Carbon Density Variation in Moist Temperate Forests of Pakistan: Influence of Altitudinal Gradients and Fragmentation

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Abstract

Forest fragmentation, driven by climate change, urbanisation, deforestation, and land-use changes, significantly impacts carbon storage in forest ecosystems. This study investigates carbon density variations in fragmented moist temperate forests across altitudinal gradients in the Malakand Division, Swat, Pakistan, focusing on both vegetation and soil carbon dynamics within forest interior and edge zones. Stratified random sampling was conducted at five elevations (1500, 1700, 1900, 2100, and 2300m) to capture comprehensive data on above-ground biomass (AGB), below-ground biomass (BGB), and soil carbon stocks. Results indicated that interior forest zones consistently exhibit higher total carbon density 1200 ± 50 tCha⁻¹ compared to exterior zones 800 ± 40 tCha⁻¹. Soil carbon content also showed a significant interior-exterior gradient, with total soil carbon storage reaching 740 ± 10 tCha⁻¹ in the interior while 670 ± 8 tCha⁻¹ in the exterior zones. Species-specific analysis revealed that larger tree diameters are associated with higher carbon sequestration, particularly in species such as Cedrus deodara and Abies pindrow, which reach mean carbon densities of>150 tCha⁻¹ and <200 tCha⁻¹, respectively, in the forest interior. This research underscores the importance of both vegetation and soil carbon contributions within forest interiors and recommends targeted conservation and restoration strategies to optimise carbon sequestration, thereby enhancing climate mitigation potential.

Keywords: Forest Fragmentation, Carbon Density, Soil Carbon Stock, Altitudinal Gradients.

Introduction

The steady rise in atmospheric carbon dioxide levels, especially over the past 50 years, correlates with the exponential increase in anthropogenic activities, notably deforestation and urban expansion (Houghton & Nassikas, 2017; IPCC, 2014). This upward trend in anthropogenic activities, with an annual increase of approximately 2.4%, accounts for a substantial share of global CO_2 emissions and intensifies climate change pressures (Friedlingstein et al., 2022). In response to this critical environmental issue, frameworks such as REDD+ (reducing emissions from deforestation and forest degradation) have been

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established to incentivise carbon-reduction efforts, especially in underdeveloped and developing nations, by offering financial and technical support (Angelsen et al., 2018).

Carbon dioxide, a primary greenhouse gas, plays a central role in regulating Earth's climate system (IPCC, 2000). Terrestrial ecosystems act as significant carbon sinks, thus mitigating climate change by offsetting atmospheric CO_2 (Pan et al., 2011). Forests, in particular, serve as critical carbon reservoirs, with substantial carbon stocks in both total vegetation biomass and soil carbon pools (Canadell & Raupach, 2008; Dixon et al., 1994). Understanding carbon storage and distribution within forest ecosystems is crucial for accurately assessing global carbon budgets and formulating effective climate change mitigation strategies (IPCC, 2022).

Over the last two decades, numerous studies have quantified carbon storage in forests, emphasising the influence of variables such as forest type, age, and management practices on sequestration rates (Keith et al., 2009; Pan et al., 2011). Additionally, research has highlighted the effect of altitude on forest carbon dynamics, revealing that higher elevations often exhibit distinct carbon sequestration patterns due to differences in climate, soil properties, and vegetation composition (Iqbal & MacLean, 2010; Moser et al., 2007).

Forest fragmentation, primarily driven by human activities such as deforestation and land-use change, poses severe challenges to forest ecosystems and biodiversity (Fahrig, 2003). Fragmentation contributes to habitat loss, isolation, and degradation, leading to reduced biodiversity and diminished ecosystem services (Haddad et al., 2015). Moreover, fragmented forests are more susceptible to disturbances from invasive species, pests, and diseases, which accelerate degradation (Laurance et al., 2014).

The forests of Khyber Pakhtunkhwa (KPK) province in Pakistan, known for their montane ecosystem and rich biodiversity, face escalating threats from degradation and fragmentation. This pressure is largely due to overexploitation, illegal logging, agricultural expansion, and urbanisation (Ali et al., 2024; Rauf et al., 2019). The degradation of these forests not only compromises ecosystem services but also exacerbates climate change by releasing sequestered carbon back into the atmosphere (Ahmad et al., 2021; Khan et al., 2020).

