*Proceedings of the Pakistan Academy of Sciences: B*
*Life and Environmental Sciences* 61(4): 417-429 (2024)

ISSN (Print): 2518-4261; ISSN (Online): 2518-427X
http://doi.org/10.53560/PPASB(61-4)952

Pakistan Academy of Sciences

Research Article

# Biomass Carbon Sequestration Potential of Conifers in Relation to Tree Structural Traits and Anthropogenic Disturbance Stimuli in Kashmir Himalaya

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**Abstract:** It is essential to quantify the amount of carbon stored in the biomass of forest species to determine the potential for mitigating climate change through forest management. This study aimed to estimate the biomass carbon stock (BCS) of coniferous tree species in 16 temperate (TFs) and 4 subalpine forests (SFs) in the state of Azad Jammu and Kashmir (AJK). BCS was calculated for individual trees using allometric equations. The total BCS was 66.5 ± 6 .8 Mg ha$^{-1}$, with 42.4 ± 7.3 Mg ha$^{-1}$ (63.7%) in TFs and 24.2 ± 4.1 Mg ha$^{-1}$ (36.3%) in SFs. The dominant species, *Pinus wallichiana* A.B. Jacks. and *Picea smithiana* (Wall.) Boiss., had corresponding BCS totals of 22.4 ± 4.6 (33.7%) and 21.7 ± 4.8 Mg ha$^{-1}$ (21.7%), respectively. *Abies pindrow* Royle had a BCS of 14.1 ± 3.8 Mg ha$^{-1}$ (21.2%), while the lowest value of 8.3 ± 1.3 Mg ha$^{-1}$ (15.5%) was found in *Cedrus deodara* (Roxb. ex D. Don) G. Don. TFs showed healthier structural attributes, with higher tree diameter at breast height (DBH) (155.7 ± 8.2 cm) and density (157.1 ± 4.2 trees ha$^{-1}$) compared to SFs, which had lower DBH (131 ± 7.4 cm) and density (113.9 ± 7.7 trees ha$^{-1}$). The forests in this region are facing significant deforestation, with 154.0 ± 6.4 stumps ha$^{-1}$ in temperate forests and 48.8 ± 2.8 stumps ha$^{-1}$ in subalpine forests. Statistical analysis revealed a significant correlation between BCS and tree girth, height, and total stem density. This study highlights the allocation trends of BCS among keystone species in a climate-sensitive region and emphasizes the need for forest conservation in the context of climate change.

**Keywords:** Biomass, Carbon, Conifers, Himalayas, Kashmir, Forest, Regeneration.

## 1. INTRODUCTION

Carbon dioxide ($CO_2$) is the most significant anthropogenic greenhouse gas (GHG) contributing to climate change, predominantly emitted through the combustion of fossil fuels, industrial processes, and deforestation.[1]. Climate change has altered the natural structural and functional ecology of the forest ecosystems in the Himalayan region where a radical transformation is observed in natural species composition, forest regeneration and phenological patterns [2, 3]. The outbreak of invasive species, increased risk of species extinction and forest carbon losses are also attributed to climate change [4, 5]. Western Himalayan forests are generally classified into coniferous and broad-leaved forests [6, 7] and provide significant ecological, economic, and aesthetic services including edible seeds, essential oils, resins, flavours and vital medicinal compounds [8]. Coniferous forests are dominant regional carbon sinks and sustain significant biomass and carbon stocks as compared to broad-leaved forests [9].

Ecological and physiological variations among the forest species are attributed to the altitudinal gradient correlated with climatic and non-climatic factors [10, 11]. These diverse ecosystems maintain differential $CO_2$ sequestration potentials depending on the site temperature, solar

Received: July 2023; Revised: November 2024; Accepted: December 2024
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radiation, precipitation, atmospheric pressure, wind velocity, slope aspect, nutrient availability, growth stage and disturbance regimes [12]. Deforestation for timber, fuelwood and raw materials in these delicate ecosystems causes a remarkable loss of tree cover, biomass and natural carbon stock [13].

Forest conservation for ecosystem balance and carbon management through rehabilitation is of great importance as natural forests play a significant role in mitigating climate change by atmospheric $CO_2$ sequestration and biomass production [8, 14]. Large trees make a higher amount of biomass and hence they capture more $CO_2$ in their woody portions as compared to the lower strata. Forest tree species, being a vital sink for ambient $CO_2$, retain about 50% carbon in their total standing biomass [15].

Analysis of the forest structure and composition is a prerequisite to assessing carbon content in the forest biomass. The species-wise analysis is still deficient and the accurate quantification of carbon in dominant tree species of the Himalayan forests region is required to evaluate climate change mitigation potential [11]. This study is intended to quantify the tree BCS in the tree species belonging to the Pinaceae family in temperate forests (TFs) and subalpine forests (SFs) of the Kashmir Himalayan region. It also aimed to find the relationship between carbon stocks and structural traits (tree density and size) and provide baseline data from the relatively less explored regions for forest conservation, carbon management and policy decisions.

## 2. MATERIALS AND METHODS

### 2.1. Study Area

The present study was carried out in the western Himalayan TFs and SFs of Azad Jammu and Kashmir (AJK), Pakistan (Figure 1). The study region is situated between Longitude 73° - 75° and Latitude 33° - 36° (Table 1) having an area of 13,297 km$^2$, enriched with unique phytodivesity and a greater species indigenousness. TFs and SFs in this region are symbolized with widespread growth of conifers including *Abies pindrow, Cedrus deodara*, *Picea smithiana*, and *Pinus wallichiana* [16, 17].

The area is characterized by mild summers (June to August) with an average temperature of 10-15 °C whereas the temperature falls below 0 °C in the winter season (November-May). The annual rainfall remains about 1500 mm with extreme in the monsoon season (July to August) in some regions whereas the entire study area accepts heavy snowfall during the winter season (November to April). Topographically, the area is steep and mountainous with carved valleys covered with vegetation. Soils are loamy and highly susceptible to erosion due to deforestation, overgrazing, and heavy precipitation [18, 19].

### 2.2. Sampling Techniques

Field surveys were conducted in the study area during spring 2019-20. Primary data was collected

