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RESEARCH ARTICLE

TREES BIOMASS AND CARBON STOCK ASSESSMENT OF TEMPERATE FOREST IN HIMACHAL PRADESH, NORTH-WESTERN HIMALAYA

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ABSTRACT

The temperate forests in the Western Himalaya play a crucial role in carbon sequestration and climate change mitigation. However, there is limited information on the biomass and carbon stock of these forests, particularly in specific regions like Maharaja Valley, Kullu. Therefore, our study aims to assess and quantify the carbon stock in the forest vegetation of Buragran Village. By estimating carbon stocks, this research seeks to provide valuable insights into the region's carbon sequestration potential, aiding conservation efforts and climate change mitigation strategies. Total of 300m^2 (0.03 Ha) was sampled. Total of 20 trees were recorded in the sampled plots. *Pinus Roxburghii* was the most dominant one in all the quadrates with 100% detection frequency. This finding suggests that the dominant species has a significant influence on the composition and structure of the community within the study site. Our overall results shows that the highest CBH (Circumference at Breast Height) of *Pinus Roxburghii* tree recorded is 158.49 cm with highest basal area of 0.199 m2/ha. This indicates that Pinus tree with highest CBH will also have maximum basal area. The maximum AGC will also be present in the tree which has highest height (i.e., 41m and the minimum AGC is present in lowest height (i.e., 13.7) and we see the similar trends for below ground biomass and below ground carbon. Our quadrate data provides valuable initial insights into the dominance of a particular species, the study acknowledges the potential for more species to occur within the area due to the limited number of samples and area covered. A more comprehensive sampling effort will be crucial to revealing the true extent of species diversity and enriching our understanding of the ecological dynamics at play in the ecologically important region.

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INTRODUCTION

Ecosystems play a crucial role in regulating the Earth's climate by acting as carbon sinks, absorbing and storing carbon dioxide from the atmosphere through photosynthesis. Carbon exists in the earth's atmosphere primarily as the gas-carbon dioxide. It constitutes a very small percentage of the atmosphere about 0.04% approximately (Vashum & Jayakumar, 2012). The quantity of carbon in a reservoir or system associated with terrestrial ecosystems, anthropogenic sources, and the atmosphere have been used in the calculation of carbon stocks (Rypdal *et al*., 2006) in relation to its capacity to accumulate or release carbon is referred to as its carbon stock. A "stock" or "pool" refers to the amount of carbon that is stored in a particular system. Forests are essential carbon stocks due to their high biomass density and long-term storage capacity. The continental crusts and upper mantle of the Earth contain the largest carbon stock on the planet (Mackenzie & Lerman, 2006) land use activities such as deforestation, land degradation, and conversion of natural ecosystems to agriculture or urban areas can lead to carbon stock depletion and increased carbon emissions. According to IPCC's report (Gitarskiy, 2019) the above-ground biomass, below-ground biomass, dead mass of litter, woody debris, and soil organic matter, makes the terrestrial ecosystem. Estimating the carbon stock in the forests is essential to understanding their potential contribution to climate change mitigation efforts at both regional and global levels. Carbon stock estimation helps in assessing the role of forests in mitigating climate change by sequestering carbon and reducing greenhouse gas emissions. It can be measured in various units, such as metric tons of carbon (tC) per hectare (ha) or metric tons of CO2 equivalents (tCO2e). It provides valuable information for assessing the carbon sequestration potential of ecosystems, monitoring changes in carbon storage over time, and developing strategies for climate change mitigation and carbon offset programs. In Himachal Pradesh total carbon stocks is 2,58,071 tonnes (Forest Survey of India, 2021). The State of Himachal Pradesh is situated in the Trans-Himalayan and Himalayan Biogeographic Zones.

Forest cover of the State has been assessed to be 15443sq.km, which is 27.73 per cent of the total geographic area. The legally designated forest areas are scattered over 37948 square kilometres, accounting for 68.16 percent of the State's geographic area (Economic and Statistics Department, 2023). The dense vegetation and biomass in Himachal Pradesh's forests contribute to the accumulation of substantial carbon stocks. The state's forests also help maintain watershed integrity, prevent soil erosion, and support the livelihoods of local communities through the collection of non-timber forest products. This study aims to assess and quantify the carbon stock in the forest vegetation of Buragran Village. By estimating carbon stocks, this research seeks to provide valuable insights into the region's carbon sequestration potential, aiding conservation efforts and climate change mitigation strategies.

OBJECTIVES OF THE STUDY

The temperate forests in the Western Himalaya play a crucial role in carbon sequestration and climate change mitigation. However, there is limited information on the biomass and carbon stock of these forests, particularly in specific regions like Maharaja Valley, Kullu. The lack of comprehensive data hinders our understanding of the carbon sequestration potential and the contribution of these forests to the regional and global carbon cycle. Therefore, the objectives of the study are:

- To generate baseline data on the tree biomass of the dominant species.
- To estimate the above-ground carbon stock in the forest vegetation of Maharaja Valley
- To assess the below-ground carbon storage potential in the forest ecosystem.
- To compare the carbon stock values with nearby forested areas and national/regional averages.

