Biomass accumulation and carbon sequestration potential of *Shorea robusta* and *Lantana camara* from the dry deciduous forests of Doon Valley, western Himalaya, India

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Abstract

The present study was conducted to quantify that dry deciduous forests of Doon Valley have enormous carbon sequestration potential and therefore, biomass estimation of invasive shrub like *Lantana* along with dominant Sal trees can provide more accurate information about the forest biomass and carbon stock assessment. Variables like DBH and plant height for both Sal and *Lantana* were found to be more suitable for allometric equation and therefore used in the present study. The maximum Sal biomass was recorded from Thano forest (597.41 Mg ha$^{-1}$) with a carbon density of 280.78 MgC ha$^{-1}$. The minimum Sal biomass was recorded from Golatappar forest (392.05 Mg ha$^{-1}$) with carbon density of 184.26 MgC ha$^{-1}$. The mean total biomass of Sal was 494.65 Mg ha$^{-1}$ with mean carbon density 232.48 Mg ha$^{-1}$ from all study sites. The maximum shrub biomass (11.15 Mg ha$^{-1}$) was recorded from Rajpur Forest periphery with a carbon density of 5.24 MgC ha$^{-1}$. The minimum shrub biomass (6.74 Mg ha$^{-1}$ and carbon density (3.16 MgC ha$^{-1}$) was recorded from Lachchiwala forest periphery. The total mean biomass of both Sal and *Lantana* accounted for 502.80 Mg ha$^{-1}$ (494.65 Mg ha$^{-1}$ + 8.15 Mg ha$^{-1}$) with the carbon density of 236.32 MgC ha$^{-1}$ (232.48 MgC ha$^{-1}$ + 3.83 MgC ha$^{-1}$).

Keywords: Above Ground Biomass, Carbon Density, Allometric equations, invasive shrub, Tree Basal Area, Tree Volume.

Introduction

Forests provide a wide range of goods and services. Goods include timber, fuelwood, as well as food products and fodder. As regards important services, forests and trees play a role in the conservation of ecosystems, in maintaining quality of water, and in preventing or reducing the severity of floods, landslides, erosion, and drought. Forests provide a wide range of economic and social benefits, such as employment, forest products, and protection of sites of cultural value.

Forests, like other ecosystems, are affected by climate change. The impacts due to climate change may be negative in some areas, and positive in others. However, forests also influence climate and the climate change process mainly effecting the changes in the quantum of carbon dioxide in the atmosphere. They absorb CO$_2$ from atmosphere, and store carbon in wood, leaves, litter, roots and soil by acting as “Carbon Sinks”. Carbon is released back into the atmosphere when forests are cleared or burned. Forests by acting as sinks are considered to moderate the global climate. Estimates made for Forest Resources Assessment [1] show that the world’s forests store 289 gigatonnes (Gt) of carbon in their biomass alone. While sustainable management, planting and rehabilitation of forests can conserve or increase forest carbon stocks, deforestation, degradation and poor forest management reduce them. For the world as a whole, carbon stocks in forest biomass decreased by an estimated 0.5 Gt annually during the period 2005–2010, mainly because of a reduction in the global forest area.

The biomass carbon stock in India’s forests was estimated at 7.94 MtC during 1880 and nearly half of that after a period of 100 years [2]. The first available estimates for forest carbon stocks (biomass and soil) for the year 1986 are in the range of 8.58 to 9.57 GtC [3, 4]. Needless to say, that the present state of forest carbon stocks owes its origin to the drive of plantation forestry in India started in the late 1950s and supplemented later by the social and farm forestry initiatives of the 1980s and early 1990.
compounded annual growth rate of CO₂ emissions in India is 4.2 per cent. Some may consider this to be higher than the desired, but the absolute value of these emissions is still one sixth that of the United States and lowest for the per capita GHG emissions [5].

Majority of the forests of Uttarakhand, India can be broadly divided into six types: subtropical forests, dry deciduous forests, moist deciduous forests, tropical coniferous forests (Pine), temperate broad leaved, and temperate coniferous forests. Biomass values of forest stands in the Himalaya tend to cluster around two very different levels – from a low approximately 200t ha⁻¹ for early successional communities such as chir pine, to a high of about 400t ha⁻¹ for late successional communities such as oaks and Sal [6].

Out of the 2 factors of habitat, climate and soil, the former decides the general distribution of Sal trees (Shorea robusta) among the climatic factors; rainfall is by far the most important. Annual precipitation normally comes with a dry season lasting 4 – 8 months (monsoon climate). At higher elevations, S. robusta can be damaged by frost. S. robusta occurs in both deciduous dry and moist forests and in evergreen moist forest. It accounts for about 14% of the total forest area in India. For example, southwest Bengal harbours luxuriant S. robusta forests. Fire is normally responsible for its frequent occurrence in pure stands or as the dominant species of mixed stands, as S. robusta is better equipped to survive conflagration than other tree species.

Estimation of above-ground biomass (AGB) is an essential aspect of studies of carbon stocks and the effects of deforestation and carbon sequestration on the global balance and also provides valuable information for many global issues. Estimating AGB is a useful measure for comparing structural and functional attributes of forest ecosystems across wide range of environmental conditions. By using information on biomass, content of carbon, energy and nutrient could be estimated rapidly. With this information, detrimental effects of harvesting can be assessed and compensatory programmes for nutrient replacement through fertilization can be considered. This is also important for evaluation and improvement of site and these form the bases for sound forest management. Forest can be a carbon source and sink. Therefore, the management of the forests can affect the global carbon cycle and climate change.

The method generally used for non-destructive calculation of biomass is through allometric equations relating destructively measured tree biomass and field measurements of circumference at breast height (CBH) or diameter at breast height (DBH) [7]. This method also poses a significant problem for regional scale comparisons because the coefficients a (intercept) and b (slope) in the allometric equations vary from species to species and site to site [7]. Therefore, for the study of regional variations in tree biomass estimates, those aspects of forest structure that vary significantly at regional scales should be used in the estimator. In this study we used the allometric equation to calculate the non-destructive biomass of the dominant Sal trees from different study sites of Doon Valley.

Defining and characterising shrub is a complex task; shrubs are the type of vegetal group with a specific structure or appearance [8]. These non-trees, woody formation of shrubs are of great significance to biophysical and biodynamic processes of different ecosystems, and have a direct impact on ecosystem dynamics and function [9]. With all the vegetative structure and formations, biomass is a key structure variable in invasive studies and research into the dynamics of different ecosystems (sub-tropical in this case), the type of bio – geographic conditions and biodiversity they sustain, their role in the atmospheric carbon cycle, and their resistibility [10].

