Chapter 6
Application of Allometric Equations to Estimate Carbon Stock and Above-Ground Biomass in Narpuh Wildlife Sanctuary, Meghalaya

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6.1 Introduction

In nature, carbon is found in the challenging form of atmospheric CO_2. It constitutes only a negligible amount of the atmosphere and about 0.04%. Even with such a little concentration, it contributes significantly to the biogeochemical cycle (carbon cycle) that supports life on earth. It was also reported that up to the year 2020, CO_2 level had increased significantly from 280 to 412 ppm which is a 46% increase [1]. Concerning the Indian scenario, the greenhouse gas emission in the year 2016 has been reported to be 2,531.07 million tonnes equivalent (MT eq) with the inclusion of "Land Use Land Use Change and Forestry" (LULUCF). In these, emissions from carbon dioxide accounted for 2,231 MT (78.59%) [2]. India also committed to adding a carbon sink of 2.5–3.0 billion tonnes of CO_2 capacity by 2030 through forest and tree cover [3]. In terms of total carbon stock, the global forest resource assessment reported that the total forest carbon stock from all its pools was estimated to be 662 Gt (163 tonnes ha^{-1}) and it was mentioned that the global carbon stock has decreased from 668 to 662 Gt between the year 1990 and 2020 due to the decline in forest area [4]. At the national level, carbon stock (from all carbon pools) from the Indian forest, including forest, scrubs and plantation, was estimated in the year 2021. This carbon stock was 7204.0 MT, with an increase of 79.4 MT in comparison with the previous year's emission of 7124.6 MT. The estimate of carbon stock from different components for the year 2021 and for the above-ground biomass was 2319.9 MT. For below ground biomass case, it was 718.9 MT. Similarly, for deadwood it was 47.7 MT, for Litter, it was 107.3 MT, and for soil, it was 4010.2 MT. In the North-East state of Meghalaya, the total Carbon stock for the year 2021 is estimated at around 107.59 MT. The primary contributor of carbon stock for the State comes from the Soil Organic Carbon at 63.37 MT and above-ground biomass at 32.41 MT. In India,

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the overall carbon stock increased by 541 MT from 6663 MT between the year 2011 to 2021 [3].

Indian forests have been divided into three classes based on the canopy density and as per the assessment of the Indian State Forest Report (ISFR) 2021. The forest has been classified as very dense forest (VDF), moderately dense forest (MDF), and open forest (OF). Together, these three classes of canopy density account only for 713,789 km^2 (21.71%) of the entire geographical area of the country. However, the forest cover of the North-East region is 64.66% of its total geographical area (169,521 km^2) [3]. Approximately 80% of India's terrestrial biodiversity is found in the forest and the forest also caters to around 300 million people to support their livelihood [3].

As per the ISFR 2021 assessment, the forest cover in Meghalaya was 17,046 km^2 (75.99%) of the total geographical area. It was found that there is a decline of − 0.43% in forest cover with respect to ISFR 2019 assessment [3]. Meghalaya is home to a variety of plants and animals with high species composition. The State is a part of the Indo-Malayan biodiversity hotspot. The region is blessed with a rich biodiversity of flora and fauna, the majority of which is found in the state's southern tropical belt and upland subtropical forest. The forests of Meghalaya can broadly be categorised into tropical, subtropical and temperate forests. The climax vegetation of the area, according to Champion and Seth [5] can be categorised as a subtropical wet hill forest. The climatic condition, topography, rainfall patterns, flora, land use, culture, diversity and ethnicity of the state varies greatly. Hence, it is certain that the carbon stock, rate of carbon sequestration and carbon dynamics will also vary across the state.

