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Research Article

ASSESSMENT OF THE SOIL AND TREE CARBON STOCKS OF A CHIR PINE FOREST IN GARHWAL HIMALAYA, INDIA

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ABSTRACT
Carbon sequestration in forest soil and vegetation is one of the key approaches to reducing atmospheric carbon concentrations. The estimation of biomass and carbon stock in a forest is crucial for understanding the dynamics of the ecosystem. The present study deals with the estimation of carbon stock of standing trees and soil in Chir Pine forest in Garhwal Central Himalaya, India. Carbon stock of the standing tree was estimated using species-specific allometric equations. *Pinus roxburghii* (327 tree ha^{-1}) dominated the forest with the presence of fewer individuals of *Rhododendron arboreum* (33 tree ha^{-1}), *Myrica esculenta* (20 tree ha^{-1}), *Pyrus pashia* (13 tree ha^{-1}) and *Lyonia ovalifolia* (10 tree ha^{-1}). Above Ground Biomass ranged from 85.17 Mg ha^{-1} to 144.30 Mg ha^{-1}, Belowground biomass from 19.47 Mg ha^{-1} to 31.73 Mg ha^{-1}. Total carbon in the standing trees ranged from 49.18 Mg C ha^{-1} to 82.73 Mg C ha^{-1}. Soil organic carbon (up to 30 cm) ranged from 50.26 Mg C ha^{-1} to 66.17 Mg C ha^{-1}.

Keywords: *Carbon Stocks, Pinus Roxburghii Forest, Biomass, Organic Carbon, Himalaya*

INTRODUCTION
Vegetation and soil play a crucial role in the global carbon cycle and global climate change. Huge quantities of carbon are stored in the forests which become a source of carbon when they are disturbed by the humans or natural causes and become a sink during re-growth after disturbances (Brown *et al.*, 1996). Carbon storage efficiency in organic matter is an indicator of the quality of climate, soil structure, and nutrient availability (Chave *et al.*, 2001). In the Central Himalaya, *Pinus roxburghii* Sarg. forests are the dominant vegetation between 1000 m to 1800 m (Rana *et al.*, 1988). Chir pine forests are less diverse compared to the mixed forests in the region (Singh and Singh, 1987). Forests of Chir pine provide a valuable resource for timber and resin industries (Chaturbedi and Singh, 1982). Due to its economic value, monoculture plantations of Chir pine have been planted in many areas. Biomass estimation helps in taking decisions for the forest management (Applegate *et al.*, 1988). Therefore, this paper deals with a case study undertaken in a Chir Pine forest in Garhwal Central Himalaya with an objective to estimate the carbon stocks in tree and soil.

MATERIALS AND METHODS
Study Area
Uttarakhand has an area of 53483 km^2. The state has a predominantly temperate climate except for the plain regions with a tropical climate. The average annual rainfall in Uttrakhand is 1550 mm, and temperatures range from sub-zero to 43°C (FSI, 2009). With a total forested area of 34691 km^2, it constitutes 64.79% of the geographical area of the state (FSI, 2009). The soil of the Uttarakhand Himalayas, in general, is quite shallow, gravelly, and are not very fertile. In vast areas of the region, the soil is mixed with fragments of the parent rocks occurring within a few centimetres, except in valleys or depressions where they go up to two meters.

The present study was carried out in Chir pine forest in Rudraprayag district, Uttarakhand. The study area in the Ukhimath block lies between 30° 31' 37.77'' N to 30° 31' 49.48'' N latitude and 79° 05' 57.06'' E to 79° 06' 10.49'' E longitude [Figure 1]. The altitude ranges between 1500 m -1700 m above sea level. The area receives 300 cm of annual precipitation of which the rainy months (June-August) contribute approximately 60%. The relative humidity varies from 35 to 85% annually. There is moderate to heavy snowfall during December-February. The mean monthly minimum temperature ranges between 2.0°C

(January) and 12.0°C (August). The mean maximum temperature ranges between 13.0° (February) and 26.0°C (June). There is with moderate to heavy snowfall in winter season from December to March [Figure 2].

