Variability Assessment for Volume, Biomass and Carbon Stock in *Cedrus deodara* (Roxb) G.Don. Forests of Garhwal Himalaya

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ABSTRACT

Deodar is typically gregarious and is usually found in pure stands. It is one of the most important timber species in the forests of North Indian Himalayas. The objective of the present study was the assessment of variation in volume and biomass along with the carbon holding capacity of different deodar forests. The present study was undertaken in ten different forests sites, assessed by laying out three 0.1 ha sample plots randomly on each location. Total enumeration of trees within the sample plot was done by measuring girth and height of all the trees. Further, data collected from stand were computed for dbh, basal area, volume, stand density and canopy cover. The above ground biomass densities (AGBD), below ground biomass density (BGBD), total biomass density (TBD), total carbon density (TCD) were examined for variation of biomass and carbon stock. The results derived from field data during the study revealed that the values range from 42.10 to 57.07 cm (diameter at breast height), 1.37 to 2.84 m^2 trees^{-1} (basal area), 19.68 to 37.64 m (height), 1.44

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m^3 tree^{-1} to 4.27 m^3 tree^{-1} (volume), 227 to 407 individual ha^{-1} (stand density) and 57.91% to 80.60% (canopy cover) respectively. The values of AGBD (428.57 to 1279.51 Mg ha^{-1}), BGBD (97.41 to 256.14 Mg ha^{-1}), TBD (525.98 to 1535.65 Mg ha^{-1}), and TCD (767.83 to 262.99 Mg ha^{-1}) were recorded in different study sites and highest values was observed in Kanasar-I site. On the basis of above results it can be concluded that the healthy stand growth means presence of trees in all diameter classes. The Kanasar-I has more prominent capacity to storage biomass and carbon stock. Deodar being a slow growing conifer will provide a long term and high carbon storage than broadleaf species forest. Therefore, protecting deodar forest would have the largest impact, per unit area, on reducing carbon emission from deforestation.

1. INTRODUCTION

The Himalayas, known as the "abode of snow" in Sanskrit (Hima- Snow + alayas (House), expanded over India, Pakistan, Afghanistan, China, Bhutan, Nepal, and Tibet. The Himalayas are the main source of water for the major river in the Asian continent like the Indus, the Yangtze, and the Ganga-Brahmaputra. There is a need for research to understand this natural self-explanatory relationship between forest and river ecosystems and its services. The Indian Himalayan region covers approximately an area of 4,19,873 km^2 [1]. The Himalaya is well known for its enormous floristic and vegetation diversity as well as unique faunal diversity. The Himalaya region is also rich in cultural diversity such as Tibetan, Afghan-Iranian, Indic, Nepalic, and Indi-Mangol.

Cedrus deodara (Roxb) G.Don. is typically gregarious and is usually found in pure stands. It occurs throughout the Western Himalayas from Afghanistan to Garhwal up to the valley of the Dhauli below the Niti pass at an elevation ranging from 1200 to 3500 m. It's being most common from 1800 to 2600 m. The altitudinal range of what may be termed as the deodar belt is higher on the southern than northern slopes. The pure forests are especially typical of the inner dry valleys. It grows best and reaches its largest dimension in the cool situations on northern aspects. At higher elevation, it occurs only on the hotter aspect. The total area under the Deodar forest in India is estimated to about 2,03,263 ha comprising of 69,872 ha, 20,391 ha, and 1,13,000 ha in Himachal Pradesh, Uttarakhand, and Jammu & Kashmir, respectively [2]. *Cedrus deodara* is one of the most important and valuable timbers of northern India. Its most important use earlier was for railway sleepers. It is now mainly used in buildings for beam, doors, window frames, shutters and classified under the group-I timbers.

The growing stock is a major predictor for assessing the above-ground biomass [3] and total above-ground biomass [4], which is a fundamental variable for estimating the net carbon dioxide exchange between the land surface and the atmosphere. Biomass is defined as a total amount of organic matter existing in a unit area at one instance and describes by the weight of organic matter in a dry condition. Woody plants and trees can accumulate large amounts of carbon ((up to hundreds of tones ha^{-1}) over their lifespan [5]. Forest can be a carbon source and management of the forest can affect the global carbon cycle and climate change. Reviewed by Brown [6], approximately fifty percent of the biomass is carbon. According to Tipper [7], deforestation contributes about 1.8 Gigaton carbons (Gt/C) per year. On the other hand, forest removes CO_2 from the atmosphere through photosynthesis and an estimated 1.1 to 1.8 Gt C per year can be sequestered in 50 years [8].