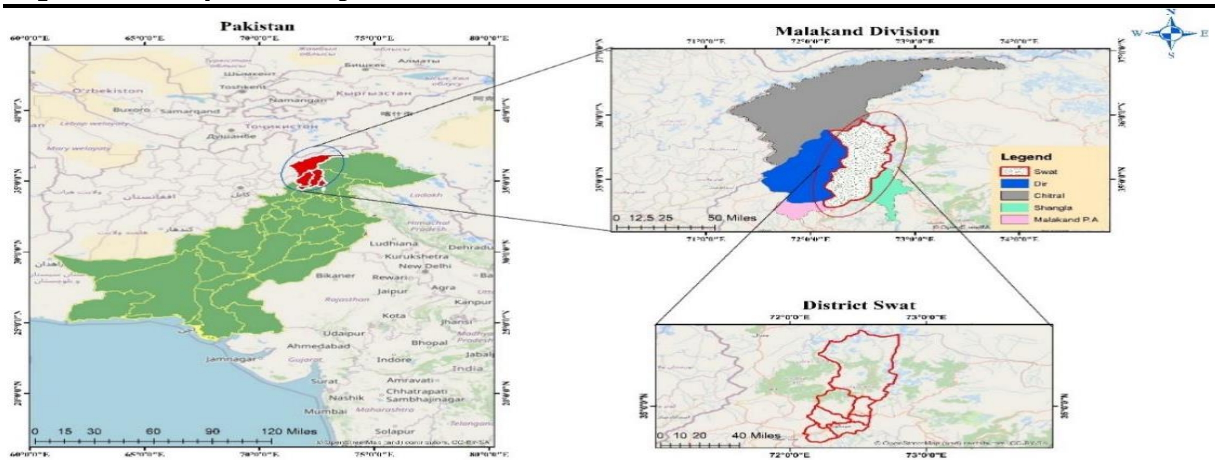
This study investigates how both total vegetation carbon and soil organic carbon (SOC) vary along altitudinal gradients, comparing interior and edge effects within fragmented forests in Khyber Pakhtunkhwa, particularly in the district of Swat, Malakand Division. By combining field surveys with analytical techniques, the research has quantified total vegetation biomass and carbon stock densities across elevations, along with SOC levels at varying depths. This approach seeks to reveal the effects of altitude and fragmentation on carbon sequestration and storage, offering valuable insights to support conservation efforts and climate mitigation strategies within forest ecosystems.

Materials and Methods

Study Area

The district Swat, located in the Malakand division of Khyber Pakhtunkhwa, Pakistan (Figure 1), lies within the coordinates 71.50° E – 73.00° E and 34.34° N – 35.84° N. Nestled within the Hindukush Mountain range, Swat is characterised by its mountainous terrain, stretching approximately 91 miles in length and shaped by the Swat River and its tributaries. This area's varied topography includes fertile alluvial soils along the river, supporting rich biodiversity in forest ecosystems, grasslands, and agricultural zones. Swat's climate and diverse elevation gradients make it an ideal setting for studying altitudinal impacts on biomass and carbon dynamics within fragmented forest landscapes.

Figure 1: Study area map of District Swat



Field Inventory and Acquisition

The study focused on the Himalayan moist temperate forest situated in the Swat district, spanning elevations from 1500 m to 2300 m above sea level, employing a stratified random sampling approach to get data across different elevation zones. The study area was stratified into five elevation zones in both the forest interior and exterior, each differing by 200 meters, with elevation serving as the primary stratification criterion. To ensure consistency, the forest interior plots (n=25) were positioned 100 meters away from the forest edge (n=25). Tree biomass was measured non-destructively using standard methods, employing diameter tape for diameter measurement and Abney level for tree height assessment. Soil carbon content was determined by collecting soil samples from three sub-plots measuring 2m2 each, at depths of 0–10 cm, 11–20 cm, and 21–30 cm. These soil samples were subsequently analyzed at the Soil and Water Testing Laboratory in The University of Haripur-Pakistan.

Estimation of tree volume in each forest stand was carried out using field measurements of diameter at breast height (DBH) and tree height. The volume of individual trees was computed using established formulas based on height and diameter values, (Kershaw; 2017). This comprehensive approach facilitated the assessment of tree biomass and soil carbon dynamics across different elevation gradients within the Himalayan moist temperate forest of the Swat district.

$$V = (\pi / 4)\, d^2 \times h \times f \tag{1}$$

here

h = tree height in meters, d = tree diameter in meters, f = form factor of the tree.

Estimation of forest carbon density using the biomass expansion factor (BEF) method

Tree stem biomass was determined by integrating wood density (kg m-3) with volume (m3) measurements. Wood density values for various tree species were sourced from relevant literature (Table 1). The calculation of stem biomass (in kilograms) followed a standardized methodology, as outlined below:

$$\text{Stem Biomass (kg)} = V \times WD \tag{2}$$

V = volume in (m^3), WD = wood density in (kg m^{-3}).

The generic wood density of the species growing in this forest types was gathered from literature (Sheikh, 1993). Biomass of the various tree components was determined from the allometric equation developed earlier (Table 2). The biomass of the entire forest was determined by multiplying the single tree biomass with the total no. of trees in particular plot.