Study area

In Himachal Pradesh real forest covers is 15,443 Sq.Kms (27.74%) of the total area, with density ranging from 10% to 70% and higher. The study area is situated in Buragran Village in Maharaja Valley of district Kullu, Himachal Pradesh. It is located between 31˚55'30''N to 31˚49'30''N latitude and 77˚1'30''E to 77˚7'30''E longitude (Fig 2). The district is bounded by Pir-Panjal range in the north; Bara Bhangal in the Northwest; the Greater Himalayas in the eastern boundary and Dhauladhar Range in the southwest. At each site, random sample was taken by laying three 10*10m quadrates. The Land Use Land Cover (LULC) map (Fig 1.) illustrates the distribution of different land cover types within a specific region. In this particular map, forests dominate the landscape, covering approximately 66.28% of the area, indicative of a rich and diverse ecosystem.

METHODLOGY

The assessment of trees biomass and carbon stock in the temperate forest of Maharaja Valley, Kullu, is crucial for understanding the carbon sequestration potential and the role of the forest in mitigating climate change. It provides valuable information for forest management and conservation strategies in the Western Himalaya region.

Our study involves field data collection, non-destructive techniques, and the use of biomass estimation models to quantify the carbon stock of trees in the temperate forest ecosystem.

Non-Destructive Method: Accurate estimation of forest carbon stocks is essential for understanding the role of forests in climate change mitigation and biodiversity conservation. Traditional methods, such as destructive sampling, involve harvesting and measuring trees, which can be time-consuming, expensive, and ecologically disruptive. To address these limitations, non-destructive methods have emerged as valuable alternatives for estimating forest carbon stocks. These innovative techniques employ advanced technologies to measure and assess carbon stocks without causing harm to the forest ecosystem

Quadrat Sampling: Field survey and quadrate sampling were performed during the summer season at the forest community of the village under Khadiyar Gram Panchayat under Kullu district. At each site, random sample was taken by laying three 10*10m quadrates. Standard ecological techniques were implemented to collect data from these quadrates (Khanduri *et al*., 2017; Mishra R., 1968; Puspwan & Pandey, 2011; A. Sharma & Samant, 2013). For each species, the circumference at breast height (CBH at 1.37m) of each tree in each quadrat was measured and recorded individually (Ghoshal & Samant, 2015). Only trees with a CBH greater than 31.5cm were selected for this study (A. Sharma & Samant, 2013). CBH values were then converted to DBH (Diameter at Breast Height), and these values were utilized for estimation of aboveground biomass (AGB), above ground biomass carbon (AGC), below ground biomass (BGB). The BGB and below ground biomass carbon was estimated with the help of Allometric equations.

Tree Height Measurement: The height was calculated with help of rangefinder. Laser rangefinders are electronic devices that emit laser beams to measure the distance to an object. To measure tree height (Fig 3) the observer aims the laser rangefinder at the tree's base and then at the top of the tree. The device calculates the vertical distance between the two points, providing the tree's height.

CBH and DBH Values: The tree the circumference at breast height (CBH at 1.37m) of each tree in each quadrat was measured with the help of the measuring tape. The circumference was used in the estimation of the tree Diameter at Breast Height (DBH), which is the diameter of tree trunk and unit of DBH is measured in centimetres (cm).

DBH= CBH/π

DBH = Diameter at Breast Height (in m)
CBH = Circumference at Breast Height (in m)
*π(pi) = 3.14 (Mathematical Constant)

Estimation of Tree Volume: Tree volume has been calculated in cubic meters, which are the product of the Basal area and the height of the tree.

