# Comparative Study of Carbon Stock and Tree Diversity between Scientifically and Conventionally Managed Community Forests of Kanchanpur District, Nepal

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## ABSTRACT

The present study was accomplished to assess and compare tree diversity, carbon stock, and to find the relationship between carbon stock and tree diversity in scientifically and conventionally managed community forests (CFs) of Kanchanpur District, Nepal. A total of 94 sample plots were overlaid with a systematic random sampling method (51 plots in scientifically managed Singhapur CF and 43 plots were established in conventionally managed Kalika CF). The height and DBH of each tree were measured to calculate biomass and carbon stock. Shannon-Wiener and Simpson's indexes were calculated for tree diversity. The data were pooled and analyzed using MS Excel and SPSS software. The values were statistically compared using a t-test. The total carbon stock and tree diversity were higher in scientifically managed CF (207.58 tons/ha and H= 0.97) than conventionally managed CF (183.72 tons/ha and H=0.85). *Shorea robusta* has a major contribution on total carbon stock in both CFs (Kalika: 66.34% and Singhapur: 70.43%) followed by *Terminalia tomentosa* (Kalika: 24.65% and Singhapur: 13.36%). The t-test did not show any significant difference for the mean values of carbon stocks and tree diversity between the CFs at a 5% level of significance. However, carbon stock showed a weak but positive relationship with species richness and negative with evenness. The result of the study recommends managing forests scientifically for increased tree diversity leading to enhanced carbon deposition.

## 1. INTRODUCTION

The sum of carbon that is sequestered from the atmosphere, and deposited within the forest ecosystems (in the form of living biomass, soil carbon, deadwood, and litter) is known as forest carbon stock (FAO, 2011a). During photosynthesis, carbon is typically stored as biomass in plants (Suryawanshi et al., 2014). Of the total dry biomass of the tree, 43-50% is carbon (Malhi et al., 2002). It is re-discharged to the atmosphere if biomass is destroyed (Vashum and Jayakumar, 2012). Forests play a crucial role in the global carbon cycle and carbon balance; storing a large amount of terrestrial carbon (~80% of above ground and ~40% of belowground carbon) (Canadell and Raupach, 2008; Pan et al., 2013); a serving as a natural buffer against climate change and related challenges (Fahey et al., 2010). The accumulation of carbon in woods vegetation differs by topographical area, plant species, structure and composition, canopy cover, and management practices (Ruiz-Benito et al., 2014; Pandey and Bhusal, 2016; Dieler et al., 2017). The estimation of carbon storage provides valuable information for greenhouse gas (GHG) reduction (Johnston and Radeloff, 2019; Adame et al., 2020). The information can be useful to formulate and implement programs and strategies related to climate change (Saatchi et al., 2011; Avitabile et al., 2016).

About 5-30 million plant species are expected to be found in the world (only 5-10% of them are identified so far) (García et al., 2008; Kunzig, 2008; Mora et al., 2011). Tropical and subtropical regions host the maximum floral diversity (WCMC, 1992).

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Tropical forests alone store about 25% of the terrestrial carbon stock (Bonan, 2008). Nepal hosts 3.2% of the world's known flora; ranks in 31st and 10th position in terms of flowering plant diversity in the world and asia respectively (GoN/MoFSC, 2014). The floral diversity is on the blink of extinction due to anthropogenic factors (such as deforestation, forest conversion, and overgrazing) and natural factors (such as climate change, invasion of alien species, and disasters) (Ribeiro et al., 2014; Thapa and Maharjan, 2014; Chaudhary et al., 2016). Due to the fragmentation of forests, causing a threat to flora, there is an increased worldwide concern on floral species richness, composition, and forest structure (Myers et al., 2000). The assessment of the floral diversity is essential to conserve, protect, and manage the floral species in the particular area (Georgieva et al., 2013; Akinyemi and Oke, 2014). The species diversity has a positive and independent relationship with carbon stock (Poorter et al., 2015; Banik et al., 2018).

About 18% of atmospheric carbon dioxide ($CO_2$) emissions can be reduced through pausing deforestation (IPCC, 2007). The proper forest management focused on Reducing Emissions from Deforestation and Forest Degradation (REDD+) programs contributes to achieving emission reduction (Skutsch and Laake, 2008). Community forests (CF) plays a pivotal role in carbon storage through forest management and conservation which ultimately contribute to the REDD and REDD+ mechanisms (Maraseni et al., 2005; Pandey et al., 2014). About 7% of the forests in the world are managed under community forestry programs (FAO, 2011b). Scientific managed forest (SFM) employs the silvicultural system which aims to improve forest growth, productivity, species diversity, regeneration, and stand dynamics (Nguyen and Baker, 2016; Awasthi et al., 2020); whereas, conventional forest management lacks this system. In Nepal, SFM has been employed mainly in *S. robusta* forests that are among the major tropical forests having enough carbon-storing potential (Shrestha, 2008).

Several pieces of research have been conducted to assess carbon stock in different regions of Nepal (Bohara et al., 2021; Charmakar et al., 2021; Måren and Sharma, 2021; Regmi et al., 2021). However, a comparative study of carbon stock and tree diversity between scientifically managed CF that employs the silvicultural system and conventionally managed CF that lacks the system was not conducted yet in Nepal. Hence, this study was performed to assess and compare carbon stock, tree diversity and to find out the relationship between tree diversity and carbon stock in scientifically and conventionally managed community forests (CF) of Kanchanpur District, Nepal. The results of the study will be useful to managers for the conservation of forest biomass and diversity. The study will help to provide baseline information regarding the present carbon pools of the proposed study areas for REDD+ as well as help users, officials, and managers to assess the forest carbon stock and relationship with tree diversity in other parts of the tropical regions.