In many studies the biomass analysis of shrub in forest and other ecosystems has been obtained through direct (destructive) or indirect (through dimensional analysis of different attributes of plants) [11]. In the destructive methods the plants are harvested and weighed in the sample plots. This method gives very accurate estimates of the biomass but harvesting and weighing a large number of samples are very laborious and costly [12]. In the indirect methods the allometric and mathematical models have been developed for estimation of total biomass which are based on the measurements of different plant attributes like shrub height, stem diameter at breast height [13], crown diameter [14], crown area and crown volume [15]. These methods give estimates that can reach to the nearest prediction levels of the destructive methods and allow us to observe a large number of physical parameters at a relatively low cost [16].

Biomass study is very important for various ecological works especially in relation with nutrient cycle, fuel property and their adaptation to different climatic conditions [17]. In addition, the calculation of above ground biomass and other variables are primarily required for the better forest, scrubland and grassland ecosystem management, development and execution of different models which help in the mapping of different characteristics of forest fuels [18], effects of invasive species on forest hydrological planning [19]. Large scale evaluation, mapping and strategic values are necessary for improving available knowledge and accurate modelling of the dynamics of ecosystems [20]. Shrub biomass is an important component of the total forest biomass, especially in natural stands. Using the right and accurate allometric equations for shrub biomass estimation in Doon Valley is very essential for at least two reasons. First, Lantana is a problem weed and the rapid growth of Lantana thickeninges are turning the grasslands into woodlands and woodlands are becoming thicker also the periphery of Doon Valley forests are heavily infested by this invasive weed, this has finely raised its importance. Second, measurement of carbon fluxes both at tree and shrub level, has local and global importance in study of the CO₂ cycle. Study of forest biomass is very important for constructing the coupling relationship between community processes and flux observations and for authenticating and regulating flux observations. Estimation of shrub biomass can help to produce more accurate estimates of forest biomass. Therefore, the objectives of the present study were to 1. Calculate the biomass and carbon stock of the dominant Sal
trees from the dry deciduous forests of Doon Valley. Calculate the biomass and carbon stock of invasive shrub *Lantana* from the periphery of dry deciduous forests of Doon valley. Combine the biomass and carbon stocks of both Sal trees and *Lantana* and to assess their further relevance in local and global carbon cycle.

**Methods and Materials**

**Study Site**

The Doon Valley is a part of Uttarakhand, India. The state of Uttarakhand is situated in the northern part of India and shares an international boundary with China in the north and Nepal in the east. It has an area of 53,483 km$^2$ and lies between latitude 28° 43′ and 31° 28′ N and longitude 77° 34′ and 81° 03′ E (Fig. 1). The state has a temperate climate except in the plain areas, where the climate is tropical. The average annual rainfall of the state is 1550 mm and temperatures range from sub-zero to 43°C [21]. Of the total geographical area of the state, about 19% is under permanent snow cover, glaciers and steep slopes where tree growth is not possible due to climatic and physical limitations [21]. The recorded forest area of the State is 34,691 km$^2$, which constitutes 64.79% of its geographical area [22].

The study area was the Doon Valley Forest Division which is a valley portion of the district Dehra Dun and is located in the South-western part of the state of Uttarakhand, India (Fig.1) The Doon Valley falls in the western Siwalik Himalayas, lying between latitudes 29°55′ and 30°30′ N and longitudes 77°35′ and 78°24′ E. It is about 20 km wide and 80 km long saucer-shaped valley with a geographical area of ca. 2100 km$^2$. The study has been conducted in the six forest ranges of Doon Valley (Table 1) named (Lachchhiwala range, Asarori range, Thano range, Golatappar range, Jhajra and Selaqui range and Rajpur forest range). A minimum of 10-30 Sample plots of 10 × 10 m were placed in all forest type within the above said forest ranges, depending upon its area and then Sal tree density was calculated.

![Figure1: Pictorial representation of District Dehradun (Doon Valley) Map](Source: www.mapsofindia.com)
Non destructive Biomass estimation of Sal trees
The various methods used in the study are as follows:

- The height of the tree was calculated with the help of geometric method [23].
- DBH of the tree was measured by using the diameter tape. The diameter tape does not measure diameter directly, but instead measures the circumference of the tree. Therefore we measured the circumference and then it was converted to diameter by solving the following DBH equation:
  \[ C = \pi \times DBH \]

Where:
- \( C = \) circumference of tree
- \( \pi = 3.14 \)
- \( DBH = \) diameter at breast height, Therefore, \( DBH = \frac{C}{\pi} \)
- To estimates the biomass of the Sal trees we used a modified biomass equation which is a simple form of allometric equation \( Y = a(DBH)^b \) suggested and recommended in earlier study [24]. The modified biomass equation used in the present study was \( Y= 0.0921 \times (DBH)^{2.5899} \) which was earlier used to calculate the biomass of the high density primary species such as Shorea spp., Hopea spp., Dipterocarpus spp. and Syzygium spp. from Ayer Hitam Forest Reserves (AHFR) Malaysia [25]. In addition, estimates of total carbon, Tree Basal Area, Tree Volume and total CO\(_2\) content are also presented in this study.
- Tree Basal Area (TBA) is the cross sectional area cover the bark at breast height (1.3m above the ground) measured in meter square (m\(^2\)). This helped us to estimate the tree volume and stand competition. We calculate the diameter at breast height in cm and calculate the basal area (m\(^2\)) using an equation based on the formula for the area of a circle \( (A = \pi r^2) \)
  \[ r = \text{radius and } \pi = 3.14 \]
  Tree basal area (TBA) = \( \left(\frac{DBH}{200}\right)^2 \times 3.14 \)

Where, 
- DBH= Diameter at Breast height in cm
- \( \pi = 3.14 \)
  - We calculated tree volume by the following formula;
  Tree Volume (m\(^3\)) = \( \left(\frac{DBH}{200}\right)^2 \times 3.14 \times \frac{Ht}{3} \)
  Or Tree Volume = \( \frac{TBA}{3} \times Ht \)
  - Volume (m\(^3\) tree\(^{-1}\)) of each tree in a sampling quadrat obtained is converted into the volume on hectare basis.
  - Calculation of below ground tree Biomass for each plot
  To calculate the below ground tree biomass we used the [26] and REDD+ prescribed formula:
  \[ C_{BB} = R \times C_{AB} \]

Where, 
- \( R = \) Root and shoot ratio
- \( C_{BB} = \) below ground biomass
- \( C_{AB} = \) above ground biomass
- Total Biomass was obtained by summing the Aboveground Biomass, Belowground Biomass and Dead Organic Matter.
  (Total Biomass = AGB + BGB + Deadwood)
- The carbon storage for each species was computed by multiplying total biomass with constant factor 0.50 [26]
  \[ C = TB \times 0.50 \]

Where,
- \( C = \text{Carbon (Mg ha}^{-1}\)\)
- \( TB = \text{Total Biomass (Mg ha}^{-1}\)\)