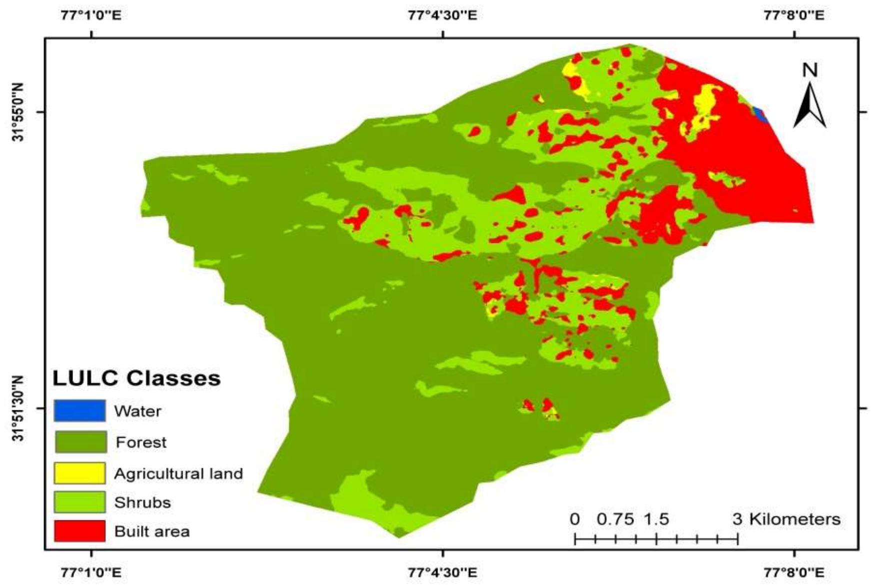


Figure 1. LULC Map of the Study Area

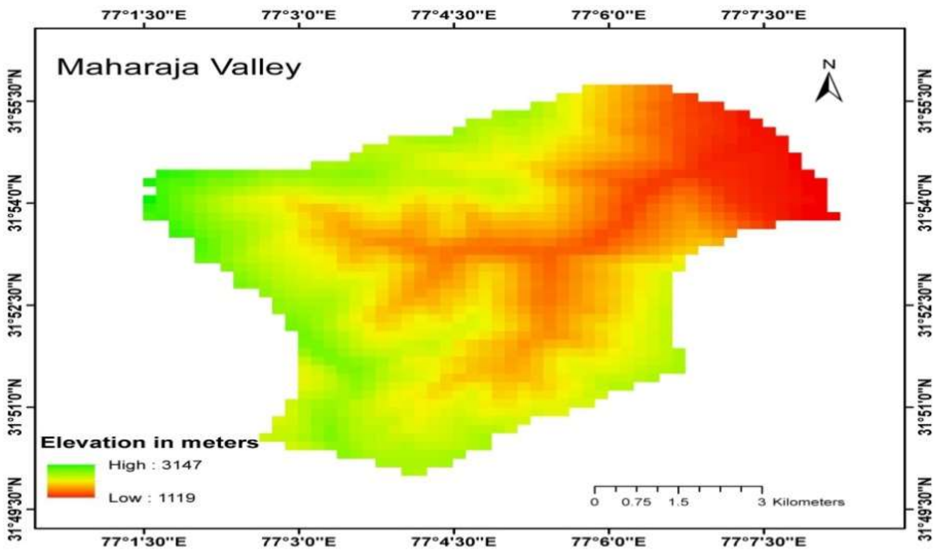
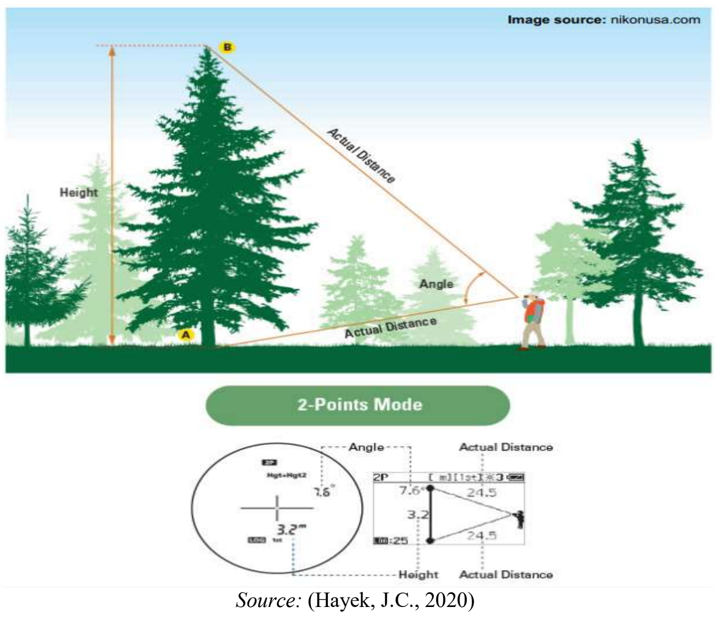


Figure 2. Digital Elevation Map (DEM) of Study Area (Maharaja Valley) in Kullu district



Source: (Hayek, J.C., 2020)

Figure 2. Two Point Tree Height Measurement

Tree volume (m^3) =0.92*×Basal Area× Height

*0.92 is the form factor to correct the cylinder volume into stem volume

Basal Area of the Tree: Basal area (in square meters, m^2) is the cross-sectional area of the tree's stem at breast height (usually measured at 1.37 meters above the ground).

Basal area=0.785*× (DBH^2)

Where, DBH is the diameter of the tree at breast height (in meters, m). The term "0.785" in the formula represents the constant (π/4) used to calculate the area of a circle, as the cross-section of the tree's stem at breast height is approximately circular.