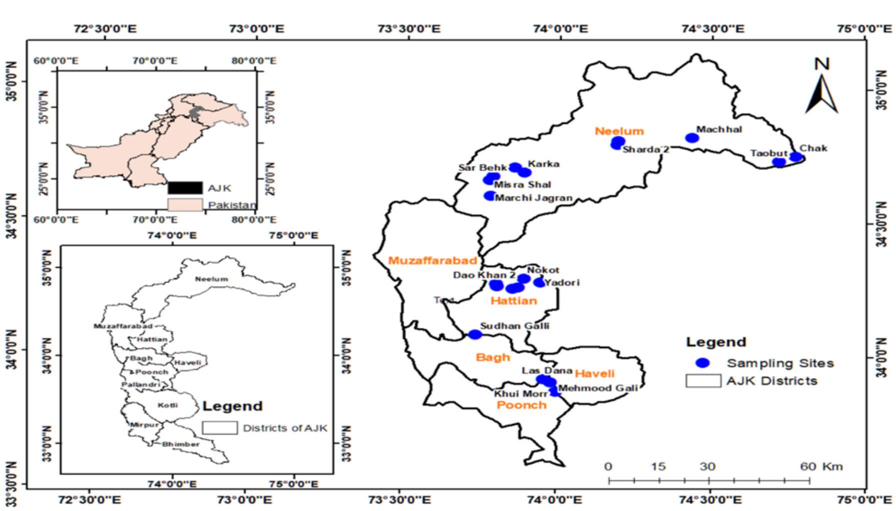


**Fig. 1.** Map of the study area indicating sampling sites in the temperate and subalpine coniferous forests.

**Table 1.** Location and characteristics of the studied coniferous forests.

| Site No. | Site name | District | Vegetation zone | Location | | |
|---|---|---|---|---|---|---|
| | | | | N | E | Elevation (m) |
| 1 | Marchi Jagran | Neelum | Temperate | 34° 35.061 | 73° 46.537 | 1930 |
| 2 | Sharda 1 | Neelum | Temperate | 34° 47.886 | 74° 11.411 | 1950 |
| 3 | Machhal | Neelum | Temperate | 34° 48.762 | 74° 25.778 | 2060 |
| 4 | Nokot | Hattian | Temperate | 34° 17.338 | 73° 53.337 | 2071 |
| 5 | Sharda 2 | Neelum | Temperate | 34º47.336 | 74°11.398 | 2100 |
| 6 | Sudhan Galli | Bagh | Temperate | 34° 04.498 | 73° 44.184 | 2185 |
| 7 | Mehmood Gali | Poonch | Temperate | 33º 52.100 | 73º 59.570 | 2225 |
| 8 | Taobut | Neelum | Temperate | 34° 43.579 | 74° 43.210 | 2286 |
| 9 | Khui Morr | Haveli | Temperate | 33º 54.230 | 73º 58.531 | 2375 |
| 10 | Misra Shal | Neelum | Temperate | 34° 39.312 | 73° 46.404 | 2458 |
| 11 | Karka | Neelum | Temperate | 34° 41.205 | 73° 52.841 | 2480 |
| 12 | Chak | Neelum | Temperate | 34° 45.050 | 74° 46.311 | 2502 |
| 13 | Las Dana | Bagh | Temperate | 33º 55.050 | 73º 57.290 | 2525 |
| 14 | Sar Behk | Neelum | Temperate | 34° 40.221 | 73° 46.767 | 2680 |
| 15 | Dao Khan 1 | Hattian | Temperate | 34° 15.488 | 73° 48.186 | 2685 |
| 16 | Dao Khan 2 | Hattian | Temperate | 34° 16.172 | 73° 27.15 | 2700 |
| 17 | Barthwar Galli Lower | Hattian | Subalpine | 34° 15.29 | 73° 51.821 | 2825 |
| 18 | Barthwar Galli Top | Hattian | Subalpine | 34°15.130 | 73° 51.232 | 2923 |
| 19 | Bichhkarla Doga | Neelum | Subalpine | 34° 41.837 | 73° 50.892 | 2984 |
| 20 | Yadori | Hattian | Subalpine | 34° 16.420 | 73° 56.530 | 3165 |

at 20 sites comprising 16 TFs and 4 SFs and in AJK (Table 1). Geographical attributes of the study sites including latitude, longitude and altitude were recorded using a GPS device. The forest sites were classified based on the intensity of anthropogenic disturbances, which included steepness of the terrain, soil erosion, and grazing pressure. The sites were categorized into three disturbance classes: low, moderate, and high. For low disturbance sites (Class 1), the terrain was relatively flat or had a gentle slope, with minimal soil erosion and limited grazing impact. Sites classified as moderate disturbance (Class 2) had moderate slopes, which contributed to some degree of soil erosion, and grazing intensity was more noticeable, affecting vegetation structure. High disturbance sites (Class 3) were characterized by steep slopes, which led to significant soil erosion, and high grazing intensity, resulting in overgrazing and noticeable degradation of vegetation. Deforestation intensity was quantified by counting the number of stumps within each plot. Similarly, seedlings count was used to describe forest regeneration potential. A total of ten square plots of 400 $m^2$ (20 × 20 m) were established at each forest site for data collection through the stratified random sampling method. Tree diameter at breast height (DBH ≥10 cm) and height (H) values were measured using standard protocols with the help of a conventional measuring tape and digital laser rangefinder respectively [20].

### 2.3. Forest Biomass and Carbon Stock Assessment

Aboveground tree biomass (AGTB) in living trees including stems, branches, twigs, and leaves was computed after calculation of the growing stock volume density (GSVD) using allometric models [21, 22]. Individual AGTB values were obtained by multiplying GSVD ($m^3$ $ha^{-1}$) with the applicable biomass expansion factor (BEF Mg/$m^3$). The BEF's of *Pinus wallichiana* were considered as 1.68 (for GSVD < 10 $m^3$ $ha^{-1}$), 0.95 (for GSVD = 10 – 100 $m^3$ $ha^{-1}$) and 0.81 (for GSVD > 100 $m^3$ $ha^{-1}$). For other coniferous trees with GSVD > 200 $m^3$ $ha^{-1}$, a BEF value of 1 was used whereas in the case of GSVD ≤ 160 $m^3$ $ha^{-1}$, a recommended BEF equation was used [23, 24]. Belowground tree biomass (BGB) of roots in tree species was estimated using recommended equation [25]. AGTB and BGB collectively made total tree biomass (TTB) in all living biomass components [8]. Biomass carbon stock (BCS) was computed by using biomass to carbon conversion factor of 0.50 applied to the obtained biomass value in each tree species [15, 26].

### 2.4. Data analysis

Multivariate analysis of BCS versus forest structural attributes and disturbance stimuli was carried out through Principal Component Analysis (PCA) using R (v4.4.2) software [27]. Generalized linear models (GLMs) with normal distribution and reciprocal function were applied for bivariate analysis for the calculated dataset. To express the similarities and statistical variations among the BCS pools, overall correlation trends among the biomass carbon stock, forest structural attributes and disturbance stimuli were presented in illustrative and numerical forms. The statistical analysis was performed using Past (v.5.0.2) software [28].

## 3. RESULTS

### 3.1. Biomass Carbon Distribution

BCS was computed in four coniferous tree species across the study region. Total BCS was computed as 66.5 ± 6.8 Mg $ha^{-1}$, from which 50.0 ± 7.1 Mg $ha^{-1}$C was recorded in the AGTB whereas BGB was recorded as having a total of 16.6 ± 4.6 Mg $ha^{-1}$C. TFs produced higher carbon content which was quantified as 42.4 ± 7.3 Mg $ha^{-1}$ with respective BCS values of 31.9 ± 4.6 and 10.5 ± 2.5 Mg $ha^{-1}$ in AGTB and BGB portions. SFs ecosystem showed comparatively lower BCS which was totaled as 24.2 ± 4.1 Mg $ha^{-1}$. Corresponding Carbon stock values in the AGTB and BGB portions in the SFs were recorded as 18.1 ± 4.3 and 6.1 ± 2.1 Mg $ha^{-1}$ (Table 2).

