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ORIGINAL PAPER

Estimation of above-ground biomass and carbon stock of an invasive woody shrub in the subtropical deciduous forests of Doon Valley, western Himalaya, India

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Abstract This study describes the different parameters used to derive the allometric equation for calculating the biomass of an invasive woody shrub *Lantana camara* L. from the subtropical conditions of western Himalaya. It identifies the most accurate and convenient method for biomass calculation by comparing destructive with non-destructive methodology. Different parameters were measured on a wide range of *Lantana* from different community levels for the non-destructive calculation of total above-ground biomass. Different explanatory variables were identified and measured such as basal diameter either as a single independent variable or in combination with plant height. The other suitable combinations of available independent variables include crown length, crown width, crown area, crown volume and coverage of the plant. Amongst the wide range of allometric equations used with different variables, the equation with D^2H as a variable was found to be the most suitable estimator of biomass calculation for *Lantana.* Sahastradhara, being the most disturbed area due to its high tourist activity round the year, showed maximum coverage (58.57 % ha^{-1}), highest biomass (13,559.60 kg ha^{-1}) and carbon density (6,373.01 kg ha^{-1}) of *Lantana*. The degree of *Lantana's* invasiveness in subtropical conditions was also calculated on the basis of importance value index (IVI). The maximum IVI (22.77) and mean coverage (26.8 % ha^{-1}) was obtained from the areas near Jolly Grant airport, indicating that physically disturbed areas are more suitable for the growth of *Lantana,* which may significantly increase shrub biomass. The importance of incorporating allometric equations in calculation of shrub biomass, and its role in atmospheric carbon assimilation has thus been highlighted through the findings of this study.

Keywords Above ground carbon pools · Allometric regression equations · Carbon density · Importance value index (IVI) · Shrub biomass

Introduction

Shrubs are a type of vegetal group with a specific structure and appearance (de la Torre 1990). These woody non-trees are of great importance to the biophysical and biodynamic processes of different ecosystems (Di Castri et al. 1981). The exotic plant species vary from their native counterpart, based on requirements such as modes of resource acquisition and more consumption which may ultimately result in changing their soil structure, soil profile, rate of decomposition, nutrient content and moisture. It results in noteworthy unwelcome impacts on the biodiversity and ecosystems. Thus, invasive species are a serious obstruction for conservation and sustainable use of biodiversity. Biological invasions now operated on global level and it will undergo rapid increase due to increasing globalization of markets, rise in global trade, travel and tourism (Eisworth et al. 2005). One such species is *Lantana camara* L. (henceforth *lantana*), native to tropical America, this

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invasive shrub has naturalized in most suitable habitats of tropical and subtropical Africa, Asia, and Australia. *Lantana* can grow up to 1.8 m in height with an equal spread depending on cultivar. The impacts of *lantana* infestations range widely across landuse situations, affecting individuals, landholders and land managers, locals, state and federal governments, community groups, and industry.

In natural ecosystems, *lantana* infests forest edges, coastal zones and riparian areas, penetrates disturbed rainforest and invades open eucalypt woodland. Its dense thickets exclude native species through smothering and allelopathic effects (*i.e.,* toxicity to other plants), dominate understoreys, and reduce biodiversity. *Lantana* thickets increase the intensity of wildfires, which can have disastrous effects on native flora and fauna. The forests and fallow lands of Doon Valley is heavily infested by this invasive shrub due to many reasons such as large forest gaps created because of round the year tourist activity and availability of resources due to heavy industrialization after its becoming capital of the state Uttarakhand. There is no second opinion that *lantana* is a threat to the nature, biomass estimation of *lantana* on the other hand can be very useful for the carbon assimilation process in the deciduous forests of the valley, also a shrub level carbon sequestration has never been calculated in Doon Valley, which can give more accurate estimation of forest biomass. Biomass is a key structural variable in invasive studies and researches into the dynamics of different ecosystems, the type of bio geographic conditions and biodiversity they sustain, their role in the atmospheric carbon cycle, and their resistibility in becoming an invasive species (Waring and Running 1996). Understanding the role of biomass in terms of nutrient cycles, fuel properties and their adaptation to different climatic conditions is also important (Terradas 1991; Rapp et al. 1999; Mary et al. 2001).

Calculation of above-ground biomass and other variables are required for better forest, scrubland, and grassland ecosystem management; development and execution of different models that help in the mapping of different characteristics of forest fuels (Nuñez-Regueira et al. 2000); and effects of invasive species on forest hydrological planning (Pastor-López and Martin 1995). Large-scale evaluation, mapping, and strategic values are necessary for accurate modelling of the dynamics of ecosystems (Oyonarte and Navarro 2003). There are a range of methods, from aerial photography and imagery to destructive sampling, for biomass estimation. Several general and local biomass tables and species-specific allometric equations have been developed for this reason; however, these are limited to tree species. Biomass analysis in forest ecosystems has been obtained in many studies through direct (destructive) or indirect (through dimensional analysis of different attributes of plants) sampling methods (Etienne 1989; Wharton and Griffith 1993).

Destructive methods involve harvesting the plants and weighing in the sample plots. This approach gives very accurate estimates of the biomass but harvesting and weighing a large number of samples is laborious and costly (Uresk et al. 1977). Indirect methods involve the use of allometric and mathematical models, which have been developed for estimation of total biomass and are based on the measurements of different plant attributes like shrub height, stem diameter at breast height (Smith and Brand 1983; Tietema 1993; Buech and Rugg 1989), crown diameter (Navarro and Oyonarte 2006), crown area and crown volume (Maraseni et al. 2005). These indirect methods produce estimates that can approach the prediction accuracy of the destructive methods and allow us to observe a large number of physical parameters at a relatively low cost (Castro et al. 1996; Uso et al. 1997; Montés et al. 2000). Shrub biomass is an important component of the total biomass, especially in the natural forests but, because of the lack of methodology and difficulty in calculation, they are omitted in some cases, which results in underestimation of the total biomass (Khanal 2001; Karki 2002). There are some limitations to the application of these equations. Equations developed for the same species in different sites would be different because of different climatic and edaphic conditions; e.g., the equations developed for *Eucalyptus resinifera,* at two different sites are different (Ward and Pickersgill 1985) and so are equations for *Acacia aneura* (Harrington 1979; Burrows et al. 2002). Also, in some cases, the range of applicable diameters or heights is not quantified (Specht and West 2003). In others, the range of diameters or heights is too narrow to apply even for the same species found in the same locality (Burrows et al. 2002; Margules Groome Pöyry Pty Ltd. 1998).