Aboveground Biomass Estimation: Above-ground biomass (AGB) refers to the total dry weight of all living plant materials found above the ground surface in a forest or ecosystem. It includes the combined weight of tree stems, branches, leaves, and any other above-ground vegetation. AGB is an essential metric for quantifying the amount of carbon stored in forests and understanding their role in carbon sequestration and climate change mitigation.

AGB (kg) = 0.0383 × (DBH^ (2.377)) × (H^ (0.942))

Or

AGB= Tree volume × wood density

AGB is measured in (Kg) or metric tonne (t)

ρ (rho): wood density refers to the mass of wood per unit volume and is usually measured in ((g/cm)^(3)) or (kg/m^3)

Estimation of Above Ground Biomass Carbon (AGBC): Above-ground biomass carbon refers to the amount of carbon stored in the above-ground components of a forest or ecosystem, including tree stems, branches, leaves, and other above-ground vegetation. AGBC is the carbon content factor which is 0.5, as about 50% of the biomass

AGBC= AGB × 0.5

Estimation of Belowground Biomass (BGB): Below Ground Biomass is the total mass of plant tissue and organic material that is located below the ground surface

BGB=AGB × 0.26

0.26 is a numerical constant or coefficient

Estimation of Below Ground Biomass (BGBC): Below ground biomass carbon refers to the carbon stored in the biomass of plant roots and other below-ground plant components

BGBC=BGB×0.5

Total carbon: Total Carbon refers to the combined amount of carbon stored in above-ground biomass, below-ground biomass, deadwood, litter, and soil organic matter within the forest ecosystem. It is an essential metric for assessing the carbon sequestration potential of forests and their role in mitigating climate change.

Carbon=AGC+BGC

Statistical Analysis and Graphical Interpretation: Pearson's correlation coefficient is a statistical measure of the strength of a two-variable linear relationship. A correlation coefficient number close to -1 or 1 denotes the strongest negative or strongest positive association between two variables, whereas a value close to 0 denotes no linear relationship between variables. In this study we have calculated correlation coefficients to examine the relationship between carbon stocks (dependent variable) and various independent variables or attributes measured in the forests. Common independent variables include tree diameter, tree height, diameter, volume etc.

RESULTS AND DISCUSSION

Overall Results: Total of 300m^2 (0.03 Ha) was sampled. Total of 20 trees were recorded in the sampled plots. *Pinus Roxburghii* was the most dominant one in all the quadrates with 100% detection frequency. This finding suggests that the dominant species has a significant influence on the composition and structure of the community within the study site. However, on each quadrate site different height has been recorded of *Pinus Roxburghii* trees. The different heights of the same species suggest the presence of multiple age and size classes within the population. This indicates that the species is reproducing and regenerating successfully, with younger individuals growing alongside older ones.

Quadrat-wise results: The table given below shows the dominant tree species *Pinus Roxburghii*; CBH values, which were measured during the quadrate sampling. The diameter and the other values were calculated as per the methodology adopted in the study. It is important to note that the quadrate data has been collected for the first time in the study area, and due to the limited number of samples and area covered, there is a possibility of encountering more species in addition to the dominant species.

Quadrate-wise Biomass Estimation: Table shows that the species *Pinus Roxburghii* commonly known as Chir Pine were prevailing in all quadrates in light of examining approach. In some cases, human activities, such as deforestation, have contributed to the dominance of this species. For example, if native forests are cleared for agriculture or other purposes, chir pine may be one of the first species to recolonize the area due to its ability to regenerate quickly. Twenty trees were measured at breast height, each with a different height and diameter. In Q1 total above ground biomass is 3327074 kg/ha and above ground carbon is 1663537 kg/ha which is 50% of AGB. Total BGB in Q1 is 865039 kg/ha and below ground carbon is 432519 kg/ha. In Q2 total AGB is 2397615 kg/ha, whereas the BGB is 623380 kg/ha and AGC is 1198807 kg/ha and BGC is 311690 kg/ha. In Q3 total AGB is 4480532 kg/ha, BGB is 1164938 kg/ha and AGC is 2240266 kg/ha and BGC is 582469 kg/ha. In Total 20 trees above ground carbon is 5102611 kg/ha and below ground carbon is 1326678 kg/ha. Sum of AGC and BGC gives total amount of carbon i.e., 2822735 kg/ha.

Statistical Analysis: Correlation matrix (i.e., Table 3) shows the correlation coefficients between multiple variables. In the context of tree biomass estimation, the correlation matrix would show the relationships between different variables that are related to tree biomass.