*Pinus wallichiana* and *Picea smithiana* were perceived as codominant species in the region with respective total BCS values of 22.4 ± 4.6 and 21.7 ± 4.8 Mg $ha^{-1}$ followed by *Abies pindrow* (14.1 ± 3.8 Mg $ha^{-1}$C). *Cedrus deodara* exhibited the lowest total BCS (8.3 ± 1.3 Mg $ha^{-1}$) in the studies region. Total BCS in the AGTB components in *Pinus wallichiana* and *Picea smithiana* was 17 ±

**Table 2.** Above and belowground biomass and carbon stock in the temperate and subalpine coniferous forests.

| Forest Type | Species | Aboveground tree biomass (Mg $ha^{-1}$) | Belowground biomass (Mg $ha^{-1}$) | Total tree biomass (Mg $ha^{-1}$) | Aboveground tree biomass carbon (Mg $ha^{-1}$) | Belowground biomass carbon (Mg $ha^{-1}$) | Total tree biomass carbon (Mg $ha^{-1}$) |
|---|---|---|---|---|---|---|---|
| **Temperate** | *Abies pindrow* | 13.4 ± 3.5 | 4.5 ± 1.4 | 17.9 ± 4.3 | 6.7 ± 1.3 | 2.3 ± 0.8 | 8.9 ± 2.4 |
| | *Cedrus deodara* | 12.4 ± 3.7 | 4.2 ± 1.5 | 16.6 ± 4.6 | 6.2 ± 1.8 | 2.1 ± 0.6 | 8.3 ± 2.1 |
| | *Picea smithiana* | 20.6 ± 4.2 | 6.6 ± 1.2 | 27.2 ± 5.4 | 10.3 ± 3.7 | 3.3 ± 0.3 | 13.6 ± 3.6 |
| | *Pinus wallichiana* | 17.5 ± 4.1 | 5.6 ± 1.6 | 23.1 ± 4.3 | 8.8 ± 2.6 | 2.8 ± 0.4 | 11.6 ± 2.5 |
| | **Sub total** | **63.8 ± 7.4** | **20.9 ± 3.5** | **84.7 ± 11.7** | **31.9 ± 4.6** | **10.5 ± 2.5** | **42.4 ± 7.3** |
| **Subalpine** | *Abies pindrow* | 7.6 ± 2.3 | 2.8 ± 0.8 | 10.4 ± 2.3 | 3.8 ± 0.6 | 1.4 ± 0.4 | 5.2 ± 1.7 |
| | *Cedrus deodara* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | *Picea smithiana* | 12.1 ± 3.2 | 4.1 ± 1.1 | 16.2 ± 4.1 | 6.1 ± 1.3 | 2.0 ± 0.3 | 8.1 ± 1.4 |
| | *Pinus wallichiana* | 16.4 ± 3.1 | 5.4 ± 1.3 | 21.8 ± 3.2 | 8.2 ± 2.4 | 2.7 ± 0.3 | 10.9 ± 2.6 |
| | **Sub total** | **36.1 ± 5.4** | **12.2 ± 3.3** | **48.3 ± 5.4** | **18.1 ± 4.3** | **6.1 ± 2.1** | **24.2 ± 4.1** |
| **BOTH** | *Abies pindrow* | 21.0 ± 4.8 | 7.3 ± 2.4 | 28.2 ± 3.3 | 10.5 ± 2.1 | 3.6 ± 1.3 | 14.1 ± 3.8 |
| | *Cedrus deodara* | 12.4 ± 1.4 | 4.2 ± 1.1 | 16.6 ± 3.2 | 6.2 ± 1.8 | 2.1 ± 0.4 | 8.3 ± 1.3 |
| | *Picea smithiana* | 32.7 ± 5.1 | 10.7 ± 3.2 | 43.4 ± 7.4 | 16.4 ± 2.3 | 5.3 ± 1.5 | 21.7 ± 4.8 |
| | *Pinus wallichiana* | 33.9 ± 6.4 | 11.0 ± 3.1 | 44.9 ± 6.3 | 17.0 ± 4.1 | 5.5 ± 1.4 | 22.4 ± 4.6 |
| **TOTAL** | | **99.9 ± 8.4** | **33.1 ± 4.3** | **133.1 ± 11.7** | **50.0 ± 7.1** | **16.6 ± 4.6** | **66.5 ± 6.8** |

4.1 and 16.4 ± 2.3 Mg ha$^{-1}$ individually while *Abies pindrow* and *Cedrus deodara* exhibited 10.5 ± 2.1 and 6.2 ± 1.8 Mg ha$^{-1}$C separately. BGB carbon content varied between the maximum of 5.5 ± 1.4 Mg ha$^{-1}$ in *Pinus wallichiana* to the minimum of 2.1 ± 0.4 Mg ha$^{-1}$ in *Cedrus deodara* (Table 2).

In the TFs region, *Picea smithiana* was the most noteworthy carbon sequestering species with 13.6 ± 3.6 Mg ha$^{-1}$ BCS followed by *Pinus wallichiana* (11.6 ± 2.5 Mg ha$^{-1}$), *Abies pindrow* (8.9 ± 2.4 Mg ha$^{-1}$) and *Cedrus deodara* (8.3 ± 2.1 Mg ha$^{-1}$). SFs revealed that *Pinus wallichiana* made the maximum total BCS (10.9 ± 2.6 Mg ha$^{-1}$) in these ecosystems whereas *Picea smithiana* (8.1 ± 1.4 Mg ha$^{-1}$) and *Abies pindrow* (5.2 ± 1.7 Mg ha$^{-1}$) were successive species (Table 2).

Considering site-specific BCS production in TFs, Sudhan Galli yielded the maximum BCS as 176.6 ± 8.4 Mg ha$^{-1}$ followed by Sharda 2 (161.2 ± 6.5 Mg ha$^{-1}$) and Nokot, (100.1 ± 5.7 Mg ha$^{-1}$) whereas Marchi Jagran TF was recorded as having the minimum site-specific BCS as 65.6 ± 4.7 Mg ha$^{-1}$. Among the SFs, Yadori produced the highest amount of site-specific BCS as 130.2 ± 8.4 Mg ha$^{-1}$ while Lower Barthwar Galli yielded the lowest total of 58.8 ± 4.6 Mg ha$^{-1}$C.

### 3.2. Forest Structural Attributes

The average DBH value in coniferous trees was recorded as 143.3 ± 6.5 cm, relatively high (155.7 ± 8.2 cm) in the SFs and low (131 ± 6.4 cm) in the TFs region. Similarly, the average tree height was noted as 27.8 ± 3.1 m with a higher value (28.1 ± 3.8 m) in the TFs and a lower value (27.4 ± 3.2 m) in the SFs region. The individual maximum tree girth (172.1 ± 7.5 cm) and height (35.51 ± 5.3 m) were recorded in *Pinus wallichiana* whereas *Cedrus deodara* showed the minimum DBH (68.14 ± 4.8 cm) and height (12.83 ± 1.8 cm) values (Table 3). Sudhan Galli, Sharda 2, Yadori, Nokot, Machhal, Chak, Dao Khan 1, Taobut and Misra Shal showed an average DBH range of 150-250 cm. All these forests and some other sites (Las Dana, Misra Shal, Sar Behk, Mehmood Gali, Dao Khan 2, Khui Morr, Sharda 1, Karka and Marchi Jagran) presented tree height range of 20-48 m. Barthwar Galli Lower, Bichhkarla Doga and Barthwar Galli Top showed minimum average tree DBH (> 100 cm) and height (> 15 m).

The total average tree density in the study region was 135.5 ± 6.4 trees ha$^{-1}$. A higher density value of 157.1 ± 4.2 trees ha$^{-1}$ was recorded in the TFs ecosystem with *Pinus wallichiana* (240.9 ± 8.8

