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BIOMASS AND CARBON STOCK VARIATION IN THE MOIST TEMPERATE FORESTS OF GARHWAL HIMALAYA

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ABSTRACT

This study aimed to measure biomass and carbon stock in the moist temperate forests positioned between latitudes 28° 43' to 31° 28' N and longitudes 77° 34' to 81° 03' E which comes under Kedarnath Forest Division (spanning between 29° 57' to 30° 06' N and 79° 11' to 79° 20' E) of the Garhwal Himalaya. A reconnaissance survey was conducted from March 2022 to April 2023 to evaluate forest cover types characterized by various species compositions and elevational gradient (1550 to 3000 m asl). The biomass expansion factor (BEF) and species-specific regression equations were utilized to estimate biomass. The results revealed that tree density ranged from 530 to 1440 individuals hectare^{-1} and mixed broad-leaved forest (FT4) exhibited the highest values for frequency (670%), abundance (35), and species richness (20). The total biomass density (TBD) varied from 279.27 mg ha^{-1} (*Quercus leucotrichophora* forest (FT1)) to 529.05 mg ha^{-1} (Conifer mixed broad leaved forest (FT5), with an average total carbon density (TCD) of 209.23 mg C ha^{-1}. TCD values ranged between 139.63 (FT1) and 264.52 (FT5) mg C ha^{-1}. Conversely, the lowest TBD values were recorded in *Quercus leucotrichophora* forest (FT1) at 279.27 mg ha^{-1}, *Alnus nepalensis* forest (FT2) at 310.42 mg ha^{-1} and mixed broad leaved forest (FT3) at 347.21 mg ha^{-1}. Conversely, forest types *Quercus leucotrichophora* forest (FT1), *Alnus nepalensis* forest (FT2) and mixed broad leaved forest (FT3), which displayed relatively lower biomass, were characterized by tree species with smaller diameters found in the sub-canopy. The high tree density and substantial carbon stock highlight the importance of these forests in carbon sequestration, making them crucial for carbon mitigation strategies in the Garhwal Himalaya. Our study underscores the importance of temperate forests in the Garhwal Himalaya as vital carbon sinks and biomass repositories. We highlight the need for conservation and sustainable management strategies to mitigate climate change and preserve biodiversity, focusing on intact forests and sustainable practices. These findings offer actionable insights for policymakers and land managers to enhance carbon sequestration and ecosystem resilience, ensuring the long-term health of these critical forests.

(Key words: Carbon stock, growing stock, temperate forests, tree, Western Himalaya)

INTRODUCTION

Forests are vital carbon sinks, absorbing CO_2 from the atmosphere and storing it in vegetation and soil. They play a crucial role in global carbon cycles through processes like photosynthesis and respiration. When disturbed, forests can become sources of atmospheric carbon, but they transition back into sinks during regrowth. Properly managed, forests offer significant ecological and economic value, contributing to climate change mitigation through strategies like afforestation and sustainable management (YU *et al.,* 2023; Case *et al*., 2021). Terrestrial ecosystems, particularly forests, absorb 30% of human-induced carbon emissions annually, highlighting their importance in carbon sequestration (Pan *et al.,* 2011). Future strategies focusing on forests could reduce emissions by 7 petagrams of CO_2 annually by 2030 (Griscom and Brinen, 2017). Assessing forest carbon storage and sequestration capacity is crucial for developing effective climate change strategies (Li *et al*., 2023). Factors such as geographic location, stand age, and plant species composition influence carbon storage in forests (Jin, 2024). Deforestation and degradation release CO_2, while changes in forest biomass, influenced by ecological succession and climate patterns, affect carbon stocks (Bu *et al.,* 2008).

Quantifying biomass is essential for understanding carbon dynamics in forests and provides crucial inventory data (Villanova *et al*., 2019). Microclimate variations within forests influence carbon dynamics, impacted by factors like solar radiation exposure and altitude (Sharma *et al*., 2011). Estimating carbon stocks helps predict and reduce

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greenhouse gas emissions from forest degradation, conserving forest carbon stocks (Guo, 2010). Forests are integral to global climate change mitigation, with initiatives like REDD+ aiming to enhance forest carbon storage and mitigate emissions (Andoh and Lee, 2018).