## 2. METHODOLOGY

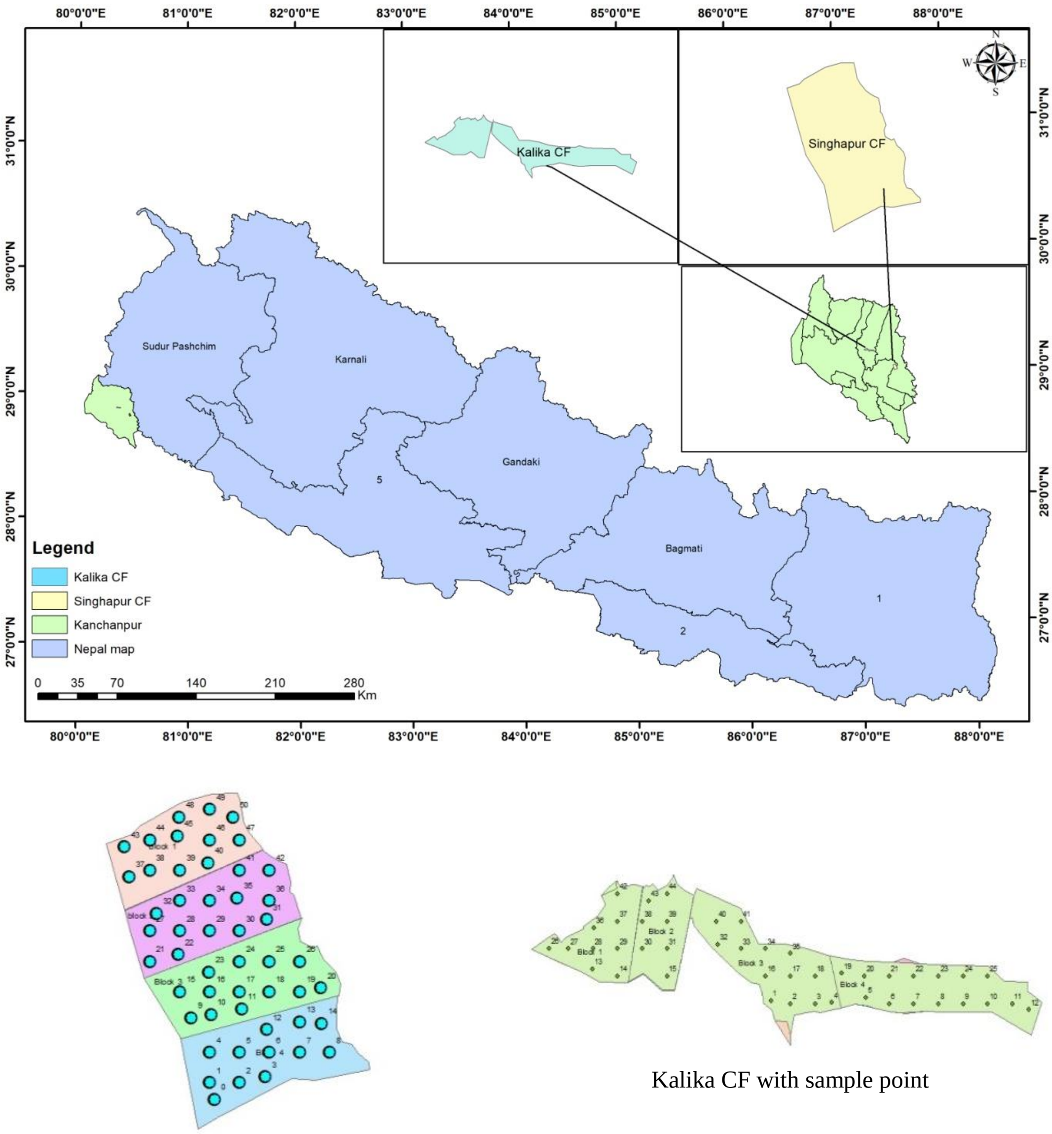
### 2.1 Study area

The study was conducted in two CFs: Kalika CF and Singhapur CF of Kanchanpur District (Figure 1). Kanchanpur (Latitude: 28°38′ to 29°28′ N and longitude: 80°03′ to 80°33′ E) is located in Sudur Pashchim Province of Nepal; covers an area of 1,610 km$^2$ with a population of 171,304 (CBS, 2011). It is bordered by India in the south and west while Kailali and Dadledhura Districts border in the east and north respectively. The elevation and climate of the district vary from 176 m.s.l. of the lower tropical region to 1,528 m.s.l. of the sub-tropical region. The dominant tree species consists of *Shorea robusta* (Sal), *Terminalia tomentosa* (Saj), *Dalbergia sissoo* (Sisso), and *Acacia catechu* (Khayer) species. Kalika CF (area: 1.665 km$^2$) is conventionally managed while Singhapur CF (area: 2.05 km$^2$) is scientifically managed (since 2017 A.D.). Kalika CF lies in ward No. 11 of the Suklaphanta municipality consisting of a total household of 271 with a population of 1,122. Singhapur CF lies in ward No. 6 of Krishnapur municipality consisting of a total household of 314 with a population of 1,834. Both the CFs lie in the tropical climatic zone with *Shorea robusta* as a dominant species.