Non-destructive estimation of shrub biomass
The dependent variable shrub biomass depends upon many independent variables. The identified independent variables to establish the allometric equation were total plant height (H), maximum basal diameter (D\(_1\)) and minimum basal diameter (D\(_2\)), maximum crown width (C\(_1\)) and minimum crown width (C\(_2\)), which were measured to calculate the average values before harvesting. Average values of crown width was calculated by \( C = (C_1+ C_2)/2 \) and used to calculate plant canopy area (CA, m\(^2\)) and plant canopy volume (CV, m\(^3\)) as (CA = \( \pi C^2/4 \)) and (CV = CAxH). However, average of D = (D\(_1+D_2)/2 \) was used to establish the allometric equation along with the plant height. Dry weight was already measured for each component by keeping it in oven at 70\(^\circ\)C for 72 hrs. The dry weight of lantana with its diameter (D) and D\(^2\)H were tested in different regression models. The following equations were tested for its best fit for the calculation of shrub biomass [27].

(1) \[ y = a + bD + cD^2 \]

(2) \[ \ln y = a + bD \]

(3) \[ \ln y = a + b \ln D \]

(4) \[ y^{0.5} = a + bD \]

(5) \[ y = a + bD^2H \] (equation used in the present study)

(6) \[ \ln y = a + bD^2H \]

(7) \[ y^{0.5} = a + bD^2H \]

(8) \[ y = a + b(CA) + c(CA)^2 \]

(9) \[ y = a + b(CV) + c(CV)^2 \]

In all the above equations y represents the biomass, D is the diameter, H is the plant height, CA is canopy area, CV is canopy volume and a, b, c are regression coefficients, and ln indicates natural logarithm. The biomass of a single Lantana shrub calculated with the above mentioned equation was then converted to the biomass ha\(^{-1}\) by multiplying the biomass of one shrub with the density of Lantana ha\(^{-1}\) and likewise the carbon stock as well.

Data Analysis
All statistical analysis was done with the help of XLSTAT (2011) for Microsoft windows 2010.

Result
We found that out of all the equations we considered for the biomass calculation of Lantana, the equation \( (y = a + bD^2H) \) was more accurate and fit into the criteria of calculating shrub biomass. We established a correlation...
between different measured parameters and biomass of *Lantanana* and received a positive relation with plant height (R² = 0.86), stem diameter at breast height (R² = 0.91) and when taken these two variable together in the form of D'H (R² = 0.88). There were more criteria to choose the accurate one i.e., the adjusted R², the Furnival index, computed F value, RMSE and the significance level of the values at 5%. The equation for the biomass calculation shall be considered more accurate and best fit if it gives a lower root mean square error (RMSE), higher value of adjusted R² and less value of Furnival index. When the computed value of F was compared with the tabular value at (1, n – 2) degrees of freedom we found that the calculated value of F (137.59) were greater than the tabular value (4.41) at (1, 18) degrees of freedom at 5% level of significance (Table 2a, 2b). This concludes that the regression coefficient, β is significantly different from 0 and the value is significant. D'H fit best on these criteria with adjusted R² = 0.88 (maximum amongst all the equations), Furnival index = 0.04123 (lowest) and RMSE = 157 (lowest amongst all the equations) (Table 2c). These results therefore, strongly suggested us to choose the allometric equation with D'H as an important variable for the non-destructive calculation of *Lantanana* biomass. For the biomass calculation of Sal tree an already tested and applied equation for the same condition was taken which is described earlier in Methodology section.

Detailed site wise biomass and carbon stock analysis are as follows:

**Thano Forest Range**

The total biomass of Sal trees 597.41 Mg ha⁻¹ was calculated from Thano forest range which include AGB – 458.84 Mg ha⁻¹, BGB – 110.12 Mg ha⁻¹, and Deadwood – 28.44 Mg ha⁻¹. The site also recorded a total tree basal area (TBA) 45.91 m² ha⁻¹ and tree volume (TV) of 502.55 m³ ha⁻¹. When the total biomass which includes AGB+BGB+Deadwood was converted to the carbon stock with the prescribed conversion factor, the site recorded a carbon storage value of 280.78 Mg C ha⁻¹. The avg. DBH of the Sal trees was between 33cm – 42cm and the density of Sal tree was 415trees ha⁻¹. The avg. height range of the tree from all the plots was between 27m – 37m.

The mean shrub height recorded from this site was 219.65 cm with mean crown diameter of 141.95 cm. The mean shrub canopy area was 1.65 m²/plant. The density of *Lantanana* from this site was 15, 300 plants ha⁻¹. The total phytovolume of *Lantanana* (75,927.76 m³ ha⁻¹) and coverage (33.16%) was recorded from this site. Total biomass of the shrub was 6.74 Mg ha⁻¹ from this site and the total carbon stock estimated from this site was 3.17MgC ha⁻¹. Some of the commonly growing plant species from the study sites are *Phlogacanthus thrysiflorus* (Roxb.), *Nees, Solanum erianthum* D. Don, *Ziziphus mauritiana* Lam., *Urena lobata* L., *Amaranthus viridis* L., *Argemone mexicana* L., *Murraya koenigii* (L.) Spreng., *Randia uliginosa* (Retz.) Poiret, *Glycosmis pentaphylla* auct. mult. non DC.

**Asarori Forest Range**

The Asarori forest recorded a Sal density of 372 trees ha⁻¹. The average height range recorded from different plots was between 26m – 37m and DBH range between 27cm – 38cm. The total biomass of Asarori forest site was 416.48 Mg ha⁻¹ which includes AGB – 319.88 Mg ha⁻¹, BGB – 76.77 Mg ha⁻¹ and Deadwood – 19.83 Mg ha⁻¹. Total basal area was 33.79 m² ha⁻¹ and tree volume was 371.83 m³ ha⁻¹. When the biomass was used in the conversion of total atmospheric carbon sequestered per hectare, the value was 195.79 MgC ha⁻¹.

The mean shrub height from this site was 258.15cm and the mean crown diameter was 159.13cm. The mean shrub canopy area was 2.17m²/plant. A mean shrub canopy projected volume of 5.27 m³/plant was recorded from this site. The density of *Lantanana* from this site was 16,600 plants ha⁻¹. The total phytovolume of *Lantanana* from this site was recorded as 87,528.48m³ ha⁻¹ and coverage of 36.10%. Total biomass of the shrub from this site was 7.03Mg ha⁻¹ and the total carbon stock estimated from this site was 3.30MgC ha⁻¹. Some of the commonly growing plant species from this site was *Alternanthera sessilis* (L.) R. DC., *Eupatorium odoratum* L., *Opuntia dilleni* (Ker Gawl.) Haw., *Parthenium hysterophorus* L., *Phyllanthus emblica* L., *Xanthium indicum* Koenig., *Sida cordifolia* L., *Murraya koenigii* L. Spreng., *Woodfordia fruticosa* L.

