https://doi.org/10.3126/banko.v32i2.50896 Banko Janakari, Vol 32 No. 2, 2022 Pp 63–76

# Tree carbon stock in middle mountain forest types: A case study from Chandragiri hills, Kathmandu, Nepal

**R. Gurung[1], H. S. Adhikari[1], R. S. Dani[1,2], and C. B. Baniya[1*]**

Received: 8, August 2022 Revised: 9, November 2022 Accepted: 14, December 2022 Published: 31, December 2022

The forest carbon stock usually depends on the forest types, forest density, age of forest, size of trees, site quality, wood density, annual precipitation, and species composition. This research aims to analyze the relationship among tree carbon stock, species richness, soil chemical properties such as soil organic carbon and soil pH in the Forests of Chandragiri Hills, Kathmandu, Central Nepal. Along this forest, five square plots ($20 \times 20$ m$^2$) each were established along the two transects at a maximum interval of 100 m. Carbon stock of each tree was estimated by using allometric equation based on measured tree height and DBH. The mean tree carbon stock was found to be highest in Mixed Forest (87.13 t/ha) followed by Oak Forest (52.75 t/ha), and Pine Forest (22.5 t/ha). The tree carbon stock showed significant negative correlation with tree species richness ($r$ = -0.56, $p$ = 0.001). The tree carbon stock showed significant positive correlation with soil organic carbon ($r$ = 0.57, $p$ = 0.001) and soil pH ($r$ = 0.37, $p$ = 0.05). Tree carbon was found positively highly significant correlation with altitude, Soil organic carbon, pH and Shannon diversity index.

**Keywords**: Mixed forest, oak forest, pine forest, soil organic carbon, soil pH, species richness, tree biomass

Forests are one of the biggest terrestrial carbon pools. Forests (vegetation and soil) store 60% of the world's terrestrial carbon (Iturbide *et al.,* 2020). Therefore, sustainable forest management is recognized as one of the best climate change mitigation measures (Arasa-Gisbert *et al.,* 2018). However, the ever-growing human population and its impacts on forests such as deforestation and forest degradation are posing a great challenge to the very existence and the vitality of forest ecosystems. Studies have indicated that anthropogenic pressures have indiscriminately degraded the forest ecosystems over the past few decades (Sundriyal & Sharma, 1996; Dhyani *et al*., 2019).

In a forest ecosystem, carbon is stored in various pools such as above and below-ground living biomasses, including standing stems, branches, foliage and roots; and necromasses, including litter, woody debris, soil organic matter and forest products (Riutta *et al.,* 2021). Among others, trees and soil are the main pools that store more carbon than the other pools (Amir *et al.,* 2018). Currently, forests store around 45% of the organic carbon on land in their biomass and soils (Bonan, 2008). About 2 gigatonnes (GtC) of carbon are absorbed annually by existing old-growth and regenerating forests collectively, which significantly contributes to the terrestrial carbon sink (Pugh *et al.,* 2019). About 40% of the global soil organic carbon (SOC) stock resides in the forest ecosystems (Eswaran *et al.,* 1999). The current global stock of soil organic carbon is estimated to be 1,443 ± 141 Pg C and 3,153 ± 312 Pg C in top soils and subsoils respectively,

1 Central Department of Botany, Tribhuvan University, Kirtipur, Nepal, * Email: cbbaniya@gmail.com
2 Trichandra Multiple Campus, Ghantaghar, Kathmandu, Nepal

totaling to be 4,596 Pg C ± 453 Pg C to a depth of 1 m (Georgiou *et al.,* 2022).

Tropical forests that cover 7% of the earth's total land surface and that are among the major carbon sinks play a significant role in global carbon cycle (Nascimento & Laurance, 2004). Studies have shown that forests have a tremendous role in lowering the net Green House Gases (GHGs) emissions to the atmosphere and mitigating the adverse impacts of climate change (Creutzig, 2015; Moomaw *et al.,* 2020). However, clearing tropical forests for non-forestry uses is destroying globally important carbon sinks that are vital for sequestering $CO_2$and future climate stabilization (Stephens *et al.,* 2007). Globally, it is estimated that tropical deforestation accounts for annual emission of about 1.7 billion tons of carbon (Nakicenovic *et al.,* 2000). The rate of emission depends on the types of disturbance such as logging, understory fires, edge effects etc. as well as the intensity and the frequency of disturbance events (Barlow *et al.,* 2012; Sullivan *et al.,* 2017). Iturbide *et al.*(2020) has shown that reducing deforestation and forest degradation lowers GHG emissions (high confidence), with an estimated technical mitigation potential of 0.4–5.8 $GtCO_2$ $yr^{-1}$ highlighting an important role of Reducing Emissions from Deforestation and Forest Degradation (REDD+) in mitigating climate change.

In Nepal, forests cover about 44.74% of the country's total land area. Nepalese forests could play an important role in the mitigation of global climate change (Ghimire *et al.,* 2018). Carbon stock estimation reflects the potentiality of forests to mitigate climate change (Ghimire *et al.,* 2018). The forest carbon stock usually depends on the forest types, forest density, and age of forest, size of trees, site quality, wood density, annual precipitation, and species composition. Furthermore, understanding the relationship between forest carbon stock and tree-species diversity and soil properties will be critical in maintaining carbon stocks of forests over the long term and improving our understandings of species-level management (Kaushal & Baishya, 2021). In this context, this research aims to analyze the relationship between tree carbon stock and tree species diversity and soil chemical properties in the mountain forests of Nepal.

Estimating carbon stocks is highly desirable in different forest types, and the community forestry program of Nepal should promote it. Conifer-dominated Forest types store more carbon than broad-leaf-dominated forest types (Sharma *et al.,* 2010; Aryal *et al.,* 2013) while Shrestha & Devkota (2013) has found the higher carbon stock in Oak Forest (90.37 $MgCha^{-1}$) than that in Pine Forest (24.82 $MgCha^{-1}$). By sequestering atmospheric carbon in the growth of wood biomass through the process of photosynthesis, trees store carbon by raising the level of soil organic carbon (Brown & Pearce, 1994). Pradhan *et al.* (2012) has shown that the tree carbon stock and Soil organic carbon was higher in *Schima-Castanopsis* (Mixed Forest) than in pine forest. Based on the existing literature, it can be hypothesized that higher species richness and better soil properties will have higher tree carbon stock.

## Materials and methods

## Study site

The study was conducted in the three forests [(Mixed Forest (MF), Oak Forest (OF), and Pine Forest (PF)] of Chandragiri Hills, which lies in Kathmandu district, Central Nepal (Figure 1). The selected forests were managed by three different community forest user groups (CFUGs) (Table 1). The geographic location of the study site extends from 27°27′E to 27°49′E longitude and 85°10′N to 85°32′N latitude. It ranges in elevation from 1600 to 2400m a.s.l. The study site has a sub-tropical to temperate climate with rainy summer and dry winter. The weather data recorded at the nearest weather station (Panipokhari weather station, provide coordinates here) showed that the average annual minimum and maximum temperature of the study site are 7.70°C and 14.12°C respectively and the site receives an annual precipitation of about 1,559.25 mm (Figure 2).