### 2.2 Data collection

*2.2.1 Sampling design and data collection*

The inventory in both CFs was taken using a systematic random sample procedure with a sampling intensity of 0.5%. GPS was used to collect and locate the coordinates of the sample plots. Arc GIS was used to assign the sample plots to the map. Altogether 94 concentric circular plots (43 plots in Kalika CF and 51 plots in Singhapur CF) of size 200 m$^2$ for a tree (>10 cm), 25 m$^2$ for a sapling (<10 cm), and 10 m$^2$ for seedling were overlaid (Figure 2). The reasons behind selecting the circular plots are easier to layout and less perimeter coverage with a greater area which reduces the probable bias due to border trees (Subedi et al., 2010). DBH of tree and sapling were measured by using Diameter tape, height of the tree and sapling was measured with Abney's level, and seedlings were counted and height was measured by measuring tape.




Singhapur CF with sample point

Kalika CF with sample point

**Figure 1.** Map of the study area showing Kalika CF and Singhapur CF

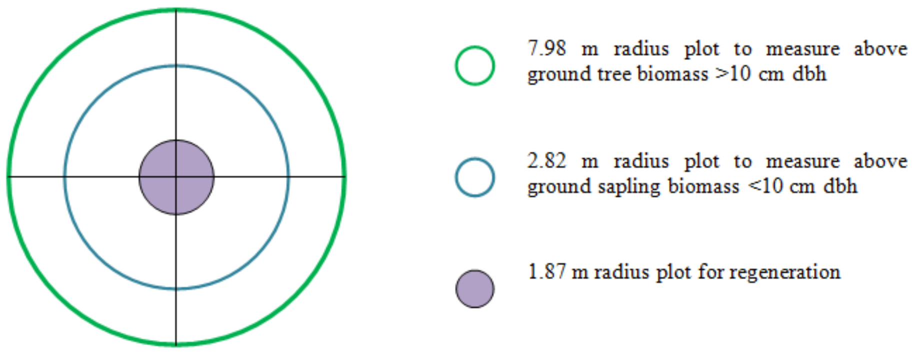



**Figure 2.** Concentric sample plots used for the inventory

**2.3 Data analysis**

*2.3.1 Carbon stock estimation*

The carbon stock measuring guideline in CFs (Subedi et al., 2010) was followed for the inventory. The allometric equation was used to calculate the above-ground biomass of a tree (DBH>10 cm) (Chave et al., 2005). A national allometric biomass table was used to determine the biomass of saplings (DBH<10cm) (Tamrakar, 2000). Below ground biomass (root biomass) was estimated from a root shoot ratio of 0.125 (MacDicken, 1997). Then summation of total biomass was done and multiplied with a default carbon fraction value (0.47) which resulted in the total carbon stock (IPCC, 2006). Similarly, to estimate the carbon stock of a single tree species, density values of the entire forest for that species were summed. The percentage contribution on carbon stock of each tree species was estimated by dividing the amount of carbon stock of a specific species in a forest by the sum of carbon stock/ha of all species in the same forest.

Above ground tree biomass (AGTB) = 0.0509 × δD2H; where, δ=wood density (g/cc), D=DBH (cm), H=height of the tree (m).

Above ground sapling biomass [Ln (AGSP)] = a + b ln (dbh); where AGSP is in Kg, Ln=natural log, a and b are constants, and D=DBH (cm).

*2.3.2 Tree diversity estimation*

Shannon-Wiener index was calculated for the species diversity. Species dominance was calculated using the Simpson index. The degree of the relative dominance of each species in that area was estimated using Pielou evenness (e). Species richness was determined by Margalefs' richness index.

$$\text{Shannon-Wiener Index (H)} = \sum \frac{\text{ni}}{\text{n}} \times \ln \frac{\text{ni}}{\text{n}}$$

$$\text{Simpson Index (D)} = \sum \frac{\text{ni}}{\text{n}}$$

$$\text{Pielou Evenness (e)} = \frac{\text{H}}{\log \text{S}}$$

$$\text{Margalefs' Richness Index (d)} = \frac{\text{S}}{\text{logN}}$$

Where; n=total number of individuals of all species in that vegetation type, ni=importance value of species, S=number of species, and ni/n=importance probability of each species in a population.

Ms Excel and SPSS software (version 20) were used to analyze the data. Before applying a hypothesis test, a non-parametric normality test was performed. The distribution of variation in total carbon stock, H, and D was tested using a one-sample K-S normality test. The t-test was used to examine the variation in H, D, d, and e in two community forests. The relationship between total carbon stock and plant diversity was investigated using the correlation coefficient test. The significance level was α=0.05.

## 3. RESULTS

**3.1 Density and diameter relationship**

The density of individual trees at different DBH classes was found to be different in two CFs. The distribution curve for tree species (>10 cm diameter) showed a subsequent decrease in individual numbers from lower DBH class to higher DBH class in both CFs (Figure 3(a) and 3(b)). However, there was variation in the DBH of trees between the CFs. In Kalika CF, there was old stock of trees with a maximum diameter of 108 cm (Figure 3(a)) while in Singhapur CF trees were comparatively younger with a maximum diameter of 92 cm (Figure 3(b)).