The concept of forest biomass is easy to understand which is a total mass of living tree measured over a particular sample plot or forest area. All the living trees contain water (fresh mass) and the percentage of water varies from trees to trees, biomass was calculated as a dry mass. Dry mass is the mass of the tree that is left after all the water is removed. For plants, scientists use an oven to remove all the water from the plant material before weighing it to determine its biomass. Typical units of biomass measurement are grams per meter squared (g/ m^2). Biomass is one of the most important biophysical parameters which define the carbon budget in a terrestrial ecosystem. Through photosynthesis; trees accumulate carbon molecules and store them as a component of biomass. A forest is therefore an accumulation of carbon in plant biomass which has further been classified into pools as above ground representing the trunk, branches, leaves and

litter, or below ground comprising the soil and roots [9]. Above ground carbon pools are most prone to changes since they are directly affected by deforestation and forest degradation. For example, logging transfers carbon from the forest while fires which burn tree components cause direct releases to the atmosphere. For a forest exposed to various levels of degradation, measuring biomass may show the role of specific disturbance activities on the carbon content of the forest and the specific pools affected.

Forests absorb CO_2 from the atmosphere and store carbon in wood, leaves, litter, roots, and soil all acting as "carbon sinks". Carbon is released back into the atmosphere when forests are cleared or burned [10]. Forests acting as sinks are considered to moderate the global climate. Overall, the world's forest ecosystems are estimated to store more carbon than the entire atmosphere [11]. Additionally, forest soils capture carbon. Trees, unlike annual plants that die and decompose yearly, are long-lived plants that develop large biomass, thereby capturing large amounts of carbon over a growth cycle of many decades. Thus, a forest ecosystem can capture and retain large volumes of carbon over long period.

Forests operate both as vehicles for capturing additional carbon and as carbon reservoirs. Carbon roughly is proportional to the forests growth in biomass. An old-growth forest acts as a reservoir, holding large volumes of carbon even if it is not experiencing net growth [12]. Thus, a young forest holds less carbon, but it is sequestering additional carbon over time. An old forest may not be capturing any new carbon but can continue to hold large volumes of carbon as biomass over long periods of time. Managed forests offer the opportunity for influencing forest growth rates and providing for full stocking, both of which allow for more carbon sequestration. Forest systems operate on a cycle of many decades and centuries, rather than annually or over a few years as would be the case with most crops and non-tree vegetation. As forest biomass expands, the amount of carbon contained increasing [13].

The majority of carbon in the terrestrial pool is stored below ground in soils. Total global carbon in soils constitutes between 1500 and 2000 G tons; the majority of it stored in forest biomes [14,15]. Forest stands are dynamic components of the ecosystem in which carbon flux changes with size, age, and species composition of trees. Although different species will influence stand development and carbon flux, general patterns exist for forest stands throughout the world [16]. In the current scenario tree, carbon stock is a burning topic for the international forestry sector deals with carbon. The carbon considers as a commodity, so nowadays carbon is sold and purchase in different forms. Almost all the nations around the world took various challenges and target to enhance additional carbon sink in forms of the forest. The present study contributing significant results regarding this to understand the management of deodar forest as well as the role of species in climate change mitigation. The objective of the present study was to assessment of variation in volume and biomass along with the carbon holding capacity of different deodar forests.

2. METHODOLOGY

The present study entitled "Variability assessment for volume, biomass and carbon stock in *Cedrus deodara* (Roxb) G.Don. forests of Garhwal Himalaya" was conducted in different parts of Garhwal Himalaya (Latitude 29° 43' to 31° 27' N and Long. 77° 34' to 81° 02' E). The present study was conducted during the years 2013 to 2015. The study sites are situated in three district of Uttarakand i.e. A) Tehri Gahrwal, B) Dehradun, and C) Uttarkashi and details of sites are given in Table 1.