An accurate allometric equation for the biomass estimation of *lantana*, especially in a subtropical condition like the Doon Valley, is essential for two reasons. First, *lantana* is rapidly invading in areas such as roadsides, suburban areas, abandoned residential plots, pastures, even the cultivated woodlands. Second, measurement of shrub level carbon flux which is not only important in regional but also in the study of global CO_2 cycle and therefore, estimation of shrub biomass can help to produce more accurate estimates of both forest biomass and biomass from other areas. Our primary objective was to compare the two previously used allometric equations for the estimation of shrub biomass proposed by Maraseni et al. (2005) and Navarro and Oyonarte (2006), and to see the compatibility of these allometric equations for *lantana* in a subtropical deciduous forest. We also wanted to develop a suitable allometric equation for the estimation of *lantana* biomass by using the different measured plant attributes from different study sites. The allometric regression equation developed for this study includes a variety of physical measurements of the different plant attributes, including circumference of the stem (which was later converted to diameter), the plant height, the maximum and minimum crown diameter (used to calculate the mean crown diameter), crown area, crown volume, phytovolume, and shrub coverage on the plot. Harniss and Murray (1976) used plant height and circumference to calculate shrub biomass while Dean et al. (1981) used maximum and minimum crown diameter, crown depth, and crown denseness.

Peek (1970) measured the maximum crown diameter, and the diameter at right angles to that, calculated canopy area for both an ellipse and a circle, and then calculated plant volume as area versus height. Bryant and Kothmann (1979) calculated crown volume as an inverted cone for four desert species. Murray and Jacobson (1982) developed many independent variables which include circumference, surface area, plant volume, diameter and height of the plant to predict leaf and twig biomass. Ferguson and Marsden (1977) were able to predict total twig length and weight for bitterbrush (*Purshia tridentata*) from the diameter at the base of the twig. Keeping the above facts in mind we decided to set our objective of the present study under the following domain; (1) To establish a dimensional relationship between different measured attributes of *lantana* such as D (basal diameter, cm), H (plant height, cm), C (crown diameter, cm), CA (canopy area, m^2), CV (canopy volume, m^3) and total biomass; (2) To establish an allometric equation for the calculation of *lantana* biomass from the dimensional relationship, as total harvesting of a large population of the shrub is impractical; (3) To compare the biomass of shrubs calculated by using the allometric equation and existing methods; and (4) To understand the present status of *lantana* in a native community through a vegetation analysis, which included the calculation of frequency, coverage, abundance and importance value index (IVI).

Materials and methods

Study area

The present study was carried out in the Doon Valley, situated in western Himalayan part of India. The Doon Valley is surrounded by hills on all the sides and has a varied range of subtropical deciduous forests mainly dominated by *Shorea robusta*, *Syzygium* spp., *Terminalia* spp., *Ehertia* spp., *Litsea* spp. and others. It is lying between latitudes 29°55′ and 30°30′N and longitudes 77°35′ and 78°24′E. It is a saucer-shaped valley about 20 km wide and 80 km long, with a geographical area of about 2,100 km^2 (Figs. 1 and 2). The valley is longitudinal, intermontane, synclinally depressed boulder (Thakur and Pandey 2004; Kumar et al. 2007) filled with coarse clastic fan-Doon gravel of the late Pleistocene and Holocene (Puri 1950). The valley is uniformly oriented in northwest-southeast direction, with lesser Himalayas in the northwest and the Siwalik ranges in the southwest. The two major hydrologic basins of the valley are the Ganga (or Ganges) in the southeast, with the Song and Suswa as its main tributaries, and the Yamuna in the northwest, with the river Asan as its main tributary. We selected eight sampling sites covering all parts of the Doon Valley: (1) Golatappar (open canopy areas), (2) Railway tracks (abandoned lands), (3) Asarori forest (dense forest areas dominated by Sal and *Syzygium* spp.), (4) Sahastradhara (a tourist place and highly disturbed areas), (5) Rajpur forest periphery (Sal-dominated forest), (6) Selaqui/Jhajra (abandoned residential plots and riverside forests dominated by Sal), (7) Jolly Grant airport (protected urban area), and (8) Mothronwala (swampy areas). The criteria for selecting these sites were to create a variation in physical factors, including different ranges of altitude, topography, habitat, and biotic interference level to calculate lantana infestation rate from the Doon Valley more effectively.

Estimation of shrub biomass

For destructive biomass, we determined biomass of lantana both destructively and non-destructively. For the destructive estimation of biomass, we followed the methods used by Navarro and Oyonarte (2006) in their study of calculating shrub biomass. We used transects in combination with the distance method in its closest individual mode, which permits the calculation of density, coverage, phytovolume, and phytomass in a relatively expeditious manner (Wharton and Griffith 1993; Navarro and Oyonarte 2006). A combination of the above mentioned variables is the best choice for obtaining an accurate description of a plant formation. The technique was as follows:

(1) Two transects were established from a randomly selected starting point in the chosen plot that was preferably located in the central region of each sampled zone. (2) Plot centres were located in the field using GPS. Transects were 50 m in length; the first transect was run in the direction of the slope gradient and the second transect perpendicular to the first at its mid-point. Fifty observations per plot were made, each 1 m apart, to encompass as high a variety of shrubs as possible. From each observation point, the distance to the nearest plant was measured, and the species of the plant recorded. (3) Four morphological variables [plant height (H, cm), largest crown diameter (C_1, cm), smallest diameter (C_2, cm) and diameter at bottom (C_3, cm)] were measured for each specimen using a measuring tape (reading range 0–5 m, precision 1 cm,

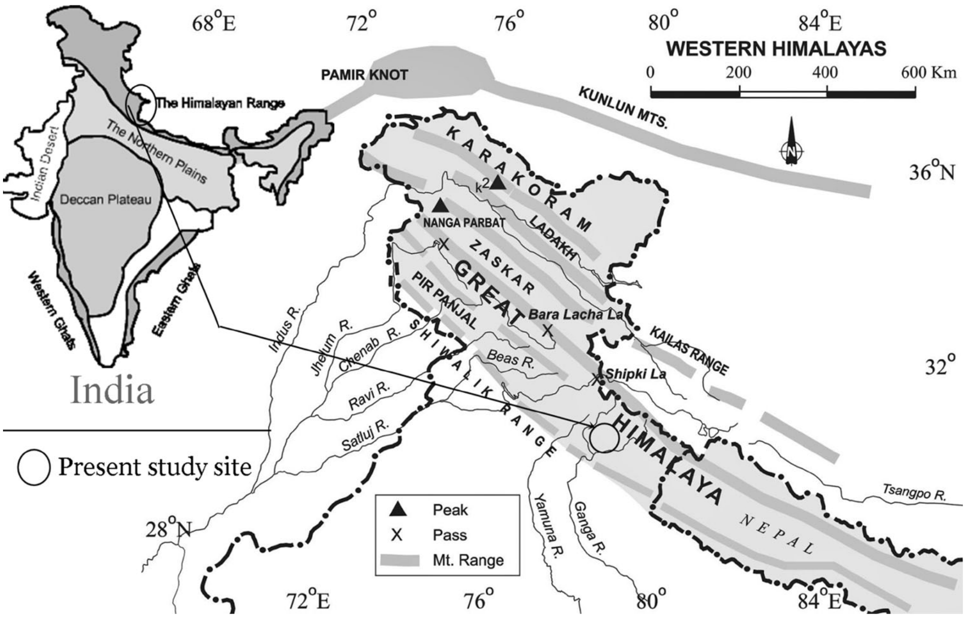

Fig. 1 Pictorial representation of present study location in Indian western Himalaya