**3.2 Species distribution at different growth phases**

The number of seedlings and saplings was highest in comparison to other successive development phases in both CFs. In the case of Kalika CF, seedlings and saplings contributed 46.17%, followed by mature regeneration (24.59%), tree (20.56%), and pole stage (8.65%) (Figure 4(a)). While, in Singhapur CF seedlings and saplings contributed 52.61%, followed by mature regeneration (23.60%), tree (12.53%), and pole stage (11.31%) (Figure 4(b)). The total number of seedlings, saplings, and trees was higher in Singhapur CF than Kalika CF (Figures 4(a) and 4(b)).

**3.3 Density, basal area, and species wise carbon stock contribution**

The density of *Shorea robusta* was highest in both CFs (Kalika: 190.48 per ha and Singhapur: 271.43 per ha), followed by *Terminalia tomentosa* (50 per ha and Singhapur: 40.48 per ha) and so on (Table 1). The basal area of the species in both CFs was maximum for *Shorea robusta* (Kalika: 57.61 $m^2$/ha and Singhapur: 48.63 $m^2$/ha), followed by *Terminalia tomentosa* (Kalika: 13.93 $m^2$/ha and Singhapur: 7.54 $m^2$/ha) and so on (Figure 5). The contribution of *Shorea robusta* was maximum (Kalika: 66.34% and Singhapur: 70.43%) followed by *Terminalia tomentosa* (Kalika: 24.65% and Singhapur: 13.36%) to the total carbon stock (Table 2).