One of the most important environmental services that a forest provides is the sequestration and storage of carbon. Tropical forests are considered to be accountable for about 25% of the world's biomass and carbon. It provides up to 40% of the terrestrial net primary output, although these type of forests covers only 12% of the total geographical area of the earth [6, 7]. The tropical forest is known to be the last standing forest that can give us hope to tackle climate change in addition to being a major carbon sink and home to the rich diversity of flora and fauna. They play a vital role in the proper functioning of the biogeochemical cycle, especially the carbon cycle. In order to be able to predict climate change and to implement efficient mitigation methods to reduce global warming, a thorough understanding of natural forests is extremely important as they contribute significantly to the carbon pool and carbon flux relating to net primary production, carbon assimilation and decomposition in biome [8]. On the other hand, governments from different nations have raised concerns about global warming and climate change for the past many decades. They have come up with laws and protocols both at the national and international levels to mitigate various problems being faced today and those that will be encountered in the near future. The key solution to all these environmental problems can be achieved from the forest as they are essential for limiting greenhouse gas emission. If one can estimate how much carbon can be stored and sequest by a particular type of forest and if one can also estimate how much carbon has been stored, the data can then be used to update and improve forest management practices. This will assist in the adoption

of sustainable methods to maximize the quantity of carbon dioxide sequestration by the forest. Forest management is also known as the land-use management system. It can help to mitigate and control environmental issues such as climate change, global warming, and biodiversity conservation [9].

As a result, the estimation of carbon stock and above-ground biomass is the focus of this research. Such efforts deploy a variety of allometric equations. Thereby, the type of allometric equation and its suitability and relevance to represent a specific forest type can be assessed. To have an in-depth understanding of carbon stock and biomass of a particular forest type, two methods have been adopted: the direct and the indirect method. The direct method measures plant biomass by felling down trees within the quadrat (which is a frame along a transect to estimate plants abundance). The components such as the roots, stem, leaves, branches and stumps are segregated and measurements for each of the components were carried out. The overall biomass of a tree is then calculated by adding the oven-dried masses of these components. The direct method is considered to be the most precise method in determining the dry biomass of the plant and this enables the development of allometric equations. Hence, the allometric mathematical model may be used to explain the connection between a tree's dry weight and its wood density, breast height diameter, or crown area. The equations developed by the direct method can be applied in the field of forestry which can also be used to measure biomass using a non-destructive method called the indirect method [10, 11].

However, the drawbacks of using the direct method are that only a limited area can be studied and the falling down of trees is carried out in large numbers. This method cannot be carried out if the forests are Government protected forests or if it is a community-protected area like sacred groves. Endangered and threatened species are affected by this method as the felling of trees is required [12]. The indirect method of biomass estimation does not involve cutting down trees or their components. Instead, a mathematical equation developed from the direct method can be deployed in the biomass estimation of trees and their components. The advantages of using the non-destructive or the indirect method are that it is less time-consuming, less labour is intensive, and low capital investment. Further, biomass study in protected areas can be carried out without any compliances. Targeting such needs research, the book chapter delineates upon the relevance of allometric equations to fairly represent carbon stock in Narpuh Wildlife Sanctuary.

6.2   Materials and Methods

6.2.1   Study Area

The selected research site is the Narpuh Wildlife Sanctuary (Fig. 6.1), located in the East Jaintia Hill district of Meghalaya. It lies between 25°05′19″ to 25°06′14″ North Latitudes and 92°21′04″ to 92°31′38″ East latitudes (Fig. 6.2). Narpuh Wildlife

Sanctuary covers an area of 59.9 km^2, and it is the only pristine forest in the eastern part of Meghalaya. The sanctuary has one of the tallest, largest evergreen and the only semi-evergreen forests left in Meghalaya. The sanctuary hosts a wide variety of fauna, having around 92 species of birds, approximately 91 species of butterflies, and Schedule I species such as Leopard, Hollock gibbons, Slow Loris, etc. [13]. By incorporating parameters such as tree height and Breast Height Diameter (DBH), an allometric equation was proposed which is also known as the regression model and the biomass or volume of the above-ground trees component can then be calculated using these models. These equations have been generated from sample trees and measured weights in relation to their DBH and height. As a result, a common and economical approach for the estimation of tree species biomass in a forest or plantation is much required in order to cover more area and be able to carry out the work rigorously and efficiently [14].