The volume, biomass and carbon stock estimation in different *C. deodara* forests stand of Garhwal Himalaya was assessed by laying out three 0.1 ha sample plots (Fig. 1) in each location. Sample plots were taken randomly on each location. Thus a total of 30 sample plots were laid out in all the ten locations. Enumeration of trees for volume and growing stock assessment was done by measuring cbh (Circumference/ girth at breast height i.e., 1.37 m above the ground level) and height individually for all the trees in each Sample plot as per Mac. Dicken [17].

The total height of trees was measured by using Ravi multimeter in all sample plot laid out randomly and expressed in meters. The volume of standing trees was estimated by using the following general volume equation for Bhagirathi, Bhilangna, and Yamuna catchment area for *C.deodara* [18] and expressed in m³

$$V= 0.06168 + 0.27696\ D^2H$$

Where, V = Volume (m^3),D = Diameter at breast height (m), and H = Total height of tree (m)

The growing stock density (GSVD) was estimated using Volume equation for deodar as given above. GSVD was calculated as sum total volume per tree within a sample plot. Sum total volume was multiplyed by 10 to convert GSVD in to m^3 ha^{-1}.

GSVD = $\sum$Volume

The estimated GSVD (m^3 ha^{-1}) was converted into above ground biomass density (ABGD) of tree which was calculated by multiplying GSVD of the sample plot with appropiate biomass expansion factore (BEF) by Brown [19]. BEF (Mg m^{-3}) is defined as the ratio of AGBD of all living trees at DBH $\geq$ 2.54 cm to GSVD for all trees of DBH $\geq$ 12.7 cm. BEF for *C. deodara* was calculated by using equation for spruce- fir. BEF was calculated using the following equations:

BEF = exp$\{1.77 - 0.34 \times \ln(GSVD)\}$

(for GSVD $\leq$ 160 m^3 ha^{-1}),

BEF = 1.0 (for GSVD > 160 m^3 ha^{-1})

AGBD was calculated using following equation:

AGBD = GSVD$\times$BEF

Using the regression equation of Carins [20], the below ground biomass density (BGBD; fine and coarse roots) was estimated for each forest types as follows:

BGBD = exp $\{-1.059 + 0.884 \times \ln(AGBD) + 0.284\}$

AGBD and BGBD were added and get the TBD.

TBD = AGBD + BGBD

Similar method for estimation of GSVD, BEF, AGBD and BGBD esatimation method was used various authore in his work earlier such as [20,21,22,23,24]. The Total biomass values was converted to carbon stock (C) using the default values of 0.50 C fraction [25,26,27,28].

TCD (Mg C ha^{-1}) = TBD (Mg ha^{-1}) $\times$ Carbon %

2.1 Statistical Analysis

The different set of data were statistically analaysed using the using SPSS software and and Microsoft office Excel 2007.

3. RESULTS AND DISCUSSION

Information on volume, biomass and carbon stock is necessary for efficient planning and successful management of forests. The stored carbon by forests remains locked up in the form of wood and wood product. Enhanced carbon sequestration through recognized and innovative silvicultural practice, eco restoration of degraded forestlands, improved biomass productivity, effective implantation of forest policy objective will help in improving forest health and vitality. So there is a need of more research work on growing stock, biomass and carbon stock related study at country leave.
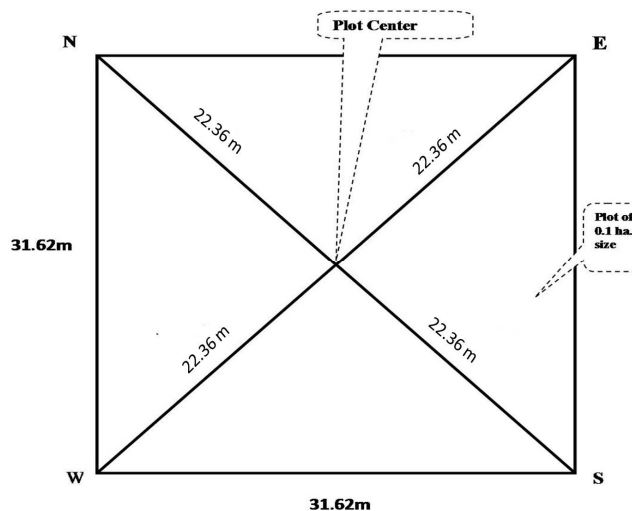