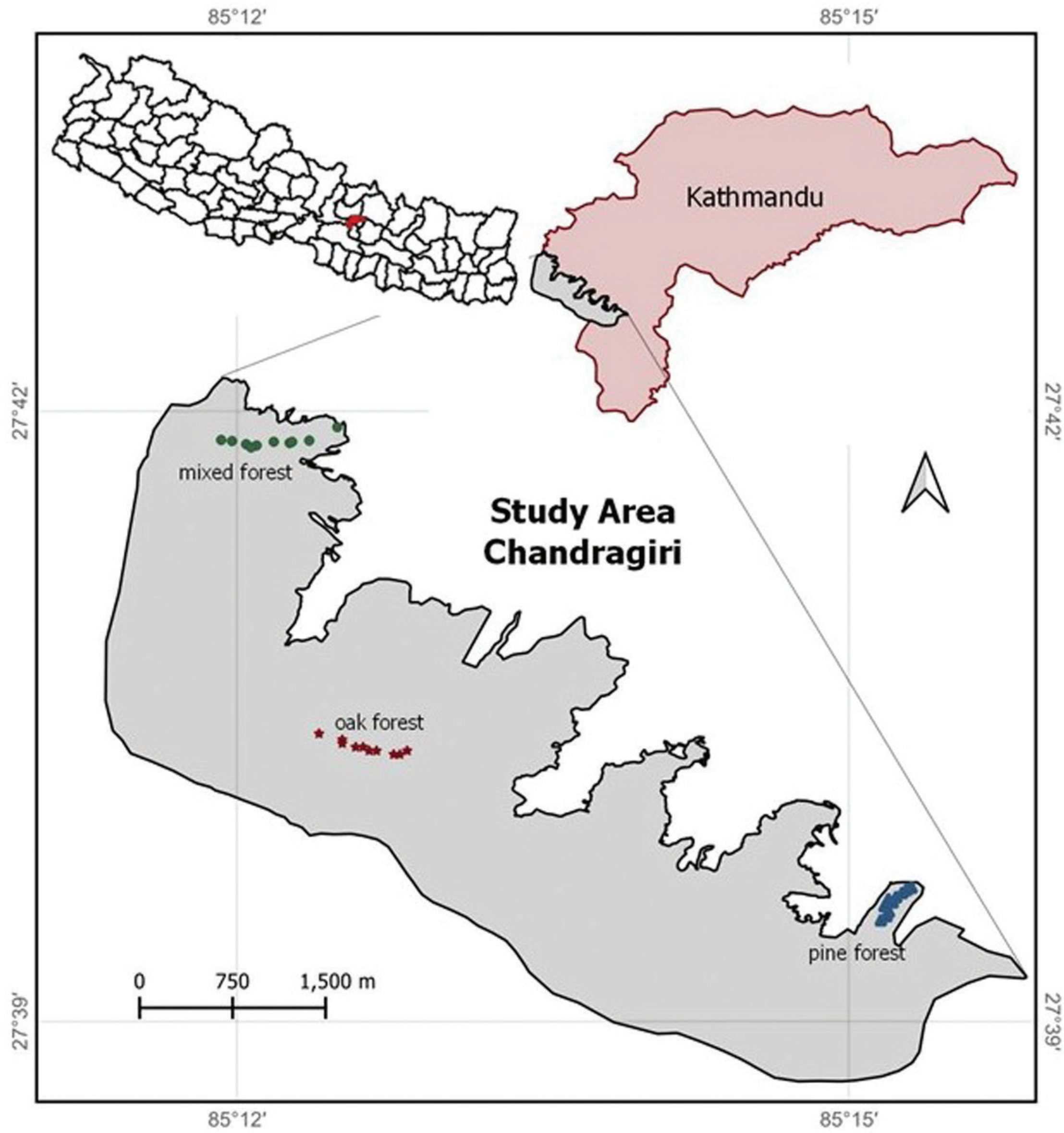


**Figure 1: Map of Kathmandu district showing the plots of studied sites of different forest types**

**Table 1: Overview of study forests. The forest types, major tree species, the names of community forest user groups managing the forests, their area and the years the forests were handed over for community management**

| Forest Types | Major tree species | Name of Community Forest User Groups (CFUGs) and their addresses | Area (ha) | Handover Year (AD) |
|---|---|---|---|---|
| **Mixed Forest** | *Schima wallichii, Myrica esculenta, Castanopsis indica, and Myrsine* sp. | Laglagepakha CFUG, Thankot | 24.509 | 1994 |
| **Oak Forest** | *Quercus semecarpifolia and Rhododendron arboreum* | Gumalchoki CFUG, Chandragiri | 80.5 | 2000 |
| **Pine Forest** | *Pinus roxburghii* | Bosan CFUG, Kirtipur | 57 | 1994 |

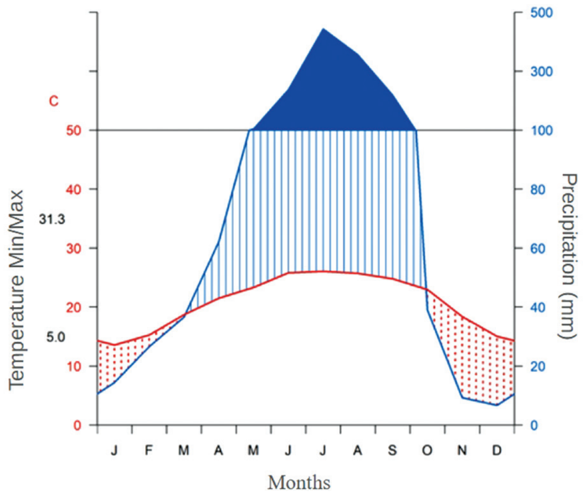


**Figure 2: Ombrothermic diagram showing mean monthly temperature and precipitation from years 2011-2020 of Panipokhari weather station, Kathmandu (Source: Department of Hydrology and Meteorology Kathmandu Nepal, DHM, 2021). Daily average Maximum temperature at station was 20.9˚C and total monthly average annual rainfall was 1559 mm.**

### *Sampling design and data collection*

The transect method was used for vegetation survey and soil sample collection. A total of six transects, two transects per study forest were laid out. A distance of 100m was maintained between two transects. Five square plots of size 20 × 20m$^2$ were established in each transect maintaining a distance of 100m between the plots (Figure 3). The geographic locations (latitude, longitude and elevation) of plots were recorded using *the Garmin eTrex GPS*. Within each plot, the height and diameter at breast height (DBH = 1.37 m) of individual trees (DBH > 5 cm) were measured using a clinometer and a DBH tape (FRTC, 2022), and tree species having diameter less than 5cm were also used for vegetation analysis. The plant specimens were identified using standard literature (Malla *et al.,* 1986; Press *et al.,* 2000) and by tallying with Tribhuvan University Central Herbarium (TUCH) specimens. The world flora online (*http://www.worldfloraonline.org/)* was followed for the specimen nomenclature.