Table 1: Wood Densities (kg m⁻³) of Selected Tree Species

Species No.	Species	Wood density (kg m^{-3})
1	*Pinus roxburghii*	377
2	*Pinus wallichana*	499
3	*Cedrus deodara*	466
4	*Picea smithiana*	382
5	*Abies pindrow*	372

Table 2: The Contribution of various tree component in Total Biomass of various Species

Species	Stem%	Branches%	Foliage%	Roots%	Reference
Pinus roxburghii	60	11	5	24	(Nizami, 2012)
Pinus wallichiana	53.74	14.25	6.26	25.75	(M. A. Sheikh et al., 2020)
Cedrus deodara	49	31	2	18	Ismail, M.S. (2017)
Picea smithiana	58.1	17.6	3.2	21	Sohail et al., 2014
Abies pindrow	55.24	16.15	4	21.6	(M. A. Sheikh et al., 2020)

Estimation of soil bulk density through direct core method

Soil bulk density (ρb) measurement stands as a pivotal aspect, tightly linked with soil compaction and a myriad of physical, chemical, and biological soil attributes (Håkansson & Lipiec, 2000). As asserted by Alam et al.,(2020), the presence of high organic matter levels typically results in diminished soil bulk density-a well-documented phenomenon. The wet weights of soil samples were initially gauged utilizing a digital balance directly at the sampling site. Subsequently, these samples were carefully encased in plastic zip bags and transported to the Soil and Water Testing Laboratory in Haripur for further analysis. In Lab the soil samples underwent air drying followed by oven drying at approximately 105°C for a duration of 24 hours. Volume determination was executed by measuring the diameter and length of a custom-made soil core. Ultimately, the soil's bulk density was computed employing the subsequent equation:

$$\text{Bulk Density } (\rho b; \text{gcm}^{-3}) = \frac{\text{WS}}{\text{VC}} \quad (3)$$

WS = weight of soil sample in grams, VC = volume of the core in cm^3

Soil carbon density and Soil Organic Carbon

Soil samples were retrieved from three distinct depths: 0–10 cm, 11–20 cm, and 21–30 cm, and securely stored in zip bags until transportation to the laboratory (n=225). For analysis, a combination of reagents including ammonium iron sulfate, orthophosphoric acid, sulfuric acid, potassium dichromate, and diphenylamine indicator were employed.

To eliminate moisture, the soil underwent a grinding process at room temperature before sieving through a 200-mm sieve. Subsequently, a mixture comprising 10 ml of potassium dichromate solution and 20 ml of sulfuric acid was introduced into a 500-ml conical flask containing 5 grams of soil. Following a 40-minute incubation period, 200 ml of distilled water and 10 ml of orthophosphoric acid were added to the flask.

Upon addition of a few drops of indicator to initiate color change, pH readings were recorded. The total organic carbon content was determined using the following formula:

$$\text{Percentage Oxidizable organic carbon } = \frac{(\text{Bv}) - (\text{Av})\,\text{x}0.3.\text{M}}{\text{Wt of soil (g)}} \quad (4)$$

here Bv: Volume of ferrous ammonium sulfate solution for the blank. Av: Volume of ferrous ammonium sulfate solution for the sample. M: Molarity of ferrous ammonium sulfate solution. Wt: Weight of air-dried soil (in grams). 0.3: A constant that accounts for equivalent weight of carbon (as per the Walkley-Black method).

Statistical Analysis

Statistical analyses were effectively conducted to assess carbon stock variations both within and outside forest fragments as well on altitudinal gradients, using a combination of descriptive and inferential statistics. Descriptive statistics, including means, standard deviations, and ranges for carbon content across different forest types, were calculated to summarize the data comprehensively.

To conduct a detailed investigation into the relationships between tree characteristics and carbon sequestration, line graphs, scatter plots and bar graphs were created for both forest interiors and exteriors using python. This analysis examined the linear relationships between other parameters with diameter (cm) and height (m), highlighting species-specific trends and providing a comparative analysis of carbon stock and biomass variations across spatial contexts.

This analysis was computed using Python version 3.12.3, utilizing libraries such as pandas for data management, matplotlib and seaborn for creating informative graphs. In contrast, Microsoft Excel was employed for processing the overall carbon density calculations and computing average carbon content ($tCha^{-1}$), ensuring robust data organization and efficient handling of the datasets for further statistical analysis. This dual-platform approach facilitated nuanced exploration and clear presentation of the data.

