

RESEARCH ARTICLE

Estimation of above ground biomass of a *Pinus caribaea* Morelet stand in lower Hantana

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Abstract: Above ground biomass production was estimated in a 25 year-old *Pinus caribaea* stand in the land belonging to the University of Peradeniya, in lower Hantana in the Central Province. Twenty four pine trees felled were used to collect data for developing allometric biomass equations and to estimate the above ground biomass. Empirical formulae were derived to estimate the above ground biomass separately for the cylindrical lower part and the conical upper part of the pine trees. Using these site-specific formulae derived from empirical data, the above ground biomass of the 25 year-old *P. caribaea* stand was found to be 194 t/ha. A second estimation of 136 t/ha for the above ground biomass was obtained using standard formulae. Of the live standing crop, the stem represented 60%, the branches 17%, leaves 13%, cones 3% and dead branches 7%. This pine stand had 695 pine trees/ha, a mean diameter at breast height (dbh) of 20.1 cm, a mean height of 20.7 m and mean basal area of 23.6 m²/ha. The estimated above ground biomass showed that the *P. caribaea* plantation studied is a good sink for sequestered carbon. Since the study was based on actual measurements through destructive sampling, yielding more accurate estimates than from standard derivations, the derived empirical formulae in this study are recommended for estimation of the above ground biomass of comparable pine tree stands in the Hantana plantation and also other plantations in similar steeply undulating topography. Based on a meta-analysis of literature data on *P. caribaea* in the tropics, it was found that a *P. caribaea* plantation up to an age of 25 years attains maximum above ground biomass when it reached ca. 22 years.

Keywords: Above ground biomass, carbon sequestration, empirical formulae, *Pinus caribaea*, tree form.

INTRODUCTION

Geographically, Sri Lanka is a small continental island in South Asia. Yet, it supports the largest biodiversity

per unit area in its natural forests¹. However, this natural forest cover is decreasing due to agriculture, agricultural land settlements, encroachments by landless poor and illegal logging. Presently, the island's natural forest cover is only 1.58 million hectares, about 25% of its total land area¹. The rise in demand for fuel wood, timber and fibre and the steady decrease in its natural forest cover paved the way to the establishment of extensive plantations of several exotic species of *Eucalyptus*, *Pinus* and *Tectona* since the early part of the 20th century. This trend continued with the introduction of Forest Policy 1970¹. Out of the 26,771 ha of pine plantation 25,091 ha are of *Pinus caribaea* (Caribbean pine), which established easily on depleted soils. Between 1980-85, *P. caribaea* was planted by the Forest Department under a reforestation project of the Mahaweli river catchment². Forests have traditionally been used for many products, including timber, fuel wood and fodder but its new role as a carbon sink has opened new opportunities in carbon trading, which require more accurate inventory of their biomass.

There are two main approaches for estimating the biomass density of woody formations based on existing forest inventory data. The first approach is based on the use of existing measured volume estimates (VOB per ha) converted to biomass density (t/ha) using a variety of "tools". The second approach directly estimates biomass density using biomass regression equations³. The present study develops empirical formulae to estimate stem biomass based on actual destructive sampling of felled trees which has been used in the estimation of above ground biomass in *P. caribaea*.

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METHODS AND MATERIALS

This study was carried out in the Lower Hantana range (500 - 700 m amsl) belonging to the University of Peradeniya in the Kandy district (7°05' N, 80°30' E) of central Sri Lanka. Climatically Hantana is a tropical humid region with an annual rainfall ranging between 2000 and 2500 mm and a mean annual temperature of ca. 24 °C⁴. The land form of the general area of Hantana mountainous land system is hilly and steeply dissected with narrow strongly sloping valleys. The soils belong to the USDA Soil Taxonomy category of Typic Troporthents (Reddish Brown Latosolic soils) underlain by residual material derived from quartz-rich middle pre-cambrian metamorphic rocks of the Highland Series⁵.