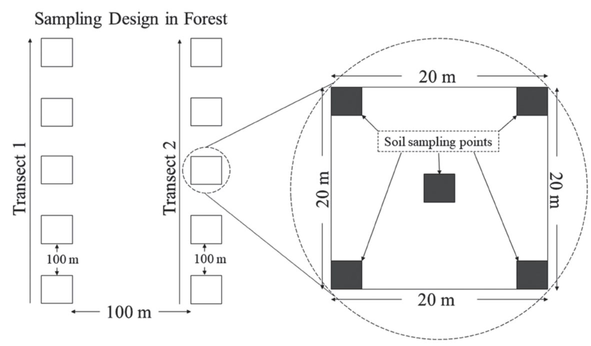


**Figure 3: Sampling design used for vegetation survey and soil sample collection. Two transects with five square plots (20 × 20m$^2$) each separated by a distance of 100 m were laid out for vegetation survey. Soil samples were collected from five points (four corners and center) of each plot.**

The soil samples were collected from five points (four corners and center) of each plot. They were collected from the depth of 10 cm. One composite soil sample of 200gm per plot was prepared by mixing soil samples from five points. The soil samples were air-dried in the shade for a week and were taken for laboratory analysis.

### *Vegetation analysis*

Frequency, density, basal area, and importance value index (IVI) were calculated by using the methods and equations (1-7) provided by Zobel *et al.*(1987), which are given below.

Frequency (%)= $\frac{Number\ of\ plots\ in\ which\ species\ occurred}{Total\ number\ of\ plots\ taken}$ ……….. (1)

Density (trees/ha)= $\frac{Total\ number\ of\ individual\ of\ a\ species}{Total\ number\ of\ plots\ taken \times plots\ (m2)}$ …….(2)

Basal Area (BA) of tree (m$^2$) = $= \frac{(DBH)^2}{4} \times \pi$ ……. (3)

Where, DBH = diameter at breast height (m), and $\pi$= 3.14

IVI=Relative frequency + Relative density + Relative basal area ……… (4)

Where,

Relative frequency (%) = $\frac{Frequency\ of\ individual\ species}{\sum\ of\ frequencies\ for\ all\ species}$ ×100 ……………….(5)

Relative density (%) = $\frac{Density\ of\ individual\ species}{densit\ of\ all\ species}$ ×100 ……………………(6)

Relative basal area (%) = $\frac{Basal\ area\ of\ individual}{basal\ area\ of\ all}$ ×100 …………………….. (7)

Simpson's diversity index and Shannon index were calculated using standard equations provided by Magurrun (2004) to estimate species diversity of the study forests. Interpretation of forest regeneration by size class distribution is better than seedling counts because the former represents longer periods (Maren & Vetaas, 2007). Trees recorded in all plots were divided into DBH classes of 5 cm interval. Then the size class distribution graph was prepared to analyze the regeneration status of the study forests.

***Biomass and carbon stock estimation***

The total above-ground tree biomass (AGTB) was calculated using the equation (model, Equation 8) developed by Chave *et al.* (2005). For moist forest types,

AGTB = 0.0509x $\rho D^2 H$ …… (8)

where, AGTB = above-ground tree biomass (kg); ρ = wood specific gravity (g $cm^{-3}$); D = tree diameter at breast height (cm); H = tree height (m).

The global database developed by Zanne *et al.* (2009) was used for the wood specific gravity. For some tree species, for which wood specific gravity information were unavailable in Zanne *et al.* (2009), information in Penman *et al.* (2003) were used. Below-ground tree biomass (BGTB) was estimated by assuming that it constitutes 15% of AGTB (MacDicken, 1997). The total tree biomass (only living) was calculated by adding the above and below-ground biomass of the trees. Finally, the living tree carbon stock was calculated by multiplying the total tree biomass with the default carbon fraction of 0.47 (Eggleston *et al.,* 2006).

***Soil analysis***

Soil samples were analyzed in the laboratory of the Agricultural Technology Centre, Jwagal, Lalitpur, Nepal. The soil properties such as pH and water holding capacity (WHC) were estimated using which methods. Soil organic carbon (SOC) was estimated using the rapid titration method developed by Walkey & Black (1934).

***Data analysis***

Descriptive statistics were used to calculate means, range, and standard errors. ANOVA was used to test the difference between the forest types. Correlation analysis and scatter plots were used to analyse the relationship between carbon stock and species diversity and soil properties. All the analyses were done using Microsoft-Excel 2007 and R version 4.1.2 (R Core Team, 2022).

## Results

***Tree community attributes of forest types***

Altogether 19 tree species belonging to 16 families were recorded in mixed forest. *Schima wallichii* (59.71) had the highest IVI, followed by *Pinus roxburghii* and *Castanopsis tribuloides* (Table 2.).On the other hand, only two species (2 families) and three species (3 families) were recorded in oak and pine forests respectively. *Quercus semecarpifolia* (254.19) and *Pinus roxburghii* (228.57) had the highest IVIs in the Oak and Pine forests respectively (Table 2).

**Table 2: Tree community attributes (BA, Basal area; RBA, Relative basal area; D, Density; RD, Relative Density; F, Frequency; RF, Relative Frequency: and IVI, Importance Value Index) of Mixed, Oak and Pine Forests of Chandragiri Hills, Kathmandu, Central Nepal.**