**Table 3.** Forest structural attributes of studied temperate and subalpine coniferous forests.

| Structural attributes | Forest type | *Abies pindrow* | *Cedrus deodara* | *Picea smithiana* | *Pinus wallichiana* | Total |
|---|---|---|---|---|---|---|
| **Tree DBH (cm)** | Temperate | 157.4 ± 9.4 | 136.3 ± 7.5 | 176.8 ± 6.6 | 152.2 ± 8.3 | 155.7 ± 8.2 |
| | Subalpine | 143.8 ± 8.3 | 0 | 188.2 ± 11.1 | 192.0 ± 10.3 | 131.0 ± 7.4 |
| | **Average** | **150.58 ± 9.3** | **68.14 ± 4.8** | **182.49 ± 9.7** | **172.1 ± 7.5** | **143.3 ± 6.5** |
| **Tree height (m)** | Temperate | 27.8 ± 2.1 | 25.7 ± 3.2 | 29.7 ± 4.1 | 29.2 ± 4.5 | 28.1 ± 3.8 |
| | Subalpine | 30.0 ± 3.7 | 0 | 38.0 ± 3.2 | 41.8 ± 3.7 | 27.4 ± 3.2 |
| | **Average** | **28.89 ± 4.7** | **12.83 ± 1.8** | **33.87 ± 3.3** | **35.51 ± 5.3** | **27.8 ± 3.1** |
| **Tree density (trees ha$^{-1}$)** | Temperate | 107.3 ± 7.4 | 123.8 ± 8.3 | 156.5 ± 6.1 | 240.9 ± 8.8 | 157.1 ± 4.2 |
| | Subalpine | 120.0 ± 5.3 | 0.0 | 130.0 ± 6.5 | 205.6 ± 8.5 | 113.9 ± 7.7 |
| | **Average** | **113.7 ± 8.3** | **61.9 ± 3.5** | **143.3 ± 6.1** | **223.3 ± 11.3** | **135.5 ± 6.4** |
| **Forest regeneration (seedlings ha$^{-1}$)** | Temperate | 80.0 ± 6.1 | 100.0 ± 6.3 | 21.0 ± 2.1 | 161.0 ± 8.3 | 90.5 ± 5.8 |
| | Subalpine | 150.0 ± 4.7 | 0.0 | 40.0 ± 5.1 | 10.0 ± 0.4 | 50.0 ± 4.1 |
| | **Average** | **115.0 ± 6.2** | **50.0 ± 4.8** | **30.5 ± 3.6** | **85.5 ± 7.2** | **70.3 ± 4.6** |
| **Deforestation intensity (stumps ha$^{-1}$)** | Temperate | 158.0 ± 7.8 | 134.0 ± 6.4 | 117.0 ± 5.1 | 207.0 ± 8.2 | 154.0 ± 6.4 |
| | Subalpine | 73.0 ± 5.1 | 0.0 | 65.0 ± 4.3 | 57.0 ± 4.2 | 48.8 ± 2.8 |
| | **Average** | **115.5 ± 5.0** | **67.0 ± 4.7** | **91.0 ± 4.7** | **132.0 ± 5.6** | **101.4 ± 4.4** |

trees ha$^{-1}$) as the most abundant species. The total tree density in SFs was 113.9 ± 7.7 ha$^{-1}$ where the minimum density of 120 ± 5.3 ha$^{-1}$ was chronicled in *Abies pindrow* (Table 3). Some sites including Sudhan Galli, Yadori, Sharda 2, Machhal, Chak, Nokot, Taobut and Misra Shal exhibited improved growth parameters and higher tree density (980 to 600 stems ha$^{-1}$) while Barthwar Galli Top yielded the lowest density of 79.2 ± 4 trees ha$^{-1}$.

Deforestation, as a threat to the sustainability of the forest ecosystem, was recorded as 101.4 ± 4.4 stumps ha$^{-1}$, ranging from 154 ± 6.4 in TFs to 48.8 ± 2.8 stumps ha$^{-1}$ in the SFs. In the TFs region, the discrete deforestation rate in *Pinus wallichiana* (207 ± 8.2 stumps ha$^{-1}$) was the highest followed by *Abies pindrow* (158 ± 7.8 ha$^{-1}$), *Cedrus deodara* (134 ± 6.4 ha$^{-1}$) and *Picea smithiana* (117 ± 5.1 ha$^{-1}$). Inversely, *Pinus wallichiana* in the SFs region showed a low deforestation count (57 ± 4.2 stumps ha$^{-1}$) but logging rates of *Abies pindrow* (73 ± 5.1 ha$^{-1}$) and *Picea smithiana* (65 ± 4.3 ha$^{-1}$) were relatively higher (Table 3). The maximum deforestation was recorded at Barthwar Galli Lower (1666.6 ± 9.7 stems ha$^{-1}$) followed by Barthwar Galli Top (933.3 ± 6.8 stems ha$^{-1}$), Bichhkarla Doga (666.6 ± 5.7 stems ha$^{-1}$) and Marchi Jagran (512.5 ± 5.1 stems ha$^{-1}$) whereas deforestation rate at Sudhan Galli was the minimum (104.2 ± 3 stems ha$^{-1}$).

The average seedlings count in both forest types was 70.3 ± 4.6 ha$^{-1}$, which was higher (90.5 ± 5.8 ha$^{-1}$) in TFs and lower (50 ± 4.1 ha$^{-1}$) in SFs. *Abies pindrow* showed the highest regeneration potential with an average of 115 ± 6.2 seedlings ha$^{-1}$ and particularly 150 ± 4.7 seedlings ha$^{-1}$ in SFs. In the TFs region, *Pinus wallichiana* also showed a noteworthy regeneration capability at the rate of 161 ± 8.3 seedlings ha$^{-1}$ but it reduced to 10 ± 0.4 ha$^{-1}$ in the SFs (Table 3). Karka, Dao Khan 1, Mehmood Gali, and Bichhkarla Doga forests were found to have healthier regeneration rates (1167-588 seedlings ha$^{-1}$) whereas a reduced regeneration was noted at Sharda 2, Dao Khan 2, and Misra Shal (50-21 seedlings ha$^{-1}$).

Multivariate analysis (PCA) revealed a significant relationship between total tree carbon content and structural attributes. PCA distinguished species based on structural attributes including tree DBH, height, density, regeneration and deforestation (Figure 2(a)). Site-wise multivariate correlation analysis also revealed the same fact that carbon stock is influenced by forest growth stage, disturbance stimuli and altitude (Figure 2(b)). Bivariate linear models explained the statistical relationships of BCS with forest structural traits and various anthropogenic disturbance stimuli (Table 4).

## 4. DISCUSSION

Forest BCS management is one of the key approaches to minimize the challenging impacts of climate change, following the Kyoto Protocol [1, 29]. Sustainable forest management by improving forest health and plantation is regarded as a significant tool for improved atmospheric $CO_2$

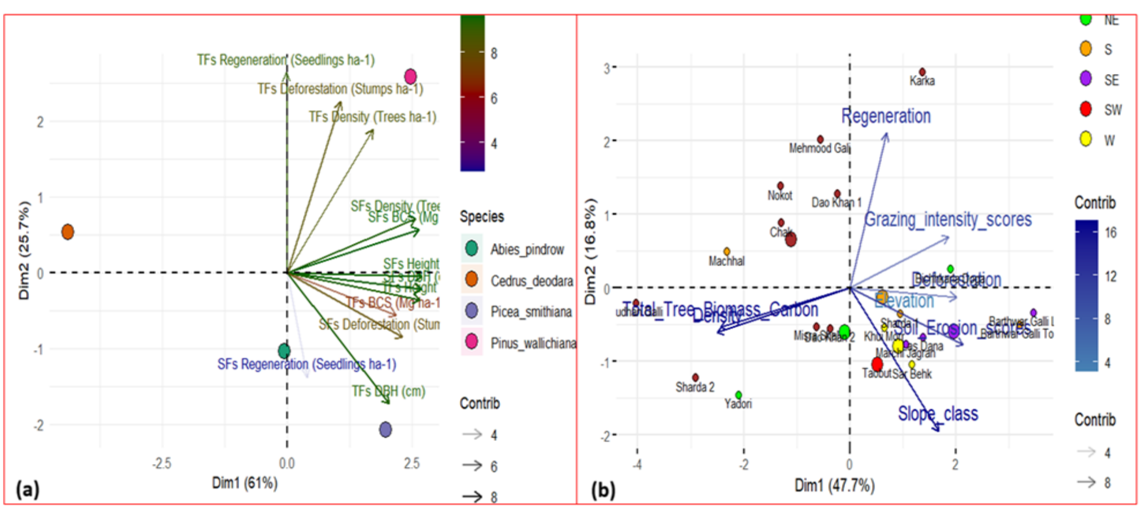


**Fig. 2.** PCA expression of correlation between (a) species-wise BCS and (b) site-wise BCS with forest structural attributes and disturbance stimuli.

