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Carbon Stock Quantities of *Shorea robusta* Gaertn. along Altitudinal Gradient in Shivalik Hills of Western Himalaya

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Abstract: The study explains altitude wise carbon stock quantities of *Shorea robusta* Gaertn. in the Bhabhar transition zone of Western Himalaya, an important zone from biodiversity conservation and climate change point of view in Uttarakhand. The area was divided into three zones viz. zone I (400-700 m), II (701-1000 m) and III (1001-1300 m). 10 sample plots (total 30 plots) were laid randomly for tree investigation and soil sampling. Based on the generated data through non-harvesting method, a gradual reduction was observed in studied parametric values from 96 trees. Tree volume and carbon stock (105.12-457.38 t ha^{-1}) were recorded highest at lower elevation. Contrary to this, soil carbon content increased from 33.33 t ha^{-1} to 40.96 t ha^{-1} as the elevation went-up from 700 to 1300 m., indicating a positive correlation with altitude. MC and BD showed weak positive correlation at mid-elevation. The findings suggested altitude as a detrimental factor for carbon stocking in trees and soil. It also provide a preliminary idea on influence of other factors such as slope, grazing pressure, choice of management practices and certain climatic factors like humidity and temperature on altitude wise reduction in carbon stocking of tree species in transitional zones.

Keywords: Altitude, Bhabhar zone, Biomass, Carbon stock, *Shorea robusta*

Carbon sequestration is often considered as a leading process reducing carbon dioxide (CO_2) emissions under changing climatic scenario. Trees are known to store the atmospheric carbon by sequestrating it in the growth of woody biomass through the process of photosynthesis. Since trees store and exchange carbon through vital physiological processes, they can be effectively managed to sequester significant quantities of carbon from the atmosphere. *Management of Shorea robusta* Gaertn., commonly known as sal, can contribute to global sustainability as the species holds immense potential in context to forest productivity and climate change. In India, the species is extended from foothills of south of Himalaya to far regions of Satpura and Eastern Ghats. In Uttarakhand, mostly found in Terai and Bhabhar regions, especially in the Shivalik hills. As a tree species in natural forests, *S. robusta* not only holds higher economic value but also serves as an important ecological benefit in the form of slackening global warming and climate change through sequestering atmospheric carbon dioxide (Shrestha et al 2023). It contributes to approximately 10.87% of total growing stock in country's forests (ISFR, 2021). However, its capacity to store carbon can vary along the elevation gradient which may, furthermore influence the amount of greenhouse gases from the atmosphere, an important phenomenon to slowdown the process of global warming.

Forests store approximately half of total carbon of earth and therefore, their role in climate change mitigation is widely recognized (Ekholm 2016, Gren and Zeleke 2016). Generally considered that as a complex terrestrial ecosystem, forests play a profound role in reducing ambient CO_2 levels as they contribute from 20 to 100 times more carbon sequestration per unit area than agrarian lands. In addition to this, mechanism to regulate regional and global carbon (C) cycle through carbon sequestration requires information on tree carbon stock for different species in different regions with varied local environmental conditions. Due to different climatic conditions, forests are markedly different in their individual types. In India, the diversity level of subtropical forests of Northern Himalayan region in Uttarakhand is different from the subtropical forests of Arunachal Pradesh with varied rate of ecological functioning (Himshikha et al 2022). Forest biomass consists of above ground and below ground biomass (Nonini and Fiala 2019, Bhandari and Chhetri 2020). On average, 50% of the biomass is estimated as the carbon content for all species of trees. Empirical measurements of below ground biomass are time consuming, costly and difficult. Therefore, BGB is often estimated using a constant proportion of AGB. In milieu of assessing sequestration potential of any tree species, AGB and BGB need to be measured to enable better calculations of total forest carbon particularly in different geographic conditions. There have been relatively few studies on below ground biomass and carbon stock, particularly in mountainous region. There is an information gap on the altitude wise differential amount of carbon stocking especially in *S. robusta* forests in Bhabhar area, a transitional zone of Shivalik Himalaya in Uttarakhand, India.