| Forest | SN | Tree species | Family | BA ($cm^2$) | RBA (%) | D ($/m^2$) | RD (%) | F (%) | RF (%) | IVI (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| Mixed Forest | 1 | *Schima wallichii* Choisy | Theaceae | 31961.15 | 24.56 | 208.00 | 25.24 | 10.00 | 9.90 | 59.71 |
| | 2 | *Pinus roxburghii* Sarg | Pinaceae | 43199.00 | 33.20 | 86.00 | 10.44 | 9.00 | 8.91 | 52.55 |
| | 3 | *Castanopsis tribuloides* A.DC | Fagaceae | 15888.57 | 12.21 | 139.00 | 16.87 | 10.00 | 9.90 | 38.98 |
| | 4 | *Myrica esculenta* Buch.-Ham. | Myricaceae | 13480.02 | 10.36 | 104.00 | 12.62 | 9.00 | 8.91 | 31.89 |
| | 5 | *Castanopsis indica* (Roxb. ex Lindl.) A.DC. | Fagaceae | 11510.34 | 8.85 | 86.00 | 10.44 | 9.00 | 8.91 | 28.19 |
| | 6 | *Rhododendron arboreum* Sm. | Ericaceae | 2537.78 | 1.95 | 47.00 | 5.70 | 8.00 | 7.92 | 15.58 |
| | 7 | *Myrsine semiserrata* Wall. | Myrsinaceae | 2588.06 | 1.99 | 52.00 | 6.31 | 7.00 | 6.93 | 15.23 |
| | 8 | *Symplocos pyrifolia* Wall. ex G. Don | Symplocaceae | 1522.51 | 1.17 | 33.00 | 4.00 | 8.00 | 7.92 | 13.10 |
| | 9 | *Syzygium cumini* (L.) Skeels | Myrtaceae | 1851.52 | 1.42 | 19.00 | 2.31 | 6.00 | 5.94 | 9.67 |
| | 10 | *Eurya acuminata* DC. | Pentaphylacaceae | 1088.74 | 0.84 | 17.00 | 2.06 | 6.00 | 5.94 | 8.84 |
| | 11 | *Fraxinus floribunda* Wall. | Oleaceae | 741.33 | 0.57 | 13.00 | 1.58 | 6.00 | 5.94 | 8.09 |
| | 12 | *Rhus javanica* L. | Anacardiaceae | 281.60 | 0.22 | 8.00 | 0.97 | 3.00 | 2.97 | 4.16 |
| | 13 | *Engelhardtia spicata* Lechen ex Blume | Juglandaceae | 867.27 | 0.67 | 4.00 | 0.49 | 3.00 | 2.97 | 4.12 |
| | 14 | *Persea gamblei* (King ex Hook. f.) Kosterm. | Lauraceae | 405.78 | 0.31 | 2.00 | 0.24 | 2.00 | 1.98 | 2.53 |
| | 15 | *Albizia lebbeck* (L.) Benth. | Leguminosae | 1460.97 | 1.12 | 2.00 | 0.24 | 1.00 | 0.99 | 2.36 |
| | 16 | *Betula alnoides* Buch.-Ham. ex D.Don | Betulaceae | 373.25 | 0.29 | 1.00 | 0.12 | 1.00 | 0.99 | 1.40 |
| | 17 | *Rhus succedanea* L. | Anacardiaceae | 248.85 | 0.19 | 1.00 | 0.12 | 1.00 | 0.99 | 1.30 |
| | 18 | *Semecarpus anacardium* L.f | Anacardiaceae | 56.75 | 0.04 | 1.00 | 0.12 | 1.00 | 0.99 | 1.16 |
| | 19 | *Pyrus pashia* Buch.-Ham. ex D.Don | Rosaceae | 50.27 | 0.04 | 1.00 | 0.12 | 1.00 | 0.99 | 1.15 |
| Oak Forest | 1 | *Quercus semecarpifolia* Sm. | Fagaceae | 613993.12 | 99.68 | 495.00 | 92.01 | 10.00 | 62.50 | 254.19 |
| | 2 | *Rhododendron arboreum* Sm. | Ericaceae | 2001.28 | 0.32 | 43.00 | 7.99 | 6.00 | 37.50 | 45.81 |
| Pine Forest | 1 | *Pinus roxburghii* Sarg | Pinaceae | 274066.75 | 95.09 | 380.00 | 80.85 | 10.00 | 52.63 | 228.57 |
| | 2 | *Schima wallichii* Choisy | Theaceae | 13057.06 | 4.53 | 76.00 | 16.17 | 7.00 | 36.84 | 57.54 |
| | 3 | *Castanopsis indica* (Roxb. ex Lindl.) A.DC. | Fagaceae | 1106.82 | 0.38 | 14.00 | 2.98 | 2.00 | 10.53 | 13.89 |

### *Regeneration status of forest types*

The DBH class distribution curve of Mixed Forest showed a reverse J-shaped distribution. Whereas that of Oak Forest showed a U-shaped distribution. Meanwhile, Pine Forest showed a bell-shaped distribution with a higher number of individuals in the middle DBH classes (Figure 4).

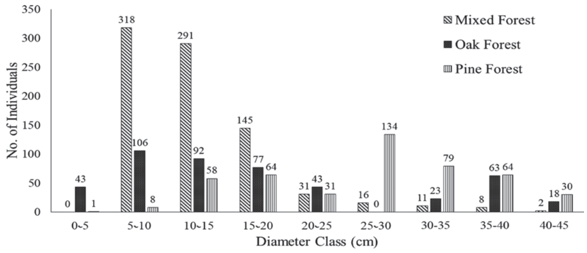


**Figure 4: Tree diameter at breast height (DBH) class distribution of Mixed, Oak and Pine Forests of Chandragiri Hills, Kathmandu, central Nepal**

***Variation in tree carbon stock with forest types***

The mean living tree carbon stock was found to be highest in Mixed Forest (87.13 t/ha) followed by Oak Forest (52.75 t/ha) and Pine Forest (22.50 t/ha). The differences in living tree carbon stock among the three forests types were significant at a 95% confidence interval (Figure 5). Regarding the species contribution to the living tree carbon stock, *Albizia lebbeck* contributed the most (34.93%)to the living tree carbon stock in Mixed Forest followed by *Betula alnoides* (12.33%), *Pinus roxburghii* (12.25%), *Myrsine semiserrata* (9.31%). The least contribution was made by *Pyrus pashia* (0.29%, Table 3).

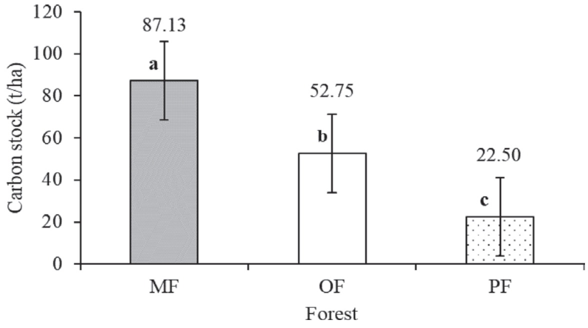


**Figure 5: Mean living tree carbon stock of Mixed Forest (MF), Oak Forest (OF) and Pine Forest (PF of Chandragiri Hills, Kathmandu, central Nepal. Differences between the forest types were tested using ANOVA. Bar diagrams with same letters at the top are not significantly different while those with different letters at the top are significantly different (name which post-hoc test was used, P<0.05). Error bars shows uncertainty in the estimation.**

**Table 3: Tree species contribution to the living tree carbon stock of Mixed Forest, Oak Forest and Pine Forest of Chandragiri Hills, Kathmandu, Central Nepal. Mean diameter at breast height (DBH), mean height (HT), total biomass (TB), and total carbon stock (CS)**