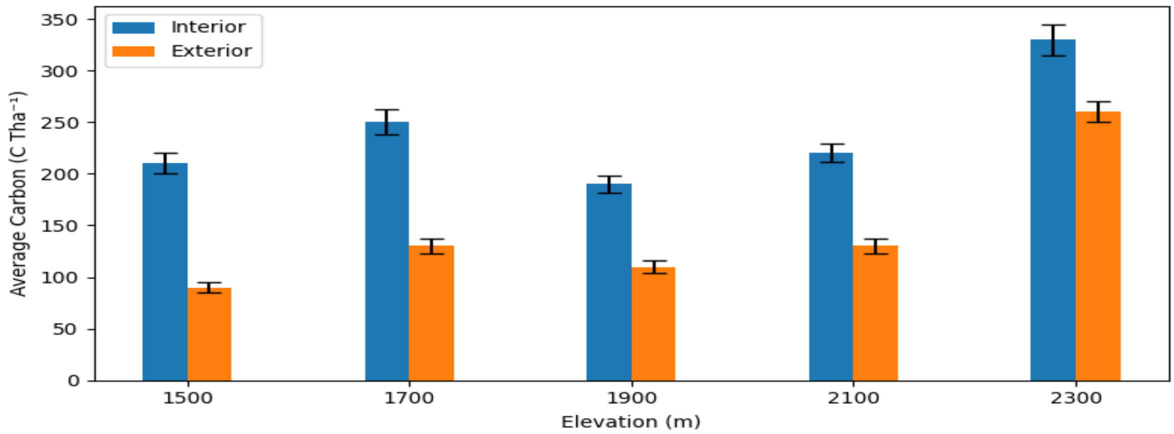
Results

The objective of the present study was to investigate the variance in carbon density in vegetation as well as in soil organic carbon within the Himalayan moist temperate forest, both in its interior and exterior fragments, along altitudinal gradients.

Carbon density in interior and exterior of the forest fragments

The study revealed that at 1500 meters, interior forests exhibit a carbon stock of approximately 200 ± 10 $tCha^{-1}$, while exterior zones store around 100 ± 8 $tCha^{-1}$. This trend continues at higher elevations, with interior carbon stocks increasing to 250 ± 12, 270 ± 15, 300 ± 18, and 340 ± 20 $tCha^{-1}$ at 1700, 1900, 2100, and 2300 meters, respectively. In contrast, exterior zones store approximately 120 ± 10, 140 ± 11, 170 ± 13, and 200 ± 14 $tCha^{-1}$ at these elevations. Figure 2 illustrates the variation in average carbon sequestration ($tCha^{-1}$) across an altitudinal gradient from 1500 to 2300 meters, comparing interior and exterior forest zones.

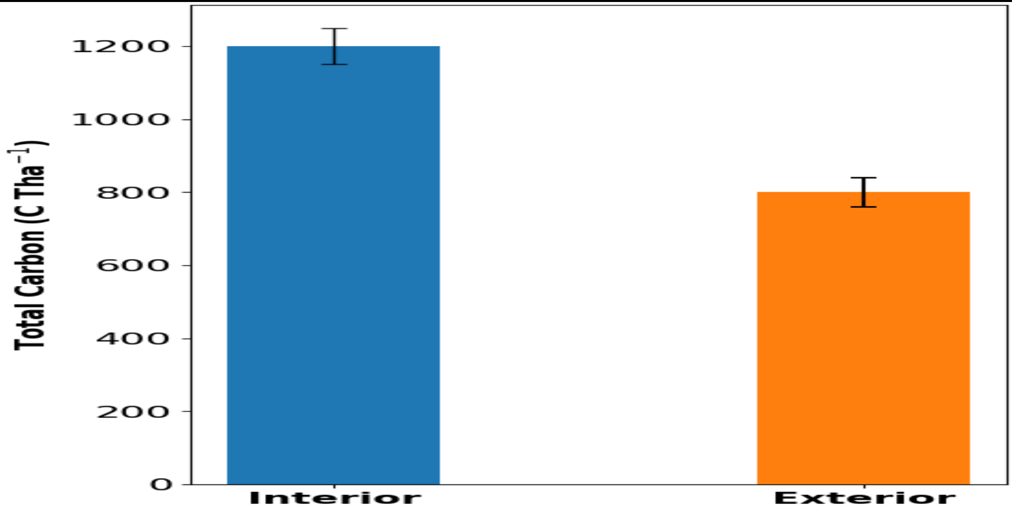
Figure 2: Carbon density in enterior and exterior of the fragments along altitudinal zonation



Total interior and exterior carbon density

The interior forests store approximately 1200 ± 50 tC ha^{-1}, whereas the exterior forests exhibit a significantly lower carbon stock of about 800 ± 40 tC ha^{-1}. These results underscore a marked difference in carbon sequestration, with interior forest zones storing nearly 35% more carbon than exterior areas. The figure 3 depicts the total carbon storage (tC ha^{-1}) in interior and exterior forest zones, including error bars to represent variability.