**Rajpur Forest range**

Rajpur forest recorded a total Sal trees biomass of 478.18 Mg ha⁻¹ which include AGB – 367.27 Mg ha⁻¹, BGB – 88.14 Mg ha⁻¹ and Deadwood 22.77 Mg ha⁻¹. The tree basal area from this site was 38.07 m² ha⁻¹ and tree volume was 439.65 m³ ha⁻¹. However, the total carbon storage capacity of the site due to the Sal forest was 224.75MgC ha⁻¹. The shrub height from this site was the maximum and a mean shrub height of 508cm was recorded. The mean crown diameter was 180.28cm. The mean shrub canopy area was 2.64m²/plant. The mean shrub canopy projected volume of 13.79m³/plant was recorded from this site. The density of *Lantanana* from this site was 14,600 plants ha⁻¹. The total...
**Table 1:** Characteristics of various study sites in Doon Valley

<table>
<thead>
<tr>
<th>Study Sites</th>
<th>Sites Blocks</th>
<th>Dominant Species</th>
<th>Point Coordinates</th>
<th>Elevation</th>
<th>Land Use</th>
<th>Avg. DBH (cm)</th>
<th>Avg. Tree height (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asarori Forest</td>
<td>Mohabbewala</td>
<td>Shorea, Syzygium</td>
<td>E 78°58′41.8″ &amp; N 30°15′22.6″</td>
<td>2024 ft</td>
<td>Forest</td>
<td>25.87</td>
<td>22.19</td>
</tr>
<tr>
<td>Thano Forest</td>
<td>Chandrabani</td>
<td>Shorea, Syzygium</td>
<td>E 78°58′36.8″ &amp; N 30°15′24.9″</td>
<td>2034 ft</td>
<td>Forest</td>
<td>27.31</td>
<td>26.06</td>
</tr>
<tr>
<td>Selaqui &amp; Jhajra</td>
<td>Rajpur Forest</td>
<td>Shorea, Syzygium</td>
<td>E 78°11′35.5″ &amp; N 30°14′51.3″</td>
<td>2411 ft</td>
<td>Forest</td>
<td>28.98</td>
<td>28.01</td>
</tr>
<tr>
<td>Rajpur Forest</td>
<td>Lachhiwala</td>
<td>Shorea, Terminalia</td>
<td>E 78°10′54.9″ &amp; N 30°13′45.0″</td>
<td>2093 ft</td>
<td>Forest</td>
<td>22.91</td>
<td>23.13</td>
</tr>
<tr>
<td>Lachelwala Forest</td>
<td>Lachhiwala</td>
<td>Shorea, Syzygium</td>
<td>E 78°55′25.2″ &amp; N 30°20′53.3″</td>
<td>1942 ft</td>
<td>Forest</td>
<td>25.66</td>
<td>28.33</td>
</tr>
<tr>
<td>Lachelwala Forest</td>
<td>Lachelwala</td>
<td>Shorea, Syzygium</td>
<td>E 78°13′10.5″ &amp; N 30°02′31.4″</td>
<td>1100 ft</td>
<td>Forest</td>
<td>27.12</td>
<td>24.65</td>
</tr>
</tbody>
</table>

**Table 2(a):** ANOVA table for the regression analysis using the model \( y = a + b D^H \)

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>SS (df = 1)</th>
<th>MS (df = 1)</th>
<th>( F )</th>
<th>Significance F</th>
</tr>
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<tbody>
<tr>
<td>Regression</td>
<td>1</td>
<td>0.237949459</td>
<td>0.237949</td>
<td>137.596</td>
<td>7.27159E-10</td>
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<tr>
<td>Residual</td>
<td>18</td>
<td>0.031127942</td>
<td>0.001729</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>19</td>
<td>0.269077401</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 2(b):** Estimates of regression coefficients along with the standard error for the regression model \( y = a + b D^H \)

<table>
<thead>
<tr>
<th>Regression coefficient</th>
<th>Estimated Regression coefficients</th>
<th>Standard Error of Estimated coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td>( a )</td>
<td>0.21162</td>
<td>0.02191</td>
</tr>
<tr>
<td>( b )</td>
<td>0.00010</td>
<td>8.5566</td>
</tr>
</tbody>
</table>

**Table 2(c):** Estimates of Adjusted \( R^2 \) and Furnival index for the model \( y = a + b D^H \)

<table>
<thead>
<tr>
<th>Regression Statistics</th>
<th></th>
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<tbody>
<tr>
<td>Multiple R</td>
<td>0.940381</td>
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<tr>
<td>R Square</td>
<td>0.884316</td>
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<tr>
<td>Adjusted R Square</td>
<td>0.877889</td>
</tr>
<tr>
<td>Standard Error</td>
<td>0.041585</td>
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<tr>
<td>Furnival index</td>
<td>0.041231</td>
</tr>
<tr>
<td>Observations</td>
<td>20</td>
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</tbody>
</table>

**Table 3:** Comparison of AGB, BGB, Deadwood, Total Biomass and total carbon sequestration potential of Sal (Shorea robusta) tree from different sites

<table>
<thead>
<tr>
<th>Name of the Sites</th>
<th>AGB (Mg)</th>
<th>BGB (Mg)</th>
<th>Deadwood (Mg)</th>
<th>TB (Mg)</th>
<th>TBA (m² ha⁻¹)</th>
<th>TV (m³ ha⁻¹)</th>
<th>Total Carbon (Mg ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thano Forest Range</td>
<td>458.841</td>
<td>110.122</td>
<td>28.448</td>
<td>597.411</td>
<td>45.919</td>
<td>302.549</td>
<td>280.783</td>
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<tr>
<td>Lachelwala Forest</td>
<td>387.230</td>
<td>92.935</td>
<td>24.008</td>
<td>504.173</td>
<td>40.046</td>
<td>247.668</td>
<td>236.962</td>
</tr>
<tr>
<td>Asarori Forest Range</td>
<td>319.883</td>
<td>76.772</td>
<td>19.833</td>
<td>416.487</td>
<td>33.798</td>
<td>213.832</td>
<td>195.749</td>
</tr>
<tr>
<td>Selaqui and Jhajra</td>
<td>445.171</td>
<td>106.841</td>
<td>27.601</td>
<td>579.612</td>
<td>43.894</td>
<td>315.204</td>
<td>272.418</td>
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<tr>
<td>Rajpur Forest Range</td>
<td>367.267</td>
<td>88.144</td>
<td>22.771</td>
<td>478.182</td>
<td>38.068</td>
<td>234.657</td>
<td>224.745</td>
</tr>
</tbody>
</table>