| Forests | SN | Tree Species | DBH (cm) | HT (m) | TB (Mg) | CS (t/ha) | CSC (%) |
|---|---|---|---|---|---|---|---|
| Mixed Forest | 1 | *Albizia lebbeck* (L.) Benth. | 29.20 | 19.85 | 647.50 | 30.43 | 34.93 |
| | 2 | *Betula alnoides* Buch.-Ham. ex D.Don | 21.80 | 13.70 | 228.67 | 10.75 | 12.33 |
| | 3 | *Pinus roxburghii* Sarg | 22.84 | 11.79 | 227.05 | 10.67 | 12.25 |
| | 4 | *Myrsine semiserrata* Wall. | 19.75 | 12.00 | 172.51 | 8.11 | 9.31 |
| | 5 | *Persea gamblei* (King ex Hook. f.) Kosterm. | 16.05 | 9.90 | 90.59 | 4.26 | 4.89 |
| | 6 | *Myrica esculenta* Buch.-Ham | 12.14 | 9.55 | 66.31 | 3.12 | 3.58 |
| | 7 | *Schima wallichii*Choisy | 13.21 | 8.88 | 60.20 | 2.83 | 3.25 |
| | 8 | *Syzygium cumini* (L.) skeels | 10.80 | 9.87 | 57.33 | 2.69 | 3.09 |
| | 9 | *Rhus succedanea* L. | 17.80 | 6.70 | 54.67 | 2.57 | 2.95 |
| | 10 | *Engelhardtia spicata* Lechen ex Blume | 15.70 | 6.93 | 53.79 | 2.53 | 2.90 |
| | 11 | *Castanopsis indica* (Roxb. ex Lindl.) A.DC. | 12.41 | 7.27 | 50.16 | 2.36 | 2.71 |
| | 12 | *Castanopsis tribuloides* A.DC | 11.44 | 9.01 | 49.09 | 2.31 | 2.65 |
| | 13 | *Fraxinus floribunda* Wall. | 8.25 | 8.26 | 22.45 | 1.06 | 1.21 |
| | 14 | *Semecarpus anacardium*L.f | 8.50 | 7.60 | 19.28 | 0.91 | 1.04 |
| | 15 | *Eurya acuminata* DC. | 8.64 | 7.42 | 19.23 | 0.90 | 1.04 |
| | 16 | *Symplocos pyrifolia* Wall. ex G. Don | 7.09 | 5.54 | 11.88 | 0.56 | 0.64 |
| | 17 | *Rhododendron arboreum* Sm. | 7.82 | 4.86 | 10.09 | 0.47 | 0.54 |
| | 18 | *Rhus javanica* L. | 6.48 | 6.10 | 7.02 | 0.33 | 0.38 |
| | 19 | *Pyrus pashia* Buch.-Ham. ex D.Don | 8.00 | 2.70 | 6.07 | 0.29 | 0.33 |
| | | Total | 264.73 | 174.05 | 1867.26 | 87.13 | 100.00 |
| Oak Forest | 1 | *Quercus semecarpifolia* Sm. | 29.12 | 13.03 | 1110.26 | 52.18 | 98.93 |
| | 2 | *Rhododendron arboreum* Sm. | 7.40 | 7.17 | 11.98 | 0.56 | 1.07 |
| | | Total | 36.52 | 20.20 | 1122.23 | 52.75 | 100.00 |
| Pine Forest | 1 | *Pinus roxburghii* Sarg | 29.47 | 14.00 | 370.36 | 17.41 | 77.38 |
| | 2 | *Schima wallichii* Choisy | 14.35 | 10.58 | 74.60 | 3.51 | 15.59 |
| | 3 | *Castanopsis indica* (Roxb. ex Lindl.) A.DC. | 9.37 | 8.79 | 33.66 | 1.58 | 7.03 |
| | | Total | 53.19 | 33.36 | 478.62 | 22.50 | 100.00 |

***Variation of soil properties with forest types***

The soil organic carbon (SOC) was found to be significantly higher in Oak Forest (5.57±1.18) than in Mixed Forest (2.54±0.86) and Pine Forest (2.82 ± 0.48, Table 4). All three forest types were found to have acidic soil. The soil pH of Mixed Forest (6.11±0.5) was found to be significantly more acidic than that of Oak Forest (6.57±0.3) and Pine Forest (6.4±0.25). In comparison to Mixed Forest and Oak Forest, Pine Forest (63.4±9.82) was found to have significantly lower water-holding capacity (WHC, Table 4).

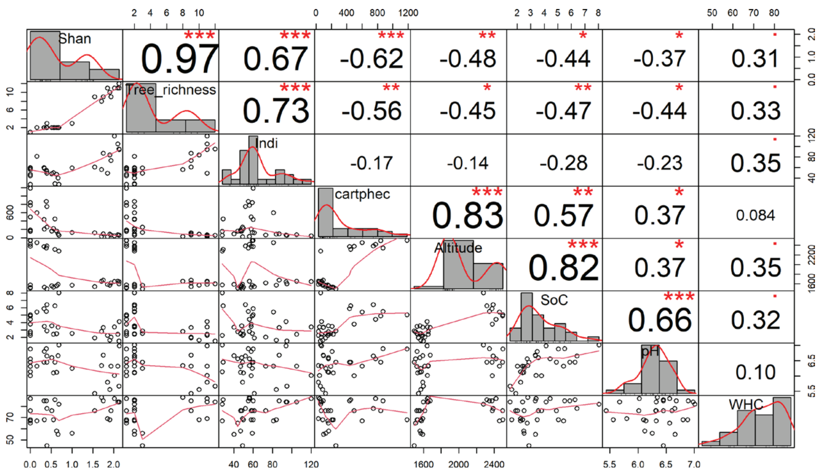


**Figure 6: Correlation coefficient matrix among different variables (Shan-Shannon Diversity Index, Tree_richnes – Tree species richness, Indi-Individuals, cartphec- Carbon stock ton per hectare, SOC – Soil organic carbon, pH – Soil pH, WHC – Water holding capacity of soil) Each value inside the box represented the correlation coefficient value, Star/s (*) indicated the level of significance. Three stars (***) indicated p < 0.000, two stars (**) indicated p < 0.001 and a single star (*) indicated p < 0.05.**

**Table 4: Soil properties (Mean ± SD) of Mixed Forest, Oak Forest and Pine Forest of Chandragiri Hills, Kathmandu, Central Nepal. Differences between the forest types were tested using ANOVA. Values with same letters in superscript are not significantly different while those with different letters in superscript are significantly different (name which post-hoc test was used, P < 0.05).**

| Forests | SOC (%) | pH | WHC (%) |
|---|---|---|---|
| Mixed | 2.54±0.86[a] | 6.11±0.5[a] | 80.1±7.33[a] |
| Oak | 5.57±1.18[b] | 6.57±0.3[b] | 79±7.29[a] |
| Pine | 2.82±0.48[a] | 6.4±0.25[b] | 63.4±9.82[b] |
| ***F*-value** | 35.63 | 3.9 | 12.88 |
| ***p*-value** | <0.0001 | 0.033 | <0.0001 |

***Relationship between tree carbon stock and tree species diversity and soil properties***

The living tree carbon stock showed a strong negatively significant (-0.56) relationship with the species richness of trees in forests. Meanwhile, such a relation with altitude was strong and positively significant (0.83). Correlation analysis (Figure 6) showed that living tree carbon stock was found to have a positively significant (0.57) relationship with Soil organic carbon. The living tree carbon stock has a fair positively significant (0.37) relationship with the pH of the soil. And in the case of the water-holding capacity of the soil, there was no significant (0.084) relationship with the carbon stock of the tree.

## Discussions

***Tree community attributes, tree species diversity and regeneration status of forest types***

The result of the tree community structure indicates the ecological success of dominant species, and their good regeneration potential utilizing most of the forest area and resources (Shameem & Kangroo, 2011) in the study area. Thus, the high IVI of *Schima wallichii*, *Quercus semecarpifolia*, *Pinus roxburghii* and associated species might be due to available resources such as low tree density, sufficient rainfall, good light availability etc. In the present study, a J-shaped DBH class distribution curve structure in Mixed and Oak Forests showed a higher number of trees with a smaller DBH class. This indicates a good natural regeneration state of these forests which are still in evolving stage (Campbell *et al.,* 1992; Basyal *et al.,* 2011). The reversed J-shaped DBH class distribution curve of Pine trees in Pinus forest indicated artificial regeneration. The mature status of the Pine Forest at the present study site is similar to the result inferred by Dar *et al.* (2017) and Sharma *et al.* (2020). This may have been accomplished by minimizing the disturbances and shifting management regimes (Bhatt *et al.,* 2015, Dar *et al.,* 2017).