**Table 4.** Supplementary table of GLM depicting statistical associations of BCS with forest structural attributes and disturbance stimuli.

| GLM-Carbon Stock VS | | Dispersion phi (estimated) | Slope a | | Intercept b | | Log likelihood | G: | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Value | Std. error. a | Value | Std. error. b | | Value | p (slope = 0) |
| Species | DBH | 961.8 | -0.000346 | 0.00019 | 0.0132 | 0.004008 | -1 | 6.3875 | 0.01149 |
| | H | 32.905 | -0.001914 | 0.000968 | 0.07062 | 0.020567 | -1 | 7.7704 | 0.00531 |
| | Density | 1247.8 | -0.00065 | 0.000357 | 0.01967 | 0.007789 | -1 | 8.949 | 0.00278 |
| Sites | DBH | 358.89 | -3.57E-05 | 3.36E-06 | 0.01001 | 0.000468 | -9 | 88.511 | 5.06E-21 |
| | H | 26.592 | -0.000195 | 2.52E-05 | 0.05354 | 0.003563 | -9 | 49.049 | 2.50E-12 |
| | Density | 28557 | -1.10E-05 | 2.11E-06 | 0.00285 | 0.00031 | -9 | 24.646 | 6.89E-07 |
| | Regeneration | 91140 | 3.03E-05 | 3.52E-05 | 0.00094 | 0.002397 | -9 | 1.3072 | 0.2529 |
| | Deforestation | 73877 | -0.034698 | 0.01024 | 8.4626 | 0.61561 | -9 | 16.226 | 5.62E-05 |
| | Altitude | 126480 | 4.71E-07 | 4.34E-07 | 0.00037 | 3.80E-05 | -9 | 1.2288 | 0.26765 |
| | Slope | 0.67211 | 0.0033508 | 0.001717 | 0.18663 | 0.12195 | -9 | 4.6155 | 0.03169 |
| | Erosion | 0.67211 | 0.0033508 | 0.001717 | 0.18663 | 0.12195 | -9 | 4.6155 | 0.03169 |
| | Grazing | 0.35495 | 0.0034115 | 0.001235 | 0.17872 | 0.087256 | -9 | 13.554 | 0.00023 |

sequestration. Assessing BCS in local carbon pools not only supports the policy decisions to mitigate climate change but reveals the challenges and offers sustainable forestry options and management approaches like species selection for reforestation and afforestation at the regional scale. Therefore, a higher volume of BCS is expected in well-managed forest ecosystems [30].

Several studies in AJK state have reported carbon counts in various terrestrial carbon pools at small landscapes with insights into factors affecting the carbon sequestration potential [31–35]. The current study focused on a cluster of four keystone coniferous tree species, widely distributed across Himalayan TFs and SFs ecosystems with a diverse range of structural and geographic considerations, growth and yield aptitudes, disturbance regimes, rejuvenation capacities and management options. It was observed that BCS was generally supported by growth parameters and variant ecological circumstances at specific forest sites whereas similar factors abandoned BCS production in other species [29].

Many regional studies reported comparatively higher BCS at different locations depending on geographical characteristics, ecological conditions, species composition, climate and forest sampling strategies [31, 35–40]. The decreased BCS presented by this study is attributed to the carbon exhaust and susceptibility of delicate Himalayan TFs and SFs ecosystems due to the combination of climatic changes, environmental circumstances and larger anthropogenic pressure that decreases forest carbon stocks and limit the livelihood options for local communities [41].

This study investigated that *Picea smithiana* and *Pinus wallichiana* yielded greater BCS totalities and contributed 33.8% and 32.6% respectively in the total tree carbon count as both species were recorded as having the greater DBH and tree height. Similarly, *Abies pindrow* yielded an intermediary BCS count (21.2%) with a medium tree size while *Cedrus deodara* exhibited the lowest BCS (12.4%) with a reduced tree size. Bivariate correlation analysis through GLM showed that besides various other factors (allometric models, tree density, wood-specific gravity, growing stock volume and site climatic conditions etc.), BCS is exclusively dependent on tree size and significantly associated with overall growth conditions as individual tree biomass remains directly proportional to tree DBH (Figure 3(a)) and height (Figure 3(b)). BCS in coniferous trees in relation to tree size emphasized that high altitude coniferous forests in are required to be conserved for carbon management as tree size in these forests is abridged as compared to some other forests in the Himalayan region [42-45].

The diversity of tree growth determinants comprising texture and structure of local soils, moisture content, nutrients availability, light duration, and quality, inter and intra-specific competition and climatic limitations may decline the tree growth and carbon accumulation potential [46]. Another important factor that directly affects BCS is overall tree density. Low density with sparse and disturbed forests produces low BCS [47]. The current study explicated the fact that the cumulative BCS in TFs was higher and was significantly supported by the larger stem density count (Figure 3(c)).

The literature review rationalized that low BCS count is attributed to lower tree density as compared to some other Himalayan forests [35, 48-52]. Species-specific trends in the BCS followed the site-specific trends where BCS was found to be dependent on individual tree DBH (Figure 4(a)), height (Figure 4(b)) and density (Figure 4(c)) in all four coniferous trees across the study area. TFs and SFs in the region are currently facing high deforestation intensity. Low tree density in the TFs and SFs has resulted from heavy deforestation, timber and fuelwood extraction, intensive grazing and browsing, soil loss through erosion and compaction, agriculture and infrastructure development as well as unsustainable use of forest resources [31]. The well-understood and expected associations between BCS and disturbance stimuli emphasize the importance of substantial forest management to achieve a reasonable carbon sequestration capacity. It demonstrates that forest conservation is a key mitigation tool against climate change [14].

Numerous anthropogenic stimuli in the region including increased rates of deforestation and cattle grazing as well as reduced rates of forest natural rehabilitation put a negative impact on the forest carbon sequestration potential. It was analyzed that deforestation rates were mostly higher in the forests with a low BCS count (Figure 5(a)). Similarly, forest sites with higher grazing intensity yielded dwindled total BCS values (Figure 5(b)). As a result of tree removal and cattle grazing, forest regeneration potential may decline and therefore BCS reduction takes place (Figure 5(c)). Tree species with higher density (i.e., *Pinus wallichiana*) were predetermined for deforestation even at the premature growth stage due to ease of access and species abundance. Forest

