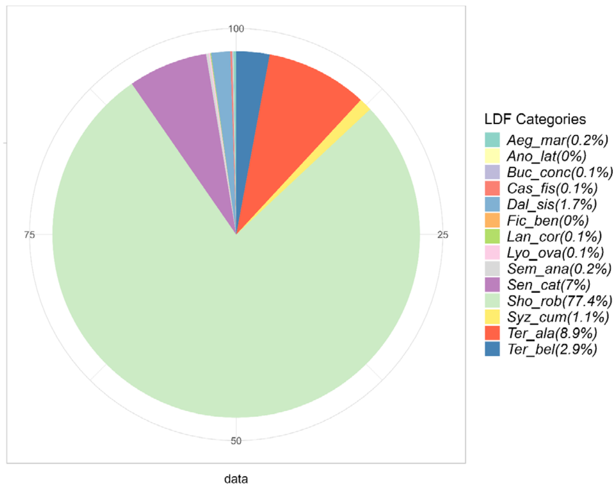

Figure 9: Contribution of the species in carbon stock in LDF

Similarly, *S. robusta* was also 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 *Phyllanthus emblica* (0.04%) (Figure 10).

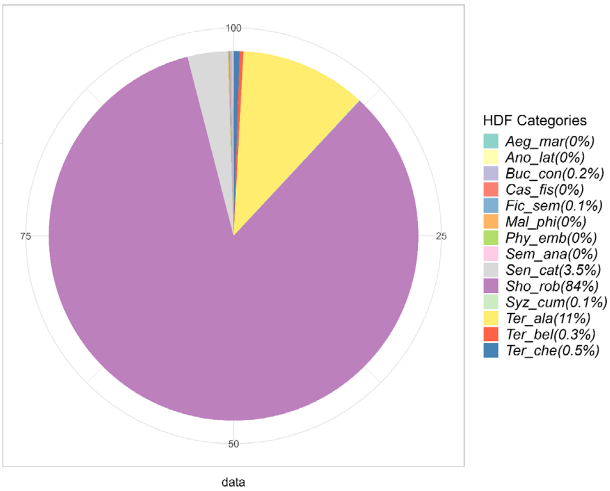

Figure 10: Contribution of the species in carbon stock in HDF

Regeneration and edaphic factor:

The density of total seedlings was higher (51474 pl/ha) in LDF compared to HDF (20316 pl/ha). There was a significant difference (p-value = 0.001) in the total number of seedlings between the study areas (Table 1). Similarly, the density of total saplings was also higher (1167 pl/ha) in LDF compared to HDF (598 pl/ha), and a significant difference (p-value < 0.001) was seen in the total saplings between the study areas. However, there was no significant difference (p-value = 0.37) in the density of trees between the study areas.

A total of 10 seedlings, 12 saplings, and 16 tree species were recorded across both the Highly Disturbed Forest (HDF) and Less Disturbed Forest (LDF) sites. In both sites, *S. robusta* had the highest density of seedlings, saplings, and trees (Table 2). 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 tree species associated with *S. robusta* in both forests.

LDF had the highest content of organic matter (OM), nitrogen (N), and potassium (K) compared to HDF (Table 3). However, phosphorus (P) content was higher in HDF compared to LDF. The pH content was found to be more acidic in LDF compared to HDF, though both sites had acidic soil. 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 significant difference 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 4). Nitrogen content also had a 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% (OM and N) and 12.5% (OM) factors among the total factors have some effects on seedling and sapling of the community forests, respectively.

Table 1: Average number of seedlings, saplings, and trees of Sal and total tree species in HDF and LDF (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 tree species	Seedlings	20316.14 ± 3749.29	51474.64 ± 7639.23	0.001
Total tree species	Saplings	598.3 ± 126.3	1167.7 ± 114.6	0.001
Total tree species	Trees	607.73 ± 42.67	557.88 ± 35.04	0.37