***Relationship of living tree carbon stock with species structure and soil properties***

The forest carbon stock is mainly determined by the nature of vegetation composition of the forest where the seedling and saplings have significantly less contribution (Hu *et al.,* 2015). Higher living tree carbon stock in Mixed Forest and lower in Pine Forest may be due to different factors such as forest types, forest age, size and density of trees, degree of disturbance, species composition and allometric equation used for the estimation of carbon stock (Mandal *et al.,* 2013; Berenguer *et al.,* 2014; Biswas *et al.,* 2020; Saimun *et al.*, 2021). The variation of living tree carbon stock among the forests with different vegetation compositions is more or less supported by Ikraoun *et al.* (2022), Poudel *et al.* (2020), Sharma *et al.* (2020), Verma and Garkoti (2019), Shrestha *et al.* (2016), Aryal *et al.* (2013) and Joshi *et al.* (2013). In these forests, all silvicultural practices (thinning, pruning, singling, litter collection, plantation, fodder collection for cattle, etc.) may have been executed, which might also be the cause of the significant variation in the species-specific contribution to the carbon stock (Forrester & Baker, 2012; Marden *et al.,* 2021).

Soil organic Carbon (SOC) was also found varied in the different forest types which might be due to the forest stand, vegetation composition, soil moisture, soil organic matter (Zhang *et al.*, 2021). Higher SOC in Oak Forest than that in Pine and Mixed Forest in the present study is comparable with the results inferred by Aryal *et al.* (2013), Shrestha *et al.* (2016), Aryal *et al.* (2018) and Kumar *et al.* (2021). In the present study, the soil pH of the all forests of different vegetation composition was acidic in nature. This may be the consequence of basic ions in the muddy soil being washed out, which led to $H^+$ rich ions in the soil and more acid being generated by the decay of organic matter. Since Yu *et al.* (2019) suggested that soil pH doesn't play a significant role in the accumulation of SOC, which strongly supports the present study. Soil organic carbon with Oak Forest found a strong positive correlation with the other two forest types which could be result from better nutrient input through litterfall and an increase in regenerating oak trees. The findings of the present study are comparable with various studies by Khanal *et al.* (2010), Gairola *et al.* (2012), Joshi & Negi (2015), and Pandey *et al.* (2019). Similar to this inference, in the present study, living tree carbon stock and biomass were higher for Mixed Forest than that for Oak and Pine forests.

Present study would be an excellent model to demonstrate to other communities that the more expansive, global conservation policies, strategies, and carbon market mechanism of REDD+ can offer significantly more protection to the forest and enhance economic benefit.

## Conclusions

The living tree carbon stock of forest depends upon the different vegetation compositions. The average living tree carbon stock was found to be higher in Mixed Forest (87.13 t/ha) and lower in Pine Forest (22.50 t/ha). Furthermore, the living tree carbon stock was found to be positively correlated with forest stand, altitude, soil organic carbon, soil pH, and WHC of soil whereas, it was found to be negatively correlated with Shannon and Weiner Index, tree species richness. Mixed Forest and Oak Forest were in good regeneration condition whereas the Pine Forest was in mature state. Furthermore, the Tree carbon stock was found to be positively correlated with forest stand, altitude, soil organic carbon, soil pH, and WHC of soil whereas, it was found to be negatively correlated with Shannon and Weiner Index, tree species richness. These findings imply that forests might be included in the REDD+ program, which would then help for better forest management.

## Acknowledgments

We are grateful to the community forest user groups (CFUG) of Laglagepakha, Gumalchoki, and Bosan Community Forest for their cooperation during the fieldwork. We are thankful to Professor Dr. Ram Kailash Prasad Yadav, Head of Central Department of Botany, T. U. for providing necessary facilities. Thanks also goes to Mr. Basudev Poudel, Mrs. Hira Shova Shrestha, Ms. Bidhya Shrestha, and Ms. Pristi Dangol for their contribution to this research. We are highly grateful to all anonymous reviewers for manuscript.

## Conflict of Interest

The authors declare that they have no conflicts of interest.

## Authors' Contributions

RG designed the study; collected data, and wrote the manuscript. HSA helped in designing the study, data collection and writing the manuscript. RSD helped with laboratory analysis; and CBB provided overall supervision and helped with manuscript correction and correspondence.

## References

Amir, M., Liu, X., Ahmad, A., Saeed, S., Mannan, A., & Muneer, M. A. (2018). Patterns of biomass and carbon allocation across chronosequence of chir pine (Pinus roxburghii) forest in Pakistan: inventory-based estimate. *Advances in Meteorology*, *2018*. https://doi.org/10.1155/2018/3095891

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

Aryal, S., Bhattarai, D. R., & Devkota, R. P. (2013). Comparison of carbon stocks between mixed and pine-dominated forest stands within the Gwalinidaha Community Forest in Lalitpur District, Nepal. *Small-scale forestry*, *12*(4), 659-666. https://doi.org/10.1007/s11842-013-9236-4

Aryal, S., Shrestha, S., Maraseni, T., Wagle, P. C., & Gaire, N. P. (2018). Carbon stock and its relationships with tree diversity and density in community forests in Nepal. *International Forestry Review*, *20* (3), 263-273. https://doi.org/10.1505/146554818824063069

Barlow, J., Parry, L., Gardner, T. A., Ferreira, J., Aragão, L. E., Carmenta, R., ... & Cochrane, M. A. (2012). The critical importance of considering fire in REDD+ programs. *Biological Conservation*, *154*, 1-8. https://doi.org/10.1016/j.biocon.2012.03.034

Basyal, S., Lekhak, H. D., &Devkota, A. (2011). Regeneration of Shorearobusta. Gaertn in tropical forest of Palpa district, central Nepal. *Scientific world*, *9*(9), 53-56. https://doi.org/10.3126/sw.v9i9.5519

Berenguer, E., Ferreira, J., Gardner, T.A., Aragão, L.E.O.C., De Camargo, P.B., Cerri, C.E., Durigan, M., Oliveira, R.C.D., Vieira, I.C.G. and Barlow, J. (2014). A largescale field assessment of carbon stocks in human modified tropical forests. *Global change biology*, *20* (12), 3713–3726. https://doi.org/10.1111/gcb.12627

Bhatt, G. D., Kushwaha, S. P. S., Nandy, S., Bargali, K., Nagar, P. S., & Tadvi, D. M. (2015). Analysis of fragmentation and disturbance regimes in south Gujarat forests, India. *Tropical Ecology*, *56* (3), 275–288.

Biswas, S., Biswas, A., Das, A., & Banerjee, S. (2020). Biomass model development for carbon stock estimation in the tropical forest of Eastern India: an allometric approach. *Tropical Ecology*, *61*(3), 360–370. https://doi.org/10.1007/s42965-020-00098-2

Bonan, G. B. (2008). Forests and climate change: forcings, feedbacks, and the climate benefits of forests. *science*, *320*(5882), 1444-1449. https://doi.org/10.3389/ffgc.2020.00058

Brown, K., & Pearce, D. (1994). The economic value of non-market benefits of tropical forests: carbon storage. *The economics of project appraisal and the environment.*, 102–123.