The Hantana pine plantations were established in the 1980s with a view to restore the degraded grasslands. These plantations had not been silviculturally managed since their establishment. Several rows of mature *P. caribaea* trees totaling 126 trees were removed in one pine stand to establish an enrichment trial with indigenous tree species which gave an opportunity to determine the biomass of a sample of the trees felled. The total tree

height, height to the lowest live branch, stem diameter at the two ends, middle and immediately below the lowest live branch of the pine trees harvested were recorded at the time of logging. Using the above diameter data as a guide, 24 harvested pine trees representing eight size classes: 1-4, 5-9, 10-19, 20-24, 25-29, 30-34, 35-39, and 40-44 cm dbh (three individuals from each dbh class) were randomly selected for the biomass estimation. From each of the 24 trees selected, fresh samples of stem discs at the root collar, middle and top were collected, and dried at 70 °C to constant weight. The fresh weight of branches, needles and cones were recorded. Sub-samples of these were taken for the determination of fresh weight:dry weight ratios. For prediction of the tree form, one tree per each dbh category was randomly taken. From each of these trees, diameters at 10 cm intervals along the stem length were recorded.

The form of pine trees was determined by selecting one harvested tree and plotting its diameter data at 10 cm intervals on the stem, versus diameter at breast height (dbh in cm)/stem length above the root collar up to the point of diameter measurement for each of the eight trees selected from each dbh class. The above ground biomass was also calculated using the merchantable wood volume.

Above ground biomass density (t/ha) = volume x wood density x biomass expansion factor³

Wood density = 0.57;

Biomass expansion factor = 1.3

Volume of cylindrical part was calculated using $\pi r^2 h$ and volume of conical part was calculated using $1/3 \pi r^2 h$

Where r = radius of stem disc; h = length of stem disc

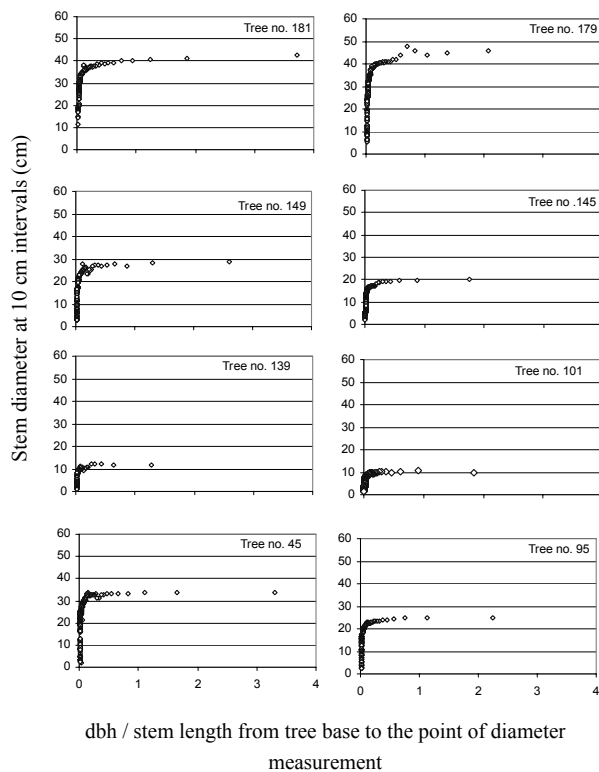


Figure 1: Scatter plots of stem diameter at 10 cm intervals versus diameter at breast height (dbh) for eight harvested trees, representing the diameter categories (1-4, 5-9, 10-14, 15-19, 20-24, 25-29, 30-34, 35-39 cm), from the *Pinus* stand in lower Hantana.