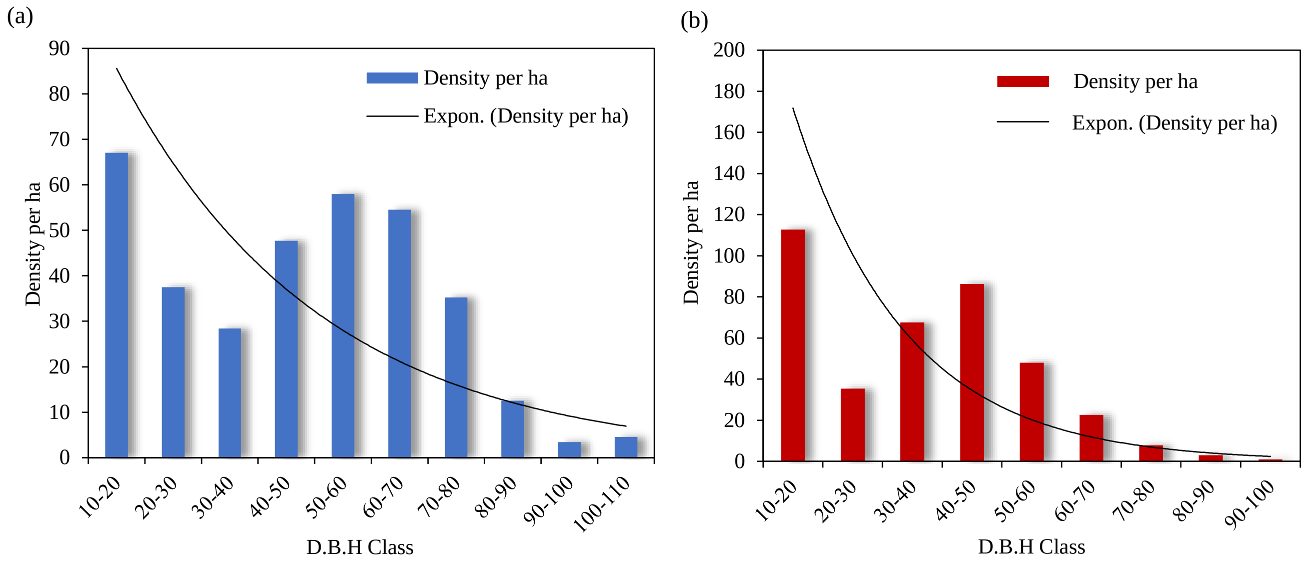



**Figure 3.** Density diameter curve of trees >10 cm and taller than 137 cm in (a) Kalika CF and (b) Singhapur CF

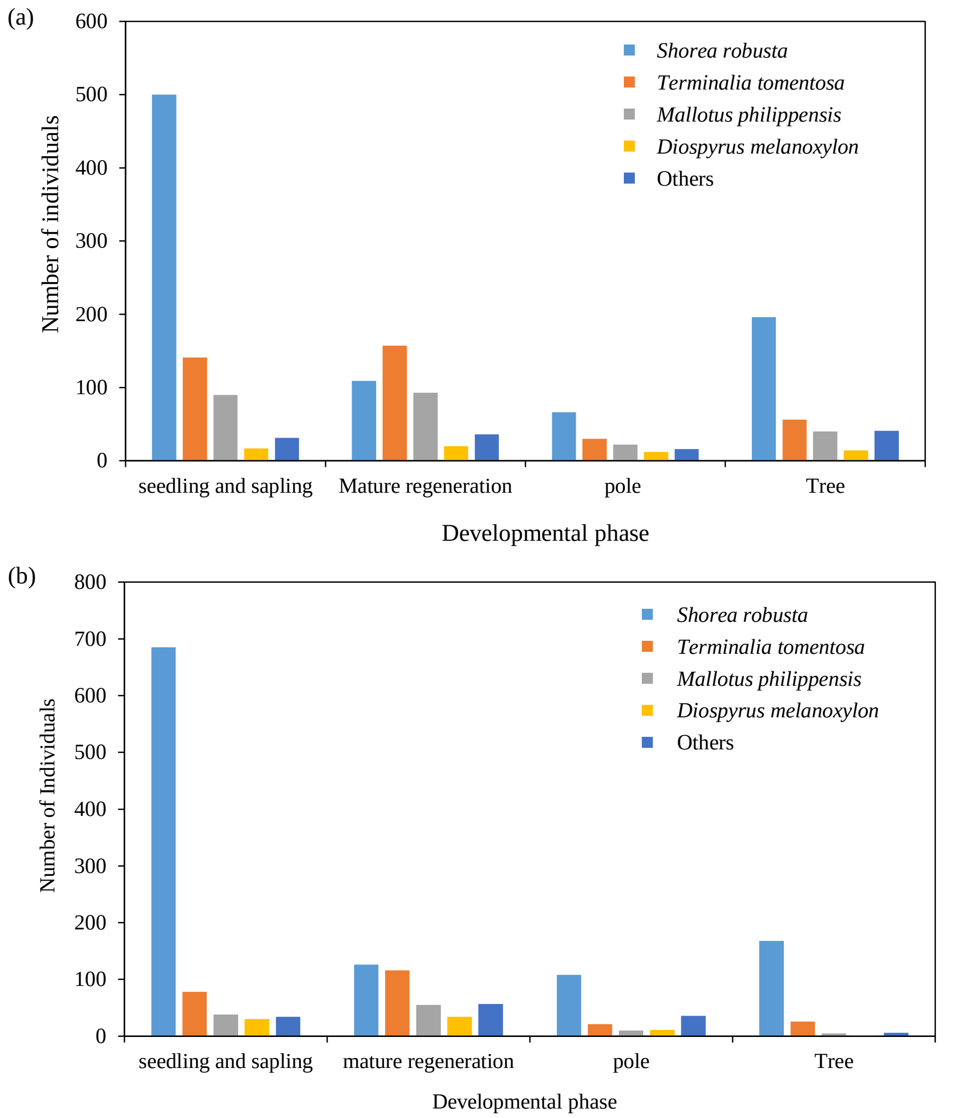


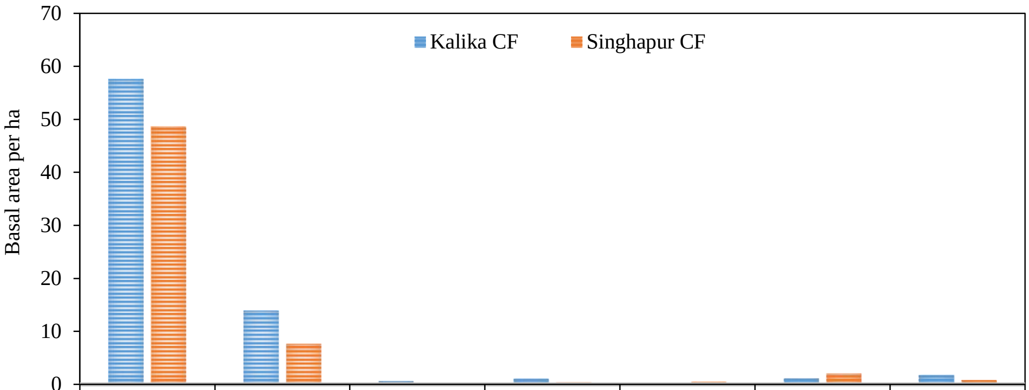

**Figure 4.** Number of individuals of species at different developmental phases in (a) Kalika CF and (b) Singhapur CF

**Table 1.** Tree species and their density per ha in the CFs

| Kalika CF | | Singhapur CF | |
|---|---|---|---|
| Species name | Density (per ha) | Species name | Density (per ha) |
| *Shorea robusta* | 190.48 | *Shorea robusta* | 271.43 |
| *Terminalia tomentosa* | 50.00 | *Terminalia tomentosa* | 40.48 |
| *Anogeissus latifolia* | 7.15 | *Anogeissus latifolia* | 16.35 |
| *Lagerstroemia parviflora* | 29.77 | *Lagerstroemia parviflora* | 36.27 |
| *Mallotus philippensis* | 30.96 | *Mallotus philippensis* | 30.72 |
| *Diospyrus melanoxylon* | 29.77 | *Diospyrus melanoxylon* | 21.91 |
| *Syzygium cumini* | 10.27 | *Syzygium cumini* | 1.93 |
| *Acacia catechu* | 5.95 | *Rhus wallichii* | 1.93 |
| *Rhus wallichii* | 1.20 | *Ficus* sp. | 13.47 |
| *Diploknema butyracea* | 1.20 | *Terminalia chebula* | 0.97 |
| *Terminalia belirica* | 2.39 | *Adina cardifolia* | 0.97 |
| *Dalbergia sissoo* | 4.77 | *Powlenia tomentosa* | 1.93 |
| | | *Eucalyptus camaldulensis* | 1.93 |
| | | *Madhuca indica* | 0.97 |