MATERIALS AND METHODS

Study area

This study was conducted during March 2022 to April 2023 in the moist temperate forest in Chamoli district, Uttarakhand, situated within the Kedarnath Forest Division. Specifically, it is positioned between 30°26' N, 79°16' E and 30°28' N, 79°13' E spanning an altitude gradient ranging from 1550 to 3000 meters above sea level. The composition of forest types along the altitude gradient was assessed using the nested quadrat method outlined by Kent and Coker (1992). To analyze tree vegetation, 10 m x 10 m quadrats, as suggested by Phillips (1959), were used. Trees were identified as per Knight (1963). Frequency, density, and abundance were assessed using the methods described by Curtis and McIntosh (1950). Species richness (SR) was simply measured by counting the total number of species present in that specific forest type. The estimation of growing stock volume density (GSVD) involved utilizing volume tables and equations obtained primarily from the Forest Research Institute (FRI) and Forest Survey of India (FSI). In cases where specific volume equations for certain species were lacking, their volumes were computed conventionally. This involved using volume tables or equations for similar species that shared comparable characteristics in terms of height, shape and growth rate. The GSVD, measured in cubic meters hectare^{-1} (m^{3} ha^{-1}), was then transformed into aboveground biomass density (AGBD). This conversion was achieved by multiplying the forest's GSVD with the appropriate biomass expansion factor (BEF), as outlined by Brown *et al*. (1999).

The estimation of belowground biomass density (BGBD), was conducted using a regression equation developed by Cairns *et al*. (1997). The equation BGBD = exp {-1.059 + 0.884 × ln (AGBD) + 0.284} was utilized to analyse forest associations across different elevations. The calculation of the total biomass density (TBD) involved the summation of the AGBD and BGBD. The total carbon density (TCD) was calculated using the formula TCD (mg C ha^{-1}) = TBD (mg ha^{-1}) x C%. The carbon percentage used in this calculation was in accordance with Negi *et al*. (2003) and Manhas *et al*. (2006).

RESULTS AND DISCUSSION

In the surveyed area, tree density varied from 530 ind ha^{-1} in *Abies pindrow* forest (FT6) to 1440 ind ha^{-1} in mixed broad leaved forest type (FT4). The highest frequency, abundance, and species richness were observed in the mixed broad-leaved forest (FT4) with values of 670%, 35, and 20, respectively. The lowest frequency was recorded in the *Abies pindrow* forest (FT6) at 280%, while the lowest abundance was in the *Quercus semecarpifolia* forest (FT8) with a value of 7. Both FT6 and FT8 had the lowest species richness, each with a value of 5 (Table 1). TBD varied from 279.27 mg ha^{-1} in *Quercus leucotrichophora* forest (FT3) to 529.05 mg ha^{-1} in conifer-mixed broad leaved forest (FT6). *Abies pindrow* forest (FT6) exhibited the highest TBD at 529.05 mg ha^{-1}, followed closely by mixed broad leaved forest (FT4) at 518.76 mg ha^{-1}, *Quercus semecarpifolia* forest (FT8) at 487.17 mg ha^{-1}, and *Acer caesium* forest (FT7) at 470.88 mg ha^{-1}. Conversely, the lowest TBD values were recorded in *Quercus leucotrichophora* forest (FT1) at 279.27 mg ha^{-1}, *Alnus nepalensis* forest (FT2) at 310.42 mg ha^{-1} and mixed broad leaved forest (FT3) at 347.21 mg ha^{-1} (Table 2). AGBD varied from 214.72 to 407.02 mg ha^{-1}, while BGBD varied from 64.55 to 123.94 mg ha^{-1}. The average TBD for the study area was 418.47 mg ha^{-1}, with AGBD contributed 77.12% (322.70 mg ha^{-1}) and BGBD contributed 22.88% (95.77 mg ha^{-1}) to the total biomass. Our study showed that the maximum AGBD recorded was 407.02 mg ha^{-1}, which is similar to the findings of Sharma *et al*. (2018) (419.57 ± 92.06 mg ha^{-1}) in this region and greater than the value (261.64 mg ha^{-1}) reported by Bora *et al*. (2013) in Assam Northeast India. In 1993, the average biomass density of Indian forests was estimated to be 135.6 mg ha^{-1}, with state-level variations ranging from 27.4 to 251.8 mg ha^{-1} (Chhabra *et al*., 2002). Additionally, the total AGBD and BGBD stocks in Indian forests were found to be 6,865.1 mt and 1,818.7 mt, respectively, indicating a ratio of 79:21 (Chhabra *et al*., 2002). Current study also observed a similar AGBD (77.12%) and BGBD (22.88%) ratio. This research estimates the biomass storage of conifer mixed broad leaved forest (FT5) exhibited the most substantial, with a value of 529.05 mg ha^{-1}, representing highest percentage of 15.80 % indicating distinct biomass accumulation. In contrast the least biomass storage of *Quercus leucotrichophora* forest (FT1) with 279.27 mg ha^{-1} which contributes only 8.34 % of the total biomass.