**Table 4:** Comparative account of calculated biomass and carbon density of Lantana from all the sites of Doon Valley

<table>
<thead>
<tr>
<th>Name of the sites</th>
<th>Average Crown Diameter (cm)</th>
<th>Average Shrub Canopy Area (plant/m²)</th>
<th>Density of Lantana ha⁻¹</th>
<th>Biomass (Mg ha⁻¹)</th>
<th>Carbon Density (Mg ha⁻¹)</th>
<th>Phytovolume (m³ ha⁻¹)</th>
<th>Carbon Dioxide (Mg ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thano Forest Range</td>
<td>141.95</td>
<td>1.65</td>
<td>15.60</td>
<td>6.82</td>
<td>3.20</td>
<td>75.988</td>
<td>25.00</td>
</tr>
<tr>
<td>Lachelwala Forest</td>
<td>141.48</td>
<td>1.67</td>
<td>15.30</td>
<td>6.74</td>
<td>3.16</td>
<td>75.927</td>
<td>247.1</td>
</tr>
<tr>
<td>Asarori Forest Range</td>
<td>159.13</td>
<td>2.17</td>
<td>16.60</td>
<td>7.03</td>
<td>3.30</td>
<td>87.528</td>
<td>25.80</td>
</tr>
<tr>
<td>Selaqui/Jhajra Forest</td>
<td>150.40</td>
<td>1.94</td>
<td>16.60</td>
<td>7.35</td>
<td>3.45</td>
<td>93.001</td>
<td>26.96</td>
</tr>
<tr>
<td>Rajpur Forest Range</td>
<td>180.28</td>
<td>2.65</td>
<td>14.60</td>
<td>11.15</td>
<td>5.24</td>
<td>201.363</td>
<td>40.89</td>
</tr>
<tr>
<td>Golatappar</td>
<td>176.63</td>
<td>2.33</td>
<td>17.00</td>
<td>9.80</td>
<td>4.61</td>
<td>120.496</td>
<td>35.96</td>
</tr>
</tbody>
</table>
Table (5): Comparison of Biomass and Carbon pools of various forest types of India with the present study

<table>
<thead>
<tr>
<th>Forest Type</th>
<th>Biomass (Mg ha(^{-1}))</th>
<th>Carbon (Mg ha(^{-1}))</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tropical Dry Forest, Varanasi, India</td>
<td>239.80</td>
<td>119.90</td>
<td>Singh, 1975</td>
</tr>
<tr>
<td>Sub Tropical Humid Forest, India</td>
<td>220.00</td>
<td>110.00</td>
<td>IPCC, 2006</td>
</tr>
<tr>
<td>Sub-Tropical Dry Forest, India</td>
<td>130.00</td>
<td>65.00</td>
<td>IPCC, 2006</td>
</tr>
<tr>
<td>Evergreen Forest, Eastern Ghats, India</td>
<td>307.30</td>
<td>153.65</td>
<td>Ramachandran et al. 2007</td>
</tr>
<tr>
<td>Deciduous Forest, Eastern Ghats, India</td>
<td>251.65</td>
<td>125.82</td>
<td>Ramachandran et al. 2007</td>
</tr>
<tr>
<td>Secondary Deciduous Forest, Eastern Ghats, India</td>
<td>241.77</td>
<td>120.88</td>
<td>Ramachandran et al. 2007</td>
</tr>
<tr>
<td>Scrub, Eastern Ghats, India</td>
<td>57.50</td>
<td>28.75</td>
<td>Ramachandran et al. 2007</td>
</tr>
<tr>
<td>Semi Evergreen, Western Ghats, India</td>
<td>202.60</td>
<td>101.30</td>
<td>Kale et al. 2009</td>
</tr>
<tr>
<td>Mixed Moist Deciduous, Western Ghats, India</td>
<td>209.30</td>
<td>104.65</td>
<td>Kale et al. 2009</td>
</tr>
<tr>
<td>Tropical Semi Evergreen, Pauri Garhwal, India</td>
<td>324.0</td>
<td>162.00</td>
<td>Baishya et al. 2009</td>
</tr>
<tr>
<td>Mixed Forest, Chattisgarh, India</td>
<td>78.31</td>
<td>39.11</td>
<td>Bijalwan et al. 2010</td>
</tr>
<tr>
<td>Teak Mixed Forest, Chattisgarh, India</td>
<td>66.34</td>
<td>33.17</td>
<td>Bijalwan et al. 2010</td>
</tr>
<tr>
<td>Degraded Forest, Chattisgarh, India</td>
<td>45.94</td>
<td>22.97</td>
<td>Bijalwan et al. 2010</td>
</tr>
<tr>
<td>Sal Mixed Forest, Chattisgarh, India</td>
<td>66.54</td>
<td>33.27</td>
<td>Bijalwan et al. 2010</td>
</tr>
<tr>
<td>Dry Siwalik Sal Forest, Pauri Garhwal, India</td>
<td>180.80</td>
<td>83.20</td>
<td>Sharma et al. 2010</td>
</tr>
<tr>
<td>Dry deciduous Sal Forest, Pauri Garhwal, India</td>
<td>162.00</td>
<td>74.50</td>
<td>Sharma et al. 2010</td>
</tr>
<tr>
<td>Moist Bhabhar Sal Forest, Pauri Garhwal, India</td>
<td>346.50</td>
<td>159.40</td>
<td>Sharma et al. 2010</td>
</tr>
<tr>
<td>Pinus roxburghii, Pauri Garhwal, India</td>
<td>159.40</td>
<td>73.30</td>
<td>Sharma et al. 2010</td>
</tr>
</tbody>
</table>

Present study

| Pure Sal (Shorea robusta) Forest of (Doon Valley), India | 494.65 | 232.49 | Present study |

Invasive Shrub (Lantana) from the forest of (Doon Valley), India

<table>
<thead>
<tr>
<th>Forest Type</th>
<th>Biomass (Mg ha(^{-1}))</th>
<th>Carbon (Mg ha(^{-1}))</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Invasive Shrub (Lantana) from this site</td>
<td>8.15</td>
<td>3.83</td>
<td>Present study</td>
</tr>
</tbody>
</table>

The phytovolume of *Lantana* from this site was recorded as 201,363.20m\(^3\) ha\(^{-1}\) with coverage of 38.63%. Total biomass of the shrub was 11.15 Mg ha\(^{-1}\) from this site and the total carbon stock estimated from this site was 5.24MgC ha\(^{-1}\). Some commonly growing plant species of this site were *Adhatoda zeylanica* L., *Asparagus adscendens* Buch.-Ham. ex Roxb., *Bambusa arundinacea* Willd., *Calotropis procera* (Aiton) Dryander., *Caryopteris grata* (Wallich) Benth., *Baliospermum montanum* (Willd.) Muell.-Arg., *Desmodium gangeticum* (Linn.) DC., *Indigofera atropurpurea* Ham ex Ham., *Dendrolobium triangulare* (Retz.) Sch., *Glycosmis pentaphylla* auct. mult. non DC., *Jasminum multiflorum* (Burm. f.) Andrews.