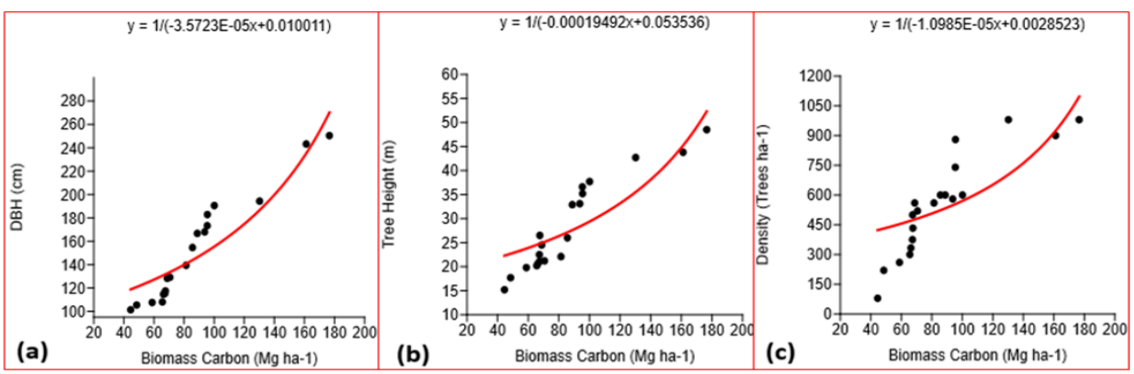


**Fig. 3.** GLM based correlation of site-wise BCS with average (a) tree DBH, (b) tree height, and (c) tree density.

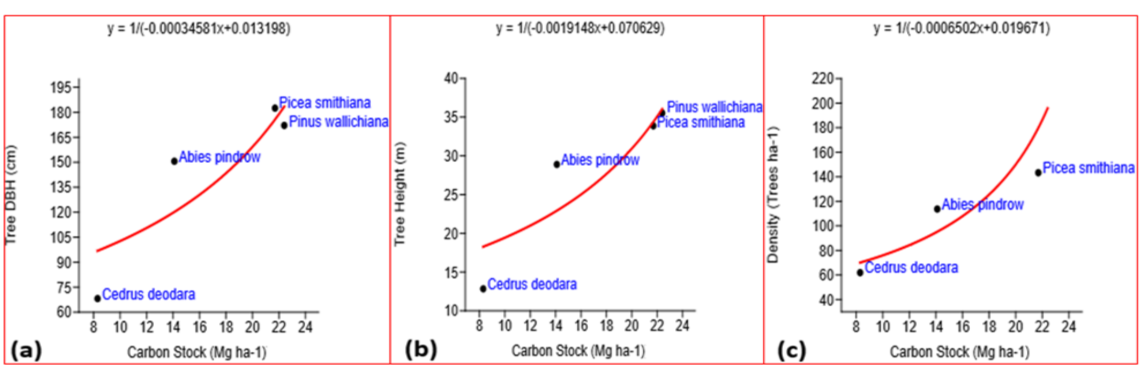


**Fig. 4.** GLM based correlation of species-wise BCS with average (a) tree DBH, (b) tree height, and (c) tree density.

degradation takes place essentially due to seasonal migration to access animal grazing supplies, trampling and unapproachability to alternate fuel and shelter resources which eventually decrease the productivity and natural biomass carbon capture [1, 13].

A remarkable verdict is that the forest ecosystem is fairly reviving without any dedicated conservation effort even with increased deforestation intensity. The overall recovering correlation was noticed between deforestation and natural regeneration rates at the studied forest sites. Although natural regeneration in *Pinus wallichiana* in the TFs and *Abies pindrow* in SFs is supporting the species endurance, all these keystone species need a comprehensive implementation of a focused conservation plan for an improved rate of carbon sequestration potential, species regeneration and forest cover [8, 9, 14].

Forest site features, especially altitude is an important factor influencing vegetation growth and BCS production [11]. This study was carried out in a broader altitudinal range (1930 to 3165 m above sea level). GLM conveyed a decrease in the total BCS along with increasing altitude. Although some sites at higher elevations showed a handsome amount of BCS but the overall relationship between the altitude and forest BCS remained negative mostly as an effect of climatic variations coupled with the decrease in the total tree DBH, tree density and deforestation (Figure 6(a)). Moreover, harsh climatic conditions at higher elevations in the Himalayan coniferous TFs and SFs are reported to suppress the growth and development of forests species, decrease species diversity and ultimately reduce the overall carbon sequestration potential of the biomass carbon pools [3, 11, 12]. Bivariate analysis through GLM disclosed that BCS production declined along the intensifying site slope (Figure 6(b)). Analogous trends were shown between the forest BCS values and soil erosion intensity (Figure 6(c)).

Besides the forest structural attributes and multiplicity of anthropogenic pressure regimes, topographical features including varying steepness and soil erosion intensity also influence the forest BCS production [39, 53]. It was perceived that grassroots reliance on the forest resources for livelihood is causing forest and soil degradation in

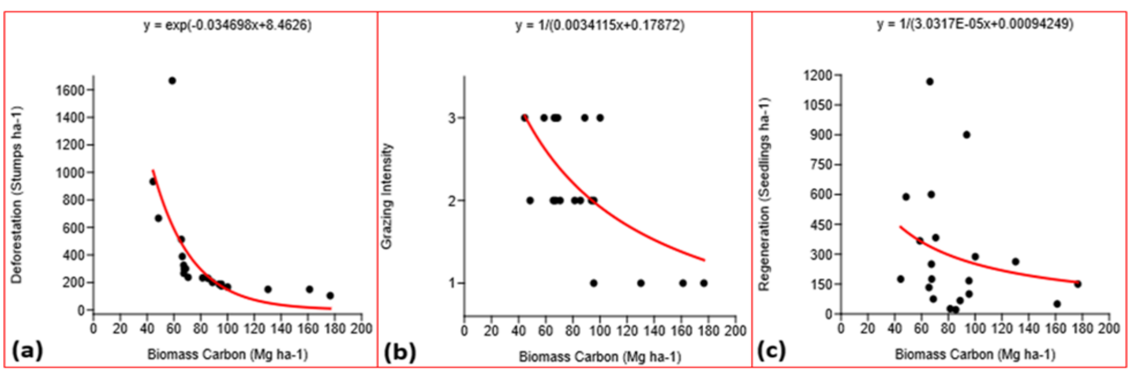


**Fig. 5.** GLM based correlation of site-wise BCS with average (a) deforestation rate, (b) grazing intensity, and (c) regeneration potential.

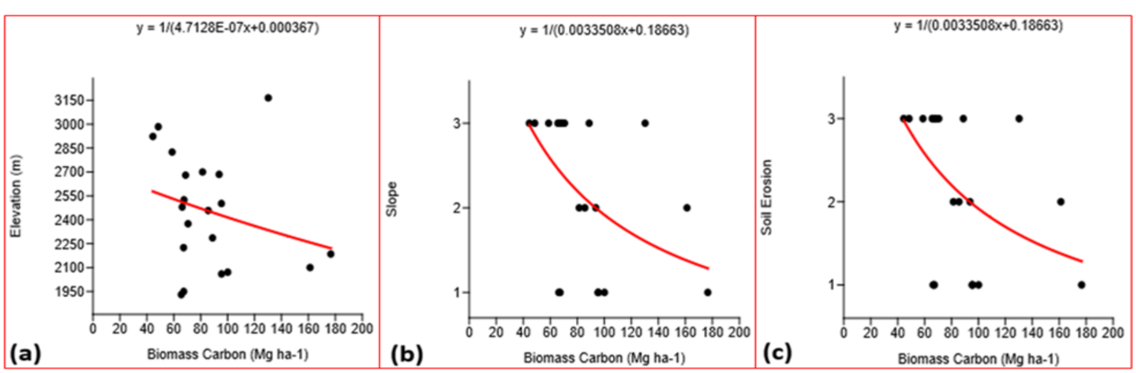


**Fig. 6.** GLM-based correlation of site-wise BCS with average (a) site elevation, (b) slope class, and (c) soil erosion.

the Himalayan region and which in turn local BCS stocks. Conservation and management of forests integrated with public policies and communal involvement, provision of alternate fuel, fodder and timber resources to the people living around these forests can dynamically recover carbon sequestration and climate change mitigation potential [54–56].

Forest carbon sequestration potential varies depending on forest type and management practices, with community-driven forest management emerging as an effective strategy to boost carbon storage while supporting local livelihoods. The socio-economic dimensions of forest conservation for carbon sequestration in the Himalayan region are crucial for both ecological health and community well-being [8, 41]. In the Western Himalayas, temperate forests play a critical role in climate change mitigation due to their significant carbon storage capacity. However, factors like topography and climate, including low temperatures and limited water availability, can hinder carbon sequestration by affecting tree growth and biomass accumulation [8, 10, 16]. Moreover, forest degradation, rather than area loss alone, represents a major threat to carbon stocks, highlighting the need for sustainable management practices [57] .