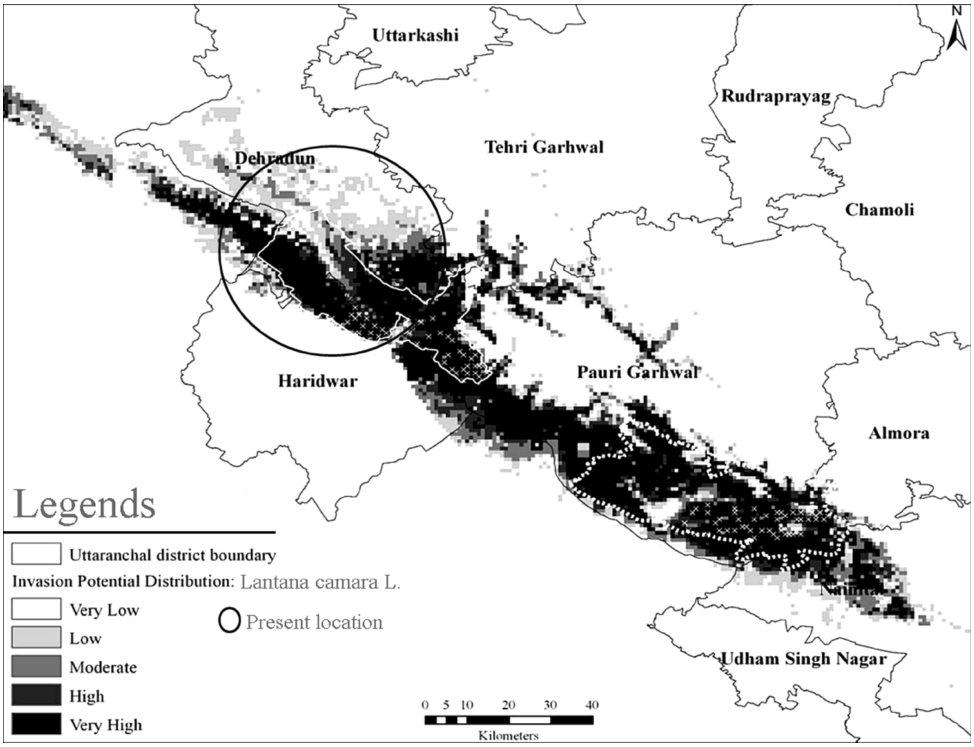

Fig. 2 Potential distribution of Lantana camara in the invasive range of Doon valley as per Genetic algorithm for rule set prediction (GARP). (*Source* Google maps)

observation error, 0.5 cm). These data were used to calculate the mean crown diameter (C_M, cm) and the phytovolume of each individual (Etienne 1989; Blanco and Navarro 2003). (4) After all the measurements were made in all plots, a sample of lantana was cut at ground level. The samples thus obtained were weighed in situ, without separating the stems and leaves, using an electric balance (*Voda Scale, India,* maximum weighing capacity 30 kg, minimum weighing capacity 1 kg, accuracy 2 g and a platter size of 400 × 240 mm stainless steel with auto calibration facility). (5) Whole individuals were transferred to the laboratory for drying in an air stove oven at 70 °C for 72 h until constant weight. The dried material was then weighed on the same balance to determine the dry weight of each fraction. (6) A set of formulas were then used to calculate the biomass of *lantana* using the oven dried mass already calculated by the methods described above. The detailed set of formulas is as follows:

The plant density per unit surface, D was calculated from

$$D = S/(\delta \times d)^2$$

where, S is the estimated area (10,000 m^2) in this study, d is the average distance between individual plants and points in a sampling, and δ is a correction factor depending upon the particular method used and equal to 2 in the closest individual method (Wharton and Griffith 1993).

The density of each species was calculated from

$$D_{(\mathrm{spi})} = \left(\frac{No.\,of\,plants\,spi}{Total\,no.\,of\,plants}\right) \times D$$

where, D $_{(\mathrm{spi})}$ is the density of individual species, D is the density per unit surface.

The mean diameter, C_M, was used to obtain the coverage C of each plant associated with the ideal circle area:

$$C = \pi(\Phi_M/2)^2$$

where, C = Coverage of each plant, $\pi = 3.142$, Φ_M = mean crown diameter

The total coverage for species i was obtained from

$$Ci = Di \times Cspi$$

The biomass per hectare for each species was calculated from the density values obtained in the samplings:

$$\frac{Biomass}{ha} = D_{(spi)} \times Dryweight_{(spi)}$$

All the above mentioned equations were adopted from Navarro and Oyonarte (2006).

For non-destructive estimation of biomass

The dependant 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 ($CV = CA \times H$). 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 °C for 72 h. The dry weight of *lantana* with its diameter (D) and D^2H were tested in different regression models. We tested and applied allometric equations described in FAO (1999). The following equations were tested for its best fit for the calculation of shrub biomass.

$$y = a + bD + cD^2$$

$$\ln y = a + bD$$

$$\ln y = a + b\ln D$$

$$y^{0.5} = a + bD$$

$y = a + bD^2H^*$ (equation used in the present study)

$$ln y = a + bD^2H$$

$$y^{0.5} = a + bD^2H$$

$$y = a + b(CA) + C(CA)^2$$

$$y = a + b(CV) + C(CV)^2$$

In all of the above equations; y = the biomass, D = the diameter, H = the plant height, CA = canopy area, CV = canopy volume, a, b, c are regression coefficients, and *ln* indicates natural logarithm.

Comparison of models

The different models were compared to determine which one has better fit compared to others. R^2 (coefficient of determination) has long been used to compare models and hence chosen one of the criteria in this study. However, for models with different set of variables, R^2 gives misleading results (Parresol 1999). The use of root mean square error (RMSE) to compare models was also not found logical in the present case because some models considered were using transformed variables. We chose Furival Index as one of the main criteria along with R^2 to compare the models. Furnival's Index was introduced by Furnival (1961) as a fit index that can be used for comparing models of different variables or weights based on the maximum likelihood concept. The advantage of this index is that it can reflect the size of the residuals and possible departures from linearity, normality and homoscedasticity (vector of random variables). Furnival Index is one of the recommended tools in statistics to compare different models (Parresol 1999; Montagu et al. 2005; Garber and Maguire 2005). The calculation is as follows:

$$R^2 = \frac{SSR}{SSTO}$$

$$Adjusted\,R^2 = 1 - \frac{n-1}{n-p}\left(1 - R^2\right)$$

where R^2 is the coefficient of determination obtained as the ratio of regression sum of squares to the total sum of squares, n is the number of observations on the dependant variables and p is the number of parameters in the model.