Among locality factors, altitude is the major factor affecting the properties of the soils in different forest ecosystems. In forests, soil is also an important pool for storing a huge amount of atmospheric carbon and twice soil organic carbon (SOC) as vegetation and two-thirds as much as the atmosphere (Shreshtha et al 2023). Soil carbon plays a critical role in the global carbon cycle and is an important tool for mitigating the effects of climate change (Fageria 2012). Sakin (2012) suggested that about 55–58% of the soil organic matter (SOM) contains SOC. Soil C stocks and forests in general, act as a carbon sink, removing CO_2 from the atmosphere and therefore mitigate climate change (Mauki et al 2023). The quantification from natural forests in vegetation transition zone becomes more important to estimate their potential in mitigating impacts of climate change as such sensitive zones are important for policy prescription and management planning and harboring ecological services from the species in the region. Species in transitional areas often display adaptive response and therefore, such areas may be crucial for long-term biodiversity conservation and mitigation of climate change. To assess the impact of deforestation and re-growth or regeneration rates on the global carbon cycle, it is necessary to know the stocks of carbon as biomass per unit area for forest types from different perspectives on locality factors under singular agro-climatic zone. The effective monitoring of forests in vegetation transition zone is essential to understand the carbon cycle and its' responses to climate change and anthropogenic activities. Additionally, can provide useful details on the structural and functional characteristics of forest ecosystems along the altitudinal gradient. The hypothesis is that tree and soil carbon stock in sal forest generally changes along with the change in altitude in Bhabhar zone of Uttarakhand.

MATERIAL AND METHODS

Study area: The experiment was conducted in three locations in sal (*S. robusta*) dominated forest along vertical elevation gradient (400-1300 m) in Duggada forest range from Pauri Garhwal Forest division, Uttarakhand. The area comes under tropical to sub-tropical forest zone of Shivalik Hills situated in Western Himalaya. All selected forest stands are managed by State Forest Department. The area lies between latitudes 78° 34' and 78° 37' E and longitudes 29° 46' and 29° 50' N. The elevation gradients were established through three elevation grids, the higher, mid and lower elevation as zone I (400-700 m), II (701-1000 m) and III (1001-1300 m).

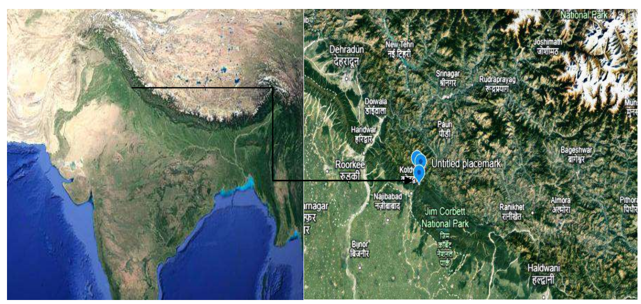
Sample plot design and tree measurements: The study employed a systematic random sampling method to collect data at each altitudinal zone. Total 30 sample plots sizes of 10 m×10 m, 10 sample plots at each altitudinal range were randomly selected for field measurement and sampling purpose of trees (Fig. 1).

For sampling of soil, 1 m x 1 m quadrates were dug to 30 cm depth to collect soil samples from each plot. Data were collected from the field survey that includes measurement of tree parameters (height and girth). Trees with ≥ 30 cm girth at breast height (≥10 cm DBH) at 1.37 m within sample plots were selected for measurement (Joshi et al 2021). For estimation of tree biomass, the quantitative data were obtained from 96 trees. Trees on the border were included if > 50% of their basal area falls within the plot and, excluded if < 50% of their basal area falls outside the plot. Determination of tree basal area and tree volume was carried out using tree form factor method.

Estimation of Biomass and Carbon Content

Above ground biomass (AGB): AGB is described by IPCC (2006).

AGB (t ha^{-1}) = Stem Volume × wood density × biomass expansion factor



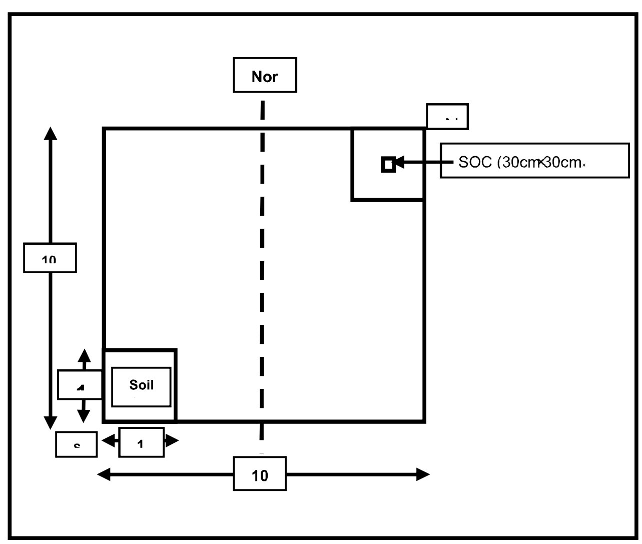


Fig. 1. Sample plot design for enumeration of trees and soil sampling

For the estimation of AGB, wood density scale was used as 0.72 and biomass expansion factor as 3.4 (IPCC, 2003).