Fig. 1. Field layout of sample plot

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For successful management of forest, achieved the national forest policy objective and sustainable use of forest and trees require accurate as well as precise information on the state, pattern and rates of change of the resource. To attain these goal needs of reliable estimates on state and change of forest biomass inventory must be carried out over a fixed time interval for developing country like India. Forests are an important component of terrestrial ecosystems, covering 30% of the world's land surface area [29]. The total forest and tree cover of the country is 8,07,276 sq. km constituting 24.56% of the geographical area. Out of this, forest cover us 7,12,249 sq. km which is 21.67% of the geographic area and tree cover is 95,027 sq. km and which is 2.89% of geographic area [30]. A carbon flux between forest and atmosphere play a crucial role in the global carbon cycle.

3.1 Volume Assessment in Different Deodar Forest

Volume has been the traditional measures of wood quality and continues to be the most important measures in spite of increasing use of weight or biomass as a measure of forest productivity. The volume measurement is an important parameter to estimate quantity of wood contained in trees not only for sale but also for research, predicting future yields, estimating increment to assess return on capital, biomass estimation, carbon gain and losses in forest. Various type of methods to estimate the volume that are volume of felled tree and standing tree [31]. Volume of felled trees include cross-cutting the tree stem in log, estimate volume of log by various formula like Smalian's, Hubers's, Prismoidal, and quarter girth, timber calculators, measurements of branch wood, solid volume of firewood by xylometric method and Specific gravity method. Volume of standing trees is measured by occular method, partly ocular and partly of measurement, direct measurement and indirect measurements. In forest management, the term increment refers usually to only volume increment [32].

The stand structure and density of *C. deodara* forest in different sites of Garhwal Himalaya have been presented in Table 2. Among all the sites, the average maximum DBH (57.07 cm) was recorded in Kanasar-I and minimum (42.10 cm) in Dhanolti. However, maximum mean basal area (2.84 m^3 tree^{-1}) in Kanasar- I and minimum (1.37 m^3 tree^{-1}) in Jakholi Juwarnath. In case of

Kanasar-II the maximum mean height (37.64 m) was recorded, which however was minimum (19.68 m) in Harshil was recorded. The maximum (4.27 m^3 tree^{-1}) mean volume was observed in Kanasar-I and minimum (1.44 m^3 tree^{-1}) in Harshil. The percent canopy cover was recorded maximum (80.67%) in Kanasar- III and minimum (57.91%) in Jakholi Juwarnath. The stand density in all the study sites was recorded between 227 and 410 ind. ha^{-1}.

Data have been presented in Table 2 showed that the stand structure and density of different *C. deodara* forest varied among different sites. Generally, DBH, height and basal area increased with increasing diameter classes [33,34]. The maximum DBH was recorded in Kanasar-I and minimum in Dhanolti. In present study higher values of DBH was observed than the values of DBH (15.95 to 34.12 cm tree^{-1}) which is recorded by Wani in *C. deodara* forest under temperate Himalaya of Kashmir [35]. Therefore higher diameter attributed to secondary or radial growth which is responsible for the increase in diameter. The range of basal area values varied from 1.37±0.55 to 2.84 ±0.99 m^2 tree^{-1}. The maximum height was recorded in Kanasar-II and minimum was recorded Dhanolti. Consequently, the volume varied from 1.44 ±0.19 to 4.27 ±0.31 m^3 tree^{-1}.The volume was changing in different sites attributed to DBH, height and stand density. Stem volume was increased with the increase in DBH and height is attributed to natural and proportionate growth of tree [36]. The lower value of stem density of 227.0 individual (ind.) ha^{-1} may be due to cutting of trees, disturbance and weak forest management by state forest department.

The values in this study were lower than the values reported by Saxesna and Singh for temperate forests of Kumaun Himalaya (420 and 1640 trees ha^{-1}) [37]. Also, Kumar have reported the density values (652-1028 trees ha^{-1}) for temperate forests of Garhwal Himalaya [38].