The estimated biomass was found to be substantial and varied significantly across different forest types. The forest types *Quercus semecarpifolia* forest (FT8), *Acer caesium* forest (FT7), *Abies pindrow* forest (FT6), conifer mixed broad leaved (FT5), and mixed broad leaved forest (FT4) exhibited higher biomass mainly resulting from the higher girth classes trees with dominating canopy and reduced occurrence of disturbances within these forest types, allowing them to thrive and accumulate biomass over time. These trees contribute significantly to the overall carbon storage capacity, serving as robust carbon sinks and playing a crucial role in maintaining ecosystem stability. Conversely, forest types *Quercus leucotrichophora* forest (FT1), *Alnus nepalensis* forest (FT2) and mixed broad leaved forest (FT3), which displayed relatively lower biomass, were characterized by tree species with smaller diameters found in the sub-canopy. The variation in biomass among these forest types underscores the significance of tree size and canopy structure in determining a forest's carbon storage potential. The present study estimates the biomass storage ranging 279.27 mg ha^{-1} (5.83%) to 529.05 mg ha^{-1} (77.17% of the total biomass) and carbon storage ranging from 139.63 to 264.52 mg C ha^{-1} , which was higher than the other reported value in the Himalayan region *viz.,* Sharma *et al*. (2016) (283.4 ±74.8 to 464.2 ± 152.5 mg ha^{-1}, 127.5 ±33.7 to 208.9±68.6 mg C ha^{-1}); Sharma *et al*. (2018) (189.38 to 520.72 mg ha^{-1}, 85.22 to 234.32 mg C ha^{-1}); Gairola *et al*. 2011 (215.5 to 468.2 mg ha^{-1}, 107.8 to 234.1 mg C ha^{-1}); Mahato *et al*. (2016) (132.74 mg ha^{-1} and 66.36 C mg ha^{-1}); Kumar and Sharma (2015) (108.26 mg ha^{-1} and 53.45 mg C ha^{-1}). In sacred forest of Tehri region of Garhwal Himalaya, Uttarakhand, biomass and total carbon density was recorded 1549.704 mg ha^{-1} and 774.77 mg C ha^{-1}, respectively, which was higher than our estimated value (Pala *et al*., 2013).

The average total carbon density (TCD) for the study area was recorded at 209.23 mg C ha^{-1}. Conifer mixed broad leaved forest (FT5) exhibited the highest TCD at 264.52 mg C ha^{-1}, followed by mixed broad leaved forest (FT4) at 259.38 mg C ha^{-1} and *Quercus semecarpifolia* forest (FT8) at 243.58 mg C ha^{-1}. In contrast, *Quercus leucotrichophora* forest (FT1) had the lowest TCD at 139.63 mg C ha^{-1}, followed by *Alnus nepalensis* forest (FT2) at 155.21 mg C ha^{-1} and FT3 at 173.6 mg C ha^{-1}. The total carbon content in the living tree biomass of the study area was estimated at 188.30 gigagrams of carbon (Gg C), derived by multiplying the average TCD by the study area size (900 hectares). We have estimated higher TBD at 529.05 mg ha$_{-1}$ and TCD at 264.5 mg ha^{-1} for conifer mixed broad leaved forest (FT5) in comparison with other forest types. This is due to it being an old-growth forest, which not only retains substantial carbon but also continues to sequester more carbon over time. (Chaturvedi *et al.,* 2011). Zhu *et al.* (2010) noted that older stands have higher vegetation and soil carbon densities. The influence of altitude on tree biomass and carbon stocks in Himalayan forests varies. Johnson and Brown (2020) reported a decline in biomass with increasing altitude due to harsher climatic conditions, reduced soil fertility, and shorter growing seasons. However, other research, including our own, has found a strong correlation between altitude and biomass in certain regions, attributed to local environmental conditions and species adaptations (Alves *et al*., 2010; Gairola *et al*., 2011). Additionally, biomass and carbon stocks also showing increasing trend with age of the stand, as mature stands accumulate more biomass (Pregitzer and Euskirchen, 2004). Cooler temperatures and high precipitation rates, as noted by Keith *et al*. (2009), further enhance carbon accumulation. Therefore, evaluating biomass and carbon dynamics in mountain forests requires considering altitude, stand age, temperature, precipitation and soil. The soil fertility status reflects the capacity of different soils to supply essential nutrients for plant growth (Sadanshiv *et al.,* 2017), which directly influences the productivity of the forests. These factors are essential for assessing commercial plantation potential, biomass productivity, and forest management, aiding in the identification of productive forest types and effective conservation strategies. In the Garhwal Himalaya, temperate forests are essential for combating climate change due to their capacity for carbon sequestration. Thus, this study aimed to provide a comprehensive understanding by estimating biomass distribution patterns across various forest types and assessing the potential carbon stock within these forests. These assessments are vital for crafting successful preservation and management approaches aimed at increasing the carbon sequestration capacity of these ecosystems.