Below ground biomass (BGB): It is recommended to estimate BGB as 26% of AGB (IPCC, 2003). IPCC (2006) has suggested carbon fraction as 0.50.

BGB (t ha^{-1}) = AGB × conversion Factor (0.26)

Total biomass: After acquiring the biomass per ha, it was multiplied by a default carbon fraction of 0.5 to calculate the net carbon content (carbon stock density per ha).

Total biomass (t ha^{-1}) = *AGB + BGB*

Carbon stock density (t ha^{-1}) =Total biomass × carbon fraction

Tree/stand biomass, volume of tree stem or bole: This was calculated as:

Stem/ bole volume ($m^3 ha^{-1}$) = Form factor × Tree height × Tree basal area

Form factor: This was calculated as:

Form factor (F) = 2 H1 / 3H

Whereas, H1 = Tree height at which diameter is half of diameter at breast height;

H = Total height of tree

Soil analysis

Soil moisture: The soil moisture content (MC %) was calculated as follow:

$$MC (\%) = \frac{\text{Fresh weight– Oven dry weight}}{\text{Fresh weight of soil}} \times 100$$

Soil organic carbon (SOC): Walkley and Black Wet Digestion Method was used to determine SOC % (Abraham 2013).

Actual soil organic carbon: There is incomplete oxidation of organic matter in this procedure. Therefore, the organic carbon was multiplied by 1.32 on the assumption that there was 77% recovery.

Actual soil organic carbon (%) = Soil organic carbon × 1.32

Soil carbon stock = SOC (%) × bulk density × soil depth

Statistical analysis: Data were analyzed using descriptive and inferential statistical tools on MS Excel 2010 and SPSS software.

RESULTS AND DISCUSSION

Tree Carbon Stock

Basal area and volume: The lowest average tree basal area and volume (7.37 $m^2 ha^{-1}$ and 44.23$m^2 ha^{-1}$) was in the lower altitude (400-700m) followed by 11.47 $m^2 ha^{-1}$and 108.58 $m^2 ha^{-1}$at middle (701-1000 m) and highest (20.27 $m^2 ha^{-1}$ and 186.84 $m^2 ha^{-1}$) in the uppermost side (1001-1300m) in the forest.

AGB and BGB: AGB and BGB was highest (288.15 t ha^{-1} and 118.92t ha^{-1}) in the lower side, followed by mid (167.47 t ha^{-1} and 69.11 t ha-1) and lowest values (66.77 t ha^{-1} and 28.14 t ha^{-1}) at higher elevations. Similarly, total tree carbon stock were as 457.38 t ha^{-1} (highest) in lower 265.82 t ha^{-1} in mid zone and, 105.59 t ha^{-1}in the uppermost elevation (Table 1).

The studied parameters decreased significantly with increasing altitude (Except tree basal area). Tree carbon stock showed strong inverse correlation with altitude, indicating a strong negative correlation with elevation gradient. It could be due to less anthropogenic disturbance and differences in temperature regime between lower (Tropical zone) and upper elevations (Subtropical zone) limiting to tree growth along the altitudinal gradient. The contribution of above-ground and below-ground biomass of trees to the total biomass in the present study was 70.79 and 29.21 % from zone I and II, while was slightly varied as 70.35 and 29.65%, respectively at zone III (Table 2). Nandal et al (2019) mentioned contribution of AGB and BGB as 81.4 to 85.9 and 14.1 to 18.6 percent in total tree biomass. The findings favor to the fact that carbon quantification varies at regional to local scale depending on microclimatic and other environmental factors followed by various silvicultural and forest management practices adopted by concerned authorities.

Table 2. Percentage of AGB and BGB for TB in study area

Zone	AGB (%)	BGB (%)
I (400-700 m)	70.79	29.21
II (701-1000 m)	70.79	29.21
III (1001-1300 m)	70.35	29.65

