Content list available at http://epubs.icar.org.in, www.kiran.nic.in; ISSN: 0970-6429

Indian Journal of Hill Farming

December 2021, Volume 34, Issue 2, Page 126-129

Development of allometric equations for estimating carbon sequestration in *Pinus kesiya* Royle ex Gordon

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ARTICLE INFO

Article history:
Received: 24 September, 2021
Revision: 10 November, 2021
Accepted: 18 November, 2021

Key words: GBH, R2, khasi pine, growth prediction.

ABSTRACT

Generalized regressions models are used for estimating biomass accumulated and carbon sequestered in different forest types. However, these generalized allometric equations results in biased estimates. Thus, species specific allometric equations were employed for estimating C-sequestration potential for *Pinus kesiya* grown naturally in Ri-bhoi district of Meghalaya. More than 50 different sizes (diameter 65.0-144.0 cm and height 10.00-23.00 m) was used. The trees used were being felled by village community for local use. Four equations were developed based on girth at breast height alone and girth at breast height and total height of the tree. The results indicated that the model based on girth over bark can be used for carbon estimation. Including height in model did not produce significant difference in adjusted R^2 values. The study will help to accurately estimate the above ground biomass and carbon contained in standing trees, and can be useful tool for implementing projects like REDD$^+$ (Reducing Emissions from Deforestation and Forest Degradation') and estimating carbon sequestration at national level.

1. Introduction

Forest is an important source as well as sink affecting the carbon dioxide dynamics in the atmosphere. United Nations Framework Convention on Climate Change (UNFCC) has adopted planting trees and sequestering carbon dioxide in biomass as one of the mitigating strategies. Above-ground biomass has been identified as one of 54 essential climate variables, by the Global Climate Observing System because of its major role in the global carbon cycle (Santaro et al, 2021). However, precise estimation of biomass in different forest ecosystems will depend on accuracy of available methods and tools. Considerable variation exists in carbon sequestered in different forests, and between similar forests at different latitudes (Goulden 1996; Jervis 1997). Total biomass produced from the forest depends on various factors of localities operating at particular site. It is dynamic interaction between edaphic, climate, and topographic factors of an area that determines species composition and biomass accumulation in different regions (Alves 2010; Lovmonier, 2010). Among these factors of locality, climatic factors are the most prominent factors that affect the growth and biomass accumulation in woody species (Xu et al, 2018; Pfizer et al 2018).

Allometric equations are used for assessment of total biomass and carbon sequestered in the biomass for national and global carbon assessments. Biomass regressions models are used to predict carbon sequestered in standing trees (Henry et al 2011; Jara et al, 2012). Researchers are using generalized allometric equations for estimating biomass accumulated and carbon sequestered in different tree species (Brown 1997; Henry et at 2011). However, accurate estimation is not possible especially using pantropical allometric equations as reported in many forests (Alverez 2014). Moreover, forest of similar composition growing different regions exhibits variations in biomass accumulation. Application of generalized equations for biomass estimation to individual tree species gives erroneous results. This further error exponentially increased when the estimate is applied to state or national scale. Formulating a species specific and site specific biomass regression model is reported as best

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approach to accurately biomass and carbon storage in the forests (van Brugel 2011; Daba and Soromesa, 2019). These tools can be helpful to accurately estimation biomass and carbon which is required for carbon trading and implementing climate change mitigation strategies like $REDD^{+}$.

In view of this, present study is intended to formulate biomass estimating allometric equations for *Pinus kesiya*. It is commonly known as khasi pine and is indigenous to the khasi hills of Meghalaya. The species is used for making local huts, shops and furniture. It contains highly inflammable oleo-resin, which is extracted and used for healing skin cracking in winter. *Pinus kesiya* is the most dominant tree species in the Jhum lands and other cultivated land uses of Meghalaya. It is the principal species occurring in the community forests around the villages. In the present study, relationship between the growth traits such as Girth at Breast Height (GBH), tree height with the above ground biomass of the individual trees was developed. This will be useful tool for estimating total above ground biomass and carbon sequestered in the standing tree with statistically sufficient confidence.

2. Material and Methods

Study site:

The study was conducted in community forest in three villages viz Mawpun (25.66 N: 92.06 E), Dingpasoh (25.58 N; 92.04 E) and Pyllum (25.68 N and 91.92 E) of Ri-Bhoi district, Meghalaya, composing pure pine forest (> 80 per cent tree density. These forests are classified as Assam sub-tropical pine forest (Champion and seth, 1968). The study site was dominated by pine tree, and *Michelia champaca, Schima wallichii* and *Rhododendron arboreum* was associated trees. The shrub layer was dominated by *Eupatorium adenophorum* and *Lantana camera*.