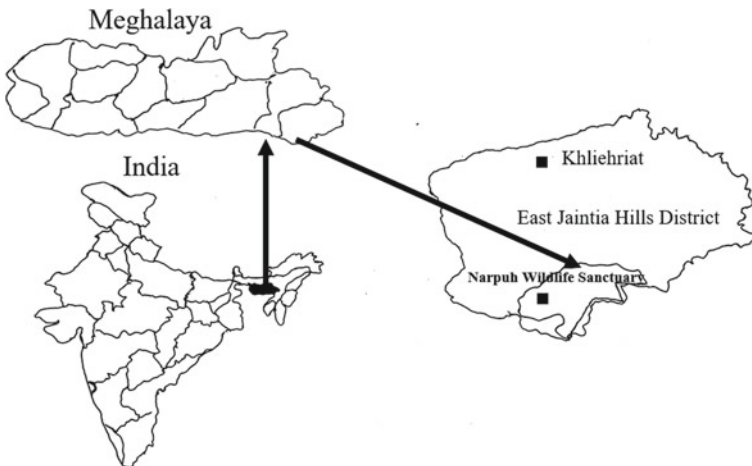**Fig. 6.1** Panoramic view of Narpuh Wildlife Sanctuary

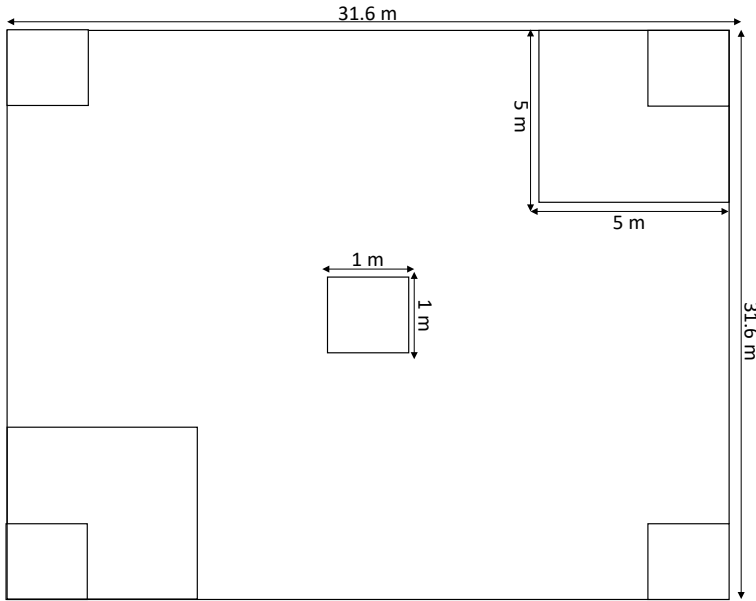**Fig. 6.2** Map of the Narpuh Wildlife Sanctuary

Fig. 6.3 Layout of permanent plot

The study involved the setting of eleven permanent plots within the Narpuh Wildlife Sanctuary during the pre-monsoon season of 2019. Each permanent plot was of the size of 31.6 × 31.6 m and within the perimeter of the permanent plot, a well-defined dimension of 5 × 5 m for shrubs and 1 × 1 m for herbs were marked. The relevant plan has been laid out in Fig. 6.3. In addition to that, a field survey, the elevation of around 50–300 m above sea level, a distance of 0.3–5 km between the plots was maintained. Thereby, field data were collected through physical measurement of tree samples above 15 cm in girth size from all eleven plots. The regression analysis was conducted on IBM SPSS statistic 2.0.

6.2.2 Allometric Equations

The traditional method for calculating the above-ground biomass of trees in a plot and region is to develop or apply allometric equations [10]. Allometric equations are required for employing a non-destructive (indirect) technique to calculate the biomass and carbon storage in the terrestrial ecosystem. It has also been observed that many regions lack accurate estimation of carbon sequestration in tropical forests due to a lack of suitable allometric models for estimating the biomass estimation in a tropical forest with a diverse range of flora [12]. As a result, the development of generalised allometric models for tropical trees has drawn the interest of many

researchers. This is due to the vast species diversity being hosted by the tropical forest [10, 15–17].