Table 2: Seedling, sapling and trees of highest three species in each site

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

Table 3: 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

Table 4: 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

Discussion

Plant diversity and structure

The Shannon diversity indices (H) were calculated to determine the diversity of both forests in terms of tree species. The value of the Shannon index for HDF and LDF was 0.447 and LDF 0.764, respectively. Dhakal et al. (2021) had reported a higher tree diversity index (2.49) compared to our study. The ideal Shannon diversity value falls between 1.5 and 3.5, seldom rising above 4.5 (Ortiz-Burgos, 2016). Plant diversity increases with H value; however, the diversity indices of this study fall between 1.5 and 3.5. It shows that there is less tree diversity across both the study 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 degradation of the diversity of trees, which was also reported by (Chaudhary & Aryal, 2025). According to Sorensen's similarity index, the similarity between HDF and LDF was 71.4%. The high similarity between the study sites may be due to the presence of the forests in a similar topographical area and experiencing similar climatic conditions. The family Combretaceae occurred with the highest species count, followed by Anacardiaceae and Fabaceae, which might suggest its ecological dominance or adaptability in the studied area and the ecological significance of these families.

Community attributes

In both sites, *S. robusta* had the highest IVI value. 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 *S. robusta* growth and development include the age of the forest, disturbances, community group management techniques, resources available, and related species (Mandal & Joshi, 2014). Therefore *S. robusta* has a significant role in shaping the forest structure and possibly indicating its ecological adaptability across varying densities. 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). *Terminalia alata* and *Senegalia catechu* also showed notable presence in both forest types, though their IVI values were considerably lower than those of *S. robusta*, suggesting they play secondary yet important roles. Similar findings were made by the previous studies (DFRS, 2014; Chaudhary & Aryal, 2025), who conducted the Terai Forest Inventory and found that *S. robusta* had the highest IVI, followed by *Terminalia alata*. The presence of different species with relatively lower IVI values in each forest type, such as *Anogeissus latifolia* in HDF and *Ficus benghalensis* in LDF, highlights the variability in species' prominence and their ecological roles within the forest ecosystems. These findings illustrate that while some species, like *S. robusta*, are central to both forest types, others exhibit variable dominance, reflecting the ecological diversity and complexity within these forest environments.

The greatest number of tree species in HDF were discovered in the categories of less than 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 less than 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 a healthy regenerating forest (Timilsina et al., 2007). Nonetheless, there have been some natural disasters, disturbances, or human activity in HDF, and the forest had begun to regenerate, or the environment around HDF does not support the growth of larger trees. As a result, no trees having a DBH greater than 40 cm have been observed. This broader size class representation in the LDF indicates a potentially more diverse and stable forest structure that supports a range of tree sizes. The difference in size class distribution between the two forest types reflects variations in forest density, growth conditions, and possibly different stages of forest development or disturbance regimes.

Tree carbon stock

The distribution of carbon stocks in the study areas ranged from 18.2 Mg/ha to 180.6 Mg/ha. In HDF and LDF, the mean carbon stock value was 46.48 Mg/ha and 72.72 Mg/ha, respectively. The significant variation shows the effect of the disturbance in carbon sequestration. The average carbon stock in the study area was lower compared to previous literature (Baral et al., 2010; Thapa-Magar & Shrestha, 2015; Pandey & Bhusal, 2016; Banik et al., 2018; Bhatta & Devkota, 2020; Chaudhary & Aryal, 2025). 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 both study areas. 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 (Meng et al., 2021).

In both forest types, *S. robusta* emerged as the dominant species, contributing most of the carbon stock. However, the relative contribution of other species varies, with *Terminalia alata* and *Senegalia catechu* also making notable contributions in both forests. The low carbon stock contributions from species like *Ficus benghalensis* and *Anogeissus latifolia* in LDF, and *Semecarpus anacardium* and *Aegle marmelos* in HDF, suggest these species have a minimal impact on overall carbon storage. These findings emphasize the importance of species composition and forest density in carbon stock assessments and highlight the need for targeted conservation strategies to enhance carbon sequestration in different forest types.

Regeneration and edaphic factor

The analysis of seedling and sapling densities reveals a significant contrast between the LDF and HDF, with LDF showing a higher density of both seedlings and saplings compared to HDF. *S. robusta* exhibited the maximum density of seedlings, saplings, and trees in both HDF and LDF, highlighting its adaptability and dominance. The consistent presence of *T. alata* and *S. catechu* as frequent associates with *S. robusta* marked their ecological relationships and potential role in forest dynamics. These findings emphasized the need for adaptive management strategies that consider species-specific dynamics and regeneration patterns to effectively maintain and enhance forest biodiversity and health (Spathelf et al., 2018). However, the moderate disturbances in the forest area may foster the various habitats, assist in soil aeration and nutrient circulation, and initiate natural succession, ultimately improving forest regeneration (Chapagain et al., 2021). This result was in agreement with the study of Timilsina et al. (2007). Nonetheless, intense disturbance can result in inadequate regeneration and deterioration of the forest ecosystem (Chapagain et al., 2021).