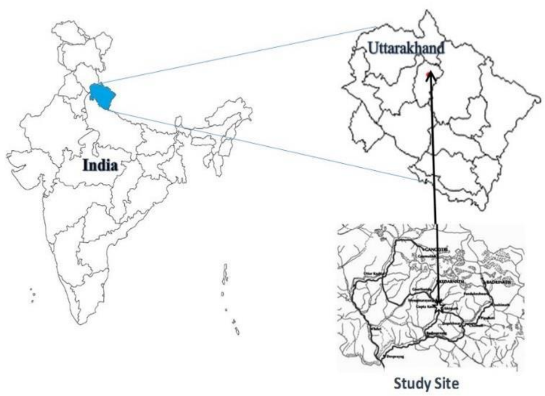

Figure 1: Location Map of the Study Site

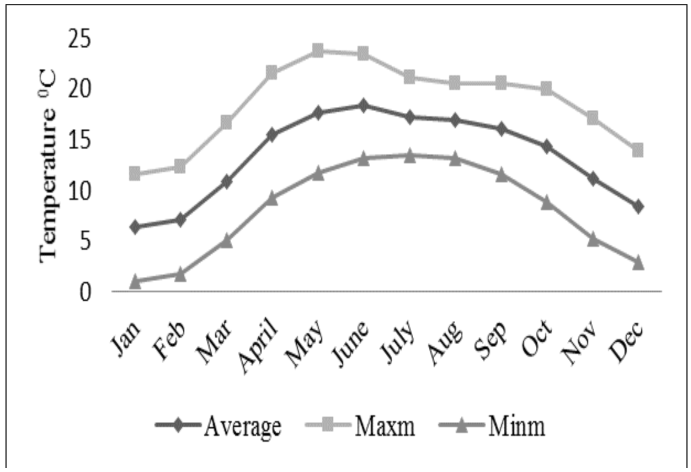

Figure 2: Monthly Temperature Variation in Study Site (Forest Department of Uttarakhand, 2009)

Sampling and Data Analysis

After reconnaissance survey, ten 10m x 10m quadrats were laid for Vegetation analysis at three altitudinal gradients in the forest. The woody vegetation was analysed for species richness, density and diversity following standard methods. The basal area of the tree (πr^2) is calculated from the circumference at breast height (CBH) measured at 1.37 m height.

The basic criteria for site selection were Chir Pine dominant forest sites, aspects, position on a hill slope and altitude. Five permanent plots have been established in Chir pine forests of Ukhimath Block along an altitudinal gradient of approximately 50 m. The size of plots to be laid was decided following Pearson *et al.* 2005 [Table 1]. Circular plots with 20 m radius were established for the present study.

Table 1: Size of Permanent Plots for Carbon Stock Measurement (Pearson *et al.*, 2005)

Stem Diameter	Circular Plot Radius	Square Plot Dimensions
< 5cm dbh	1m	2m x 2m
5–20cm dbh	4m	7m x 7m
20–50cm dbh	14m	25m x 25m
> 50cm dbh	20m	35m x 35m

While placing permanent plots, if the slope was >10%, a correction for the area was performed using the following formula:

L = Ls x cosS

Where, L is the true horizontal plot radius, Ls is the standard radius measured in the field along the slope and S is the slope in degrees.

After the correction, the plot area will be:

Area = π x standard radius (Ls) x slope plot radius (L)

The Diameter at Breast Height (DBH) at 1.37 m of individual trees greater than or equal to 5 cm DBH were measured in each permanent plot and the trees were marked with paint. Existing species-specific allometric equations were used to calculate the biomass of the tree following Chaturvedi and Singh, (1982). The sum of the biomass of all the trees in the plot provides the plot biomass. The carbon stock of the tree is calculated by assuming that the carbon content is 47% of the total tree biomass (IPCC, 2006).