In this study, the number of stems from all woody species with a diameter of more than 15 cm was measured and counted for each plot in all eleven plots. The girth of a tree was measured by using a measuring tape, and the tree height was measured with a Nikon forestry Pro. The herbarium and other published literature were used to identify all woody species. The allometric equation or regression equation used for the estimation of biomass in this research was developed by Chambers et al. [18], FAO [19], Brown et al. [20], Nath et al. [21], Chave et al. [22], (Table 6.1). While the total above-ground carbon was calculated by approximately considering 55% of the total above-ground biomass [23], the below-ground biomass estimation was calculated by using the regression model of Cairns et al., regression equation [24] (Table 6.2). The allometric used in this study were then selected based on the model's input components, with DBH as the only component required for the allometric equations. Furthermore, other factors that affect the selection of allometric equations also include the type of forest to which they are applied. A statistical test was done on all equations to assess the R^2 value and the adjusted R^2. Thereby, the best-fitted model with the highest R^2 value has been selected for the estimation of biomass and carbon stock. A higher R^2 value implies that the allometric equation is more suitable for its utility to a particular forest in terms of biomass and carbon estimates.

6.3 Results and Discussion

From eleven plots, 155 woody species were identified. Among these, some plots had the lowest count of 49 trees and the greatest count of 87. In total, 746 trees exist in all eleven plots. These eleven plots together have an area equivalent to one hectare. Common trees species found in the forest include *Ficus sp.*, *Michelia champa, M. globosa, Castonopsis sp., Eleocarpus sp., Albezia lebbeck, Prunus undulate, Arvaena coronania, Docynia indica.* It was found that out of 746 trees, 542 had girth sizes of 15–70 cm, accounting for 32.759 tonnes ha^{-1} of total aboveground biomass and 18.017 tonnes ha^{-1} of total aboveground carbon. The balance 204 trees have a girth size of 70 cm and above, accounting for 201.669 tonnes ha^{-1} of total aboveground biomass and 110.918 tonnes ha^{-1} total above-ground carbon.

Eight models were used and compared for above-ground biomass estimation in the Narpuh Wildlife Sanctuary before deciding upon the best model fit by considering all dependent variables (above-ground biomass) and (DBH) from all the woody species within the 31.6 × 31.6 m plot. The dependent variables have been calculated by using regression analysis in all eight equations.

The findings from the regression analysis in terms of above-ground carbon for the altered DBH have been presented in Fig. 6.4. It was found that Chambers et al. [18] developed the allometric equation with the greatest R^2 value of 0.804, whereas FAO [14] developed the equation with the lowest R^2 value of 0.5902 (Fig. 6.4). Figure 6.4

Table 6.1 A summary of alternate allometric equations deployed for the estimation of biomass and carbon stock

Authors	Publication year	Allometric equation/model	Vegetation type	Region	Country	Notes
Chambers et al.	2001	$AGB = \exp [0.37 + 0.33 \times \ln(D) + 0.933 \times \ln (D)^2$ $0.122 \times \ln (D)]^3$	Tropical rainforest	Latin America	Brazil	The equation was developed by harvesting 315 trees from 0.04 ha (20 × 20 m) plot
FAO 3.2.3	1997	$AGB = 42.69 - 12.800 \times (D) + 1.242 \times (D)^2$	Tropical trees in moist climatic zone	Pan-tropical	N/A	The model was developed by harvesting 170 trees from three sites on the montane forest in New Guinea and from the unpublished data near La Selva, Costa Rica
FAO 3.2.4		$AGB = \exp \{-2.134 + 2.530 \times \ln(D)\}$				
FAO 3.2.5		$AGB = 21.297 - 6.953 \times (D) + 0.740 \ (D)^2$				
Brown et al.	1989	$AGB = 38.4908 - 11.7883 \times (D) + 1.1926 \times (D)$	N/A	N/A	N/A	N/A
		$AGB = 13.2579 - 4.8945 \times (D) + 0.6713 \times (D)$	N/A	N/A	N/A	N/A
Nath et al.	2019	$AGB_{est} = 0.18D^{2.16} \times 1.32$	Tropical semi-evergreen and wet evergreen, sub-tropical broad-leaved and pine forest of North East India	North-East India	India	The model was developed by sampling 303 trees from four major forest types ranging from tropical to sub-tropical