**Selaqui and Jhajra Forest Range**

From Selaqui and Jhajra forest region the total biomass of Sal tree was 579.61Mgha\(^{-1}\) which include AGB – 445.17 Mg ha\(^{-1}\), BGB – 106.84 Mg ha\(^{-1}\) and Deadwood 27.60 Mg ha\(^{-1}\). Amongst all the forest study sites this obtained the maximum total biomass. This site recorded a maximum TBA of 43.89 m\(^3\) ha\(^{-1}\) and a TV of 513.20 m\(^3\) ha\(^{-1}\). Since biomass has a direct role in determining the total carbon therefore, the Sal forest recorded a maximum carbon stock of 272.41MgC ha\(^{-1}\) from this site.

The mean shrub height as obtained from this site was 280.5cm and the mean crown diameter was 150.40cm. The mean shrub canopy area was 1.93m\(^2\)/plant. The mean shrub canopy projected volume of 5.60m\(^3\)/plant was recorded from this site. The density of *Lantana* from this site was 16,600plants ha\(^{-1}\). The total phytovolume of *Lantana* from this site was recorded as 93,001.50m\(^3\) ha\(^{-1}\) whereas the coverage was of 32.14%. Total biomass of the shrub was 7.35 Mg ha\(^{-1}\) from this site and the total carbon stock estimated was 3.45MgC ha\(^{-1}\). Some abundantly found species from this site were *Murraya koenigii* L. Spreng., *Parthenium hysterophorus* L., *Xanthium indicum* Koenig., *Jasminum nudiflorum* Lindl., *Celtis ovata* Desv., *Alternanthera sessilis* (L.) R. DC., *Plagiotheca niruri* (Roxb.) Nees., *Pogostemon benghalense* (Burm. f.) Kunth., *Ziziphus mauritiana* Lam., *Androscace umbellata* (Lour.) Merrill, *Anisomeles indica* (L.) Kunth., *Asparagus racemosus* Willd.

**Golatappar Forest Range**

Minimum biomass (392.05 Mg ha\(^{-1}\)) was recorded from Golatappar, due to its open patches of Sal trees. This includes a combined value of AGB – 301.12 Mg ha\(^{-1}\), BGB – 72.26 Mg ha\(^{-1}\) and Deadwood18.67 Mg ha\(^{-1}\). TBA of 31.52 m\(^2\) ha\(^{-1}\)and TV of 324.19 m ha\(^{-1}\) was recorded from this site. The total amount of atmospheric carbon which was sequestered due to Sal forest was 184.27MgC ha\(^{-1}\). The mean shrub height from this site was 296.8cm and the mean crown diameter was 170.63cm. The mean shrub canopy area was 2.33m\(^2\)/plant. The mean shrub canopy projected volume of 7.08m\(^3\)/plant was recorded from this site. The density of *Lantana* from this site was 17,000plants ha\(^{-1}\). The total phytovolume of *Lantana* from this site was recorded as 120,496.00 m ha\(^{-1}\) with coverage of 39.64%. Total biomass of the shrub was 17,040Mg ha\(^{-1}\) from this site and the total carbon stock estimated from this site was 4.61MgC ha\(^{-1}\). Some dominant plant species of the site were *Adenostemma lavenia* L. Kunz, *Curculigo*

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**Discussion**

Numerous biomass equations have been reported for estimating forest biomass for a given species under various conditions. However, many of these equations have been presented inconsistently in terms of their form and regression parameters, and this inconsistency has complicated their application. In the current study a number of biomass equations were considered and has chosen the most suitable approach for evaluating the biomass through allometric equations, which is already tested for its accuracy and used accordingly in a similar condition and for the similar tree species. However, the allometric equation chosen for the biomass calculation of *Lantana* was adopted from FAO statistics manual for Asia pacific to calculate the biomass of shrubs and trees. The particular equation used in this study was tested for its relevance and accuracy to the present condition, which is discussed in the result section.

The present study is focused in calculating the biomass and carbon stock of dominant Sal trees and the noxious, invasive woody shrub *Lantana* from the periphery of different forest sites chosen for the present study and also to give suitable and accurate method for the calculation of shrub biomass as this aspect of shrub is always neglected by researchers. In the present study we chose the equation with variables like DBH and plant height to calculate the biomass of both Sal trees and *Lantana* but in some of the studies other attributes like north and south aspects of the trees, biomass of different components (bole, branch, twig, foliage, stump roots, lateral roots, and fine roots) in different girth classes were also calculated separately from its measured circumference to calculate the biomass [28]. In some studies the tree height, basal area of the tree and importantly the WSG (Wood Specific Gravity) of the trees were used to calculate the biomass and carbon stock [29, 30]. Some studies reported that the density of carbon per unit volume is highly correlated with WSG and, therefore, WSG has direct applied importance for estimating ecosystem carbon storage and fluxes [31]. WSG is expected to be greater in less fertile soils with drought stress conditions [32].

The AGB carbon pool consists of all living vegetation above the soil, inclusive of stems, stumps, branches, bark, seeds and foliage. The most comprehensive method to establish the biomass of this carbon pool is destructive sampling, whereby vegetation is harvested, dried to a constant mass and the dry-to-wet biomass ratio established. Destructive sampling of trees, however, is both expensive and somewhat counter-productive in the context of promoting carbon sequestration and in Indian context the destructive sampling is not legal as well. According to some worker both tropical and temperate forests, biomass calculated through such diameter measurements explain more than 95% of the variation in tree biomass [33]. There are a number of database and publications, presenting default regression equations, stratified by rainfall regime and region [26, 34]. These default equations, based on a large sample of trees, are commonly applied, as the generation of local allometric equations is often not feasible. However, the application of default equations tends to reduce the accuracy of the biomass estimate. Sometime as the elevation increases, potential evapo – transpiration of the trees decreases, making the forest wetter at a given rainfall, thus a regression equation applied to highland forest may give inaccurate biomass estimates.

The BGB (Below Ground Biomass) carbon pool consists of the biomass contained within live roots of trees. Although with AGB (Above Ground Biomass), for which less data exists, regression equations from root biomass data have been formulated which predict root biomass based on above-ground biomass carbon [33, 35]. A review of 160 studies covering tropical, temperate and boreal forests found a mean root-to-shoot (RS) ratio of 0.26, ranging between 0.18 and 0.30 [35]. The wood carbon pool includes all non-living woody biomass and includes standing and fallen trees, roots and stumps with diameter over 10cm [35].

