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Variation in Tree Biomass and Carbon Stock of *Pinus roxburghii* Sarg. along an Altitudinal Gradient in Jammu-J&K, India

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***Abstract*:** The current study was carried out in the *Pinus roxburghii* forest of Billawar forest range in Kathua district of Jammu to estimate the tree biomass, carbon stock and soil organic carbon (SOC) at three altitudinal range i.e. lower (1000-1300 m), middle (1300-1500 m) and upper (1500-1800 m). Tree density, tree diameter, tree height, growing stock volume density (GSVD) and tree basal area decreased with increase in altitude. Similarly, above ground biomass density (AGBD), below ground biomass density (BGBD), total carbon density (TCD) and equivalent CO_2(eCO_2) in Mg ha^{-1} was recorded maximum at lower altitude i.e. 225.97 ± 14.04, 63.27 ± 3.93, 135.94 ± 8.44 and 498.90 ± 31.00 respectively. Soil bulk density and pH also decreased with increase in attitude. Reverse trend was observed for SOC which was maximum (13.70 ± 0.50 g kg^{-1}) at upper altitude and minimum (9.73 ± 0.64 g kg^{-1}) at lower. *Pinus roxburghii* recorded maximum growth and biomass production at an altitudinal gradient around 1000-1300 m therefore, resulting in maximum CO_2 sequestration in this range.

***Keywords*:** Biomass, Carbon stock, Soil organic carbon, *Pinus roxburghii*, Altitude, Billawar

Global warming is responsible for the climate change, which is a burning issue of today. Despite of all the efforts, there is a continuous rise in global average temperature due to increasing green house gases. Carbon dioxide (CO_2) is the major green house gas contributing to about 76% (EPA 2017) of all other gases such as chlorofluro carbons, ozone, methane, water vapour and nitrous oxide. The concentration of CO_2 in the atmosphere is increasing due to the anthropogenic activities such as deforestation, burning of fossils fuel and change in land use and land cover. Globally during the last decade, the concentration of CO_2 in the atmosphere has increased from 391 to 414.66 ppm (NOAA 2021). Growing global concern over increasing levels of CO_2 in the atmosphere has led to underlining the various mitigation options. Sequestering carbon in trees is one such option. Among all the ecosystems, forests are considered to be the best and most reliable reservoir of carbon due their long term storage in the form of wood (Liu and Nan 2018) making them suitable for combating climate change. Globally, forests cover an area of 4.06 billion ha i.e. 31% of total land area, that contains 557 billion m^3 of growing stock with a total of 662 gigatonnes of carbon stock (FAO 2020). Forest biomass contributes approximately 90% of all the living terrestrial biomass and thus is the largest carbon pool (Khera 2001). However, deforestation due to natural and human activities have certainly reduced their role in mitigating climate change. In the last five years, globally deforestation rate was 10.20 million ha yr^{-1} (GFGR 2021). Estimation of carbon preserved in the forest is significant towards calculating the efficiency of the forests and its positive contribution to global change (Litton et al 2004). It is also useful for achieving the targets of $REDD^+$ (Reducing Emission from Deforestation and Forest Degradation) policy initiated at the Kyto Protocol (Djomo et al 2010). Different forest species are adapted to different climatic conditions, therefore knowledge of a species with respect to its carbon sequestration potential at a particular location is essential (Chauhan et al 2004).