A healthy forest's nature and sustainability are demonstrated by the abundance of seedlings and saplings in the forest. It is thought that having more than 5000 seedlings and 2000 saplings of Sal per hectare is a very good quantity for replacing older *S. robusta* trees with new ones (DoF, 2004). Comparing the Community Forests Inventory guideline (DoF, 2004), the status of sapling in both the sites are very poor ($p < 0.001$) and can affect the healthy and sustainable growth of forest (Figure 11). 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 as a result of looping, cattle grazing at higher intensities, gathering fodder and firewood, and being close to a settlement. Despite this, the density of mature trees does not significantly differ between the two forests, suggesting that both forest types have reached a similar stage of tree maturity.

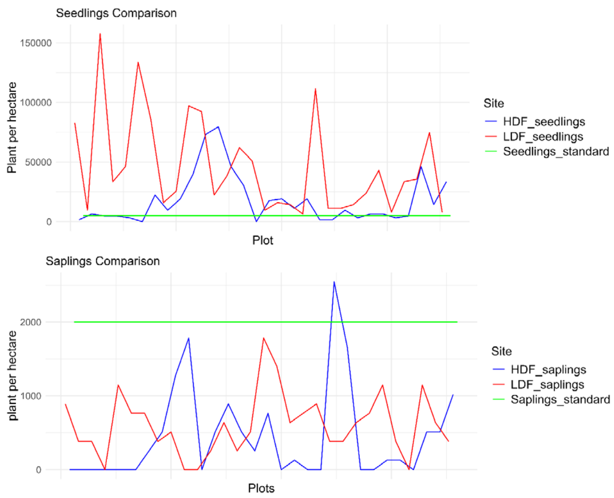

Figure 11: Comparison of seedlings and saplings with the standard number given by CI inventory guidelines

The analysis indicates that organic matter content and nitrogen availability positively influenced seedling and sapling densities in community forests, as reflected in the Spearman correlation and multiple regression results. Specifically, higher OM content is associated with increased seedling and sapling densities, suggesting that improved soil fertility and structure may enhance regeneration potential. Nitrogen content also positively correlates with seedling density, supporting the role of this essential nutrient in promoting early plant growth (Lim et al., 2021). As the total content of OM and N in the study areas is significantly high in the LDF, and a positive correlation was also observed between the number of seedlings and saplings with OM and N. These findings explained the importance of soil nutrient management in fostering forest regeneration but also highlight the need to explore additional variables and their interactions to fully understand the dynamics of seedling and sapling establishment in community forests.

Conclusion

The comparative analysis between the HDF and LDF definitively establishes the critical role of anthropogenic disturbance in compromising the ecological integrity of Terai community forest. The LDF consistently outperformed the HDF across all measured parameters, demonstrating significantly higher species diversity, carbon sequestration, and overall regeneration success. Analysis of community attributes showed that *S. robusta* was the most dominant species in both forest types, as indicated by its high Important Value Index (IVI), yet its lower size-class representation and reduced carbon stock in the HDF clearly reflects the negative impact of high degradation. Regeneration dynamics showed a higher density of seedlings and saplings in LDF compared to HDF, supported by positive correlations with soil organic matter (OM) and nitrogen (N). The deficit of saplings in both HDF and LDF, despite management efforts, indicates that current levels of disturbance pose a significant, immediate threat to long-term sustainability of the entire forest stand. The findings emphasized the importance of forest management and conservation practices that minimize disturbances to enhance forest health, biodiversity, and carbon sequestration. Effective management strategies in community forests should focus on mitigating anthropogenic impacts, improving soil conditions, and supporting natural regeneration processes to sustain forest ecosystems and their ecological functions.

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No potential conflict of interest was reported by the author(s).

Authors' contributions statement

SC, CD, and MPD: Designed the study. **SC, CD, NSK, and SA**: Collected the data. **SC and CD:** Analyzed the data. **SC, SK, and CD**: Prepared the manuscript. The final manuscript was edited and approved by all the authors.

Data availability statement

The raw data of regeneration and carbon stock will be made available on request.

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