Figure 3: Carbon in enterior and exterior of the fragments



Influence of tree diameter and height within interior of forest fragments on biomass and carbon sequestration efficiency

It was illustrated that biomass and carbon accumulation patterns change among species as tree diameter and height increases. The trend of biomass accumulation in all the given tree species is same when we analyze with respect to height while if we analyze according to the height, *Pinus roxburghii* stores greater amount of biomass at a height of 20m as compared to the other species (Figure 4). *Pinus roxburghii* demonstrates a gradual rise, peaking at approximately 125 $tCha^{-1}$ at 80 cm diameter. *Pinus wallichiana* exhibits around 100 $tCha^{-1}$ at a diameter of 80 cm. *Cedrus deodara* displays a steaper increase, culminating at approximately 160 $tCha^{-1}$ from 0.8 to 1.0 meter. *Picea smithiana* achieves the lowest carbon storage, peaking at 65 $tCha^{-1}$ at 0.8m diameter. Similarly, *Abies pindrow* follows a highest trend, with carbon storage 200 $tCha^{-1}$ at 1.0 diameter. The biomass for each tree component and average carbon storage (tC ha^{-1}) across varying DBH and heights as well as percentages of no. of trees with respect to each diameter class, for tree species namely, *P.roxburghii, P. wallichiana, C.drus deodara, P.smithiana,* and *A. pindrow* within the interior forest regions. These patterns underscore the varying contributions of tree species to carbon sequestration within forest interiors.

Figure 4: Biomass and Total Carbon

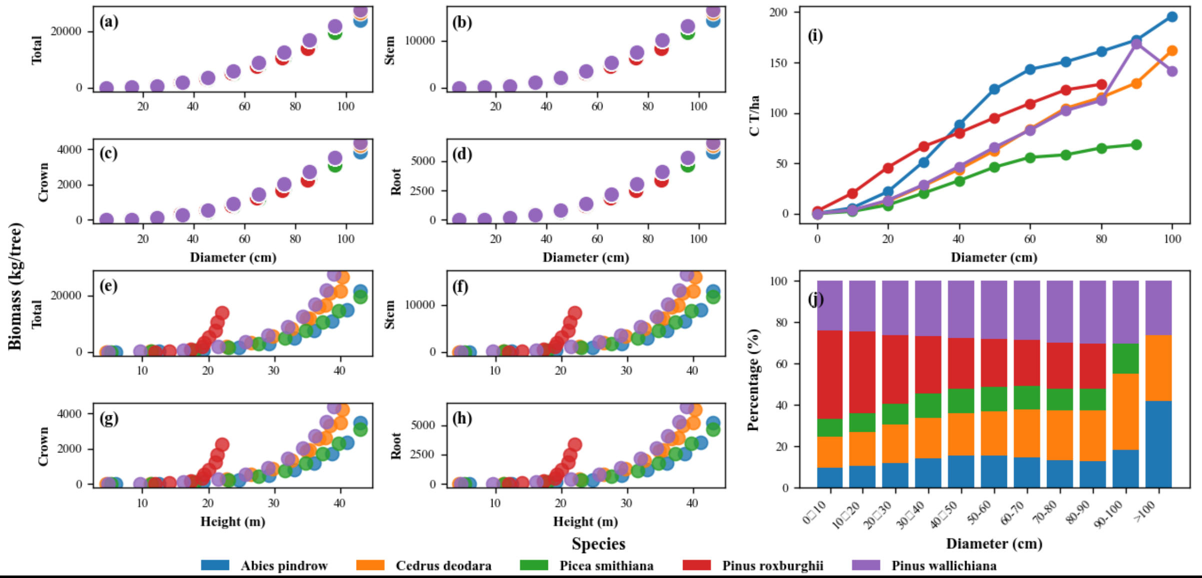


Figure 4 shows biomass and total carbon (tCha^{-1}), diameter class and height wise in the interior of the forest fragments (a–d) Relationship between diameter at breast height (DBH) and (a) total biomass, (b) stem biomass, (c) crown biomass, and (d) root biomass (kg) for each tree species. (e–h) Corresponding relationships between tree height and (e) total biomass, (f) stem biomass, (g) crown biomass, and (h) root biomass. (i) Relationship between total carbon stored and DBH across species. (j) Percentage distribution of trees within diameter classes for each species.

Influence of tree diameter and height within exterior of forest fragments on biomass and carbon sequestration efficiency

Figure 5 illustrates the average carbon storage (C t ha^{-1}) for five tree species *Pinus roxburghii*, *Pinus wallichiana*, *Cedrus deodara*, *Picea smithiana*, and *Abies pindrow* across various DBH and tree heights within the exterior forest regions. The trends indicate varying capacities of tree species for carbon sequestration with increasing tree diameter and height. Amount of biomass in all tree species is increasing linearly with diameter while if we analyze with respect to height in the exterior forest fragments, *Pinus roxburghii* show a tremendous increase in biomass at a height of just 20 m. If we compare carbon sequestered at a diameter of about 0.8 m in all species, both Pinus roxburghii and *Picea smithiana* show a similar increase, peaking at approximately 37 t C ha^{-1}. In contrast, *Abies pindrow* displays the steepest trend, reaching about 85 tC ha^{-1} at the same diameter highlighting its substantial carbon sequestration potential. It is followed by Cedrus deodara and *Pinus wallichiana*, achieving around 80 tC ha^{-1} and 75 tC ha^{-1} respectively at the same diameter.