The Furnival Index was computed as follows:

(a) The value of the square root of error mean square was obtained for each model under consideration through analysis of variance.
(b) The geometric mean of the derivative of the dependant variable with respect to y was obtained for each model from the observations.
(c) The geometric mean of a set of n observations was defined by the nth root of the product of the observations.

The Furnival Index for each model is then obtained by multiplying the corresponding values of the square root of mean square error with the inverse of the geometric mean.

For example, if the derivative of *ln* y is (1/y) and the Furnival Index in that case would be:

$$Furnival\,Index = \sqrt{MSE}\left[\frac{1}{Geometricmean(y^{-1})}\right]$$

If the derivative of *y* is 1 then the Furnival Index would be:

$$Furnival\,Index = \sqrt{MSE}$$

The model $y = a + bD^2H$ was found having a lower Furnival Index compared to the other sample equations used in this study, and therefore given preference over other models (as model with lower Furnival Index and higher adjusted R^2 is considered more fit and accurate than the others).

Population Dynamics

Data on different parameters were collected from all sites. To study plant population dynamics, a quadrat of 5 m^2 in size was laid at random after collecting the field data. Parameters like relative frequency, relative density, relative dominance, and the IVI of species were calculated using the formulae given below and used in previous studies (Oosting 1958; Phillips 1959; Hanson and Churchill 1961; Knox et al. 2011).

$$Relative\,density = \frac{Total\,no.\,of\,individuals\,of\,a\,species}{Total\,no.\,of\,individuals\,of\,all\,the\,species} \times 100$$

$$Relative\,frequency = \frac{Frequency\,of\,the\,species}{Total\,frequency} \times 100$$

$$Relative\,abundance = \frac{Total\,basal\,area\,of\,the\,species\,in\,all\,the\,quadrat}{Total\,basal\,area\,of\,all\,the\,species\,in\,all\,the\,quadrat} \times 100$$

$$Average\,basal\,area = \sum \frac{\pi r^2}{N}$$

$$Total\,basal\,area = Average\,basal\,area \times \frac{Number\,of\,individuals\,per\,quadrat}{Size\,of\,quadrat\,(sq.m)} \times 100$$

$$(IVI) = Relative\,frequency + Relative\,density + Relative\,dominance$$

Carbon density was calculated by multiplying the biomass with the IPCC (Intergovernmental Panel on Climate Change 2006) default value for carbon conversion (0.47). Atmospheric carbon dioxide (CO_2) removal was calculated by multiplying the carbon density or carbon fraction with 44/12 (the ratio of CO_2:C).

We assigned the following numbers to the equations that were compared for accuracy, suitability, and compatibility with *lantana* for subtropical deciduous forests (Maraseni et al. 2005; Navarro and Oyonarte 2006).

$$W = -625.03 + 155.16(\mathrm{G10}) + 0.000382(\mathrm{Cr} - \mathrm{V}) \quad (1)$$

where W = biomass of shrub, G_{10} = girth of plant at 10 cm, Cr V = crown volume

$$\frac{Biomass}{ha} = D_{(spi)} \times Dryweight_{(spi)} \quad (2)$$

where, $D_{(spi)}$ = density of individual shrubs

$$y = a + bD^2H \quad \text{(Developed and used in this study)} \quad (3)$$

where, y = biomass of shrub, D = diameter at breast height, H = plant height, a and b = coefficients

All the data were stored and processed for statistical analysis by using *Microsoft Excel 2010* and SPSS (v 10).

Result

A comparison of the biomass calculated by the previously available methods and the equation developed for this study was made to check the compatibility of the equations under the present scenario. We chose an equation given by Maraseni et al. (2005) (Eq. 1), although it was not exclusively made for *lantana* in subtropical conditions, and then calculated the biomass of *lantana* by using both Eqs. 1 and 3 and compared the results. The estimated dry weights were closer to the predicted dry weight of *lantana* when we used Eq. 3 (Table 1). However, there was much more disparities in the estimated dry weight and the predicted dry weight of *lantana* when we used Eq. 1 and as a result did not match.

Since Eq. 1 did not work in our case, we had to find a suitable one that can be exclusively used for *lantana* in subtropical Himalaya. Our next step was to check the compatibility of already obtained oven dried mass of the

Table 1 Estimated dry weight and predicted [calculated] biomass of 20 samples of *Lantana camara* L. regression model used ($y = a + b\ D^2H$)

Observation	Predicted dry weight in (Kg) (by using the equation)	Dry weight in (Kg) [actual (oven dried mass of the plant)
1	0.4026	0.44
2	0.2468	0.15
3	0.4776	0.45
4	0.3912	0.4
5	0.3209	0.34
6	0.2999	0.3
7	0.2795	0.31
8	0.5107	0.53
9	0.4818	0.48
10	0.4685	0.44
11	0.3517	0.39
12	0.5264	0.55
13	0.5927	0.58
14	0.4194	0.45
15	0.5308	0.51
16	0.3687	0.31
17	0.6426	0.62
18	0.62	0.59
19	0.4718	0.56
20	0.483	0.48

whole plant with the independent variables such as D and H individually. A high adjusted R^2 values ($R^2 = 0.91$) for D and ($R^2 = 0.86$) for H (Figs. 3 and 4) were recorded. The individual correlation of these variables with oven dried mass was good but in search of a better one we then used the combined variables as D^2H and tested its compatibility with the dry mass, a comparatively better value of adjusted R^2 was obtained ($R^2 = 0.88$). Based on R^2, it was found that the best independent variable to use in the regression model was D^2H. This was not the only criteria used for choosing the best fitted allometric equation. When all the equations were tested for their best suitability, we followed more criteria to choose the best one *i.e.,* the adjusted R^2, the Furnival Index, computed F value, RMSE, and the significance level of the values at 5 %. The regression model for the biomass calculation is considered more accurate and best fitted if it gives a lower RMSE, higher value of adjusted R^2, and less value of Furnival Index. Out of all the variables we used, D^2H was found to be the best fitted variable considering all these above criteria with adjusted $R^2 = 0.88$ the maximum, Furnival Index (0.04123), and RMSE (157) lowest amongst all the equations (Table 2c).

However, 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 % significance level (Table 2a). This result shows that the regression coefficient, β is significantly different from 0 and the value is statistically significant. Some independent variables had considerably higher influencing power over the dependent variables in one combination of independent variables (high t values and low significance level), but in other combinations, the influencing power was very poor (low t values but high significance level). Therefore, considering all the facts we found that the regression model with D^2H as a variable was most suitable for the estimation of shrub biomass and hence chosen for this study (Fig. 5).