Pinus roxburghii (Chir Pine) is an indigenous tree species of subtropical region of the Himalayan range spreading from Afghanistan, India, Nepal and Bhutan covering an area of about 8.90 lac ha (Jasrotia and Raina 2017). According to Champion and Seth (1968) classification of Indian forests, Chir Pine forests are categorised under Himalayan subtropical pine forest ($9/C_1$). It is a climax species and almost forms a pure forest at an elevation of 900-1800 m, however, it descends down to an altitude of 500 m and ascends up to 2200 m. Microclimate varies from elevation to elevation and will seriously impact the production of biomass and carbon stock, therefore it is very important to know the altitudinal range in which it sequesters maximum carbon. Biomass and carbon stock in a forest are affected by various locality factors (Climatic, edaphic, topographic and biotic) which are responsible for the growth of vegetation and distribution of species diversity (Bhatt et al 2020). Among these factors, altitude (topographic) is the most important environmental gradient as it decides the temperature system and diversification of forest species (Enright et al 2005) which is responsible for the distribution and storage of carbon. Increase in altitude affects the precipitation and temperature which brings about change in climate along the elevation thus influences the productivity of vegetation and affects the amount of soil organic matter and soil organic carbon (SOC) (Tao et al 2019). Twenty four per cent of the global land area is covered by mountains which is facing rapid climate change from past many years. In the past many studies have been carried out in relation to the species composition and distribution along the altitudinal gradients (Becker et al 2007) but studies related to pattern of biomass and carbon stock distribution along the attitudinal gradients are limited to few researchers like Bhardwaj et al (2021) in Himachal Pradesh, Kumar et al (2013) and Singh et al (2009) in Uttarakhand. Therefore, the present study was carried out in the Billawar forest division of Kathua district of Jammu division, Union territory of Jammu & Kashmir to study the pattern of biomass and carbon stock distribution in *Pinus roxburghii*, as well as SOC along the three altitudinal gradients.

MATERIAL AND METHODS

Study area : The study was carried out in the year 2020-21 at the Billawar forest range of Billawar forest division in Kathua district of Jammu division in the union territory of Jammu & Kashmir, India (Fig. 1) in the *Pinus roxburghii* forest along the three altitudinal gradients i.e. lower (1000-1300 m), middle (1300-1500 m) and upper (1500-1800 m). The area lies within the 32^{0} 38.68'' N to 32^{0} 40.09'' N latitude and 75^{0} 35.17'' E to 75^{0} 37.70'' E longitude. Billawar forest division is bounded by Bhaderwah and Ramnagar forest division in the north, Kathua forest division in the south, Jammu forest division in the west and towards the east it is separated from Chamba district of Himachal Pradesh by the river Ravi. The climate is subtropical in the lower elevation which gradually changes to temperate on the higher altitudes. The mean annual rainfall is around 1500 mm. (Billawar forest working plan). The famous spot around the sampling plots were Sukrala Mata temple and Machedi Mata temple. The site had almost pure Chir Pine forest but in some patches, species like *Phoenix sylvesteis* was also found. Towards the upper limit of Chir Pine was associated with temperate tree species such as *Quercus leucotrichophora*, *Quercus semicarpifolia*, *Rhododendron arboretum*, *Lyonia ovilifolia*, and *Pyrus pashia*.