Table 1. Quadrate Wise Results of Dominant Tree Species of Maharaja Valley

QUADRATE 1							
Number	Species	CBH(cm)	Diameter (cm)	height (m)	Basal Area (cm2)	Basal Area (m2/ha)	Volume m3
1	*Pinus roxburghii*	128	40.76433	26	1304.459	0.130446	3.120265
2	*Pinus roxburghii*	124.96	39.79618	25	1243.233	0.124323	2.859435
3	*Pinus roxburghii*	118.87	37.85669	22.4	1125.006	0.112501	2.318413
4	*Pinus roxburghii*	94.48	30.08917	14.5	710.7062	0.071071	0.948082
5	*Pinus roxburghii*	97.53	31.06051	15.5	757.3329	0.075733	1.079957
6	*Pinus roxburghii*	143.25	45.62102	41	1633.803	0.16338	6.162704
QUADRATE 2							
Number	Species	CBH(cm)	Diameter (cm)	height (m)	Basal Area (cm2)	Basal Area (m2/ha)	Volume m3
1	*Pinus roxburghii*	94.48	30.08917	18.7	710.7062	0.071071	1.222699
2	*Pinus roxburghii*	134.11	42.71019	28	1431.966	0.143197	3.688744
3	*Pinus roxburghii*	112.77	35.91401	17.8	1012.506	0.101251	1.65808
4	*Pinus roxburghii*	94.48	30.08917	13.7	710.7062	0.071071	0.895774
5	*Pinus roxburghii*	94.48	30.08917	23.2	710.7062	0.071071	1.516931
6	*Pinus roxburghii*	125.27	39.8949	28.8	1249.409	0.124941	3.310433
QUADRATE 3							
Number	Species	CBH(cm)	Diameter (cm)	height (m)	Basal Area (cm2)	Basal Area(m2/ha)	Volume m3
1	*Pinus roxburghii*	73.15	23.29618	18.3	426.0289	0.042603	0.717262
2	*Pinus roxburghii*	128	40.76433	31	1304.459	0.130446	3.720316
3	*Pinus roxburghii*	118.87	37.85669	20.3	1125.006	0.112501	2.101061
4	*Pinus roxburghii*	140.2	44.64968	23.1	1564.971	0.156497	3.325877
5	*Pinus roxburghii*	109.72	34.94268	19.5	958.4776	0.095848	1.719509
6	*Pinus roxburghii*	103.63	33.00318	23.7	855.03	0.085503	1.864307
7	*Pinus roxburghii*	158.49	50.47452	27.5	1999.927	0.199993	5.059815
8	*Pinus roxburghii*	149.35	47.56369	20.5	1775.909	0.177591	3.349365

Table 2. Quadrate-wise Biomass Estimation

Q1 (Total 6 Trees)	Q2 (Total 6 Trees)	Q3 (Total 8 Trees)
AGB =3327074 kg^{-ha}	AGB =2397615 kg^{-ha}	AGB =4480532 kg^{-ha}
BGB =865039 kg^{-ha}	BGB =623380 kg^{-ha}	BGB =1164938 kg^{-ha}
AGC =1663537 kg^{-ha}	AGC =1198807 kg^{-ha}	AGC =2240266 kg^{-ha}
BGC = 432519 $\text{kg}^{-\text{ha}}$	BGC = 311690 $\text{kg}^{-\text{ha}}$	BGC = 432519 $\text{kg}^{-\text{ha}}$

*Allometric Equation: AGB = 0.0383 * (DBH^2.377) * (H^0.942)*

Table 2. Correlation Matrix of the tree variables

Variables	Diameter (cm)	Height (m)	Basal Area (cm^2)	Volume (m^3)	AGB (Kg/ha)
Diameter (cm)	1				
Height (m)	0.639913	1			
Basal Area (cm2)	0.994554	0.633258268	1		
Volume (m^3)	0.892288	0.892176366	0.898483572	1	
AGB (Kg/ha)	0.901031	0.872271891	0.91052985	0.99887235	1

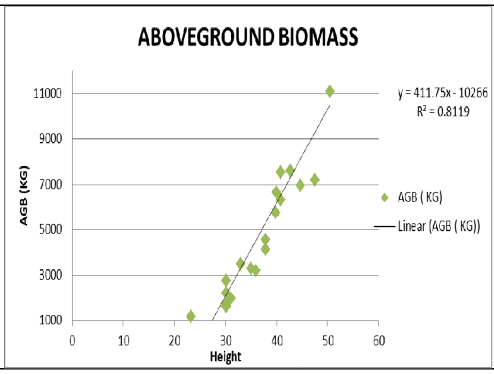


Figure 3. AGB Scatter Plot

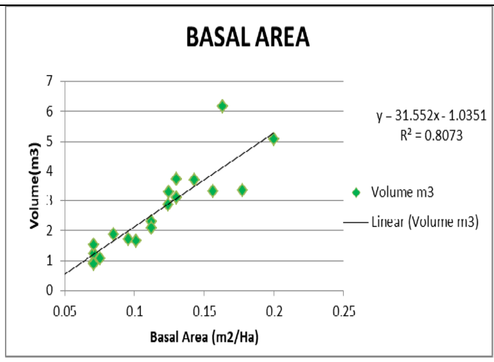


Figure 5. Basal Area Scatter Plot

These variables include tree diameter, tree height, basal area, volume and above-ground biomass (AGB). Each cell in the table represents the correlation coefficient between the variable in the corresponding row and column. The correlation coefficient ranges from -1 to 1, where -1 indicates a perfect negative correlation, 1 indicates a perfect positive correlation, and 0 indicates no correlation.