On the basis of data mentioned in above Table 3, indicated significant and strongly positive correlation among the parameters i.e. diameter, basal area, height and volume. Among all the parameters, diameter and basal area shows a highest correlation (.987**) value whereas diameter and height shows the lowest correlation value (.888**). Volume is important parameter from management point of view and its value is derived by using diameter, height and form of trees in volume equation. So, study of correlation of volume with other parameter is an important to

Table 1. Geographic information of study sites of *Cedrus deodara* forests of Garhwal Himalaya

S. no	Name of site	Latitude (N)	Longitude (E)	Altitude (m asl)
1	Dandachalli	30^0 18' 107" to $30^0$18 140"	078^0 24' 821" to 078^0 24'887"	1972 to 2001
2	Dhanolti	30^0 25' 655" to 30^0 25' 715"	078^0 40' 517" to 078^0 14' 563"	2269 to 2329
3	Dharali	31^0 01' 961"to $31^0$01' 978"	078^0 45' 162" to 078^0 45' 228"	2506to2567
4	Harshil	31^0 02' 307" to 31^0 02' 336"	078^0 45' 003"to$078^0$45' 060"	2548 to2557
5	Jakholijuwarnath	31^0 20' 093" to 31^0 24' 466"	$078^0$24' 287"to078^0 17' 975"	2272to2351
6	Kanasar –I	30^0 46' 644"to 30^0 46' 823"	077^0 50' 030"to077^0 49' 895"	2088to2183
7	Kanasar –II	30^0 40' 402" to 30^0 46' 455"	077^0 48' 833"to077^0 48' 812"	2057to2082
8	Kanasar -III)	30^0 45'486" to 30^0 45' 787"	077^0 47' 180"to077^0 47' 466"	2127to2129
9	Kunain	30^0 47' 556" to 30^0 47' 617"	077^0 53' 509"to077^0 53' 808"	2100to2394
10	Thangdhar	30^0 25' 611"to30^0 24' 840"	078^0 14' 565"to078^0 20' 582"	2274to2286

m asl: meters above sea level

Table 2. Stand structure and density of *C. deodara* forests on different sites of Garhwal Himalaya

S. no.	Site name	DBH (cm)	Basal Area (m^2 tree^{-1})	Height (m)	Volume (m^3 tree^{-1})	Canopy cover (%)	Stand density (ind. ha^{-1})
1	Dandachalli	47.24 (±1.18)	1.79 (±0.40)	28.23 (±0.36)	1.89 (±0.09)	62.074 (±3.489)	227.0 (±3.3)
2	Dhanolti	42.10 (±2.15)	1.37 (±0.55)	23.63 (±0.43)	1.57 (±0.29)	65.33 (±1.638)	383.0 (±7.4)
3	Dharali	46.05 (±1.90)	1.84 (±0.73)	27.63 (±0.99)	2.11 (±0.20)	69.71 (±4.668)	240.0 (±2.1)
4	Harshil	44.43 (±2.16)	1.59 (±0.79)	19.68 (±0.45)	1.44 (±0.19)	68.36 (±0.780)	370.0 (±10.0)
5	Jakholi Jwarnath	44.57 (±0.88)	1.61 (±0.39)	29.09 (±0.33)	1.78 (±0.07)	57.91 (±3.172)	410.0 (±7.9)
6	Kanasar – I	57.07 (±2.15)	2.84 (±0.99)	36.59 (±1.16)	4.27 (±0.31)	65.89 (±5.656)	300.0 (±5.0)
7	Kanasar –II	55.49 (±1.99)	2.62 (±0.90)	37.64 (±0.95)	3.86 (±0.28)	67.99 (±5.894)	267.0 (±5.7)
8	Kanasar –III	54.87 (±1.16)	2.42 (±0.53)	34.17 (±0.50)	3.07 (±0.13)	80.69 (±2.348)	297.0 (±3.9)
9	Kunain	48.85 (±1.44)	2.04 (±0.71)	31.95 (±0.67)	2.60(±0.16)	69.65 (±2.980)	407.0 (±5.8)
10	Thangdhar	51.19 (±1.03)	2.10 (±0.45)	30.23 (±0.33)	2.37 (±0.10)	65.55 (±8.182)	313.0 (±4.8)