(continued)

Table 6.1 (continued)

Authors	Publication year	Allometric equation/model	Vegetation type	Region	Country	Notes
Chave et al.	2001	AGB = exp (−2.00 + 2.42) × ln(D)	Wet rainforest in Lowland	Latin America	French Guiana	The Regression model was inferred from previously published datasets of Araujo et al. (1999) [25], Ovington and Olson (1970) [26], Edward and Grubb (1977) [27], and Brown (1997) [28]—equivalent to 378 trees with DBH greater than 10 cm

Model	Regression equation	Parameters
Cairns et al. (1997)	Exp $(-1.0589 + 0.8836 \times \ln$ (AGB))	AGB

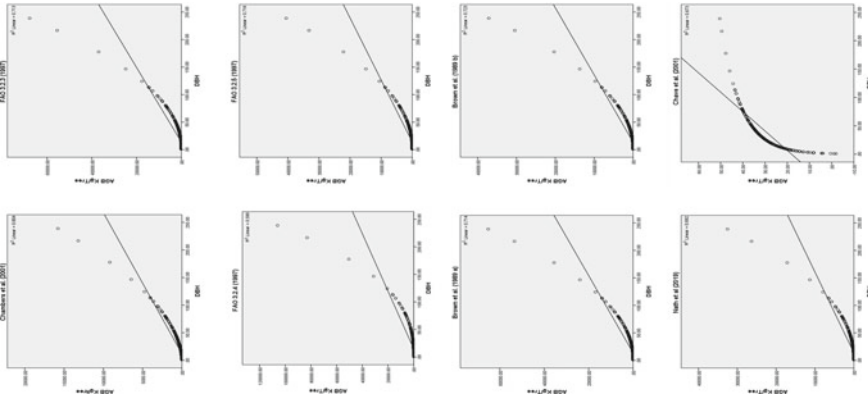**Table 6.2** Regression model for estimation of the belowground biomass

Fig. 6.4 Fitness plots for alternate allometric equation models to estimate biomass in Narpuh Wildlife Sanctuary

shows the pictorial representation of various regression analysis of various allometric equations developed by various authors for a specific vegetation type, region and country. The result indicates that using the allometric model developed by Chambers et al. was suitable and more acceptable for the Narpuh Wildlife Sanctuary. The equation developed by Chambers et al. can be used for the forest types similar to the Narpuh Wildlife Sanctuary i.e., that is tropical evergreen and semi-evergreen forest of North-East India.

The analysis affirmed that the Chambers et al. [18] model possessed the best R^2 value of 0.804. The corresponding total above-ground biomass value was 234.43 tonnes ha^{-1}, and the total above-ground carbon was 128.94 tonnes ha^{-1}. The Chambers model did not overestimate or underestimate the total above-ground biomass and carbon. Depending on the deployed model, the above-ground biomass estimates altered from 17.89 to 736.14 tonnes ha^{-1}, (Table 6.3). In comparison to the model created by Chambers et al. [18], the FAO [14] model had the lowest R^2 value of 0.590, with 736.14 tonnes ha^{-1} of total above-ground biomass and 404.87 tonnes ha^{-1} of total above-ground carbon. Thereby, the model overestimated the total above-ground biomass and carbon by 3.14 times that indicated by Chambers et al. model [18]. The model created by Chave [22] with an R^2 value of 0.673 produced the lowest total above-ground biomass and carbon content of 17.89 and 9.84 tonnes ha^{-1}. Correspondingly, the biomass and Carbon were underestimated by 13.1 times by the model in comparison to the Chambers et al. model [18] (Table 6.3). The other allometric models which include FAO 3.2.3, FAO 3.2.5, Brown et al. (1989) and Nath et al. (2019) models enabled an overestimate of the total above-ground biomass and