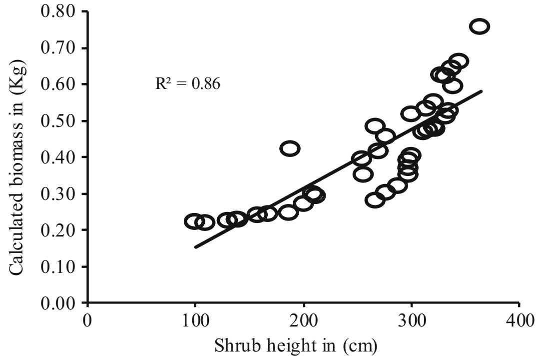

Fig. 3 Scatter plot to show the correlation between shrub height and calculated biomass (Eq. 3)

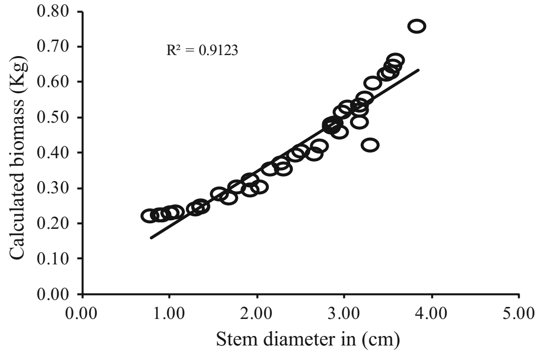

Fig. 4 Scatter plot to show correlation between stem diameter and calculated biomass (Eq. 3)

The findings of this study (using Eq. 3) show that Rajpur forest periphery has the greatest per-plant biomass (0.764 kg/plant), followed by Mothronwala (0.637 kg/plant), which is slightly ahead of Sahastradhara (0.622 kg/plant). The per-hectare biomass of shrub was found highest in Sahastradhara (13,559.60 kg ha^{-1}), followed by Mothronwala (12,956.58 kg ha^{-1}) and Rajpur forest periphery (11,154.40 kg ha^{-1}) (Fig. 6). Sahastradhara has the highest density of the shrub than the other sampling sites (21,800 plants·ha^{-1}) because the per-hectare biomass was highest here. These values were closer to the biomass values

Table 2 ANOVA table (**a**), estimates of regression coefficients along with the standard error (**b**), estimates of adjusted R^2 and Furnival index (**c**) for the regression analysis using the model $y = a + b\ D^2H$

(a) ANOVA

Source	df	SS	MS	F	Significance F
Regression	1	0.23794946	0.23795	137.596	7.27E−10
Residual	18	0.03112794	0.00173		
Total	19	0.2690774			

(b)

Regression coefficient	Estimated regression coefficients	Standard error of estimated coefficients
a	0.21162	0.0219
b	0.0001	8.5557

(c) Regression statistics

Multiple R	0.940381
R square	0.884316
Adjusted R square	0.877889
Standard error	0.041585
Furnival index	0.041231
Observations	20

obtained by Eq. 2 with a marginal difference, but the biomass values obtained by Eq. 1 were found significantly different from the other two values (Table 3).

Carbon density was highest in Sahastradhara with ($0.637\ kg\ m^{-2}$) and ($6{,}373.01\ kg\ ha^{-1}$); followed by Mothronwala ($0.609\ kg\ m^{-2}$) and ($6{,}090\ kg\ ha^{-1}$); and Rajpur forest ($0.524\ kg\ m^{-2}$) and ($5{,}242.56\ kg\ ha^{-1}$). The least was recorded from Jolly Grant ($0.317\ kg\ m^{-2}$) ($3{,}170.99\ kg\ ha^{-1}$). The above carbon density shows that *lantana*'s CO_2 removal capacity was greatest in Sahastradhara at the rate of $23{,}367.71\ kg\ ha^{-1}$, followed by in Mothronwala at the rate of ($22{,}328.50\ kg\ ha^{-1}$), and in Rajpur forest ($19{,}222.74\ kg\ ha^{-1}$). The lowest CO_2 removal site was found to be the Jolly Grant airport with a rate of $11{,}626.98\ kg\ ha^{-1}$ (Table 4).

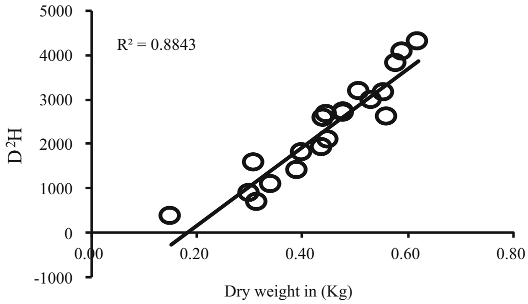

Fig. 5 Scatter plot to show correlation between dried weight and D^2H

From the above results, it was clear that Sahastradhara has the maximum density of *lantana* and the maximum CO_2 removal site amongst the entire study sites. Sahastradhara was the most disturbed site because of round the year tourist activities. High anthropogenic activity and abundant resource availability with less competition level probably favoured the growth of *lantana* at a tremendous rate in this site (Table 4). Incidentally, the shrub canopy area from Sahastradhara was also the highest ($2.68\ m^{-2}$); followed by Rajpur forest periphery ($2.64\ m^{-2}$); and Mothronwala ($2.45\ m^{-2}$).

The coverage of *lantana* was calculated from all sites and was found highest in Sahastradhara ($5.86\ m^{-2}$); followed by Mothronwala ($5.00\ m^{-2}$); and in Golatappar ($3.96\ m^{-2}$). The smallest canopy area was calculated from Jolly Grant airport ($1.67\ m^{-2}$); and railway tracks ($1.66\ m^{-2}$) (Fig. 7). Some findings of this study were found surprising because the railway tracks and most of the areas near Jolly Grant airport are fallow abandoned lands with more available resources and light availability, but these sites still showed less canopy area and phytovolume than other areas. However, the density of *lantana* in these areas was found satisfactory with 18,100 plants ha^{-1} and 20,200 plants ha^{-1} respectively. Phytovolume of *lantana* from all of the sites was also calculated and was found highest in Rajpur forest periphery ($201{,}363.20\ m^{-3}$), followed by Sahastradhara ($155{,}584.42\ m^{-3}$), and Mothronwala ($144{,}932.67\ m^{-3}$).