Soil samples are collected with the help of a metal core (8cm diameter) from 5 random places in each permanent plot. With the metal core, soil samples are retrieved from three depths *viz.* 0-10cm, 10-20 cm and 20-30 cm. Soils are brought to the lab in polybags for analysis. Soil samples are air-dried, crushed and sieved through a 2 mm mesh sieve. For organic carbon estimation, Walkley and Black's (Walkley, 1947) was used, which is a widely used procedure (Pearson *et al.*, 2005). In Walkley and Black's method, only about 60–86 % of soil organic carbon (SOC) is oxidised; therefore, a standard correction factor of 1.32 (considering recovery of 76% organic C) was used to obtain the SOC values (De Vos *et al.*, 2007). For the estimation of bulk density, undisturbed soil cores from three depths (0–10cm, 10–20cm, and 20–30 cm) would be taken by soil core sampler. The soil samples are oven-dried at 105±5 °C for 72 h and weighed. The coarse fragments in the soil are separated by a 2 mm mesh sieve and weighed. The bulk density is calculated using the following formula (Pearson *et al.*, 2005).

Bulk density (g cm^{-3}) = Oven dry mass (g cm^{-3}) / Core volume (cm^3) - (Volume of rock fragments cm^{-3})

Soil Carbon stock is calculated for each soil layer based on the thickness of the soil layer, its bulk density and Carbon concentration. The total Carbon content is estimated by summing up the Carbon content of all layers (Pearson *et al.*, 2005).

SOC = (ρ x d x C) x 100

Where,

SOC = soil organic carbon stock per unit area (Mg/ha)

ρ = soil bulk density (g/cm3)

d = soil depth (cm)

C =carbon concentration

RESULTS AND DISCUSSION

The forest under study was dominated by *Pinus roxburghii* (327 tree ha^{-1}) with the presence of fewer individuals of *Rhododendron arboreum* (33 tree ha^{-1}), *Myrica esculenta* (20 tree ha^{-1}), *Pyrus pashia* (13 tree ha^{-1}) and *Lyonia ovalifolia* (10 tree ha^{-1}). *Pinus roxburghii* had the highest total basal area (28.66 m^2 ha^{-1}) followed by *Rhododendron arboreum* (0.78 m^2 ha^{-1}), *Myrica esculenta* (0.64 m^2 ha^{-1}), *Pyrus pashia* (0.42 m^2 ha^{-1}) and *Lyonia ovalifolia* (0.14 m^2 ha^{-1}) [Table 2].

Table 2: Vegetation Analysis of Trees in the Chir Pine Forest

Species	**Density (Individual ha^{-1})**	**Frequency (%)**	**Abundance**	**A/F Ratio**	**TBA (m^2 ha^{-1})**	**IVI**
Pinus roxburghii	327	100	3.27	0.032	28.66	238.34
Rhododendron arboreum	33	20	1.67	0.083	0.78	23.58
Myrica esculenta	20	20	1	0.05	0.64	19.38
Pyrus pashia	13	6.67	2	0.3	0.42	8.92
Lyonia ovalifolia	10	10	1	0.1	0.14	9.33

TBA= Total Basal Area, IVI= Important Value Index

Site parameters of the five permanent plots established in the Chir pine forest are given in table 3. Among the five plots, Plot P2 had the highest tree density (438 tree ha^{-1}), and plot P5 had the lowest (350 tree ha^{-1}).

Trees were categorized into the following DBH (Diameter at Breast Height) classes 5-10 cm, 10-20 cm, 20-30 cm, 30-40 cm, 40-50 cm, 50-60 cm and 60-70. There were 7, 103, 133, 87, 57, 7 and 10 trees ha^{-1}, respectively, in the above girth classes [Figure 3].

Table 3: Site Parameters of the Five Permanent Plots Established in the Chir Pine Forest

Plot	Latitude	Longitude	Elevation	Aspect	Slope	Tree Density (ind. ha^{-1})	TBA (m^2 ha^{-1})
P1	30º 31' 46.2" N	79º 06' 00.1" E	1545 m	North West	17º	366	31.64
P2	30º 31' 43.4" N	79º 06' 00.7" E	1590 m	North West	15º	438	35.7
P3	30º 31' 41.2" N	79º 06' 03.8" E	1645 m	North West	19º	366	27.3
P4	30º 31' 37.5" N	79º 06' 06.9" E	1700 m	North West	22º	414	31.56
P5	30º 31' 43.1" N	79º 06' 08.3" E	1655 m	North West	27º	350	24.75