Table 6.3 Data summary of regression parameters and predicted values of total carbon, biomass below ground and biomass above ground

Allometric models	R^2	Adjusted R^2	TAGB (tonne/ha)	TAGC (tonne/ha)	TBGB (tonne/ha)	TBGC (tonne/ha)
Chambers et al. (2001)	0.804	0.80	234.43	128.94	–	–
FAO 3.2.3 (1997)	0.713	0.71	692.56	380.91	–	–
FAO 3.2.4 (1997)	0.590	0.59	736.14	404.87	–	–
FAO 3.2.5 (1997)	0.716	0.72	419.67	230.82	–	–
Brown et al. (1989)	0.714	0.71	670.70	368.89	–	–
Brown et al. (1989)	0.723	0.72	397.43	218.59	–	–
Nath et al. (2019)	0.692	0.69	322.99	177.65	–	–
Chave et al. (2001)	0.673	0.67	17.89	9.84	–	–
Cairns et al. (1997)		–	–	–	36.57	20.11

carbon by 1.37–2.96 times with respect to the corresponding values obtained from the Chambers model.

A model established by Cairns et al. [24] was used for the estimation of total carbon and biomass below ground. The values were 36.57 tonnes ha^{-1} for total belowground biomass and 20.11 tonnes ha^{-1} for total below-ground carbon (Table 6.3). Thereby, the carbon stock and biomass asset data can be estimated as one of the important variables to prepare an assessment report and thereby submit to the State Forest Department and Ministry of Environment, Forest and Climate Change (MOEF).

6.4 Conclusions

The findings reported in this chapter indicate that the forest of Narpuh Wildlife Sanctuary has a high biomass and carbon stock capacity, only when the forest continues to be undisturbed and maintained with a sustainable management policy. The study shows that a wide variety of tree species and valuable live timber can effectively store the highest content of biomass and carbon. Therefore, a non-destructive (indirect method) method is preferred for the estimation of biomass and carbon asset.

The benefit of using an indirect method is that it consumes less time and work, and it can be carried out on all types of species including endangered and threatened species without disturbing the forest ecosystem. It is also important to consider trees with a girth size less than 70 cm because they are higher in numbers in comparison to those with of girth size greater than 70 cm. This confirmed natural regeneration and reforestation. These young trees with small girth sizes will ultimately replace the old aged trees in the forest to sequest atmospheric carbon and store large volumes of carbon and biomass. Mitigation of climate change by carbon sequestration through forests will develop initiatives to acquire more funding from the public and private sectors to safeguard the environment and address problems of global warming and promote biodiversity conservation for the locals living on the fringe of Narpuh Wildlife Sanctuary.

The above study concludes that all the allometric equations should be tested prior to the selection of a suitable allometric equation or model. Thereby, depending on the multiple regression findings and the type of forest best allometric equation can be identified. Such an approach will allow accurate estimation of biomass and carbon using only tree diameter as an explanatory variable. The equation also compliments the topography and floral biodiversity of the forest. Allometric equations derived for natural tropical evergreen and semi-evergreen are few and unreliable. Hence, allometric equation testing will allow the researcher to offer unbiased and consistent data evaluation of the immaculate forest's carbon stock and biomass of Narpuh Wildlife Sanctuary. In summary, allometric equations are critical in estimating carbon stocks and biomass. This is due to the variation in the tree species, sizes and age within forests and stand density. It can be concluded that the distribution of biomass among different girth sizes between woody species may also be affected by the topography, climate, edaphic properties and developmental activities outside the wildlife sanctuary. The Chambers model has been the best fit to represent the biomass and carbon asset of the sanctuary. Through such research emphasis, plant bio-diversity conservation in North-East India can be most practically achieved through the dissemination of knowledge that fosters renewed interest in the desired subject of interest.

Conflict of Interest This is original research, and it has not been published in any journals, newspaper and no conflict of interest with anyone.

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