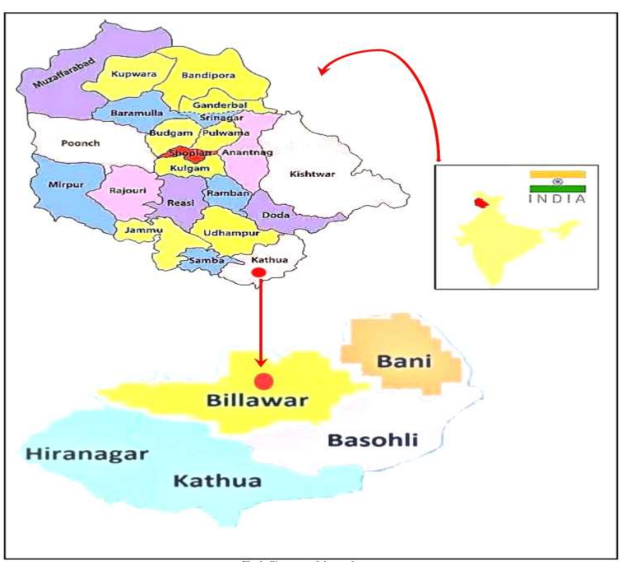

Fig. 1. Study area

Sampling and data collection: Random sampling method was used for collecting the data, sampling plots were selected after going through topographical maps. The data were collected along an altitudinal gradient from 1000 m to 1800 m and was divided into three categories namely lower (1000-1300 m), middle (1300-1500 m) and upper (1500-1800 m). Five quadrates of size 20 x 20 m^2 were laid out in each category. All the trees within the quadrate were painted with yellow paint at breast height (1.37 m) and diameter at breast height (dbh) was recorded with help of tree calliper. The tree height was measured with help of Nikon Forestry Pro Laser Rangefinder 8381. The growing stock volume density (GSVD) (m^3 ha^{-1}) was determined with the help of species specific regression equation ($\sqrt{V}$=0.05131+ 3.98598D–1.0245$\sqrt{D}$) (D: dbh) developed by FSI (1981) for *Pinus roxburghii* of western Himalayas. The above ground biomass density (AGBD) was estimated by multiplying GSVD with the wood density of *Pinus roxburghii* which was taken as 0.46 g cm^{-3} (Uniyal et al 2002), this was further multiplied with suitable biomass expansion factor of 1.3 (Brown 1997) to calculate AGBD for tree components such as stem, twigs, branches and leaves. The below ground biomass density (BGBD) was determined by multiplying the factor 0.28 to the AGBD (Mokany et al 2006). Total biomass density (TBD) was obtained by adding AGBD and BGBD. For calculating above ground carbon density (AGCD) and below ground carbon density (BGCD), factor 0.47 (IPCC 2006) was multiplied to AGBD and BGBD respectively. Likewise, total carbon density (TCD) was estimated by summing AGCD and BGCD. Carbon dioxide equivalent (eCO_2) was calculated by multiplying TCD to factor 3.67 (ratio of CO_2 to C) (Siraj 2019).

Composite soil samples were collected from each quadrate at a soil depth of 0-30 cm in a randomized pattern. The soil samples were collected in poly bags and were shade dried, sieved with 2 mm sieve and stored in zip lock poly bags for further analysis at the laboratories of the Division of Soil

Science & Agricultural Chemistry, SKUAST-Jammu. The bulk density was determined with the help of core tube method (Johnson 1962), the soil samples for bulk density were oven dried at 105°C till all the moisture was removed. The weight of oven dried sample was dived by its initial volume to obtain the bulk density on dry weight basis. Soil pH was determined in 1:2.5 soil: water suspension with the help of glass rod pH meter (Jackson 1973). Soil organic carbon (SOC) was estimated with the wet digestion method as suggested by Walkley and Black (1934).

RESULTS AND DISCUSSION

Tree growth parameters: Mean tree density of *Pinus roxburghii* was maximum (433 trees ha^{-1}) in lower altitude, whereas, lowest (269 trees ha^{-1}) in the upper altitude (Table 1). Mean tree diameter was maximum (35.10 cm) at middle altitude and minimum (31.84 cm) at upper altitude. Similarly, mean tree height was maximum (18.25 m) in the lower altitude and minimum (15.83) at upper altitude. There was a decrease in GSVD with increase in altitude, highest (377.87 m^3 ha^{-1}) reported from lower altitude and lowest (217.29 m^3 ha^{-1}) from upper altitude. The maximum and minimum tree basal area was 37.67 and 22.60 from the lower and from upper altitude. In the current study, tree growth parameters such as tree density, diameter, height, GSVD and basal area decreased with increase in altitude. This variation in growth parameters could be due to various site factors, lower altitudes have better moisture condition and higher temperature whereas, higher altitude suffer from nutrient leaching and moisture deficiency (Singh et al 2016). Chir Pine is a subtropical tree growing in warmer locations and its growth is affected by temperature which decreases with increase in altitude. Such decrease in growth parameters of *Pinus roxburghii* has been reported by earlier researchers (Bhardwaj et al 2021, Kumar et al 2013 and Singh et al 2009). The higher mean tree density, mean diameter and mean tree height at lower altitude are similar to the results reported by Banday et al (2017). However, at lower altitude higher tree density, lesser diameter and lesser tree height was reported by Kumar et al (2013) and Singh et al (2009) from Garhwal Himalayas. Similarly, less tree density, more tree diameter and more tree height from lower altitude was reported by Kumar et al (2021). Theses variation at similar altitude in growth parameters from place to place may be due to the difference in the ages of trees and due to various biotic and abiotic factors, aspect, soil characteristics etc.