**Table 2.** Species contribution on the carbon stock

| Kalika CF | | Singhapur CF | |
|---|---|---|---|
| Species name | Carbon stock (%) | Species name | Carbon stock (%) |
| *Shorea robusta* | 66.34 | *Shorea robusta* | 70.43 |
| *Terminalia tomentosa* | 24.65 | *Terminalia tomentosa* | 13.36 |
| *Anogeissus latifolia* | 0.36 | *Anogeissus latifolia* | 2.18 |
| *Lagerstroemia parviflora* | 2.12 | *Lagerstroemia parviflora* | 3.93 |
| *Mallotus philippensis* | 1.38 | *Mallotus philippensis* | 6.33 |
| *Diospyrus melanoxylon* | 2.45 | *Diospyrus melanoxylon* | 1.71 |
| *Syzygium cumini* | 2.06 | *Syzygium cumini* | 0.99 |
| *Acacia catechu* | 0.46 | *Rhus wallichii* | 0.04 |
| *Rhus wallichii* | 0.11 | *Ficus* sp. | 0.40 |
| *Madhuca indica* | 0.13 | *Terminalia chebula* | 0.16 |
| | | *Terminalia belirica* | 0.01 |
| | | *Adina cardifolia* | 0.14 |
| | | *Powlenia tomentosa* | 0.16 |
| | | *Eucalyptus camaldulensi* | 0.22 |




| | Shorea robusta | Terminalia tomentosa | Mallotus philippenis | Diospyros melanoxylon | Anogeissus latifolia | Lagerstroemia parviflora | other |
|---|---|---|---|---|---|---|---|
| Kalika CF | 57.606 | 13.927 | 0.67 | 1.151 | 0.213 | 1.186 | 1.775 |
| Singhapur CF | 48.631 | 7.639 | 0.293 | 0.416 | 0.553 | 2.114 | 0.83 |

Name of tree species

**Figure 5.** Tree species wise basal area in Kalika CF and Singhapur CF

### 3.4 Total carbon stock

The total carbon stock was estimated to be 183.72 tons/ha in Kalika CF and 207.579 tons/ha in Singhapur CF (Figure 6). The mean value of carbon stock (of tree layers) was 183.722±14.13 tons/ha and 207.58±11.50 tons/ha, respectively in Kalika CF and Singhapur CF. However, the t-test between Kalika CF and Singhapur CF did not show any significant difference in mean values of carbon stock.

### 3.5 Tree diversity in the CFs

The Shannon-Wiener diversity was greater in Singhapur CF (H=0.97) than Kalika CF (0.85). This indicates the higher tree diversity in Singhpur CF than Kalika CF. The Simpson's index, species richness, and evenness also support this statement. Statistically, the t-test showed that there were no significant differences in the values of Shannon-Wiener indices, Simpson's index, species richness, and evenness (0.83<0.5) between the CFs at 5% level of significance (Table 3).

### 3.6 Relationship between carbon stock with species richness, and evenness in the CFs

The $r^2$ values in both CFs ranged from 0.0657 to 0.149, indicating a positive but weak relationship of carbon stock with species richness (Figures 7(a) and 7(b)). The values of $R^2$ ranged from 0.0342 to 0.061 which showed a weak and negative relationship of carbon stock with species evenness in the CFs (Figures 8(a) and 8(b)).

**Table 3.** Diversity indices for tree species

| Biodiversity indices | Kalika CF | Singhapur CF |
|---|---|---|
| Shannon-Wiener biodiversity index | 0.845 | 0.9745 |
| Simpson's index | 0.4907 | 0.479 |
| Average species richness | 3.078 | 3.023 |
| Simpson's evenness (mean value) | 0.715 | 0.73058 |