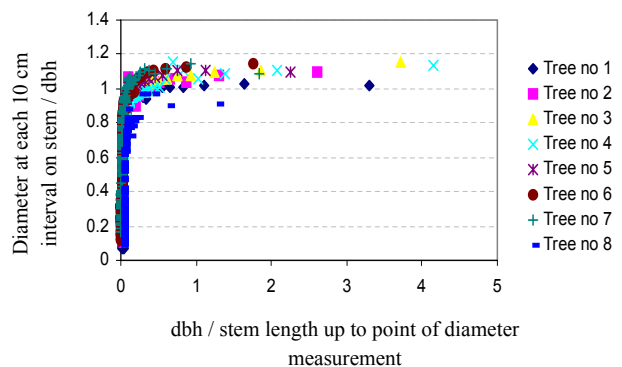


Figure 2: Scatter plots of diameter at each 10 cm interval on stem / diameter at breast height (dbh) versus dbh / stem length from tree base to the point of diameter measurement for eight harvested trees, representing the diameter categories (1-4, 5-9, 10-14, 15-19, 20-24, 25-29, 30-34, 35-39 cm), from the *Pinus* stand in lower Hantana.

RESULTS

Graphs in Figure 1 show that the *Pinus* trunk is cylindrical at its lower part and conical at its upper part. Therefore, two different formulae were constructed to estimate the cylindrical and conical parts of the stem.

Formulae for the cylindrical part of the stem

To estimate the biomass of the cylindrical part of the stems, diameter at 10 cm intervals/dbh (cm) versus dbh (cm)/stem length up to the point of diameter measurement (cm) were plotted for 8 trees using the Curve Expert Program (Curve Expert 1.3, A comprehensive curve fitting system for windows) (Figure 2). Then, the best-fitted regression equation was constructed, which took the following form.

$$Y = a e^{(b/x)}$$

Where, Y= diameter (d) at each 10 cm interval on stem/dbh (D) and X= dbh (D)/corresponding stem length (L) up to the point at which diameter was measured

$$a = 1.074 ; b = - 0.013 ; e = \exp$$

$$d / D = 1.074 e^{-(0.013 L / D)} \quad \dots (1)$$

$$R^2 = 0.78^{**} (p < 0.01)$$

Model validation

Diameters of the 24 trees were also predicted using equation (1). Then, the predicted and observed diameters were plotted to check whether the model is valid. Values of the upper part of the tree (diameters < 15 cm) deviated. These deviated values, which imply a conical shape, represent the tree tops.

Then, using the Curve Expert Program, a best-fit regression equation was developed for the graph (b) in

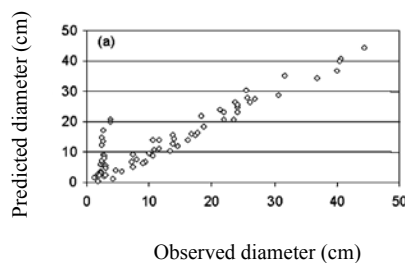


Figure 3 to calculate the weight per tree stem, as given below. It took the following form.

$$Y = a X^b$$

where, Y = diameter (d) at each 10 cm interval on stem and X= weight/1 cm disc ($w_{per\ cm}$)

$$a = 1.89; b = 0.462; R^2 = 0.97^{**}$$

$$d = 1.89 (w_{per\ cm})^{0.462} \quad \dots (2)$$

Integration of $w_{per\ cm}$ along the total stem length up to 15 cm stem diameter gives the weight per stem ($W_{stem > 15}$)

$$W_{stem > 15} = \int w_{per\ cm} dL \quad \dots (3)$$

By solving and rearranging the three equations (1), (2) and (3), we get the following equation.

$$W_1 = 10.5 \left. \begin{aligned} &\sum D e^{\log \exp (2.16D)} - \\ &10.5 \sum D \exp (\log e^{2.16D - 0.028 h/D}) \end{aligned} \right\} \quad \dots (4)$$

where, W_1 = weight of tree stem up to 15 cm diameter on the trunk;

D = diameter at breast height (dbh)

h = length of the tree stem up to 15 cm stem diameter on the trunk.