Biomass and carbon stock: AGBD decreased with increasing altitude, maximum (225.97 Mg ha^{-1}) was at lower altitude whereas, minimum (129.94) at upper (Table 2). BGBD also followed the same trend as AGBD. TBD decreased with increasing altitude, maximum (289.24 Mg ha^{-1}) was from lower altitude whereas, minimum (166.32 Mg ha^{-1}) from upper. AGCD, BGCD and TCD also decrease with increasing elevation. The highest from the lower altitude (106.20 , 29.74 and 135.94 Mg ha^{-1}) while, lowest from the upper altitude (61.07, 17.10 and 78.17 ± 13.32 Mg ha^{-1}). eCO_2 was also maximum (498.99 Mg ha^{-1}) in lower altitude and minimum (286.89 Mg ha^{-1}) in the upper altitude. In the present study, biomass and carbon content per unit volume in different parts of tree (*Pinus roxburghii*) i.e. AGBD, BGBD,

Table 1. Growth parameters of *Pinus roxburghii* at different altitudinal gradient in Jammu, J&K, India

Altitude gradient (m)	Tree density (Trees ha^{-1})	Mean tree diameter (cm)	Mean tree height (cm)	GSVD (m^3 ha^{-1})	Mean tree basal area (m^2 ha^{-1})
Lower, 1000-1300 m	433 ± 30.05	32.68 ± 0.93	18.25 ± 0.19	377.87 ± 23.47	37.67 ± 1.79
Middle, 1300-1500 m	350 ± 62.91	35.10 ± 4.48	17.96 ± 1.71	302.86 ± 29.47	31.68 ± 4.53
Upper, 1500-1800 m	269 ± 52.42	31.84 ± 3.76	15.83 ± 0.70	217.29 ± 37.03	22.60 ± 3.34
Mean	351 ± 47.51	33.21 ± 0.98	17.35 ± 0.76	299.34 ± 46.39	30.43 ± 4.20
($p \leq 0.05$)	0.140	0.902	0.224	0.027	0.043

±: Standard error and GSVD: Growing stock volume density

Table 2. Biomass and carbon stock of*Pinus roxburghii* along thealtitudinal gradient (Mg ha^{-1})*in Jammu, J&K, India

Altitude gradient (m)	AGBD	BGBD	TBD	AGCD	BGCD	TCD	eCO_2
Lower, 1000-1300 m	225.97± 14.04	63.27± 3.93	289.24± 17.97	106.20± 6.60	29.74± 1.85	135.94± 8.44	498.90± 31.00
Middle,1300-1500 m	181.11± 17.62	50.71± 4.93	231.82± 22.55	85.12± 8.28	23.83± 2.32	108.96± 10.60	399.87± 38.91
Upper,1500-1800 m	129.94± 22.15	36.38± 6.20	166.32± 28.35	61.07± 10.40	17.10± 2.91	78.17±13.32	286.89± 48.90
Mean	179.01± 27.74	50.12± 7.76	229.13± 35.50	84.13± 13.03	23.56± 3.65	107.69± 16.69	395.22± 61.25
($p \leq 0.05$)	0.027	0.027	0.027	0.027	0.027	0.027	0.027

*Mega gram per hector, Mean ± Standard error, AGBD: Above ground biomass density, BGBD: below ground biomass density, TBD: total biomass density, AGCD: above ground carbon density, BGCD: below ground carbon density TCD: total carbon density and eCO_2: equivalent CO_2

Table 3. Soil pH, bulk density and soil organic carbon (SOC) in the *Pinus roxburghii* forest along the altitudinal gradient in Jammu, J&K, India