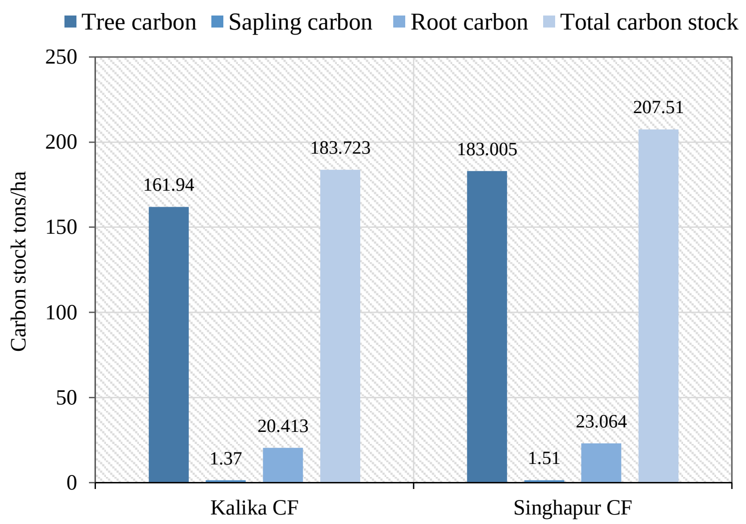



**Figure 6.** Total carbon stock in the CFs

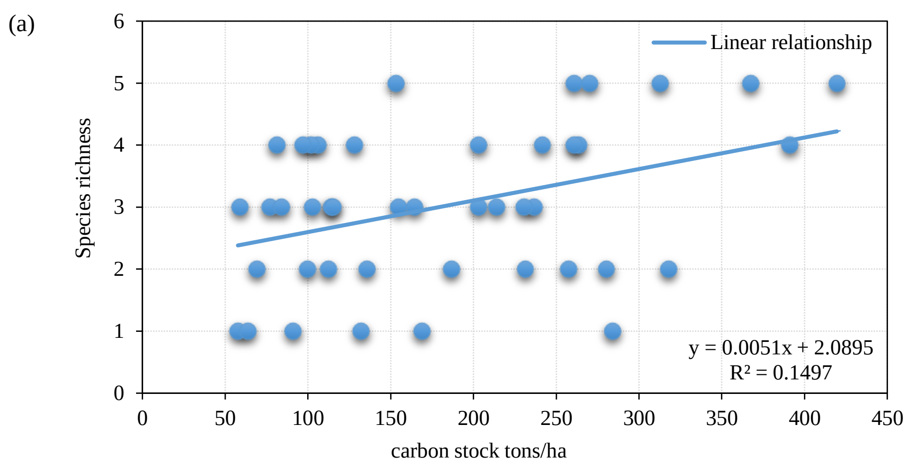



**Figure 7.** Relationship between carbon stock and species richness in (a) Kalika CF and (b) Singhapur CF

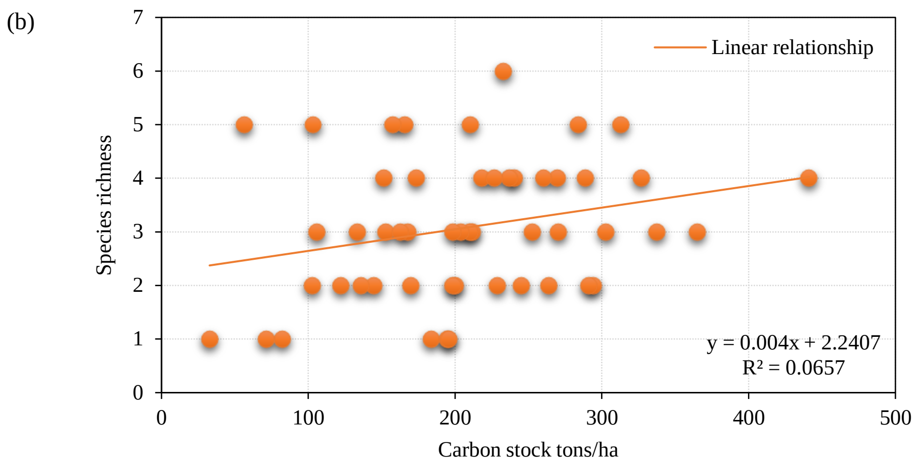



**Figure 7.** Relationship between carbon stock and species richness in (a) Kalika CF and (b) Singhapur CF (cont.)

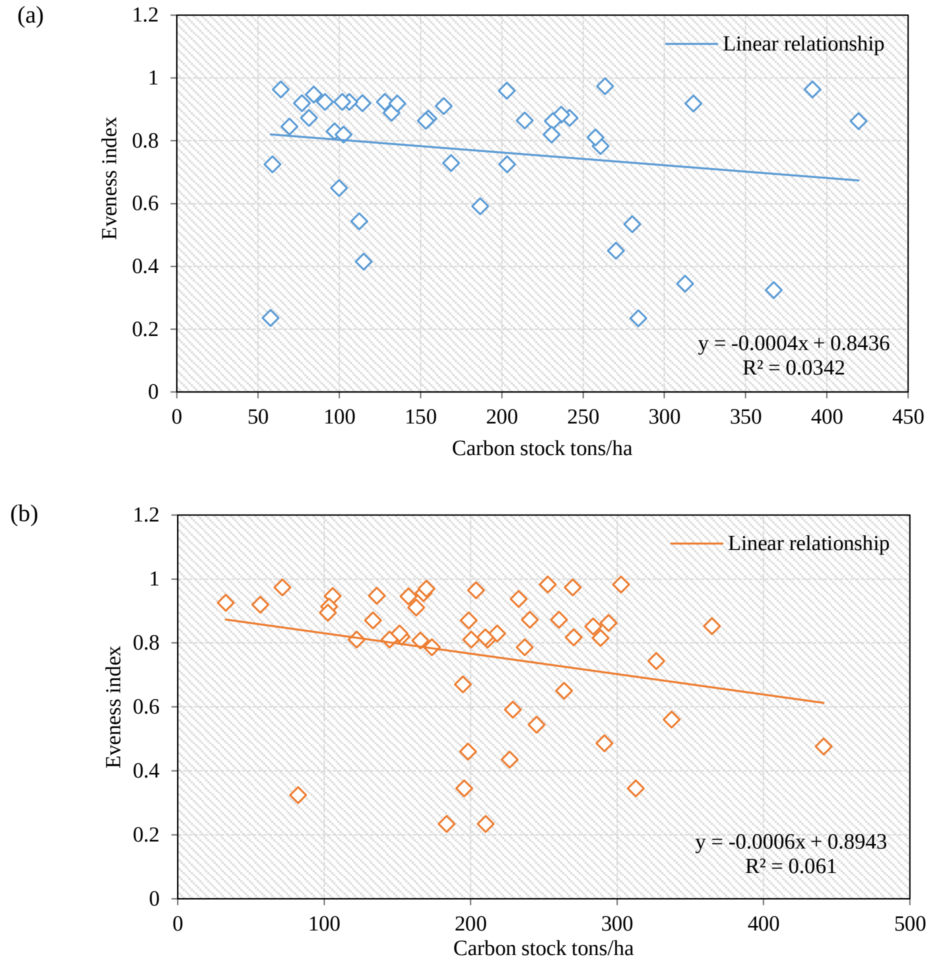



**Figure 8.** Relationship between carbon stock and species evenness in (a) Kalika CF and (b) Singhapur CF

## 4. DISCUSSION

The overall number of individuals of species was seen to be decreasing from the early regeneration phase to subsequent development phases in both CFs. The number of regeneration and pole phases was higher in Singhapur CF than Kalika CF, but large trees were higher in Kalika CF. This result indicates that the number of individuals at different phases was affected by the disturbance and two different management practices. The total number of seedlings, saplings, and trees was higher in Singhapur CF than Kalika CF. *S. robusta* was the dominant species in both the CFs in all successive developmental phases (seedlings, saplings, pole, and tree). The higher density of *S.*

*robusta* might be due to the presence of low canopy cover allowing abundant sunlight to reach the understory which favors the abundant growth of seedlings as well as saplings of the species (Sapkota et al., 2009; Joshi et al., 2020). The high abundance of *S. robusta* in Singhapur CF than Kalika CF might be due to the artificial regeneration and management strategies i.e., the annual regeneration is done each year in the different compartment, fire line construction and fencing has set free the Singhapur CF from livestock and anthropogenic disturbance. The great density and number of seedlings and saplings show that the CF has a good regeneration capacity (Pallardy, 2010). Variations in regeneration, sapling, and mature tree size may be attributable to variations in any of the study site's location characteristics, such as topography, climate, soil nutrients, stand, disturbances (type and intensity) (Gautam and Devoe, 2006; Sapkota et al., 2009). The study area has two different management practices which might be reason for the variation in regeneration, sapling, and mature tree size.

The total carbon stock was estimated to be greater in Singhapur CF than Kalika CF. The variation in carbon stock between two CFs may be due to drivers and management factors influencing them (Mandal et al., 2013). As Klika CF was stressed by the high anthropogenic disturbances and stand structure was poor as comparison to the Singhapur CF. The higher carbon stock might also be due to the greater density of matured trees. The study conducted by (Neupane and Sharma, 2014) in two *S. robusta*-dominated CFs of Gorkha District Laxmi Mahila CF and Jalbire Mahila CF) found higher carbon stock in Jalbire Mahila CF which contained a higher proportion of mature trees. Sejuwal (1994) has reported a carbon stock of 468 tons/ha in *S. robusta* forest (tree layer only) of Chitwan National Park which is higher than the present study. This might be due to the maturity of the forest (old aged stand store more carbon) (Singh et al., 2006). The standing