Evaluating tree stem height up to 15 cm diameter on the trunk (h)

By substituting d = 15 cm to equation (1), we get,

$$15/ D = 1.074 e^{-(0.013 L / D)}$$

$$L = D/ 0.013 \ln (D* 1.074) / 15 \quad \dots (5)$$

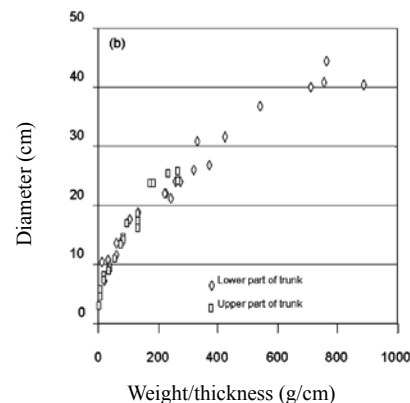


Figure 3: Scatter plots for model validation of predicted diameter versus observed diameter (a), and diameter versus weight/thickness of stem discs for upper and lower portions of tree trunks (b) of 24 trees harvested from the *Pinus* stand in lower Hantana

As the length of the tree stem (L) up to 15 cm stem diameter on the trunk is h, h in the equation (4) can be substituted by the equation (5).

Formulae for conical part of the tree stem (part above 15 cm stem diameter)

The plot of diameter versus weight/thickness for tree tops was constructed and an equation was developed to estimate the biomass of the conical part of the stem. It took the following form,

$$Y = a + b X$$

where, Y = weight/thickness (g/cm) (W) and X = diameter (cm) (d)
 $a = - 2.288$; $b = 1.937$; $R^2 = 0.94^{**}$
 $W = 1.937 d - 2.288$... (6)

As the shape of the *Pinus* tree-top is conical, we can use the following equation.

$$r = 7.5 L / L_o; \quad d = 2 r$$

r = radius of base of the conical tree-top
 L_o = observed tree height – predicted tree height

$$d = 15 L / L_o$$
 ... (7)

Integration of $w_{per\ cm}$ along the stem with diameter < 15 cm gives the weight per stem ($W_{stem < 15}$)

$$W_{stem < 15} = \int w_{per\ cm} dL$$

$$W_u = \sum W_{stem < 15} = 12.24 \sum L_o$$
 ... (8)

where, W_u = weight of tree stem beyond 15 cm diameter on the trunk (tree-top).

Biomass of tree trunk was calculated using equations (4) and (8). Biomass of branches, needles and cones were determined using fresh weight to dry weight ratio.

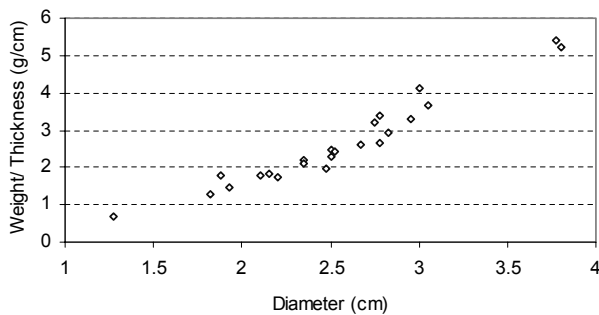


Figure 4: Scatter plot of weight/thickness of stem discs versus diameter of tree trunk above 15 cm stem diameter of 23 trees harvested from the *Pinus* stand in lower Hantana.

The characteristics of the pine stand and dry weight of each component of the pine trees are presented in Table 1. The total above ground biomass estimated for the 25 year-old *P. caribaea* stand in the lower Hantana was 194 t/ha. The stem represented 60% of the total dry weight.

Table 2 shows the quantities of above ground biomass produced by various stands of Pine plantations, as found in literature. Figure 5 depicts the relationship between the above ground biomass and age of stands of *Pinus caribaea* found in tropics, as of Table 2.

DISCUSSION

The higher value for the above ground biomass of *P. caribaea* stand obtained from the formulae developed from the site-specific empirical relationships (194 t/ha) than that obtained from allometric equations derived from standard volume functions (136 t/ha) suggest that, among others, site-specific climatic and topographic factors and the management history of the plantation may contribute to this difference. A study on biomass estimation of Virginia pine trees in the USA⁶ indicated that although the equations relating stem height of trees to measurements of size (stem diameter and height) could have more general applicability, the equations for the canopy components (live branches, canopy depth and needle mass) may be less reliable and vary considerably from tree to tree due to variability in canopy conditions, available growing space, land form, environmental conditions etc. They further report that the variables like crown length and stem diameter at the base of the crown apparently lag behind changes in foliage and live branch weight which respond more rapidly to immediate changes in the environment of the tree. Similar reasoning could be given for the differences we have observed when using allometric equations derived from standard volume functions and our own empirical determinations