Despite the fact that the density of *lantana* (21,800 plants ha^{-1}) was found maximum in Sahastradhara, the

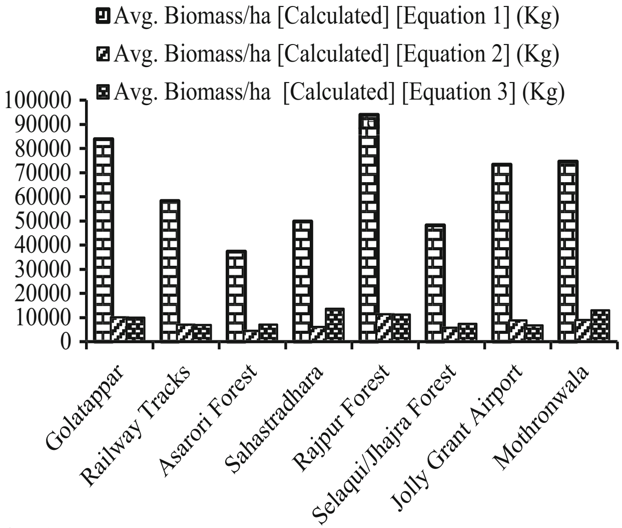

Fig. 6 Comparison of *lantana* biomass with all the three equations considered in this study

phytovolume was highest in Rajpur forest because the average shrub height (5.08 m) and average crown diameter (180.28 cm) per shrub was highest in Rajpur forest peripheries, which were found essential parameters for calculating phytovolume of *lantana* (Table 5). During the plant community analysis for the assessment of current status of *lantana* under the present climatic conditions, we found that *lantana* was dominant in all the study sites with maximum coverage and IVI in its class and was not favouring the growth of all the species in its vicinity. Only a few species were co-dominantly growing with *lantana* including *Parthenium hysterophorus* L., *Ageratum conyzoides* L., *Chromolaena odorata* (L.) King and Robinson, *Callicarpa macrophylla* Vahl., *Opuntia dillenii* (Ker Gawl.) Haw., *Adhatoda zeylanica* L., *Murraya koenigii* (L.) Spreng., *Cassia occidentalis* L., *Arundinella spicata* Dalzell., *Floscopa scandens* Lour., *Achyranthes aspera* L., and *Reinwardtia indica* Dum. The maximum IVI of *lantana* (27.43) was calculated at Jolly Grant airport, which was followed by Sahastradhara (22.77); Rajpur forest areas (21.93); Selaqui/Jhajra forest areas (18.72); and Asarori forest areas (17.51). However, the IVI of *Parthenium* was dominant in the areas like Golatappar (18.94); railway tracks (24.12); and Mothronwala swamp (19.14). The frequency of *lantana* in all the study areas was 100 %. Table 6 shows a detailed account of five co-dominant species that were found growing along with *lantana* frequently without any problem, with 100 % frequency from all the sites.

Discussion

Estimation of shrub biomass is very important as it can provide more accurate estimates of forest biomass and carbon sequestration. A rapid, nondestructive method is needed to make biomass estimates because the labour and expense necessary to clip and weigh large plants are more and impractical to preserve the ecosystem (Ludwig et al. 1975). Methods to establish a relationship between easily obtained plant measurements and plant biomass include a technique termed dimension analysis (Whittaker 1970) and further its utilization in shrub biomass estimation through regression analysis (Rutherford 1979). In a study by Rana et al. (1989), the herbs and shrubs of each quadrat were harvested and the litter from each quadrat was placed in paper bags and brought to the laboratory. The samples were oven dried at 80 °C to constant weight and then the net

Table 3 Comparison of calculated biomass with dry weight of *Lantana camara* from all the sites of Doon Valley using all three methods

Name of the site	Avg. dry weight/plant (gm)	Density of plants/ha	Avg. biomass/ha [calc.] (Kg)(Eq. 1)	Avg. phytomass/ha ((Kg) [calc.] (Eq. 2)	Biomass/plant* (Kg) [calc.](Eq. 3)	Biomass/ha* (Kg) [calc.] (Eq. 3)
Golatappar	591.62	17,000	83,813.45	10,057.6	0.57	9,809
Railway tracks	385.71	18,100	58,179.07	6,981.49	0.37	6,823.7
Asarori forest	269.71	16,600	37,310.97	4,477.32	0.42	7,038.4
Sahastradhara	273.49	21,800	49,684.49	5,962.14	0.62	13,559.6
Rajpur forest	771.57	14,600	93,875.29	11,265	0.76	11,154.4
Selaqui/ Jhajra	348.42	16,600	48,198.32	5,783.8	0.44	7,353.8
Jolly Grant	435.61	20,200	73,328.6	8,799.43	0.33	6,746.8
Mothronwala	439.39	20,340	74,477.19	8,937.26	0.63	12,956.6

Eq. 1: Maraseni et al. (2005); Eq. 2: Cerrillo Navarro and Oyonarte (2006); Eq. 3: derived in situ and used in this study

* Regression model, $y = a + b\ D^2H$, where, Y = biomass of shrubs, D = diameter of shrub at 10 cm, H = the height of the shrub

Table 4 Comparison of calculated biomass of *Lantana camara* from all the sites of Doon Valley (Carbon density was calculated by multiplying biomass with IPCC default value 0.47 for carbon conversion)

Name of the sites	Biomass/plant (Kg)	Density of *Lantana*/ha	Biomass/ha (Kg)	Biomass/m^2 (Kg)	Carbon density (Kg)/m^2	Carbon density (Kg)/ha	Carbon dioxide/m^2	Carbon dioxide/ha
Golatappar	0.577	17,000	9,809	0.981	0.461	4,610.23	1.69	16,904.2
Railway tracks	0.377	18,100	6,823.7	0.682	0.321	3,207.13	1.176	11,759.5
Asarori forest	0.424	16,600	7,038.4	0.704	0.331	3,308.04	1.213	12,129.5
Sahastradhara	0.622	21,800	13,559.6	1.356	0.637	6,373.01	2.337	23,367.7
Rajpur forest	0.764	14,600	11,154.4	1.115	0.524	5,242.56	1.922	19,222.7
Selaqui/Jhajra Forest	0.443	16,600	7,353.8	0.735	0.346	3,456.28	1.267	12,673
Jolly Grant Airport	0.334	20,200	6,746.8	0.675	0.317	3,170.99	1.163	11,627
Mothronwala	0.637	20,340	12,956.58	1.296	0.609	6,089.59	2.233	22,328.5

Carbon density = Biomass × 0.47 (IPCC Default). Carbon dioxide calculation = Carbon fraction × 44/12 (IPCC, 2006)

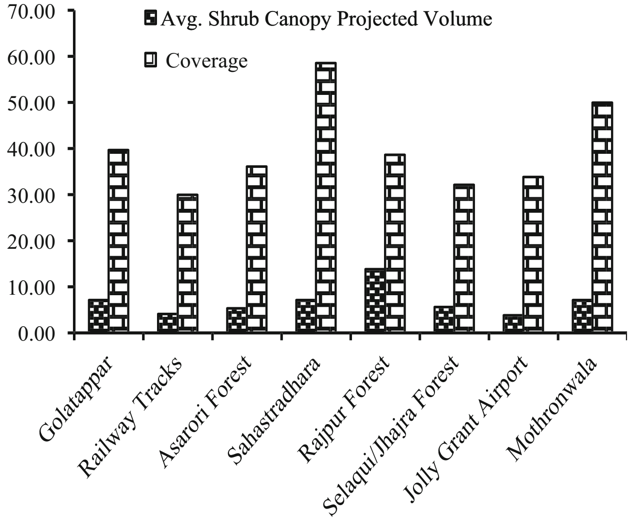

Fig. 7 Site wise comparison of canopy coverage (% ha^{-1}) and canopy volume (m^3) of *lantana* in Doon Valley

primary production for the tree, shrub and herb layers was calculated from each site. In the present study we give more emphasis in using the allometric equation for non-destructive biomass calculation of *lantana* over the destructive calculation as it is time saving and easy to use, this was advocated by some previous study where power model and quadratic models were used and found to be the most appropriate equations to describe size biomass relationships (Zeng et al. 2010). Some workers gave more emphasis in using a quadratic equation as a common model to estimate shrub biomass (Sah et al. 2004; Foroughbakhch et al. 2005), and the present results are in line with previous reports that the biomass of shrub populations can be well described with measured architectural variables such as diameter at breast height (DBH) and plant height (H) (Foroughbakhch et al. 2005).