Diameter and Height have a positive correlation (0.639), indicating that as tree diameter increases; tree height tends to increase as well. Diameter and AGB have a strong positive correlation (0.90) indicating that larger-diameter trees tend to have higher above-ground biomass. Height and AGB also have a strong positive correlation (0.87), indicating that taller trees tend to have higher above-ground biomass.

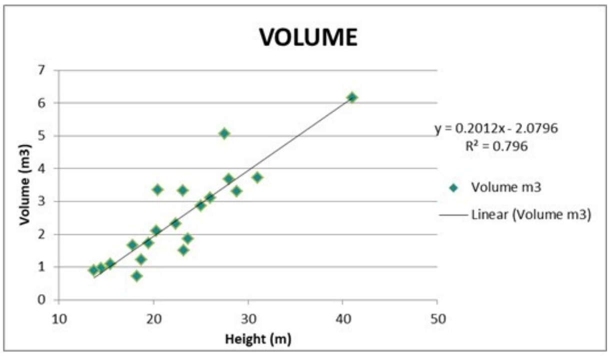


Figure 4. Volume Scatter Plot

Scatter Plots: Scatter plots were created to enhance the interpretation and understanding of correlation results in tree biomass estimation and other ecological studies. Scatter plots provide a clear and intuitive visual representation of the relationship between two variables that have been selected. Each data point represents an observation, and the scatter plot shows how the data points are distributed along the two axes.

•**Aboveground Biomass and Tree Height:** Each data point in the scatter plot represents an individual tree, where the x-axis represents the tree height, and the y-axis represents the above-ground biomass.

Table 3 shows a positive correlation between height and above-ground biomass, therefore we see a general upward trend in the scatter plot. As tree height increases, we would anticipate the above-ground biomass to increase as well.

•**Basal Area and Volume:** In the scatter plot, we plot each data point according to its Basal Area value on the x-axis and its Volume value on the y-axis. The resulting scatter plot will show a collection of points scattered across the graph, with each point representing a tree in the dataset.

In Table 3, there is positive correlation between basal area and volume (0.89), therefore we see a general upward trend in the scatter plot. As Basal Area increases, we would anticipate the Volume to increase as well. This makes intuitive sense as larger trees with larger basal areas are likely to have more wood and, therefore, more volume.

•**Volume and Height:** In the scatter plot, we plot each data point according to its Height value on the x-axis and its Volume value on the y-axis. Our results indicate that there is a positive correlation between Height and Volume (0.892); we would expect to see a general upward trend in the scatter plot. As tree Height increases, we would anticipate the Volume to increase as well. Taller trees are likely to have more wood and, therefore, more volume.

DISCUSSION

Our overall results show the Highest CBH of *Pinus Roxburghii* tree recorded is 158.49 cm with highest basal area of 0.199 m^2/ha. This indicates that Pinus tree with highest CBH will also have maximum basal area. The maximum AGC will also be present in the tree which has highest height (i.e., 41m and the minimum AGC is present in lowest height (i.e., 13.7) and we see the similar trends for below ground biomass and below ground carbon. This is also due to maximum height of the tree and the aging of the tree. Our findings suggests that younger the tree, lower will be the CBH and basal area of the tree. When the tree reaches its maturity, all the factors such as AGB, BGB will have gradual increase (Bhardwaj *et al*., 2021; Kumar *et al*., 2013; Singh *et al*., 2009) have also observed that *Pinus roxburghii* growth is influenced by temperature, which drops with elevation. This decrease in biomass accumulation with elevation caused by various factors like temperature, leaching, nutritional deficiency and increased runoff in upper elevation etc. Banday *et al*., 2018 has also observed increased biomass and carbon stock in lower altitude in pinus. Low tree biomass and carbon stock in Chir Pine from upper altitude (>1600 m) have also been observed by earlier researchers ((Kaur & Kaur, 2016; Lal & Lodhiyal, 2015; Pant & Tewari, 2013, 2020; C. M. Sharma *et al*., 2010). Latest study done by Kaushal & Baishya, 2021 has observed higher biomass from upper altitude. According to Dimri *et al*., 2018in temperate forest had higher carbon stock because of age factor of tree, mature tree with large diameter shows high carbon stock (Kumari *et al*., 2022) observed similar factor the smaller trees currently do not have a high potential for carbon storage, but they will soon be able to store high carbon sequestration potential in the future.