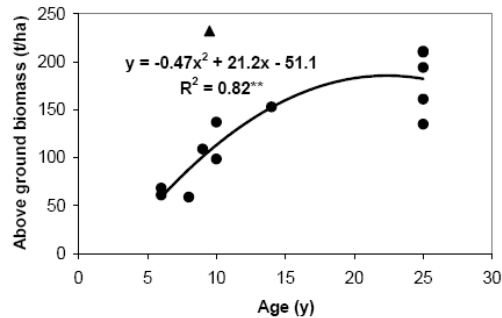


Figure 5: Relationship between above ground biomass and age of stands of *Pinus caribaea* found in tropics, as of Table 2. Filled triangle shows the data point of Russell et al.¹², which is an outlier.

of biomass. These derivations observed suggest that in rugged terrains in which pine plantations have been established in Sri Lanka, the site-specific variables, especially in the conical crown region may be less predictable from standard formulae. Therefore, further

investigations of relationships between crown weights, growing space and age of pine plantations in different agro-ecological zones may be necessary to obtain more reliable prediction equations especially for the crown components of individual trees⁶.

Table 1: Tree characteristics (A), biomass partitioning and total dry weights (B) of two *Pinus* stands studied in lower Hantana in the present investigation, and the corresponding values obtained from Khadka⁷ in a similar study of the same plantation.

(A)

Characteristics of the Pine stand	Present study	Khadka's study
Plot area (ha)	0.8	-
Age (yr)	app. 25	20
No. of trees (ha)	695	899
Mean dbh (cm)	20.1	19.6
Mean height (m)	20.7	23.4
Basal area /ha (m ² /ha)	23.6	27.1

(B)

Component parts	Biomass (t/ha)	
	Present study	Khadka's study
Stem (with bark)	117 (60)	185 (80)
Branches	47 (24)	37 (16)
Needles (with twigs)	25 (13)	9 (4)
Cones	5 (3)	-
Total biomass	194 (100)	231 (100)

Values within parentheses are percentages of total biomass.

Khadka⁷ studied the above ground biomass of the *P. caribaea* plantations established in the foothills of the Hantana on land belonging to the University of Peradeniya which lies at an altitude between 1000 and 1500 msl. In that study, stem and bark represented 79.7% of total biomass; branches and dead branches 16.1%; needles and twigs 4.1%. They are comparable with the values obtained in the present study (Table 1). The stand characteristics in his study were as follows: 899 trees/ha; 19.6 cm mean dbh; 27.1 m²/ha basal area; 23.4 m mean tree height. He reported an above ground biomass of 231 t/ha, which was higher than that of the present study. Dharmaparakrama⁸ reported above ground biomass estimates of a 23-27 year old *P. caribaea* plantations in Knuckles in the mid country wet zone as 211 t/ha and mid and up country intermediate zone as 161 t/ha and 135 t/ha, respectively. In that study, density, dbh and height of the trees in the mid country wet zone were 673 trees/ha, 18 cm and 26 m, respectively, mid country - intermediate zone 351 trees/ha, 25 cm and 27 m, respectively and up country intermediate zone 463 trees/ha, 19 cm and 21 m, respectively. He has further reported that tree

height and dbh varied according to the climate and soil conditions prevailing at the sites. Rainfall (75% annual rainfall expectancy) of wet zone-mid country site, and the intermediate zone-mid and up country sites were > 1400, > 2000 and > 2400 mm, respectively and mean sea levels of low country, mid country and up country were 300, 300 - 1000 and 100 - 2500 m, respectively.

In our study site at lower Hantana, which lies at an altitude between 500 and 700 m, the altitude, rainfall, and the variability of soil and wood density may have been responsible for the differences in above ground biomass recorded in the present study, compared to those of the Knuckles region.