The Root Shoot (RS) ratios were constant between latitude (tropical, temperate and boreal), soil texture (fine, medium and coarse), and tree-type, both angiosperm and gymnosperm [35]. Roots are believed to depend on climate and soil characteristics [36]. As with AGB, the application of default RS ratios represents a trade-off between costs of time, resources and accuracy. BGC can also be assessed locally by taking soil cores from which roots are extracted; the oven dry weight of these roots can be related to the cross-sectional area of the sample, and so to the BGB on a per area basis [37]. Often ignored, or assumed in equilibrium, this carbon pool can contain 10% - 20% of that in the AGB pool in mature forest [38]. However, in immature forests and plantations both standing and fallen dead wood are likely to be insignificant in the first 30-60 years of establishment.

Tropical forests have a strong vertical structure, with much of the leaf biomass and fruits in the brightly lit canopy, seed germination, seedling growth, and juvenile recruitment in the dark understory [39]. Tropical forest canopies have a layered structure. Tall trees comprise the
upper layer, followed by a main canopy layer, and a sub canopy of smaller trees and shrubs near the ground level [40]. Trees in tropical forests have relatively large leaves and are often characterized by buttresses, palms, climbing plants, epiphytes and hemi-epiphytes [41]. In contrast to tropical evergreen forests, tree species diversity is lower in tropical deciduous forests. Furthermore, canopies are shorter and the structure is more open compared to the tropical rainforests. Tropical forests contain more than half of the Earth’s terrestrial species [42]. Furthermore, tropical forests predominantly contribute to global biodiversity ‘hotspots’ or the areas which are featuring exceptional concentrations of endemic species and experiencing exceptional loss of habitat. Biodiversity is generally high but little is known as tropical forests are extensive, highly variable and generally more difficult to study than any other vegetation type [43]. About 44% of the world’s relatively undisturbed forest lies in the tropics [44].

In India, as much as 86% of the forest area is under tropical forest, of which 53% is dry deciduous, 37% moist deciduous and the rest evergreen [45]. Terrestrial ecosystems of India are extensively studied for point biomass and productivity estimations using ecological methods [46, 47, 48]. There is need to perform extensive studies for biomass estimation in order to know the role of forest in carbon cycle patterns. Creation of reliable biomass data requires region-specific allometric equations to estimate the biomass and carbon stock and the values of which can be further extrapolated to the local and regional levels using appropriate techniques.

From the present result it is clear that Golatappar range is an open canopy forest where the density of the Sal trees is also very less, this is the most probable reason why Golatappar has shown the least per hectare biomass (392.05 Mg ha⁻¹). The maximum total biomass was recorded from Thano range (597.41 Mg ha⁻¹). These results are in relation with the early findings of the ecosystem valuation services and forest governance [49]. In some previous work it was shown that biomass values of forest stands in the Himalaya tend to cluster around two very different levels – from a low approximately 200t ha⁻¹ for early successional communities such as chir pine, to a high of about 400Mt ha⁻¹ for late successional communities such as oaks and Sal [6].

Tree biomass in excess of 700t ha⁻¹ has been reported for old growth Sal in the Himalayan foothills as well as mixed oak forests at mid altitudes which are higher than biomass values reported for many tropical rain forests [6]. In addition, old growth forests have high levels of soil carbon making, while late successional Himalayan forests are very valuable in terms of carbon storage potential. This finding again supports the present result where a large amount of biomass (494.65 Mg ha⁻¹) is recorded from the salforest of Doon Valley. Carbon storage in the Uttarakhand Himalayan forests range from an average of about 175t C ha⁻¹ for chir pine forests to approximately 300t C ha⁻¹ for oak and Sal dominated forests [6]. Whereas, the present result shows that from the Sal dominated dry deciduous forest 232.84 MgC ha⁻¹ carbon is sequestered. Some worker reported that above ground biomass had 48.30 Mg ha⁻¹C to 97.30 Mg ha⁻¹C (approximately 50% of the biomass) in tropical deciduous forests of India [50]. The carbon storage in the present study is much similar to in range as compared to the estimates made in different tropical forests [51, 52]. Estimate also state that the carbon storage was from 94.30 to 190.96 Mg ha⁻¹C in semi-evergreen forests of Karnataka, India [52].

Some other previously obtained data shows that the biomass of subtropical Sal forests of the entire Himalayan foothills was 10.10 Mt C [6] but in this case the carbon stock was calculated by using a conversion factor 0.63 and not with the IPCC default. However, in the present study a carbon conversion factor 0.47 [26, 34] is used instead of 0.63 [6]. In Uttarakhand, community forestry has been strongly institutionalized; issues of ecosystem services can directly affect their economic condition and processes leading to the empowerment of local people. However, in the current scenario the forests of Doon valley are heavily infested by invasive shrub species like Lantana which is also a great source of carbon sink from the atmosphere. But this woody shrub was never considered for its immense carbon storage property. Though Lantana pretence several serious threat to the environment but apart from the threat if we can consider Lantana as a good carbon sequestering agent along with the subtropical forests (dominated by Sal trees) as in the case of the present study, it will always be a better alternative to the sequestration of carbon from the atmosphere of developing countries like India, where the situation is alarming. The present study shows that an average Lantana biomass (8.15 Mg ha⁻¹) and an average carbon density 3.83 MgC ha⁻¹ are recorded from the forest periphery of Doon Valley.

Though many workers reported shrub biomass in their studies from different parts of globe [14, 15, 20, 53, 54] but never for invasive shrub like Lantana from the Doon Valley. Therefore information on Lantana biomass and its role in global carbon sequestration would be helpful in near future. Given that, there are large areas infested with this plant, it is reasonable to consider if large scale use could be made of its biomass. From the present and previous research work it is clearly revealed that Lantana is a problem weed across the country and globe as it has many negative impacts on the biodiversity but despite their negative impacts this weed can also be considered as one of the very good source of carbon sink from the atmosphere, as it is equally contributing in the eradication of CO₂ along with the deciduous forests.

The C balance of a tropical forest based on atmospheric, eddy covariance or ground based studies may differ among each other [55]. The global CO₂ flux caused by the land use changes, however, is dominated by tropical deforestation as about 13 million hectare tropical forest are felled or grazed each year [56].

Workers reported the aboveground biomass values for tropical forests between 2,250 and 32,450 g C m⁻² [57]. Estimates for the aboveground C ranges between 2,250 and 20,300 g C m⁻² for mature tropical forests, and between 2,300 and 27,300 g C m⁻² for mature seasonally dry tropical forests [58]. In general, values for aboveground
live biomass range between 1,800 and 26,600 g C m⁻², and those for the root biomass between 400 and 5,700 g C m⁻² for moist tropical forests [59, 60].