In some other studies, the carbon stock and carbon sequestration rates were estimated as 50 % of the dry weight of biomass and 50 % of net primary productivity, respectively (Hamberg 2000; Brown 2001). The fuel value of a biomass is solely dependent on its calorific value. The amount of heat generated by any fuel depends on the quantitative conversion of carbon and hydrogen present in the fuel to water and carbon dioxide, and is a function of chemical composition of the fuel (Kumar et al. 2009). In our study, the maximum above-ground biomass of *lantana* amongst all the sites of Doon Valley is 0.764 kg/plant and was recorded from the Rajpur forest 11,154.40 kg ha^{-1}. This is a great source of fuel in an ecosystem characterized as deciduous because its invasion rates are extremely high in all kinds of geographical conditions except the native areas where it originally grows.

However, in some studies the biomass is also calculated and its importance is recognized by using the wood density and logarithmic regression (Barasa et al. 2010; Chaturvedi et al. 2011). The previous method is accurate but it is laborious and time consuming: in a place like the Doon Valley, where the infestation of *lantana* is very high, it is difficult to calculate the biomass by harvesting methods and oven-dried weight for all the areas. The model developed and used in this study makes it possible to calculate the biomass of *lantana* in the subtropical deciduous conditions of the Doon Valley by nondestructive means. The accuracy is high and when compared and tested with the oven-dried mass of *lantana* gave a very positive result. The method will surely save time and labour when applied on a large scale.

Table 5 Measured and calculated attributes of 20 samples of *lantana* from different sites (Canopy cover and Phytovolume were also considering for developing the allometric equation)

Name of the sites	Avg. crown diameter (cm)	Avg. shrub canopy area (*Lantana* cover) (m^2)	Avg. shrub canopy volume (m^3)	Density of *Lantana*/ha	Coverage (%/ha)	Phytovolume (m^3/ha)	Biomass/ha (Kg)
Golatappar	176.63	2.332	7.088	17,000	39.64	120,496	9,809
Railway tracks	141.95	1.6565	4.066	18,100	29.98	73,594.6	6,823.7
Asarori forest	159.13	2.1748	5.2728	16,600	36.1	87,528.48	7,038.4
Sahastradhara	178.7	2.6869	7.1369	21800	58.57	155,584.4	13,559.6
Rajpur forest	180.28	2.6461	13.792	14,600	38.63	201,363.2	11,154.4
Selaqui/Jhajra Forest	150.4	1.9363	5.6025	16,600	32.14	93,001.5	7,353.8
Jolly Grant Airport	141.48	1.6757	3.7588	20,200	33.85	75,927.76	6,746.8
Mothronwala	175.33	2.457	7.1255	20,340	49.98	144,932.7	12,956.58

The present study shows that the biomass of *lantana* is best predicted by one (basal diameter), (plant height) or two (the basal diameter and total plant height) variables. In some recent studies, allometric equations are used for environmental studies (Satoo and Madgewick 1982; Araújo et al. 1999; Montés et al. 2000). The findings of this study also suggest that allometric equations are the most trustworthy method for estimating the biomass of shrubs which is consistent with the previous studies (Foroughbakhch et al. 2005; Maraseni et al. 2005; Zeng et al. 2010).

Out of all the study sites, Sahastradhara, Rajpur forest periphery, Jolly Grant airport and its adjacent areas were found very disturbed due to tourist activities; construction works and heavy grazing, thus the *lantana* density, frequency and IVI from these areas were found elevated. In contrast, places like Golatappar, Railway tracks, and Mothronwala were less disturbed and therefore IVI of *lantana* was recorded less from these sites. Our results on the basis of high IVI from Jolly Grant airport and Rajpur forest periphery clearly show that *lantana* is found not only in the fallow abandoned land and in the human disturbed areas but has also started invading in a very strong way to the periphery of the forests and the protected areas.

Though the present study is mainly focused on the calculation of above-ground *lantana* biomass from the subtropical conditions of the Doon Valley, a lesser attempt was made to understand the invasive nature of *lantana* in these conditions on the basis of site characteristics, IVI, coverage of plants, and other community analyses. But these findings are not sufficient as the suitability of *lantana* depends not only on physical disturbance of the site but also on other factors like topography, altitude, soil profile, role of herbivory, and plant attributes.

One interesting finding was *lantana*'s tremendous power of competition with native trees; e.g., shrub height was greater in the forest periphery (Rajpur forest periphery) and adjacent places than that of the fallow and abandoned land. This observation also shows that *lantana*, due to its aggressive nature and competitive ability, can very well increase its height and further growth to obtain the resources.

In recent times, the biomass and carbon budget from all types of forests have gained considerable attention of researchers across the globe. However, the role of invasive shrubs in the carbon budget has been elusive due to the lack of proper methodology and resources. Taking a broader look, India is the third largest emitter of CO_2 in the world, with emissions of 1,427.6 million tones of CO_2 per year (India Climate Portal 2010); China and USA are on the first and second positions, respectively. According to the data, percent change in CO_2 emissions from 1990 to 2008, emissions have shot up 146 % in India, second only to China. In contrast, the United States and Japan have only increased in proportion to 14.9 and 8.2 % respectively, which is still manageable. These results show that the conditions in India are very alarming and these forests and shrub-lands can be very useful to sequester CO_2.

Lantana invasion in different areas is a much more recent phenomenon and is reducing species richness of native understory species while also causing compositional changes in the herbs and shrubs, as well as tree seedlings (Sharma and Raghubanshi 2010; Sharma and Raghubanshi 2011). Nevertheless its enormous potential to be an abundant fuel source and sequester CO_2 from the atmosphere should not be overlooked.