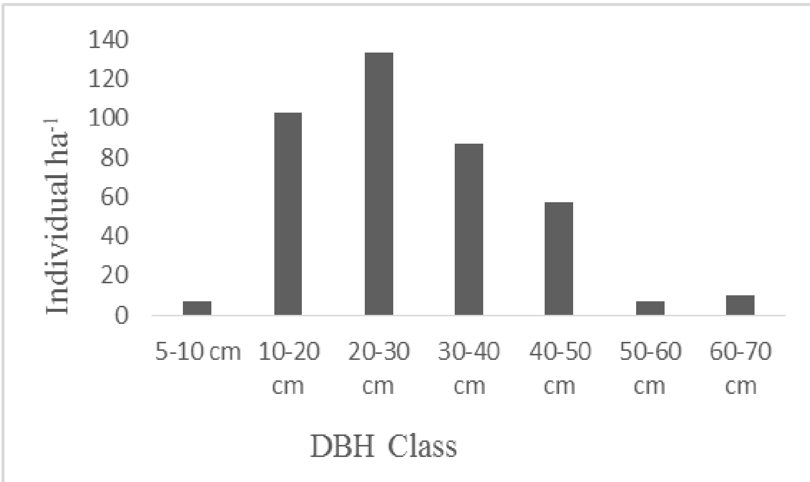

Figure 2: Density-Diameter Distribution of the Trees in the Forest

Total carbon in the tree ranged from 49.18 Mg C ha^{-1} (plot P5) to 82.73 Mg C ha^{-1} (plot P4), and the total soil carbon ranged from 50.26 Mg C ha^{-1} (plot P5) to 66.17 Mg C ha^{-1} (plot P4) [Figure 4 and Figure 5]. Figure 6 shows depth-wise soil carbon stock and figure 7 shows depth-wise soil carbon stock variation in the plots.

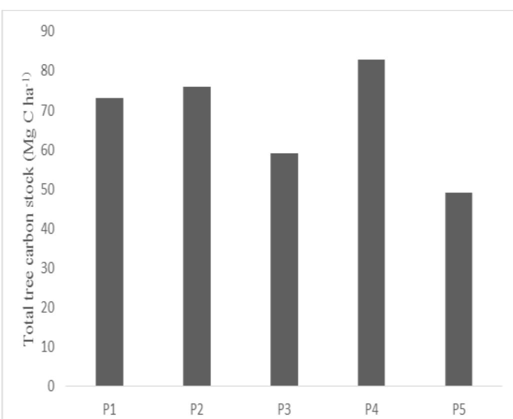

Figure 4: Tree Carbon Stocks in the Plots

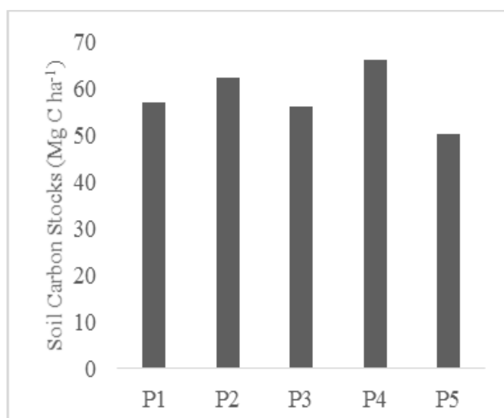

Figure 3: Soil Carbon Stocks in the Plots

Tree density ranged from 350 individual ha^{-1} to 438 individual ha^{-1} in the plots which is comparable to 485 individual ha^{-1} reported for the pine dominated forest in Uttrakhand Himalaya. It is higher than 130.4 individual ha^{-1} reported for Oak-Pine forest in Kumaun region (Ahmed, 2012). The density is on the lower side than 920-1345 individual ha^{-1} reported for natural forests of Lohaghat (Lodhiyal *et al.*, 2014), 540-1630 individual ha^{-1} for pine forests in Kumaun region (Chaturvedi and Singh, 1987) and 685.0 ± 108.0 individual ha^{-1} for pine forest in Garhwal region (Sharma *et al.*, 2010).