Figures in parenthesis are standard errors of mean

Table 3. Correlations between diameter, basal area, height and volume in *Cedrus deodara* forests of Garhwal Himalaya

		Diameter	Basal area	Height	Volume
Diameter	Pearson Correlation	1	.987**	.888**	.944**
	Sig. (2-tailed)		.000	.001	.000
	N	10	10	10	10
Basal Area	Pearson Correlation	.987**	1	.896**	.976**
	Sig. (2-tailed)	.000		.000	.000
	N	10	10	10	10
Height	Pearson Correlation	.888**	.896**	1	.912**
	Sig. (2-tailed)	.001	.000		.000
	N	10	10	10	10
Volume	Pearson Correlation	.944**	.976**	.912**	1
	Sig. (2-tailed)	.000	.000	.000	
	N	10	10	10	10

**. Correlation is significant at the 0.01 level (2-tailed)

study. As per the Table 3 volume and basal area showed highest value (.976**) of correlation followed by volume and diameter and volume and height. An earlier study also reported that height was used to measures the site quality/ productivity. It means both the parameter contributing in volume gain of trees was different amount and reaches to optimum level of volume at different time. Wood is anisotropic in properties. During the study measurement of all the trees was young to mature age tree. Unidirectional growth in trees was not good (only height or diameter growth) to obtain a good quality of timber in desirable timer interval with enhance productivity of forest per unit area. To obtain desired quality of timber from forest there is need of silvicultural management practices like thinning, pruning and tending operation. Growth of trees also affected by locality condition but it can be improved after study to obtain desired objective concern to forest growth.

3.2 Biomass and Carbon Stocks

Volume is generally used in timber trade; weight is always used for certain special categories of forest product and sometimes in case of wood. Especially for the minor forest product in forestry sector weight is an important measure. The overall quantity of weight of wood mainly affected through density, moisture content, bark and foreign material factor. Biomass is the weight of the above ground vegetative matter produced per unit area. Biomass estimation was carried out by destructive sampling and regressions equation method. The biomass and carbon stock in different *C. deodara* forests on different sites are presented in Table 4. Among different sites, highest AGBD (1279 Mg ha^{-1}) was observed in

Kanasar-I and lowest (91.42 Mg ha^{-1}) in Dandachalli. The maximum (256.14 Mg ha^{-1}) BGBD was reported in Kanasar-I and minimum (97.41 Mg ha^{-1}) in Dandachalli sites, followed by Dhanolti, Dharali and Harshil. The total biomass density (TBD) ranged between 525.98 Mg ha^{-1} to 1535.65 Mg ha^{-1}. Average TBD in different study sites was recorded as 933.71 Mg ha^{-1}, out of which average AGBD accounted for 82.55% (770.84 Mg ha^{-1}) of TBD and average BGBD accounted for 17.44% (162.86 Mg ha^{-1}) of the TBD. The estimated total BGBD was 21.12% of the total AGBD. The highest (767.33 Mg ha^{-1}) values of total carbon density were observed in Kanasar-I and lowest value in Dandachalli sites.

The recorded values of present study and earlier reported values of AGBD, TBD and TCB from Garhwal Himalaya and other Uttarakand region presented in Table 5. A comprehensive comparison of the biomass and carbon estimates of the present study with other works is difficult because of variation in the methods employed for estimation in different studies. In some studies biomass was directly estimated, whereas in others allometric and regression equations were used. Some other results of ground study were coupled with the remote sensing and GIS techniques to obtain estimates of large regions. The fraction of C used to convert biomass to C stocks also varied in different studies (generally between 0.45 and 0.50%). However, Table 5 provides the extent of information available in the scientific literature about the living tree biomass and C stock in forests of Garhwal Himalaya, Uttarakhand.