There are many alien and invasive species in the Doon Valley forests (see Table 6), growing with *lantana*. Together these alien influences could be gradually changing these tropical and subtropical forests, causing significant structural and compositional changes in the vegetation which is likely to have cascading effects on consumer communities, in addition to altering the dynamics and function of this endangered ecosystem. According to 2006 data from the Wildlife Institute of India, India has 778,229

Table 6 Dominant species from each side with highest frequency, abundance and Importance Value Index (IVI)

Name of the site	Name of the species	Frequency	Density	Mean % cover	IVI	Name of the site	Name of the species	Frequency	Density	Mean % cover	IVI
Golatappar	*Parthenium hysterophorus*	100	40.5	41	18.94	Sahastradhara (tourist place)	*Ageratum conyzoides*	100	11	11	11.61
	Lantana camara	100	1.14	17	15.78		*Chromolaena odorata*	100	8.5	8.5	9.96
	Ageratum conyzoides	100	22.5	22.5	13.44	Rajpur forest periphery	*Lantana camara*	100	0.94	23.5	21.93
	Callicarpa macrophylla	100	0.53	13.2	9.77		*Murraya koenigii*	100	0.42	10.6	12.34
							Parthenium hysterophorus	100	10.3	10.3	12.12
	Chromolaena odorata	100	10.8	11	8.9		*Reinwardtia indica*	100	0.36	9.1	11.23
Railway track	*Parthenium hysterophorus*	100	38	38.4	24.12		*Chromolaena odorata*	100	9	9	11.15
	Lantana camara	100	1.2	29	19.54	Selaqui/Jhajra forest	*Lantana camara*	100	1.08	26.9	18.72
	Ageratum conyzoides	100	26	26	18.04		*Parthenium hysterophorus*	100	16.6	16.6	13.16
	Adhatoda zeylanica	100	0.9	21.5	15.89		*Cassia occidentalis*	100	0.59	14.8	12.19
	Polygonum multiflorum	100	0.8	19.2	14.77		*Ageratum conyzoides*	100	12	12	10.68
							Adhatoda zeylanica	100	0.46	11.6	10.46
Asarori forest periphery	*Lantana camara*	100	0.85	21.2	17.51	Jolly grant airport	*Lantana camara*	100	1.07	26.8	27.43
	Opuntia dillenii	100	0.71	17.8	15.48		*Arundinella spicata*	100	15.7	15.7	17.93
							Ageratum conyzoides	100	11.2	11.2	14.09
	Adhatoda zeylanica	100	0.64	16	14.41		*Parthenium hysterophorus*	100	9	9	12.21
	Murraya koenigii	100	0.44	11.1	11.49		*Achyranthes aspera*	100	8.8	8.8	12.04
						Mothronwala (Swamp)	*Parthenium hysterophorus*	100	25.2	25.2	19.14
	Parthenium hysterophorus	100	10.8	10.8	11.31		*Lantana camara*	100	1	25.1	19.07
Sahastradhara (tourist place)	*Lantana camara*	100	1.12	27.9	22.77		*Ageratum conyzoides*	100	20.2	20.2	16.19
	Adhatoda zeylanica	100	0.83	20.8	18.08		*Chromolaena odorata*	100	14.5	14.5	12.82
	Parthenium hysterophorus	100	15.5	15.5	14.58		*Floscopa scandens*	100	11.3	11.3	10.94

sq. km forest area, which is 23.68 % of the total area of the country (Wildlife Institute of India 2006). Of that total forest area, 20.04 % comes under the protected areas network, of which 24.37 % are national parks and 75.59 % are wildlife sanctuaries. These protected areas are prime wildlife habitats and harbor diverse forest communities. A number of trees and shrubs in these forests are invasive and threatening the native species. The biomass value of these invasive species will not only divulge the accurate carbon sequestration potential of these forests but also reveal their positive aspects for which they are not very well known. The biomass values of forest stands in the Himalayan forests tend to cluster around two very different levels, from a low of approximately 200 t ha^{-1} for early successional communities such as pine, to a high of about 400 t ha^{-1} for late successional communities such as the oaks and sal (Singh et al. 1992).

Carbon storage in the Uttarakhand Himalayan forests (the present study sites) ranges from an average of about 175 t C ha^{-1} for pine forests to approx 300 t C ha^{-1} for oak and sal dominated forests (Singh et al. 1985). Our findings clearly show how important shrubs are in these areas because they greatly contribute to carbon storage (Table 4). The eight study sites of the present study are storing 75,442.28 kg ha^{-1} carbon, which were found sequestered by only invasive shrub *lantana*. It is therefore very important to calculate the biomass and to find out the fuel properties of *lantana* so that it can be used in the restoration of ecosystems. From the previous literature, it has been clear that the biomass of this shrub in most of cases was calculated or measured by the harvesting methods (Sharma and Raghubanshi 2011) but seldom by using allometric regression models where the measured attributes of plants are considered.

The surroundings of Doon Valley include Rajaji National Park, (which is famous for its mammalian and bird species). Conservation of this endangered forest and its wildlife perhaps hinges on addressing the role of these pervasive factors in driving ecological change. Forests, particularly tropical forests, contribute more than other terrestrial biomes to climate- relevant cycles and processes. This particular forest is a great habitat of the natural sal trees, though it is a protected forest but human activities are still in progress. Heavy human activities in recent years resulted in large gaps in these forests further providing corridors to the success invasive understory species. It would be possible to increase the carbon storage capacity of these forests if we positively consider sal trees and the understory invasive vegetation as a good carbon sink. Proper forest management is required which include adoption of the methods for afforestation, reduced deforestation techniques and invasive species management (Shukla 2006; Sharma et al. 2006). In India, very little information exists about the rate at which different forest ecosystems sequester carbon. Although details on annual net carbon uptake of biomass are available for a few specific ecosystems, they are usually carried out for small plots and do not exist for all the forest types in India.

Therefore, the need to accurately estimate carbon in shrubs will become even more vital in the future as land use and global climate changes increasingly alter both forested and non-forested ecosystems. Such changes will have implications for wildlife, biodiversity, nutrient cycling, fire, and other management issues where carbon sequestration, especially in soils, may become key objectives. We have summarized three methods that might be used to estimate carbon in shrubs but the compatibility and fitness of the equation depends on type of shrubs, growth patterns, physiographic conditions, soil types and disturbance level. The job now is to develop appropriate equations and workable field measurement techniques that together will enable researchers and managers to measure carbon in shrubs quickly, consistently, and rigorously in the future.

Conclusion and recommendation

Our findings show that because of *lantana*'s good fuel properties and ability to store carbon, it does have some role to play in the ecosystem restoration. There is a clear need to calculate the biomass of *lantana* and it is possible to estimate biomass nondestructively. The different variables used in this study reveal its close relationships between total biomass and diameter, height, and, up to some extent the canopy area, canopy volume and their combinations. These combinations enabled us to develop and use allometric equations to estimate total biomass of *lantana* in subtropical Himalaya. This equation was developed and used exclusively for *lantana* found in a similar climatic region of the study area but because of its effectiveness, we strongly recommend the equation ($y = a + b\ D^2H$) for the nondestructive estimation of *lantana*.

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