The Chir pine forest under study had 117.96 ± 9.54 Mg ha^{-1} total above ground tree biomass (AGB) and 26.67 ± 2.04 Mg ha^{-1} total belowground tree biomass (BGB). Total tree biomass (TB) was 144.63 ± 11.57 Mg ha^{-1}, and total tree carbon stock (TC) was 67.98 ± 5.44 Mg C ha^{-1}. These values are comparable to the total biomass reported by Chaturvedi and Singh (1987) and Lal and Lodhiyal (2015), and lower than the value reported by Sharma et al. (2010 and 2011) in Pinus roxburghii forest. The total carbon stock in the soil was 58.36 ± 2.43 Mg C ha^{-1} [Table 4]. Total basal area (30.19 ± 1.90 m^2 ha^{-1}) in this study was comparable with 25-45 m^2 ha^{-1} (Chaturvedi and Singh, 1987). It is lower than 36.3-56.4 m^2 ha^{-1} (Lal and Lodhiyal, 2015) reported for pine forest in Kumaun Himalaya and 58.66-93.00 m^2 ha^{-1} reported for natural forests (Lodhiyal *et al.*, 2014).

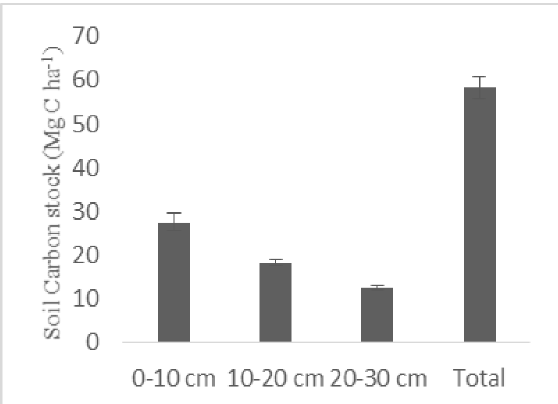

Figure 6: Soil Carbon Stocks in the Forest

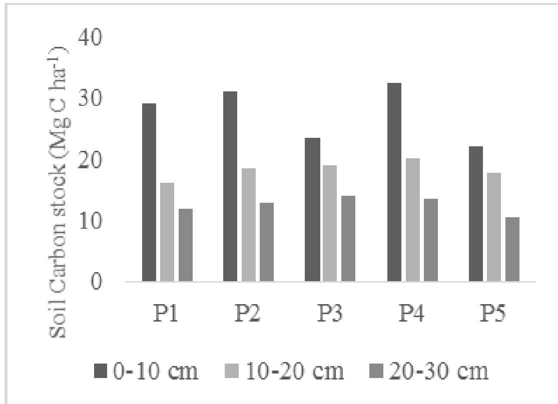

Figure 4: Soil Carbon Stocks in the Plots

Table 4: The Tree Carbon Stock Values (Mg ha^{-1})

Forest Community	n	AGB	BGB	AGC	BGC	TB	TC
Pinus roxburghii dominated community	5	117.96 ± 9.54	26.67 ± 2.04	55.44 ± 4.49	12.54 ± 0.96	144.63 ± 11.57	67.98 ± 5.44

AGB= Above Ground Biomass, BGB= Below-Ground Biomass, AGC= Above-Ground Carbon, BGC= Below Ground Carbon, TB= Total Biomass, TC= Total Carbon, n= number of plots. Values are in the form of mean ± standard error.

Conclusion

It is a well-known fact that vegetation and soil play a crucial role in the global carbon cycle and global climate change. Estimation of the biomass and carbon stock helps in taking decisions for the forest management.

The present study and various other studies regarding biomass and carbon stock conducted in the Chir pine forests have reported that these conifer forests sequester a significant amount of carbon. This information will greatly help in the efficient management of these ecosystems.

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Authors' Contributions

Mr B. K. Mishra developed the main research design; did all the field work, made the final discussion, conclusion, wrote the manuscript and also is the corresponding author of this paper.

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