In conclusion, forests, despite their potential as carbon sinks, face challenges such as degradation, deforestation, land-use changes, and impacts from climate variability (Canadell *et al*., 2007). Uncertainties persist regarding the long-term stability of carbon stored in forests and the complex interactions between climate change and forest dynamics (Bonan, 2008). Our study highlights temperate forests in the Garhwal Himalaya as essential carbon sinks and biomass repositories. We emphasize the need for conservation and sustainable management to mitigate climate change and preserve biodiversity. Given the continuous decrease in the land-to-people ratio and the constant population growth in emerging nations like India, the only way to meet the demand for agricultural goods is to enhance productivity without compromising forest conservation or environmental sustainability (Pandey *et al.,* 2024). Targeted strategies should focus on intact forests and sustainable practices. Our findings provide actionable insights for policymakers and land managers to boost carbon sequestration and enhance ecosystem resilience, ensuring the long-term health of these critical forests.

Table 1. General details and diversity attributes of the studied forest types

SI.	**FT**	**Forest Type**	**Elevation (m asl)**	**Main associates**	**Den (m^2 ha^{-1})**	**FR**	**Ab (%)**	**SR**
1.	FT1	*Quercus leucotrichophora* forest	1500-1650	*Q. leucotrichophora, R. arboreum*	920	380	20	12
2.	FT2	*Alnus nepalensis* forest	1550-1700	*A. nepalensis, Q. leucotrichophora*	550	300	11	6
3.	FT3	Mixed Broad-leaved forest	1900-2150	*D. himalense, B. alnoides, M. odoratissima*	800	630	23	18
4.	FT4	Mixed Broad-leaved forest	2150-2400	*D. himalense, M. duthiei, S. paniculate, L. ovalifolia*	1440	670	35	20
5.	FT5	Conifer mixed broad leaved forest	2400-2550	*A. pindrow, A. caesium, A. indica*	690	520	13	10
6.	FT6	*Abies pindrow* forest	2500-2650	*A. pindrow, Q. semecarpifolia*	560	280	9	5
7.	FT7	*Acer caesium* forest	2650-2750	*Q. leucotrichophora, R. arboreum, A. indica*	1050	360	22	9
8.	FT8	*Quercus semecarpifolia* forest	2750-2950	*Q. semecarpifolia, R. arboreum, L. ovalifolia*	530	310	7	5

Abbreviations: Den= Density; **FR**= Frequency; **Ab**= Abundance; **SR**= Species richness

Table 2. Biomass and carbon stock values in the different forest types

FT	AGB(mg ha^{-1})	BGB(mg ha^{-1})	TBD(mg ha^{-1})	TCD(mg C ha^{-1})
Ft1	214.7	64.5	279.2	139.6
FT2	240.3	70.1	310.4	155.2
FT3	260.9	86.2	347.2	173.6
FT4	394.8	123.9	518.7	259.3
FT5	407.0	122.0	529.0	264.5
FT6	315.6	89.4	405.0	202.5
FT7	363.7	107.1	470.8	235.4
FT8	384.4	102.7	487.1	243.5

Abbreviations: AGB= Above ground biomass density; **BGB=** Below ground biomass density; **TBD=** Total biomass density; **TCD=** Total carbon density; **FT**= Forest type

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