## 5. CONCLUSIONS

This research focused on the quantification of BCS in keystone tree species grown in Western Himalayan coniferous TFs and SFs of the Kashmir region using standard protocols. It was concluded that BCS is markedly depleted and vitally dependent upon the growth of forest species, maturity stage and tree density. *Picea smithiana* and *Pinus wallichiana* are dominant $CO_2$ sequestering species having larger DBH, height and density scores. Forest BCS showed a decrease along an altitudinal gradient as severe climates limit tree growth rates. Currently, anthropogenic drivers of deforestation and forest degradation including settlements, agriculture, wood fuels, seasonal migration and intensive grazing are major threats to existing carbon stocks in Himalayan coniferous forests. TFs ecosystem holds much significant importance to achieving a sustainable climate change mitigation potential as they can sequester an adequate amount of atmospheric $CO_2$ subjected to forest conservation. Although Himalayan coniferous forests are naturally regenerating, it is necessary to implement a precise conservation plan intended for GHG management using indigenous natural forest resources. Besides adding numbers to the national and regional forest carbon inventory, this document recommends an accurate estimation of carbon stocks in all other forest species and soil. Improved forest cover and accurate species-wise estimations of carbon stocks can reinforce the national economy through Reducing Emission from Deforestation and Forest Degradation (REDD$^+$) initiatives of the United Nations Framework Convention on Climate Change (UNFCCC).

## 6. ACKNOWLEDGEMENT

The authors are thankful to the researchers of the Plant Ecology and Environmental Science Laboratory, Department of Botany, University of Azad Jammu and Kashmir, for the provision of logistic support and a working environment during this study.

## 7. CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

## 8. REFERENCES

1. M.F. Rabbi and S. Kovács. Quantifying global warming potential variations from greenhouse gas emission sources in forest ecosystems. *Carbon Research* 3: 70 (2024).
2. Chakraborty, S. Saha, K. Sachdeva, and P.K. Joshi. Vulnerability of forests in the Himalayan region to climate change impacts and anthropogenic disturbances: a systematic review. *Regional Environmental Change* 18: 1783–1799 (2018).
3. M. Kumar, R. Kumar, B. Konsam, M.A. Sheikh, and R. Pandey. Above-and below-ground biomass production in *Pinus roxburghii* forests along altitudes in Garhwal Himalaya, India. *Current Science* 116: 1506–1514 (2019).
4. P. Pokhriyal, S. Rehman, G. Areendran, K. Raj, R. Pandey, M. Kumar, M. Sahana, and H. Sajjad. Assessing forest cover vulnerability in Uttarakhand, India using analytical hierarchy process. *Modeling Earth Systems and Environment* 6: 821–831 (2020).
5. M. Rawat, K. Arunachalam, A. Arunachalam, J. Alatalo, and R. Pandey. Associations of plant functional diversity with carbon accumulation in a temperate forest ecosystem in the Indian Himalayas. *Ecological Indicators* 98: 861–868 (2019).

6. H.G. Champion and S.K. Seth (Eds.). A revised survey of the forest types of India. *Manager of publications, New Delhi, India* (1968).
7. S.K. Shah, M. Shekhar, and A. Bhattacharyya. Anomalous distribution of *Cedrus deodara* and *Pinus roxburghii* in Parbati valley, Kullu, Western Himalaya: An assessment in dendroecological perspective. *Quaternary International* 325: 205–212 (2014).
8. S. Gairola, J. Sharma, and D. Vyas. Carbon Stocks and Anthropogenic Disturbances in Temperate Coniferous Forests of Jammu Region in Western Himalaya, India. *Research & Reviews in Biotechnology & Biosciences* 7: 1-19 (2020).
9. Global Forest Resources Assessment. FAO Forestry Paper No. 1. *UN Food and Agriculture Organization, Rome* (2015). https://openknowledge.fao.org/server/api/core/bitstreams/5100a18e-1432-42b1-945e-398daac0176e/content.
10. Z.A. Malik, R. Pandey, and A.B. Bhatt. Anthropogenic disturbances and their impact on vegetation in Western Himalaya, India. *Journal of Mountain Science* 13: 69–82 (2016).
11. M.A. Sheikh, M. Kumar, N.P. Todaria, J.A. Bhat, A. Kumar, and R. Pandey. Contribution of *Cedrus deodara* forests for climate mitigation along altitudinal gradient in Garhwal Himalaya, India. *Mitigation and Adaptation Strategies for Global Change* 26: 5 (2021).
12. Y. Bhutia, R. Gudasalamani, R. Ganesan, and S. Saha. Assessing forest structure and composition along the altitudinal gradient in the state of Sikkim, Eastern Himalayas, India. *Forests* 10: 633 (2019).
13. S.P. Hubbell, R.B. Foster, S.T. O’Brien, K.E. Harms, R. Condit, B. Wechsler, S.J. Wright, and S.L. De Lao. Light-gap disturbances, recruitment limitation, and tree diversity in a neotropical forest. *Science* 283: 554-557 (1999).
14. J. Naveenkumar, K.S. Arunkumar, and S.M. Sundarapandian. Biomass and carbon stocks of a tropical dry forest of the Javadi Hills, Eastern Ghats, India. *Carbon Management* 8: 351–361 (2017).
15. Intergovernmental Panel on Climate Change (IPCC). Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller (Eds.). *Cambridge University Press, Cambridge, United Kingdom* (2007).
16. S.M. Khan, P. Sue, A. Habib, S. Hamayun, A. Mushtaq, and D. Harper. Phyto-climatic gradient of vegetation and habitat specificity in the high elevation western Himalayas. *Pakistan Journal of Botany* 45: 223–230 (2013).
17. M. Sheikh. *Trees of Pakistan* (1993). https://pdf.usaid.gov/pdf_docs/PNABW250.pdf.
18. Government of Azad Jammu and Kashmir. Azad Jammu & Kashmir at a Glance. *AJK Bureau of Statistics, Planning & Development Department Muzaffarabad, AJ&K, Pakistan* (2017). https://pndajk.gov.pk/uploadfiles/downloads/At%20a%20Glance%202017.pdf
19. Pakistan Meteorological Department, Islamabad, Pakistan (Pak-Met). *The normal of climatic data of Azad Jammu and Kashmir*, Islamabad (2017). *Pakistan Meteorological Department. Climate Data Processing Centre*, Government of Pakistan (2020). https://cdpc.pmd.gov.pk.
20. R. Sagar and J.S. Singh. Tree density, basal area and species diversity in a disturbed dry tropical forest of northern India: implications for conservation. *Environmental Conservation* 33: 256–262 (2006).
21. FSI. Volume equations for forests of India, Nepal and Bhutan. Forest Survey of India. *Ministry of Environment and Forests, Government of India* (1996). https://fsi.nic.in/uploads/documents/volume-equations-for-forests-of-india-nepal-and-bhutan-2803-2023.pdf
22. FSI. Carbon stocks in India’s forests. Forest Survey of India. *Ministry of Environment and Forests, Government of India* (2001). https://fsi.nic.in/isfr-2021/chapter-9.pdf.
23. S.L. Brown and P.E. Schroeder. Spatial patterns of aboveground production and mortality of woody biomass for eastern US forests. *Ecological Applications* 9: 968–980 (1999).
24. S.L. Brown, P. Schroeder, and J.S. Kern. Spatial distribution of biomass in forests of the eastern USA. *Forest Ecology and Management* 123: 81–90 (1999).
25. M.A. Cairns, S. Brown, E.H. Helmer, and G.A. Baumgardner. Root biomass allocation in the world’s upland forests. *Oecologia* 111: 1–11 (1997).
26. J. Negi, R. Manhas, and P. Chauhan. Carbon allocation in different components of some tree species of India: a new approach for carbon estimation. *Current Science* 85: 1528–1531 (2003).
27. R Core Team. R: A language and environment for statistical computing (Version 4.4.2). R Foundation for Statistical Computing (2024). https://www.R-project.org/.
28. Ø. Hammer, D.A.T. Harper, and P.D. Ryan. PAST: Paleontological statistics software package for

education and data analysis. *Palaeontologia Electronica* 4: 1-9 (2001).