Estimation of total tree biomass for model development

A total of 50 trees were randomly selected from felled trees.Girth at Breast Height (GBH) DBH, total height, mid diameter of felled tree was measured. The tree was separated into branch, twig, needle and the main stem was converted into 6-7 feet logs. Fresh weight of all these components was taken. About 2 kg sample of each component from each tree and each log was oven dried at 70º C till constant weight was achieved. Stump height and diameter was recorded and no of annual rings was counted at 30 cm height for estimating age of the tree. Various oven dried component of biomass was added to estimate above ground biomass. The total below ground biomass was taken as 26% of the above ground biomass as per the IPCC guidelines. Carbon percent is taken as 0.50 for converting biomass into carbon.

Development of allometric models

Regression model was developed considering tree DBH, height and form factor as independent variable and biomass and carbon as independent variables. For selecting best fit models, the coefficient of determination (R^2), standard deviation, sum of square error, mean square error and root mean square were compared with those of existing models developed for *Pinus* spp. (Brown 1997; Delrio et al 2008; Ter-Mikaelian and Korsukhum, 1997; Baishya and Barik 2011)

3. Results and Discussion

The aboveground biomass data for 50 trees was regressed against the DBH and height using regression models developed by earlier workers for *Pinus* spp. The GBH and height recorded for 50 trees ranged between 65.0-144.0 cm and 10.00-23.00 m respectively. None of these models yielded satisfactory coefficient of determination (R^2). We developed following models by log transforming the data which yielded better (R^2).

SN	Equation	b_1	b_2	C	$p_{0.05}$ for b_1	$p_{0.05}$ for b_2	$p_{0.05}$ for C	R^2	Adjusted R^2
1	$Y_1 = b_1X_1 + C$	8.88	-	-405.75	1.3E-15	-	2.3E-06	0.74	0.73
2	$Y_1 = b_1X_1 + b_2X_2 + C$	6.76	8.11	-434.46	6.8E-15	0.04	1.8E-06	0.75	0.76
3	$Y_2 = b_1X_1 + C$	4.44	-	-202.88	1.3E-15	-	2.3E-06	0.74	0.73
4	$Y_2 = b_1X_1 + b_2X_2 + C$	4.26	5.11	-273.71	6.8E-15	0.04	1.8E-06	0.75	0.76

Y_1= Total above ground biomass per tree in kg, Y_2=Total carbon (both above and below ground) per tree in kg, X_1=Girth at Breast Height in cm, X_2=Total Height of the tree in m

From the above models, equation 1 & 2 are for prediction of total above ground biomass with the help of GBH and height whereas, model 3 & 4 are for total carbon per tree accrued both from above and below ground biomass. It was observed that there is not much difference in the adjusted R^2 values between equation 3 & 4.

Trautenmüller et al (2021) have reported that in equations for individual trees, a high correlation exists between total biomass and the biomass of its constituent parts, with diameter at 1.30 m aboveground (*DBH)*, alone or combined with the tree total height (H). Similar observations have been reported by various workers and tree diameters is considered as most important source of variation making *DBH* as the most important variable in such equations (Chave et al. 2014, Oliveira et al., 2017, Behling et al., 2018).

Other variables such as height, tree shape, trunk-crown ratio have been used for various species to explain additional sources of variation. Combining *DBH* with other dendrometric variables may explain other important variation in tree shape (Balbinot et al., 2017), trunk and crown ratio (Brown, 1978, Dieguez-Aranda, 2016), and among different species. However, in our results inclusion of height did not improve R^2 value. GBH alone produced expectable estimates. Height measurement may have additional sources of error such as lean of the trees, slope of the ground etc.

4. Conclusion

Four regression models were developed to estimate total above ground biomass of *Pinus kesiya* trees growing in sub-tropical pine forests of Meghalaya specially Ribhoi Disrict. Model based on GBH and height was more accurate. However, equation based on GBH alone can be used for carbon estimation as GBH measurement. Including height in model did not produce significant difference in adjusted R^2 values.

5. Acknowledgements

The authors are thankful to ICAR for financial assistance through NICRA Project (OXX01713). The authors are also thankful to Forest Department, Meghalaya and management authority of community for allowing the study.

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