Figure 5: Biomass and total carbon distribution

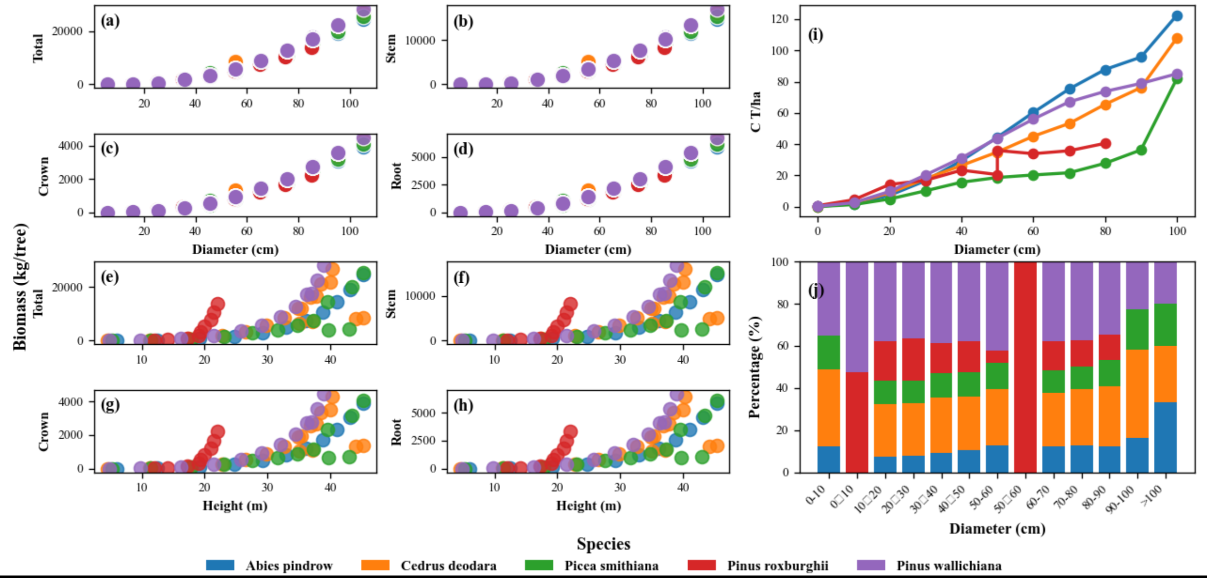
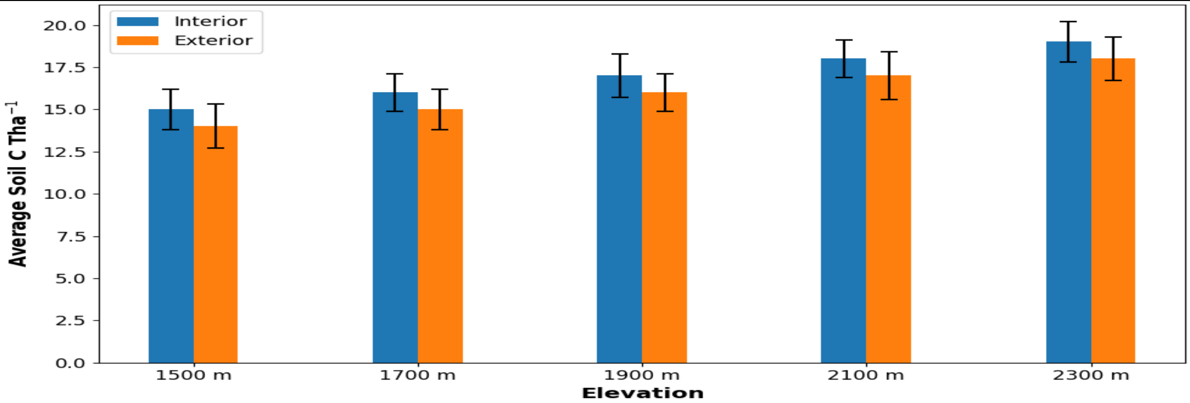


Figure 5 shows biomass and total carbon distribution (tC ha⁻¹) by diameter class and tree height in the exterior of forest fragments. (a–d) Relationships between diameter at breast height (DBH) and (a) total biomass, (b) stem biomass, (c) crown biomass, and (d) root biomass (kg) for each tree species. (e–h) Corresponding relationships between tree height and (e) total biomass, (f) stem biomass, (g) crown biomass, and (h) root biomass. (i) Relationship between total carbon storage and DBH across species. (j) Percentage distribution of trees across diameter classes for each species in forest exterior fragments. Points represent individual trees; solid lines indicate fitted allometric models, and shaded areas denote show diversity of tree species in percentage in forest exterior regions.