Egunjobi¹¹, and Egunjobi and Bada¹² reported above ground biomass ranging from 59 to 137 t/ha for 6-10 year old *P. caribaea* stands in Ibadan, Nigeria (Table 2). These values are not comparable with the values of the present study as they are much younger stands. On the other hand, a *P. caribaea* stand of 9.5 years from eastern Amazon¹¹ was reported to have an above ground biomass

Table 2: Above ground biomass produced by various stands of Pine plantations, as found in literature.

Species and stand age (y)	Location	Biomass (t/ha)	Reference
<i>Pinus caribaea</i>			
25	Lower Hantana	194	Present study
25	Lower Hantana	231	8
23-27	Wet zone - Mid country (Knuckles)	211	9
23-27	Intermediate zone, Mid country (Knuckles)	161	
23-27	Intermediate zone, Up country (Knuckles)	135	
14	Agudos (Brazil)	153	12
10	Northern Guinea savanna (Nigeria)	98.7	13
9.5	Eastern Amazon	232.2	14
10	Ibadan (Nigeria)	137	11
9	Ibadan (Nigeria)	109	
8	Ibadan (Nigeria)	59	
6	Ibadan (Nigeria)	61	10
6	Ibadan (Nigeria)	68.3	
<i>P. radiata</i>			
7	Australia	50.7	10
<i>P. ensiflora</i>			
15	Japan	52.8	16
<i>P. nigra</i>			
18	Scotland	27.7	17
<i>P. sylvestris</i>			
18	Scotland	54.9	

of 232.2 t/ha⁷, a value much higher than that of an older plantation. Different climatic and soil conditions may have influenced those differences.

The above ground biomass of *P. caribaea* in Sri Lanka ranged from 135-231 t/ha (Table 2). Other research on *P. caribaea* have focused on the basic density and fibre length in a 24-year *P. caribaea* at Erabedde in the montane zone¹³ and tree volume and taper function for 7 year old *P. caribaea* in the wet zone¹⁴.

Comparison of the stand productivity of tropical pine with that of temperate ones indicates that the tropical pine is more productive (Table 2). The longer growing season in the tropics may have contributed to the high productivity. Another probable contributing factor is the high density of trees in the stands. The 24 year old *Dalbergia sissoo* Roxb. in India yields a total of 186 t/ha dry above ground biomass¹⁵, which is lower than that of pine trees. Similarly, the above ground biomass of a 30 year old Teak (*Tectona grandis*) plantation, another

popular plantation species in Sri Lanka, was 141 t/ha¹⁵. Negi and Sharma¹⁷ report an above ground biomass of 121 t/ha for a *Eucalyptus* hybrid; another study reports 112-300 t/ha for *Eucalyptus grandis*¹⁸ and 175 t/ha for *Populus deltoides*¹⁹, the second most popular exotic species widely planted in the Indian sub-continent. Another important species of the sub-continent is Sal (*Shorea robusta*). The above ground biomass of a 100 year old sal forest was reported to vary from 200-710 t/ha, that of a *Pinus roxburghii* stand was 233.78 t/ha²⁰ and a *Pinus tabulaeformis* stand was 146.05 t/ha^{19,20}. The relationship shown in Figure 5 can also be used to predict the above ground biomass of *P. caribaea* found in tropics, at different ages, up to 25 years. It is apparent that in *P. caribaea* stands up to the age of 25 years in the tropics, the highest above ground biomass is attained at the age of ca. 22 years (Figure 5). This may be a useful guide for the management of the pine plantations in the humid tropics which needs to be validated for plantations in different climatic and topographic conditions.

CONCLUSION

The above ground biomass of 25 year old *P. caribaea* stands in lower Hantana was 194 t/ha. Thus, it seems that this exotic species is a good sink of sequestered carbon. The derived empirical formulae in this study are best recommended for pine tree stands in the Hantana plantation, and other plantations if the stand characteristics are comparable. The analysis of available data from the tropics suggest that the *P. caribaea* plantations gain maximum above ground biomass when it reaches ca. 22 years.

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