Campbell, D. G., Stone, J. L., & Rosas Jr, A. R. I. T. O. (1992). A comparison of the phytosociology and dynamics of three floodplain (Várzea) forests of known ages, Rio Juruá, western Brazilian Amazon. *Botanical journal of the Linnean Society*, *108*(3), 213–237. https://doi.org/10.1111/j.1095-8339.1992.tb00240.x

Chave, J., Andalo, C., Brown, S., Cairns, M.A., Chambers, J.Q., Eamus, D., Fölster, H., Fromard, F., Higuchi, N., Kira, T. and Lescure, J.P. (2005). Tree allometry and improved estimation of carbon stocks and balance in tropical forests. *Oecologia*, *145*(1), 87–99. https://doi.org/10.1007/s00442-005-0100-x

Creutzig, F., Ravindranath, N.H., Berndes, G., Bolwig, S., Bright, R., Cherubini, F., Chum, H., Corbera, E., Delucchi, M., Faaij, A., & Fargione, J. (2015). Bioenergy and climate change mitigation: an assessment. *Gcb Bioenergy*, *7* (5), 916–944. https://doi.org/10.1111/gcbb.12205

Dar, J. A., Rather, M. Y., Subashree, K., Sundarapandian, S., & Khan, M. L. (2017). Distribution patterns of tree, understorey, and detritus biomass in coniferous and broad-leaved forests of Western Himalaya, India. *Journal of Sustainable Forestry*, *36* (8), 787-805. https://doi.org/10.1080/10549811.2017.1363055

Dhyani, S., Maikhuri, R. K., & Dhyani, D. (2019). Impact of anthropogenic interferences on species composition, regeneration and stand quality in moist temperate forests of Central Himalaya. *Tropical Ecology*, *60* (4), 539–551. https://doi.org/10.1007/s42965-020-00054-0

Eggleston, S., Buendia, L., Miwa, K., Ngara, T., & Tanabe, K. (2006). IPCC guidelines for national greenhouse gas inventories. Hayama : Institute for Global Environmental Strategies (IGES), Japan.

Eswaran, H., Beinroth, F., & Reich, P. (1999). Global land resources and population-supporting capacity. *American Journal of Alternative Agriculture*, *14* (3), 129–136. https://doi.org/10.1017/S0889189300008250

Forrester, D. I., & Baker, T. G. (2012). Growth responses to thinning and pruning in Eucalyptus globulus, Eucalyptus nitens, and Eucalyptus grandis plantations in southeastern Australia. *Canadian Journal of Forest Research*, *42* (1), 75–87. https://doi.org/10.1139/x11-146

FRTC (2022). Field Manual, 2022 (Remeasurement of Permanent Sample Plot), Forest Resource Assessment (FRA), Forest Research & Training Center (FRTC), Nepal.

Gairola, S., Sharma, C. M., Ghildiyal, S. K., & Suyal, S. (2012). Chemical properties of soils in relation to forest composition in moist temperate valley slopes of Garhwal Himalaya, India. *The Environmentalist*, *32* (4), 512–523. https://doi.org/10.1007/s10669-012-9420-7

Georgiou, K., Jackson, R.B., Vindušková, O., Abramoff, R.Z., Ahlström, A., Feng, W., Harden, J.W., Pellegrini, A.F., Polley, H.W., Soong, J.L., & Riley, W.J. (2022). Global stocks and capacity of mineral-associated soil organic carbon. *Nature communications*, *13*(1), 1-12. https://doi.org/10.1038/s41467-022-31540-9

Ghimire, P., Kafle, G., & Bhatta, B. (2018). Carbon stocks in Shorearobusta and Pinusroxburghii forests in Makawanpur district of Nepal. *Journal of AFU*, *2*, 241–248.

Hu, Y., Su, Z., Li, W., Li, J., & Ke, X. (2015). Influence of tree species composition and community structure on carbon density in a subtropical forest. *PLoS One*, *10* (8), e0136984. https://doi.org/10.1371/journal.pone.0136984

Ikraoun, H., Nassiri, L., El Mderssa, M., & Ibijbijen, J. (2022). Assessment of the organic carbon stock in the green oak forest in the Morrocan Oulmes Central Plateau. In *E3S Web of Conferences* (Vol 351, p. 01096). EDP Sciences. https://doi.org/10.1051/e3sconf/202235101096

Iturbide, M., Gutiérrez, J.M., Alves, L.M., Bedia, J., Cerezo-Mota, R., Cimadevilla, E., Cofiño, A.S., Di Luca, A., Faria, S.H., Gorodetskaya, I.V., & Hauser, M. (2020). An update of IPCC climate reference regions for subcontinental analysis of climate model data: definition and aggregated datasets. *Earth System Science Data*, *12*(4), 2959–2970. https://doi.org/10.5194/essd-12-2959-2020

Joshi, G., & Negi, G. C. S. (2015). Physico-chemical properties along soil profiles of two dominant forest types in Western Himalaya. *Current Science*, *109* (4), 798–803.

Joshi, N. R., Tewari, A., & Chand, D. B. (2013). Impact of Forest fire and aspect on phytosociology, tree biomass and carbon stock in Oak and Pine mixed Forests of Kumaun central Himalaya, India. *Researcher*, *5* (3), 1–8.

Kaushal, S., & Baishya, R. (2021). Stand structure and species diversity regulate biomass carbon stock under major Central Himalayan forest types of India. *Ecological Processes*, *10*(1), 1–18. https://doi.org/10.1186/s13717-021-00283-8

Khanal, Y., Sharma, R. P., & Upadhyaya, C. P. (2010). Soil and vegetation carbon pools in two community forests of Palpa district, Nepal. *BankoJanakari*, *20* (2), 34–40. https://doi.org/10.3126/banko.v20i2.4800

Kumar, M., Kumar, A., Kumar, R., Konsam, B., Pala, N. A., & Bhat, J. A. (2021). Carbon stock potential in Pinus roxburghii forests of Indian Himalayan regions. *Environment, Development and Sustainability*, *23* (8), 12463-12478. https://doi.org/10.1007/s10668-020-01178-y

Magurran, A. E. (1988). *Ecological diversity and its measurement*. Princeton university press.

Malla, S.B., Rajbhandari, S.B., Shrestha, T.B., Adhikari, P.M., Adhikari, S.R., & Shakya, P.R. (1986). Flora of Kathmandu valley. *Bulletin of Department of Medicinal Plants of Nepal*.