carbon stock of trees depends upon the succession stage of the forest and the carbon sequestration potential depends on the age, forest type, stand condition, density, and size of trees (Brown et al., 1989; Dixon et al., 1994; Dieler et al., 2017). The FRA report of 2014 showed that the total carbon stock from the forests (*S. robusta* dominated) of the Terai region of Nepal be 89.18 tons/ha. In contrast to this, the present study reported higher carbon stock where *S. robusta* was the highest contributor of carbon stock in both the CFs.

In the present study, the tree diversity (Shannon-Wiener diversity) was higher in Singhapur CF which is regenerated than the Kalika CF which is old. The Simpon's index was higher in Kalika CF with dominant species: *S. robusta*. However, the t-test showed no significant difference in values of Shannon-Wiener and Simpson's diversity index at a 5% significant level. Mandal et al. (2013) has also reported no significant difference in Shannon-Wiener and Simpson's diversity index in three collaborative forests of the Terai region. The species richness and evenness were higher in Singhapur CF. The diversity of both CFs was found to be lower than the *S. robusta*-dominated CF of hilly Nepal (H=2.42) (Sapkota et al., 2009), Namjung CF (H=1.09), and Khari CF (H=1.30) of Gorkha district (Shrestha, 2005). In the present CFs, carbon stock and species richness showed a weak but positive relationship. Mandal et al. (2013) have also found weak but positive relation (hump-shaped relationship) between carbon stock and species richness in collaborative forests of Terai. Nakakaawa et al. (2010) have found a positive relationship between tree carbon stock and species diversity in pilot carbon offset projects in southwestern, Uganda. Wang et al. (2011) have also reported a positive correlation of carbon stock with diversity in the Spruce-dominated forest of Uganda. The relationship of carbon stock with species evenness was weak and negative. The present finding is similar to a study (Vance-Chalcraft et al., 2010) that found a negative relationship of aboveground biomass with species evenness in Puerto Rico's subtropical forest. Mandal et al. (2013) have also reported a weak but negative relationship (opposite hump-shaped relationship) of carbon stock with species evenness.

## 5. CONCLUSION

The study showed that the carbon stock and tree diversity were higher in scientifically managed CF than the conventionally managed CF. Scientifically managed CF has good regeneration status with higher seedlings and saplings. *S. robusta* was the most dominant species with the highest contribution to the carbon stock in both the CFs. Carbon stocks of both CFs have a positive relationship with the species richness of the trees that indicates species diversity has a positive impact on carbon sequestration potentiality. As a result, this study strongly encourages the use of sustainable forest management practices or silvicultural systems in community-managed forests. These community-managed forests should also be included in the REDD+ system so that they may profit from carbon credits, which will assist to improve forest conditions and provide a source of cash for the local community.

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