Table 1. Average basal area, volume and total carbon stock in *Shorea robusta*

Elevation zone	Basal area (m^2 ha^{-1})	Volume (m^3 ha^{-1})	AGB (t ha^{-1})	BGB (t ha^{-1})	TB (t ha^{-1})	Total carbon stock (t ha^{-1})
I (400-700 m)	20.27 ± 2.26	186.84 ± 27.73	288.15 ± 42.77	118.92± 17.65	407.07	457.38 ± 67.88
II (701-1000 m)	11.47 ± 2.10	108.58 ± 23.57	167.47 ± 36.63	69.11 ± 15.12	236.58	265.82 ± 58.15
III (1001-1300 m)	7.37 ± 0.00	44.23± 6.51	66.77 ± 9.77	28.14 ± 4.15	94.91	105.59 ± 17.17
r value	0.99	0.99	0.99	0.99	0.99	0.99
p value (≤ 0.05)	0.13	0.04*	0.03*	0.04*	0.04*	0.03*

r = Correlation coefficient, p-value = Significance level*

Table 3. Correlation of soil properties (Moisture, BD, SOC% and SOC stock) with altitude

Elevation zone	Soil moisture (%)	BD (g cm)$^{-3}$	SOC (%)	SOC Stock (t ha^{-1})
I (400-700 m)	1.94 ± 0.34	0.87 ± 0.5	1.24± 0.18	33.33 ± 6.23
II (701-1000 m)	1.43 ± 0.26	0.97 ± 0.03	1.22 ± 0.23	35.38± 5.99
III (1001-1300 m)	2.19 ± 0.23	0.86 ± 0.03	1.55 ± 0.23	40.96 ± 6.66
r Value	0.32	0.08	0.84	0.97
p Value (≤ 0.05)	0.79	0.95	0.37	0.17

r = Correlation coefficient, p-value = Significance level*

Soil Properties

Soil moisture, SOC% and BD: The highest value of soil moisture (2.19%), soil carbon stock (40.96) and SOC% (1.55%) was at higher elevation (1001-1300m). The lowest value of soil moisture and SOC (1.43 % and 1.22%) was in the middle altitude respectively. Opposite to SOC%, the highest value of BD was in middle altitude as 0.97g cm^{-3} whereas lowest BD (0.86g cm^{-3}) was in higher elevation (Table 3).

SOC stock (t ha^{-1}): Maximum amount of SOC stock (40.96 t ha^{-1}) was estimated from upper elevation while minimum (33.33 t ha^{-1}) at lower elevation. Soil samples from all three altitudinal gradients showed weak positive correlation between moisture, bulk density, SOC % and SOC with altitude. By depicting weak positive correlation, the statistical analysis confirmed that soil carbon stock increases as the elevation goes up. It might be possible due to change in temperature and at higher elevations, the soils generally exhibit low nutrient absorption due to increased slope. This may also happen because of the soil texture, constant input of carbon with less loss, decrease in the microbial and enzymatic activity due to the decreasing temperature (Imtimogla et al 2021). Jeyakumar et al. (2020) mentioned general trend of decreasing SOC and biomass carbon as altitude increases at higher side. Therefore, additional research efforts are required to explore effects of other locality factors on SOC content. The overall effect of elevated atmospheric CO_2 on soil structure is not very well understood yet and enhanced atmospheric CO_2 may result in the increase in photosynthesis and ensuing increase in photosynthate, roots and microbial communities and hence increased amount of SOC in certain species dominated forests such as *S. robusta*.

Other factors such as slope, grazing pressure, certain climatic factors such as humidity, precipitation aspect and temperature may accelerate the influence of altitude on carbon stocking in the species. One of the limiting factors might be that the upper altitude range selected for this study falls under the fire prone area of the Duggada forest range under state forest dept. The estimates acquired in the study suggest that natural population of Sal at lower elevations has the potential to store a large amount of CO_2 than the population found at upper elevations in the region. Overall, though altitude as alone, impacts negatively on carbon stocking potential of this species, the study suggest that other parameters such as stand structure, choice of management practices, slopes, vegetation dynamics, succession stages of the forest community, biological factors such as anthropogenic disturbance, management regime, grazing pressure, environmental factors such as temperature, precipitation and seasonal Indices etc. should also be considered while estimating the carbon stocking potential of tree species.

CONCLUSION

The findings confirmed that the elevation gradient factor significantly influences the rate of carbon sequestration in the natural population of *S. robusta* present at transition zone. The population from lower elevation showed potential to store a large amount of CO_2. Low carbon stocking in trees present at higher side was probably due to certain limiting factors such as successional stages, stand structure, fire, and anthropogenic influence at higher side. Increased SOC content with altitude might be an outcome of decreasing temperature and less microbial activity in the forest soil present in the higher elevation. Overall, the variations in carbon stocking is attributed to altitudinal characteristics in transitional zones. Hence, periodic inclusive research with multidimensional evaluation of local factors is recommended considering each critical factor while determining carbon stock quantities of tree species in transition zones such as Bhabhar in Shivalik Himalaya.

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