Soil carbon in interior and exterior of the fragments

It was pointed out that distribution of average soil carbon storage ($tCha^{-1}$) along an altitudinal gradient ranged from 1500 to 2300 meters, comparing the interior and exterior forest zones. At 1500 meters, interior forest soils contain approximately 15.5 ± 0.8 $tCha^{-1}$, whereas exterior soils hold around 14.0 ± 0.7 $tCha^{-1}$. This pattern persists across elevations, with interior soil carbon stocks rising to 16.0 ± 0.9, 17.0 ± 1.0, 17.5 ± 1.2, and 18.0 ± 1.3 $tCha^{-1}$ at 1700, 1900, 2100, and 2300 meters, respectively (Figure 6). By comparison, exterior zones record average carbon stocks of 14.0 ± 0.8, 15.0 ± 0.9, 16.5 ± 1.0, and 17.5 ± 1.2 $tCha^{-1}$ at the corresponding elevations. These findings demonstrate a consistent difference in soil carbon reserves, with interior zones exhibiting slightly higher values than exterior zone throughout the elevation gradient.

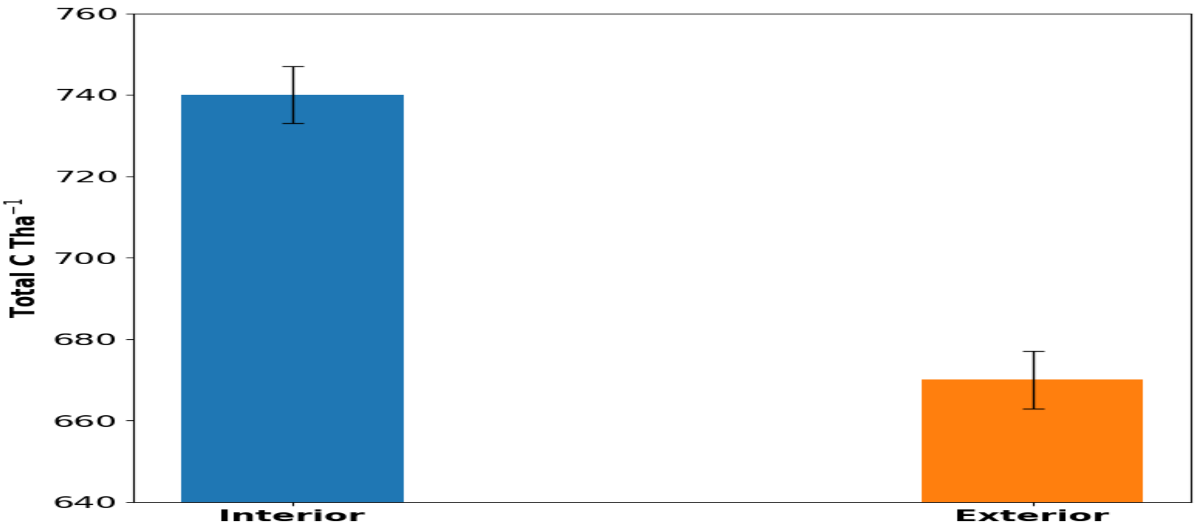
Figure 6: Carbon density in interior and exterior of the fragments



Total interior and exterior soil carbon density

The total soil carbon content (t C ha^{-1}) comparison between interior and exterior forest zones reveals a notable difference (Figure 7). The interior zones store approximately 740 ± 10 tC ha^{-1}, significantly exceeding the carbon content in the exterior zones, which is estimated at around 670 ± 8 $tCha^{-1}$. These results provide a clear quantification of the higher soil carbon levels within interior forest areas compared to their exterior regions.

Figure 7: Total soil carbon ($tCha^{-1}$) in interior and exterior of the fragments



Discussion

Important quantitative characteristics in forest ecosystems that vary along altitudinal gradients include biomass and carbon stocks (Kaushal & Baishya, 2021; Thakur et al., 2024). Altitude significantly impacts abiotic factors in the Himalayan hilly region, determining species cohabitation, diversity, and ultimately shaping the forest community (Negi et al., 2024; Rawal et al., 2024). The Himalayan region's highly fragmented mountainous terrain causes bioclimatic conditions to shift quickly and can vary over short distances, leading to a noticeable variability of soil types and their chemical and physical characteristics (Shaheen et al., 2023). Both biotic and abiotic factors contribute to fluctuations in carbon density across altitudinal gradients in Himalayan forests (Marifatul et al., 2022; Sharma et al., 2018). The present study investigated how carbon density varied across altitudinal gradients in fragmented moist temperate forests, revealing distinct patterns in carbon storage driven by both biotic and abiotic factors. Previous research has shown that the variation in carbon density showed significant dynamics over the altitudinal gradients in various regions (Ao et al., 2024; Cojoc et al., 2016; Dar & Sundarapandian, 2015; Gairola et al., 2011; Liu & Nan, 2018; Saeed et al., 2019; Sharma et al., 2011; Sheikh et al., 2020; Tesfaye et al., 2019; Thakur et al., 2024; Yu et al., 2014). The findings demonstrated that forest interiors consistently store more carbon than forest exteriors across various elevations (1500m to 2300m), with the total carbon content significantly higher in interior zones compared to exterior zones. This difference is particularly noticeable at an elevation of 2300 meters, where more precipitation and colder temperatures further improve interior carbon storage.