Altitude gradient (m)	Soil pH	Bulk density (g cm^{-3})	SOC (g kg^{-1})
Lower, 1000-1300 m	5.21 ± 0.09	1.29 ± 0.14	9.73 ± 0.64
Middle, 1300-1500 m	4.95 ± 0.10	1.23 ± 0.18	11.57 ±0.67
Upper, 1500-1800 m	4.87 ± 0.35	1.10 ± 0.15	13.70 ± 0.50
Mean	5.01± 0.10	1.21 ± 0.06	11.67 ± 1.15
($p \leq 0.05$)	0.650	0.667	0.005

Mean ± Standard error

TBD, AGCD, BGCD, TCD and eCO_2 decreased with increase in altitude. Similar trend of decrease in tree biomass and carbon stock along the altitudinal gradients have been reported by many researchers (Bhardwaj et al 2021, Kumar et al 2013, Singh et al 2009, Leuschner et al 2007 and Kitayama et al 2002).Various factors could be responsible for this decline in biomass accumulation with increase in altitude such as decline in optimum temperature, nutrient deficiency due leaching and higher runoff in upper altitude etc. The higher biomass and carbon stock in *Pinus roxburghii* forest from the lower altitude is similar to the findings of Banday et al (2017) from Himachal Pradesh. Low tree biomass and carbon stock in Chir Pine from upper altitude (>1600 m) have also been observed by earlier researchers (Pant and Tiwari 2020, Singh 2019, Kaur and Kaur 2016, Lal and Lodhiyal 2016, Kumar et al 2013, Pant and Tiwari 2013. Sharma et al 2010). Kaushal and Baishya (2021) have reported higher biomass from upper altitude. These variations in biomass and carbon stock of *Pinus roxburghii* at similar altitudes from different parts of the Himalayas may be due to the difference in the age of forest and due to the site quality factors.

Soil organic carbon (SOC): Soil pH decreased with an increase in altitude, maximum pH (5.21) was at the lower altitude and minimum pH (4.87) at upper (Table 3). Soil bulk density also followed the similar trend, it decreased with increasing altitude, maximum soil bulk density (1.29 g cm^{-3}) was at lower altitude, whereas, minimum soil bulk density (1.10 g cm^{-3}) was at upper altitude. Reverse trend was observed for SOC which increased with an increase in altitude, maximum (13.70 g kg^{-1}) at the upper altitude and minimum (9.73 g kg^{-1}) at the lower. In the present study, soil pH and bulk density were negatively related with the increasing elevation while SOC was positively related. Soil pH and bulk density are negatively correlated to SOC hence, maximum SOC led to minimum soil pH and bulk density in the upper altitude (Zhou et al 2020). Increase in SOC with increase in altitude may be due the slower decomposition of organic matter in the higher elevation and also due to the gradual change in vegetation composition. The increase in SOC in the *Pinus roxburghii* forest with increasing altitude are similar to the findings of Joshi et al (2021), Shapkota and Kafle (2021), Thakur et al (2020), and Kumar et al (2013_b), However, few researchers have also reported decrease in SOC with an increase in altitude (Bhardwaj et al 2021, Kumar et al 2013 and Sheikh et al 2010). The trend in variation of SOC from place to place may be due the variation in diversity of vegetation at different regions. Other factors such climatic conditions; soil texture, aspect and slope may also affect the SOC at a particular site.

CONCLUSIONS

The variations in tree growth parameters, biomass and carbon stock and soil organic carbon along the three altitudinal gradients are clearly marked in the present study. *Pinus roxburghii* which has a vast altitudinal and geographical stretch was found to accumulate maximum biomass and carbon stock in the altitudinal range around 1000-1300 m. Therefore, we can conclude that *Pinus roxburghii* sequesters maximum CO_2 in this altitudinal range in the Billawar forest of Jammu. Anthropogenic activities both directly and indirectly affect the regeneration and potential of forest in sequestering the CO_2, which can be controlled by proper supervision and management of the forest area.

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