CONCLUSION

Our finding suggests that the dominant species has a significant influence on the composition and structure of the community within the study site. However, on each quadrate site different height has been recorded of *Pinus Roxburghii* trees. The different heights of the same species suggest the presence of multiple age and size classes within the population. This indicates that the species is reproducing and regenerating successfully, with younger individuals growing alongside older ones. The carbon stock was calculated individually for all 20 trees of *Pinus Roxburghii*.

However, it is important to note that the accuracy of carbon stock estimation can vary depending on factors such as the level of data availability, the quality of field measurements, and the complexity of the ecosystem being studied. While estimating carbon stocks in an area with only one species may simplify calculations, it may not represent the complexity and dynamics of a larger ecosystem with multiple species. To gain a comprehensive understanding of carbon sequestration and climate change mitigation, it's crucial to consider the broader ecological context. Combining multiple methods and validating estimates with ground-truthing can enhance the accuracy of carbon stock assessments. Due to a variety of approaches and techniques, the results may vary, and our study site is relatively tiny and has little data for estimation. To address these issues, nowadays remote sensing is increasingly being employed for more precise estimates of carbon stocks. Using remote sensing techniques to assess biomass and carbon stocks in *Pinus Roxburghii* forests can help overcome the challenges arising from these discrepancies in biomass and carbon stocks at similar altitudes from various Himalayan regions may be caused by the varying ages of the forests and by site quality considerations. The presence of the dominant species across all quadrates indicates its significance in this particular habitat, but it does not preclude the possibility of other species co-occurring within the study area. To gain a more comprehensive understanding of the species diversity and community structure, further sampling efforts and a larger sample size would be required. Expanding the number of quadrates and increasing the total area covered would help capture a more representative picture of the plant community, including the potential presence of additional species alongside the dominant one. In conclusion, while the quadrate data provides valuable initial insights into the dominance of a particular species, the study acknowledges the potential for more species to occur within the area due to the limited number of samples and area covered.

REFERENCES

Banday, M., Bhardwaj, D. R., & Pala, N. A. (2018). Variation of stem density and vegetation carbon pool in subtropical forests of Northwestern Himalaya. *Journal of Sustainable Forestry*, *37*(4), 389–402.

Bhardwaj, D. R., Tahiry, H., Sharma, P., Pala, N., Kumar, D., Kumar, D., & Juneja, B. (2021). Influence of Aspect and Elevational Gradient on Vegetation Pattern, Tree Characteristics and Ecosystem Carbon Density in Northwestern Himalayas. *Land*, *11*.

Chave, J., Andalo, A. C., Brown, A. S., Cairns, A. M. A., Chambers, J. Q., Eamus, A. D., Foïster, A. H., Fromard, A. F., Higuchi, N., Kira, A. T., Lescure, J.-P., Nelson, A. B. W., Ogawa, H., Puig, A. H., Rie´ra, A. B., Ae, R., Yamakura, T., Brown, S., Cairns, M. A., … Rie´ra, B. R. (2005). *ECOSYSTEM ECOLOGY Tree allometry and improved estimation of carbon stocks and balance in tropical forests*.

Chisanga, K., Bhardwaj, D. R., Pala, N. A., & Thakur, C. L. (2018). Biomass production and carbon stock inventory of high-altitude dry temperate land use systems in North Western Himalaya. *Ecological Processes*, *7*(1).

Dimri, S., Baluni, P., & Sharma, C. M. (2018). Carbon Dynamics in Quercus semecarpifolia (Kharsu Oak) and Quercus floribunda (Moru Oak) Forests of Garhwal Himalaya, India. *Proceedings of the National Academy of Sciences, India Section B: Biological Sciences*, *88*(3), 1157–1168.

Economic and Statistics Department. (2023). *Government of Himachal Pradesh Economic Survey 2022-23*.

Forest Survey of India. (2021). *India State of Forest Report 2021: Carbon Stock in India's Forest*.

Ghoshal, S., & Samant, S. (2015). 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 and Technology*, *10*, 51–61.

Gitarskiy, M. L. (2019). The refinement to the 2006 IPCC guidelines for national greenhouse Gas inventories. *Fundamental and Applied Climatology*, *2*, 5–13.

Hayek, J. C. (2020). *The Sine Method: A Better Tree Height Measuring Technique Using a Laser Rangefinder and a Clinometer to Precisely Measure Total Tree Height*.

Kaur, R., & Kaur, S. (2016). Growth, biomass, carbon sequestration and soil nutrient dynamics under pine forest in North-West Himalayas. *International Journal of Advanced Research*, *4*(6), 738–746.