Mandal, R. A., Dutta, I. C., Jha, P. K., & Karmacharya, S. (2013). Relationship between carbon stock and plant biodiversity in collaborative forests in Terai, Nepal. *International Scholarly Research Notices*, *2013*. https://doi.org/10.1155/2013/625767

Marden, M., Lambie, S., & Burrows, L. (2021). Species-specific basic stem-wood densities for twelve indigenous forest and shrubland species of known age, New Zealand. *New Zealand Journal of Forestry Science*, *51*. https://doi.org/10.33494/nzjfs512021x121x

Måren, I. E., & Vetaas, O. R. (2007). Does regulated land use allow regeneration of keystone forest species in the Annapurna Conservation Area, Central Himalaya. *Mountain Research and Development*, *27*(4), 345–351. https://doi.org/10.1659/mrd.0893

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

Moomaw, W. R., Law, B. E., & Goetz, S. J. (2020). Focus on the role of forests and soils in meeting climate change mitigation goals: summary. *Environmental Research Letters*, *15* (4), 045009. https://doi.org/10.1088/1748-9326/ab6b38

Nakicenovic, N., Alcamo, J., Davis, G., de Vries, B., Fenhann, J., Gaffin, S., Gregory, K., Gr¨ubler, A Jung, T.Y., Kram, T., & La Rovere, E.L. (2000), Special Report on Emissions Scenarios, Working Group III, Intergovernmental Panel on Climate Change (IPCC), Cambridge University Press, Cambridge, UK, (http://www.grida.no/climate/ipcc/emission/index.htm).

Nascimento, H. E., & Laurance, W. F. (2004). Biomass dynamics in Amazonian forest fragments. *Ecological applications*, *14* (sp4), 127–138. https://doi.org/10.1890/01-6003

Pandey, H. P., Pandey, P., Pokhrel, S., & Mandal, R. A. (2019). Relationship between soil properties and forests carbon: Case of three community forests from Far Western Nepal. *BankoJanakari*, *29* (1), 43–52. https://doi.org/10.3126/banko.v29i1.25154

Penman, J., Gytarsky, M., Hiraishi, T., Krug, T., Kruger, D., Pipatti, R., Buendia, L., Miwa, K., Ngara, T., & Tanabe, K. (2003). Good practice guidance for land use, land-use change and forestry. Institute for Global Environmental Strategies.

Poudel, A., Sasaki, N., & Abe, I. (2020). Assessment of carbon stocks in oak forests along the altitudinal gradient: A case study in the Panchase Conservation Area in Nepal. *Global Ecology and Conservation*, *23*, e01171. https://doi.org/10.1016/j.gecco.2020.e01171

Pradhan, B. M., Awasthi, K. D., & Bajracharya, R. M. (2012). Soil organic carbon stocks under different forest types in Pokhare Khola sub-watershed: a case study from Dhading district of Nepal. *WIT Transactions on Ecology and the Environment*, *157*, 535–546. https://doi.org//10.2495/AIR120471

Press, J. R., Shrestha, K. K., & Sutton, D. A. (2000). *Annotated checklist of the flowering plants of Nepal*. Natural History Museum Publications.

Pugh, T. A., Lindeskog, M., Smith, B., Poulter, B., Arneth, A., Haverd, V., & Calle, L. (2019). Role of forest regrowth in global carbon sink dynamics. *Proceedings of the National Academy of Sciences*, *116* (10), 4382–4387. https://doi.org/10.1073/pnas.1810512116

Riutta, T., Kho, L. K., Teh, Y. A., Ewers, R., Majalap, N., & Malhi, Y. (2021). Major and persistent shifts in below ground carbon dynamics and soil respiration following logging in tropical forests. *Global change biology*, *27* (10), 2225–2240. https://doi.org/10.1111/gcb.15522

R Core Team. (2022). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL: https://www.R-project.org/.

Saimun, M. S. R., Karim, M. R., Sultana, F., & Arfin-Khan, M. A. (2021). Multiple drivers of tree and soil carbon stock in the tropical forest ecosystems of Bangladesh. *Trees, Forests and People*, *5*, 100–108. https://doi.org/10.1016/j.tfp.2021.100108

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.

Sharma, C. M., Baduni, N. P., Gairola, S., Ghildiyal, S. K., & Suyal, S. (2010). Tree diversity and carbon stocks of some major forest types of Garhwal Himalaya, India. *Forest Ecology and Management*, *260* (12), 2170–2179. https://doi.org/10.1016/j.foreco.2010.09.014

Sharma, K.P., Bhatta, S.P., Khatri, G.B., Pajiyar, A., & Joshi, D.K. (2020). Estimation of carbon stock in the chir pine (Pinusroxburghii Sarg.) plantation forest of Kathmandu valley, Central Nepal. *Journal of Forest and Environmental science*, *36* (1), 37–46. https://doi.org/10.7747/JFES.2020.36.1.37

Shrestha, L. J., Devkota, M. P., & Sharma, B. K. (2016). Are sacred groves of Kathmandu valley efficient in sequestering carbon?. *Journal of Botany*. http://dx.doi.org/10.1155/2016/7695154

Shrestha, B. P., & Devkota, B. P. (2013). Carbon stocks in the oak and pine forests in Salyan district, Nepal. *Banko Janakari*, *23* (2), 30–36. https://doi.org/10.3126/banko.v23i2.15478

Stephens, B.B., Gurney, K.R., Tans, P.P., Sweeney, C., Peters, W., Bruhwiler, L., Ciais, P., Ramonet, M., Bousquet, P., Nakazawa, T., & Aoki, S. (2007). Weak northern and strong tropical land carbon uptake from vertical profiles of atmospheric $CO_2$. *Science*, *316* (5832), 1732–1735. https://doi.org/10.1126/science.1137004

Sullivan, M.J., Talbot, J., Lewis, S.L., Phillips, O.L., Qie, L., Begne, S.K., Chave, J., Cuni-Sanchez, A., Hubau, W., Lopez-Gonzalez, G., & Miles, L. (2017). Diversity and carbon storage across the tropical forest biome. *Scientific reports*, *7* (1), 1–12. https://doi.org/10.1038/srep39102

Sundriyal, R. C., & Sharma, E. (1996). Anthropogenic pressure on tree structure and biomass in the temperate forest of Mamlay watershed in Sikkim. *Forest Ecology and Management*, *81* (1-3), 113–134. https://doi.org/10.1016/0378-1127(95)03657-1

Verma, A. K., & Garkoti, S. C. (2019). Population structure, soil characteristics and carbon stock of the regenerating banj oak forests in Almora, Central Himalaya. *Forest Science and Technology*, *15* (3), 117–127. https://doi.org/10.1080/21580103.2019.1620135

Walkley, A., & Black, I.A. (1934). Rapid titration method of organic carbon of soils. *Soil Science*, *37*, 29–33.

Yu, M., Wang, Y., Jiang, J., Wang, C., Zhou, G., & Yan, J. (2019). Soil organic carbon stabilization in the three subtropical forests: importance of clay and metal oxides. *Journal of Geophysical Research: Biogeosciences*, *124* (10), 2976–2990. https://doi.org/10.1029/2018JG004995

Zanne, A.E., Lopez-Gonzalez, G., Coomes, D.A., Ilic, J., Jansen, S., Lewis, S.L., Miller, R.B., Swenson, N.G., Wiemann, M.C., & Chave, J. (2009). Global wood density database. http://hdl.handle.net/10255/dryad.235

Zhang, Y., Liu, T., Guo, J., Tan, Z., Dong, W., & Wang, H. (2021). Changes in the understory diversity of secondary Pinustabulaeformis forests are the result of stand density and soil properties. *Global Ecology and Conservation*, *28*, e01628. https://doi.org/10.1016/j.gecco.2021.e01628

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.

*http://www.worldfloraonline.org/ accessed on 03/12/2022*