29. T.M. Yen, K.L. Huang, L.E. Li, and C.-H. Wang. Assessing carbon sequestration in plantation forests of important conifers based on the system of permanent sample plots across Taiwan. *Journal of Sustainable Forestry* 39: 392–406 (2020).
30. T.M. Yen and C.T. Wang. Assessing carbon storage and carbon sequestration for natural forests, man-made forests, and bamboo forests in Taiwan. *International Journal of Sustainable Development & World Ecology* 20: 455–460 (2013).
31. S. Aziz, F.M. Chughtai, H. Shaheen, R.W.A. Khan, and M.E.U.I. Dar. Biomass and soil carbon stocks assessment in western Himalayan alpine and subalpine vegetation zones of Kashmir. *Pakistan Journal of Botany* 51: 973–978 (2019).
32. R.W.A. Khan and H. Shaheen. Biomass carbon stock estimation in lesser Himalayan subtropical broadleaf forests of Kashmir. *Taiwania* 67: 47–54 (2022).
33. R.W.A. Khan, H. Shaheen, A. Mehmood, and S. Naseer Awan. Grazing intensity impacts on soil carbon stocks of Western Himalayan Alpine paddocks. *Carbon Management* 10: 533–540 (2019).
34. H. Shaheen, S.N. Awan, R.W.A. Khan, A.R. Khalid, W. Ahmed, and F.M. Chughtai. Variations in soil organic carbon stocks under different land-use categories in subtropical ecosystems of Kashmir. *Forest Science* 67: 525–536 (2021).
35. H. Shaheen, R.W.A. Khan, K. Hussain, T.S. Ullah, M. Nasir, and A. Mehmood. Carbon stocks assessment in subtropical forest types of Kashmir Himalayas. *Pakistan Journal of Botany* 48: 2351–2357 (2016).
36. S. Ghoshal and S.S. Samant. Assessment of Tree Carbon Stocks of Forests: A Case Study of the Sarwari Khad Watershed, Western Himalaya, India. *Environment & We: An International Journal of Science & Technology* 10: 51-61 (2015).
37. B.S. Jina, P. Sah, M.D. Bhatt, and Y.S. Rawat. Estimating carbon sequestration rates and total carbon stockpile in degraded and non-degraded sites of Oak and Pine forest of Kumaun Central Himalaya. *Ecoprint: An International Journal of Ecology* 15: 75–81 (2008).
38. N.A. Pala, A.K. Negi, Y. Gokhale, S. Aziem, K.K. Vikrant, and N.P. Todaria. Carbon stock estimation for tree species of Sem Mukhem sacred forest in Garhwal Himalaya, India. *Journal of Forestry Research* 24: 457–460 (2013).
39. C.M. Sharma, S. Gairola, N.P. Baduni, S.K. Ghildiyal, and S. Suyal. Variation in carbon stocks on different slope aspects in seven major forest types of temperate region of Garhwal Himalaya, India. *Journal of Biosciences* 36: 701–708 (2011).
40. K.K. Vikrant and D.S. Chauhan. Carbon stock estimation in standing tree of Chir pine and Banj Oak pure forest in two Van Panchayats forest of Garhwal Himalaya. *Journal of Earth Science & Climatic Change* 5:(10) 240 (2014).
41. J.A. Dar and S. Sundarapandian. Variation of biomass and carbon pools with forest type in temperate forests of Kashmir Himalaya, India. *Environmental Monitoring and Assessment* 187(2): 55 (2015).
42. S.K. Baral, R. Malla, and S. Ranabhat. Above-ground carbon stock assessment in different forest types of Nepal. *Banko Janakari* 19: 10–14 (2009).
43. A. Mishra, S. Nautiyal, and D.P. Nautiyal. Growth characteristics of some indigenous fuelwood and fodder tree species of sub-tropical Garhwal Himalayas. *Indian Forester* 135: 373 (2009).
44. N. Nautiyal and V. Singh. Carbon stock potential of oak and pine forests in Garhwal region in Indian Central Himalayas. *Journal of Pharmacognosy and Phytochemistry* 2(1): 43–48 (2013).
45. S. Shrestha, B.S. Karky, A. Gurung, R. Bista, and O.R. Vetaas. Assessment of carbon balance in community forests in Dolakha, Nepal. *Small-scale Forestry* 12: 507–517 (2013).
46. Y. Pan, R.A. Birdsey, O.L. Phillips, and R.B. Jackson. The structure, distribution, and biomass of the world's forests. *Annual Review of Ecology, Evolution, and Systematics* 44: 593–622 (2013).
47. G.E. Kindermann, M. Obersteiner, E. Rametsteiner, and I. McCallum. Predicting the deforestation-trend under different carbon-prices. *Carbon Balance and Management* 1: 15 (2006).
48. M. Ahmed, T. Husain, A.H. Sheikh, S.S. Hussain, and M.F. Siddiqui. Phytosociology and structure of Himalayan forests from different climatic zones of Pakistan. *Pakistan Journal of Botany* 38: 361 (2006).
49. M.S. Hussain, A. Sultana, J.A. Khan, and A. Khan. Species composition and community structure of forest stands in Kumaon Himalaya, Uttarakhand, India. *Tropical Ecology* 49: 167 (2008).
50. G. Kharkwal. Qualitative analysis of tree species in evergreen forests of Kumaun Himalaya, Uttarakhand, India. *African Journal of Plant Science* 3(3): 49–52 (2009).
51. S. Saeed, M.I. Ashraf, A. Ahmad, and Z. Rahman.

The Bela forest ecosystem of district Jhelum, a potential carbon sink. *Pakistan Journal of Botany* 48: 121–129 (2016).

52. O. Salunkhe, P.K. Khare, T.R. Sahu, and S. Singh. Above Ground Biomass and Carbon Stocking in Tropical Deciduous Forests of State of Madhya Pradesh, India. *Taiwania* 59: 353-359 (2014).
53. R. Lal. Soil erosion and the global carbon budget. *Environment International* 29: 437–450 (2003).
54. G. Bala, K. Caldeira, M. Wickett, T. Phillips, D. Lobell, C. Delire, and A. Mirin. Combined climate and carbon-cycle effects of large-scale deforestation. *Proceedings of the National Academy of Sciences* 104: 6550–6555 (2007).
55. N. Bora, A.J. Nath, and A.K. Das. Aboveground biomass and carbon stocks of tree species in tropical forests of Cachar District, Assam, Northeast India. *International Journal of Ecology and Environmental Sciences* 39: 97–106 (2013).
56. A.A. Wani, P. Joshi, O. Singh, and R. Pandey. Carbon sequestration potential of Indian forestry land use systems-a review. *Wetlands* 354: 182–187 (2012).
57. S. Shrestha, U.B. Shrestha, and K.S. Bawa. Contribution of REDD+ payments to the economy of rural households in Nepal. *Applied Geography* 88: 151–160 (2017).