The variation in soil carbon between interior and exterior zones could be attributed to differences in microclimatic conditions, decomposition rates, or organic matter inputs, all of which affect soil carbon sequestration potential (Figure 5-6). These findings are consistent with those of Saeed et al. (2019), who also reported that higher SOC was observed in the forest interior than in the exterior and that soil carbon increased with elevation at both locations. The findings of the other study likewise showed a tendency for soil carbon density to increase with elevation (Ping et al., 2013; Tashi et al., 2016; Zhu et al., 2019). Consequently, soil at lower elevations tends to contain less carbon compared to that at higher elevations, regardless of the zone (interior or exterior).

The study's findings indicate a strong relationship between tree diameter and carbon storage, with larger trees such as *Picea smithiana, Cedrus deodara,* and *Pinus roxburghii* storing significantly more carbon. This emphasises the need to manage tree growth, especially by conserving larger trees and prioritising species with high carbon storage capacity during afforestation and reforestation efforts. Such strategies can optimise carbon capture, utilising forests more effectively as carbon sinks(Hunter, 2015; Poudel et al., 2020).

Furthermore, our study's average aboveground biomass and carbon stock levels are consistent with those reported in previous research in the temperate Himalayan region (Behera et al., 2017; Joshi et al., 2021; Kaushal & Baishya, 2021). On the other hand, decreased basal area stem density, the distribution of larger individuals in lower diameter classes, and increased human pressure could be the cause of the low carbon sequestration and total biomass in lower elevation zones (Thakur et al., 2024; Verma & Garkoti, 2019). High carbon sequestration was consistently associated with larger trees as elevation increased. Shifting climatic conditions along altitudinal gradients can also significantly impact plant growth and, consequently, carbon accumulation(Sang, 2009).

A comprehensive study was conducted on live tree biomass and carbon variation along an altitudinal gradient in the moist temperate valley slopes of the Garhwal Himalaya (India), exploring the potential of Western Himalayan land use sectors for carbon sequestration (Rawat et al., 2021). The altitudinal variation of soil organic carbon stocks in the temperate forests of the Kashmir Himalayas, India, was studied, revealing significant differences influenced by elevation (Dar & Sundarapandian, 2015). Sheikh et al. (2020) conducted a study on biomass and soil carbon along altitudinal gradients in temperate *Cedrus deodara* forests of the Central Himalaya, India, highlighting its implications for climate change mitigation. Pandey (2016) examined the structure, composition, and diversity of forests along an altitudinal gradient in the Himalayas, Nepal. Thakur et al. (2024) recently conducted a comprehensive study in the temperate Himalayan region, focusing on the dynamics of aboveground vegetation biomass and carbon stocks across altitudinal gradients and overstorey composition types. Research has already demonstrated that promoting taller tree growth can significantly increase a forest's capacity to sequester carbon dioxide (Terakunpisut, 2007). Therefore, focusing on species with high carbon-sequestration capacity in afforestation and reforestation would greatly enhance carbon capture and storage (Rawat et al., 2021). Furthermore, the trend can serve as a useful visual aid for observing the varying carbon storage capacities of different species at different diameters, highlighting the importance of species selection in forest management. Thus, by identifying and promoting species that store more carbon, forest managers may finally devise the best thinning or reforestation plan to optimise carbon capture. The study's conclusions are especially relevant in view of the current phenomena of global climate change, where forests are essential for reducing greenhouse gas emissions. For long-term sustainability and climate resilience, integrating strategic species selection and tree growth management will maximise carbon sequestration potential.

Conclusion and Recommendations

The study revealed significant effects of fragmentation on carbon density, providing important new insights into the dynamics of carbon storage in soil and plants across different elevations. In general, the findings showed that the interior of the forest has a higher carbon density than the perimeter, with a 35% decrease. The most significant aspect of an eclosed forest system in the current scenario is its ability to sequester more carbon; it is one of the crucial combatants against climate change. Above all, there is a linear relationship between elevation and carbon density, while also showing the edaphic and microclimatic factors related to carbon accumulation. In sum, this study provides strong evidence on the broader issues of climate change and its impact on forest fragmentation as a general principle. If the objective of forest management is to conserve trees to enhance C stocks, then *A. pindrow* and P. smithiana are highly recommended species for their potential to sequester carbon in fragmented forests. Interior forest areas have a conspicuously higher carbon density and, hence, require adoption and follow-up with a focus on these areas. The effectiveness of these conservation management practices needs to be monitored in terms of carbon storage within and outside the forest area. Ideally, local communities should be involved in the conservation and reforestation of the forest area, as this will ensure they support the strategic use of resources in line with sustainability. Since land-use planning involves forest management strategies that can reduce climate change, the biological requirements of the keystone tree species must be at the focus of these studies.

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