The average biomass of natural tropical forests is estimated at 9,400 g C m⁻² [61]. Average above-ground biomass estimates for tropical forests of Africa range from 85 Mg ha⁻¹ for closed deciduous forests to 251 Mg ha⁻¹ for swamp forests [62]. The estimate of average carbon content (in the biomass and forest soil) in Indian forests is 126 Mg C ha⁻¹ of which 36% (45.8 Mg C ha⁻¹) is in biomass and 64% (79.8 Mg C ha⁻¹) in forest soils [63]. The results of the base scenario show that Indian forests and forest sector activities in 1994 are a source of 12.8 Tg C.

Sal mixed forest in Chhattisgarh, India had recorded the carbon stock of 33.27 Mg C ha⁻¹ [64], while in the present study dry deciduous forest which has the largest share of S. robusta has recorded a carbon stock of 232.48 Mg C ha⁻¹. This might be due to the forests of Chhattisgarh, not being fully mature as compared to the forests in the present study which resulted in higher carbon storage (Table 5).

Carbon stock of 159.40 Mg C ha⁻¹ from the Shorea robusta forest of moist Bhabhar region in India was calculated [65] while in the present study, 232.48 Mg C ha⁻¹ of carbon stock was recorded from all the Sal dominated dry deciduous forest. Carbon density (74.50 Mg C ha⁻¹) was reported from the dry-sub deciduous forest of Bhabhar region [65] while in the present study, the carbon density of 232.48 Mg C ha⁻¹ was recorded from the dry-deciduous forests of Doon Valley (Table 5).

Some workers studied the carbon sequestration potential in India by considering three distinct scenarios – Business as usual, conservation and plantation forestry [66]. They used Land use and Carbon Sequestration (LUCS) model with software developed at the World Resources Institute, Washington DC, USA. It was estimated that under business as usual scenario 6.65 bt (billion tonnes) of carbon (or 13.3mt of carbon annually) and under plantation scenario 6.94 bt of carbon (or 13.88 mt of carbon annually) will be sequestered during 2000-2050.

From the undisturbed Himalayan foothill Sal forests in Doon valley, some recorded 2.95 t C ha⁻¹ yr⁻¹ under natural forests, 6.7 t C ha⁻¹ yr⁻¹ in planted forest and 9.05 t C ha⁻¹ yr⁻¹ for growing stand [67], while in another study [68] the carbon sequestration potential for natural Sal forest has been estimated as 5.45 t C ha⁻¹ yr⁻¹. The old growth forest of Sal and high altitude oak (Quercus semicarpifolia) are demonstrated to sequester respectively 3.33 t C ha⁻¹ yr⁻¹ and 4.51 t C ha⁻¹ yr⁻¹ from above ground component with major contribution (75.8 % for the former and 71 % for the latter) from bole [69].

In India, CO₂ emissions from forest diversion or loss are largely offset by carbon uptake due to forest increment and afforestation. Many authors concluded that for the recent period, the Indian forests are nationally a small source with some regions acting as small sinks of carbon as well [3, 4, 70]. The improved quantification of pools and fluxes related to the forest carbon cycle is important for understanding the contribution of Indian forests to net carbon emissions as well as their potential for carbon sequestration in the context of the Kyoto Protocol [4]. It was estimated that under this options 4.936 mt (million tonnes) of carbon would be sequestered over a 40 years period of time. A sustainable forestry scenario (baseline) and a commercial scenario (meeting biomass demands through plantation and restoring forests) needs to be developed for better forestry in India [70].

Estimation of carbon content in forest woody biomass is important with regard to Greenhouse effect mitigation, and regarding mandatory reporting about carbon dioxide (CO₂) emissions and removals in forestry sector for countries which signed the Kyoto treaty. Plants in their growth process like photosynthesis absorb CO₂ from the air and in such a manner sequester carbon through biomass, and thus decreasing the concentration of this quantitatively most significant greenhouse gas (GHG) in the air. For this reason, forest stands are called carbon Pool or carbon sinks.

The carbon sequestration function of forests has been well researched during the last 20 years, and forest ecosystems, depending on their capacity, have been found to be the biggest carbon sinks among all other terrestrial ecosystems. The discussion above shows that, instead of being linear and wholesome, 'constant' constructs, Indian forests (like any other tropical forests) are part of a larger, dynamic, and ever-changing socio-political and socio-ecological discourse and can contribute immensely in global carbon cycle along with its trees and invasive shrubs.

**Conclusion**

Our study provides relevant information on total biomass and carbon stocks in different forest types of Doon Valley. The results of the present study will be helpful for understanding the patterns of carbon storage in Sal forest types and the invasive woody species of sub-tropical regions in other parts of India and the Globe having similar species composition. The following are the conclusion of the present study:

1. The mean biomass of Sal forest from Doon Valley is 507.58 Mg ha⁻¹ and the carbon density is 238.56 Mg C ha⁻¹. This is higher than the previously recorded value from similar forest in different parts of India.
2. The total volume, total biomass and total carbon stock of Sal trees when compared with the previous studies, found far more than in all the forest types wherever Sal existed.
3. Non-destructive method of biomass calculation through allometric equation is found the best method not only for trees but also for shrubs because it is less laborious, less time consuming and more accurate. The measured attributes like, DBH and plant height for both Sal tree and Lantana were the best variables to analyse the regression and to derive the allometric equation for non-destructive biomass calculation.
4. The allometric equation (y = a + bD²H) was found more accurate for calculating the non destructive biomass of Lantana from the deciduous forests of Doon Valley.
5. The mean biomass of invasive shrub Lantana from Doon Valley forest is 8.15 Mg ha⁻¹ and the carbon
density is 3.83 Mg C ha\(^{-1}\).

6. The total mean biomass of both Sal tree and Lantana accounted for 502.80 Mg ha\(^{-1}\) (494.65 Mg ha\(^{-1}\) + 8.15 Mg ha\(^{-1}\)) with the carbon density of 236.32 Mg C ha\(^{-1}\) (232.48 Mg C ha\(^{-1}\) + 3.83 Mg C ha\(^{-1}\)).

7. The periphery of the forest is heavily infested by Lantana but a shrub level carbon sequestration was never calculated from Doon Valley (especially an invasive shrub) and therefore, Lantana’s carbon storage potential can also be used in a positive way despite the fact that Lantana is a threat to the biodiversity, along with the Sal forest of Doon Valley especially when the Sal trees shed of their leaves.

The results of the present study will help the policy-makers at both National and International levels to find most efficient solutions to the problems that are threatening the similar ecologically fragile regions. It is therefore, necessary to obtain more accurate and precise biomass estimation of Doon Valley forests in order to improve our understanding of the role of Doon Valley forests in the global carbon cycle.

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References


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