Kaushal, S., & Baishya, R. (2021). Stand structure and species diversity regulate biomass carbon stock under major Central Himalayan forest types of India. *Ecological Processes*, *10*(1).

Khanduri, A., Biswas, S., Vasistha, H. B., Rathod, D., & Jha, S. (2017). A Status of Invasive Alien Species Plant Diversity in Tehri District Forest Ecosystem of Garhwal Himalayan Region. *Current World Environment*, *12*, 377–388.

Kumar, M., Singh, H., Bhat, J., & Rajwar, G. (2013). Altitudinal Variation in Species Composition and Soil Properties of Banj Oak and Chir Pine Dominated Forests. *Journal of Forest Science*, *29*, 29–37.

Kumari, B., Tiwari, A., & Anjum, J. (2022). Carbon sequestration potential in natural forests of Himachal Pradesh, India. *Current Science*, *122*(7), 846.

Lal, B., & Lodhiyal, L. S. (2015). Vegetation structure, biomass and carbon content in Pinus roxburghii. Dominant forests of Kumaun Himalaya. Int. J. Sci. & Tech. 10, 117–124. *Int. J. Sci. & Tech.*, *10*, 117–124.

Lu, D. (2006). The Potential and Challenge of Remote Sensing–Based Biomass Estimation. *International Journal of Remote Sensing*, *27*.

Mackenzie, F., & Lerman, A. (2006). Carbon in the Geobiosphere: Earth's Outer Shell. *Topic in Geobiology*, *25*, 89–116.

Maynard, C., Lawrence, R., Nielsen, G., & Decker, G. (2006). Modeling Vegetation Amount Using Bandwise Regression and Ecological Site Descriptions as an Alternative to Vegetation Indices. *GIScience & Remote Sensing*, *43*, 1–14.

Mishra R. (1968). *Ecology Work Book*. Oxford and IBS Publishing Company.

Neigh, C. S. R., Bolton, D. K., Diabate, M., Williams, J. J., & Carvalhais, N. (2014). An automated approach to map the history of forest disturbance from insect mortality and harvest with landsat time-series data. *Remote Sensing*, *6*(4), 2782–2808.

Pant, H., & Tewari, A. (2013). Carbon Sequestration Potential of Chir Pine Forest on Two Contrasting Aspects in Kumaun Central Himalaya between 1650-1860 m Elevation. *Applied Ecology and Environmental Sciences*, *1*(6), 110–112.

Pant, H., & Tewari, A. (2020). Green Sequestration Potential of Chir Pine Forests Located in Kumaun Himalaya. *Forest Products Journal*, *70*(1), 64–71.

Puspwan, K. S., & Pandey, B. N. (2011). Quantitative vegetation analysis of tree species in the forest adjacent to villages on the periphery of Kedarnath wildlife sanctuary. *Journal of Applied and Natural Science*, *3*(2), 303–306.

Rajput, B. S., Bhardwaj, D. R., & Pala, N. A. (2017). Factors influencing biomass and carbon storage potential of different land use systems along an elevational gradient in temperate northwestern Himalaya. *Agroforestry Systems*, *91*(3), 479–486.

Ravindranath, N., & Ostwald, M. (2008). *Carbon Inventory Methods Handbook for Greenhouse Gas Inventory, Carbon Mitigation and Roundwood Production Projects*.

Rypdal, K., Paciornik, N., Eggleston, S., Goodwin, J., Irving, W., Penman, J., & Woodfield, M. (2006). *Volume 1: General Guidance and Reporting, in 2006 IPCC Guidelines for National Greenhouse Gas*.

Sharma, A., & Samant, S. S. (2013). Diversity, structure and composition of forest communities in Hirb and Shoja Catchments of Himachal Pradesh, North West Himalaya, India. *International Journal of Botany*, *9*(1), 50–54.

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

Singh, H., Kumar, M., & Sheikh, M. A. (2009). Distribution Pattern of Oak and Pine along Altitudinal Gradients in Garhwal Himalaya. *Nat Sci*, *7*, 81–85.

Sundquist, E. T., Burruss, R. C., Faulkner, S. P., Gleason, R. A., Harden, J. W., Kharaka, Y. K., Tieszen, L. L., & Waldrop, M. P. (2008). *Carbon Sequestration to Mitigate Climate Change: U.S. Geological Survey, Fact Sheet 2008–3097*.

Thakur, M., & Verma, R. K. (2019). *Biomass and Soil Organic Carbon Stocks Under Cedrus deodara Forests in Mandi District of Himachal Pradesh*.

UNFCCC. (2015). *Measurements for Estimation of Carbon Stocks in Afforestation and Reforestation Project Activities under the Clean Development Mechanism: A Field Manual*.

Vashum, K., & Jayakumar, S. (2012). Methods to estimate above-ground biomass and carbon stock in natural forests. A review. *Journal of Ecosystem and Ecography*, *2*.

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