The AGBD, TBD and TBC values were higher than observed values by Adhikari et al. for

Table 4. Biomass and carbon stock values in different *C. deodara* forest on different sites of Garhwal Himalaya

S. no.	Site name	AGBD (Mg ha^{-1})	BGBD (Mg ha^{-1})	TBD (Mg ha^{-1})	TCD (Mg ha^{-1})
1	Dandachalli	428.57	97.41	525.98	262.99
2	Dhanolti	493.63	110.17	603.80	301.9018
3	Dharali	505.24	112.99	618.23	309.12
4	Harshil	532.65	118.25	650.90	325.45
5	Jakholi Juwarnath	729.39	156.30	885.68	442.84
6	Kanasar – I	1279.51	256.14	1535.65	767.83
7	Kanasar – II	1030.10	211.83	1241.93	620.9649
8	Kanasar – III	909.67	190.12	1099.78	549.89
9	Kunain	1057.34	217.15	1274.49	637.24
10	Thangdhar	742.36	158.25	900.60	450.30

AGBD: Aboveground biomass density; BGBD: Belowground biomass density; TBD: Total biomass density, and TCD: Total carbon density

Table 5. Comparison of AGBD, TBD and TCB values of present study with earlier recorded values for Garhwal Himalaya, Uttarakhand

Study	Forest type and location	Altitude (m asl)	AGBD (Mg ha^{-1})	TBD (Mg ha^{-1})	TCB (Mg ha^{-1})
Present study (2013-15)	*C. deodara,* Garhwal Himalaya	1972-2057	1279.51	1535.65	767.83
Kumar and Sharma (2015) [22]	*C. deodara,* BRF Tehri Garhwal (*study area between elevation350-6578* m)	1850-2500	86.20	108.92	41.92
Adhikari et al. (1995) [39]	*Abies pindrow,* Kumaun	2500	454.6	565.0	265.6
Sharma et al. (2010) [40]	*Abies pindrow,* Pauri Garhwal	2600-3100	305.3	377.7	173.7
Sharma et al. (2010) [40]	*C. deodara,* Pauri Garhwal	2200-2500	434.4	533.3	245.3
Sharma et al. (2010) [40]	*Pinus roxburghii,* Pauri Garhwal	750-1250	126.2	159.4	73.3
Rana et al. (1989) [41]	*Pinus roxburghii,* Kumaun	1750	163.0	199.0	93.5

Abies pindrow (Royle ex D. Don) in Kumaun region, Sharma et al. for *Abies pindrow* (Royle ex D. Don)*, Pinus roxburghii* (Sarg.) and *C. deodara* (Roxb) G.Don. in Pauri Garhwal and Kumau [39,40,41]. This may be due to higher growing stock value, more number of old growth tree with maximum average diameter trees on studied sites and the lack of disturbance in stand. The maximum BGBD was recorded in Kanasar-I and minimum in Dandachalli and BGBD ranged between 97.41 Mg ha^{-1} and 256.14 Mg ha^{-1}. The results of estimated total biomass BGBD to total AGBD was all in lines with Gairola et al. and Brown and Lugo [42,43]. The TCD ranged from 525.98 Mg ha^{-1} to 1535.65 Mg ha^{-1} and total C density was between 262.99 Mg ha^{-1} to 767.83 Mg ha^{-1}. Higher value of biomass and carbon might be due to higher density, growing stock, and fully stocked stands. The biomass and carbon value was higher than the earlier reported value given in Table 5.

4. CONCLUSION

The *C. deodara* forests play an important role in Himalayan moist temperate forests and Himalayan dry temperate forests. Kanasar-I showed the highest value and lowest in Dandachalli for AGBD, BGBD, TBD, TCD as compared to other sites. The range of total carbon density of *C. deodara* forest in present study indicated a good range of carbon stock i.e. 262.99 and 767.83 Mg ha^{-1}. It will indicated that *C. deodara* have a strong carbon storage potential due to slow growing in nature with long rotation periods. *C. deodara* is improving ecosystem services including biodiversity, hydrological services and carbon sequestration. Hence, *C. deodara* is recommended for large scale plantation under national mission for a green India. To achieving the objective of the national mission for a green India i.e. increasing forest cover/ tree cover on 5 million hectares of forest/non-forest lands and improving quality of forest cover on another 5 million hectares of forest/non-forest land. The increasing forests cover area under this species by afforestation will be helping in mitigation of climate change impact in higher Himalayas. The present study will help to understand the green carbon percent contribution of *C. deodara* forests in the Himalayan ecosystems. It will be helpful to the scientific community, forester and other stockholders to figure out the importance of natural forest for tangible and intangible services, biomass, carbon stock and need of silviculture for management of such valuable forest.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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