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# Biomass and carbon stock along an altitudinal gradient in the forest of Manipur, Northeast India

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**Abstract:** Forests are natural storehouses of biomass and store more carbon than any other terrestrial ecosystem. The relationship between species richness, aboveground biomass and carbon stock at different altitudes can have crucial implications for the management and conservation of carbon sinks. The study was undertaken to assessthe aboveground biomass and carbon stock in ten forest stands along an altitudinal gradient in Manipur, Northeast India. Stand density varied from 128 to 168 trees ha$^{-1}$ across the study sites with the highest stand density at higher altitude. The aboveground biomass varied between 124.56 and 254.99 t ha$^{-1}$ and carbon stock ranged from 60.09 to 121.43 t C ha$^{-1}$ across the study sites. Our results show that there is a significant positive correlation of stand density, aboveground biomass and carbon stock with increasing altitude. This positive relationship could be attributed to less disturbance and the dominance of larger trees at higher altitudes as compared to lower altitudes. Our results could be helpful to devise appropriate strategies in the restoration of degraded forests ecosystems to enhance carbon sequestration and to mitigate climate change.

**Key words:** Disturbed forest, species richness, stand density, sub-tropical forest, tropical forests, undisturbed forest.

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## Introduction

Forests influence the global climate by changing the concentration of carbon dioxide in the atmosphere. They can act as “carbon sinks” by fixing $CO_2$ from the atmosphere as well as “carbon sources” by releasing $CO_2$ into the atmosphere through decomposition of plant debris and burning of forest. Overall, the world’s forest ecosystems are estimated to store more carbon than the entire atmosphere (FAO 2006). The significant role of forests in carbon storage and sequestration has been considered more vital in the present climatic context and therefore it is at the centre-stage of climate change mitigation strategies (Kishwan *et al.* 2009).

Carbon sequestration is an important part of an overall carbon management strategy in the reduction and mitigation of global $CO_2$ emission. The United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol had an international agreement on incorporating forestry activities to counter this major environmental challenge (Ramachandran *et al.* 2007; Yadava 2010). The Global Environmental Facility (GEF), Clean Development Mechanism (CDM) and Reduced Emission from Deforestation and Forest Degradation (REDD) are effective initiatives to reduce the emission of $CO_2$ through forestry in the developing countries. Recently IPCC (2006) has also emphasized to understand the role of forests in carbon capture and storage

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under anthropogenic changes.

Tropical forests constitute as much as 86% of the forested area in India containing approximately 39% of global soil carbon and 77% of global vegetation carbon (Bolin *et al.* 2000). In tropical forests, the live aboveground biomass (AGB, hereafter) pools play an important role in the global carbon cycle, accounting for a significant fraction of the total carbon pool and nutrient stocks (Brown & Lugo 1984). The quantity of AGB in a forest determines the potential amount of carbon (C, hereafter) that can be added to the atmosphere or sequestered on the land when forests are managed for meeting emission targets (Brown *et al.* 1999). The quantification of biomass is required as the primary inventory data to understand C pool changes and productivity of forests. Thus, forest biomass estimation, its spatial distribution and changes over time, strategies for increase and conservation of forests have been subject of intensive research (Brown & Lugo 1984).

Aboveground biomass stocks vary widely among the tropical forests due to regional differences in stem size distribution, soil fertility and topography as well as disturbances (Castilho *et al.* 2006; Dewalt & Chave 2004; Murthy *et al.* 2016; Salunkhe *et al.* 2016; Urquiza-Haas *et al.* 2007). Several environmental factors change systemically with altitude. Therefore, altitudinal gradients are among the most powerful natural experiments for testing ecological and evolutionary responses of biota to environmental changes. Information on forest carbon stock and its allocation along the altitudinal gradients will help to better predict the responses of regional and global C balance to future climate change.

Northeast India represents only 8.0% of geographical area of India but accounts for nearly 25% of its forest cover of the country (FSI 2013). Northeast India is represented by a variety of forest ecosystems ranging from tropical rainforest to sub tropical and temperate forests (Champion & Seth 1968). These forests are rich in biodiversity and fall into the Indo-Burma hot spot of the world biodiversity (Myers *et al.* 2000). Thus, the forests of Northeast India play an important role in the sequestration of $CO_2$ from the atmosphere in the Indian scenario but shifting cultivation, and the dependence of local people on forest resources are the main biotic disturbances in these forest ecosystems (FSI 2013).

The altitudinal pattern of biomass and carbon stock in forest ecosystems have been reported by several workers in different parts of the world (Alves *et al.* 2010; Dar & Sundarapandian 2015; Do *et al.* 2017; Ensslin *et al.* 2015; Gairola *et al.* 2011; Sharma *et al.* 2010) but information on changes of biomass and C stocks along the altitudinal gradient in forests of Northeast India is lacking. The present study was undertaken with the objectives to assess aboveground biomass and carbon stock in the different forests of Manipur, North-east India along an altitudinal gradient.

## Materials and Methods

### *Study area*

The present study was carried out in the five districts Tamenglong, Chuurachandpur, Imphal East (Jiribam), Bishnupur, and Thoubal of Manipur state in Northeast India (Fig. S1) between January 2010 and January 2011. The study areas within the districts were located between 24º08′37.01″N and 25º25′28.60″N latitude and 93º03′39.88″E to 93º48′41.51″E longitude (Table S1). The topography of the study areas were gently hilly with an altitude ranging from 730 to 1030 m a.m.s.l. Ten study sites were selected in the different districts based on forest cover, forest vegetation and tree density in the forests (FSI 2013). Tree densitywas used as index of level of disturbances between the different sites (Sagar *et al.* 2003).

### *Climate*

The climate of the study area is monsoonic with warm moist summer and cool dry winter. The year is divided into three seasons: mild season summer (March to May), rainy (June to October) and winter (November to February) seasons. Meteorological data of the last thirteen years (2000–2012) was collected from the Indian Meteorological Department, Imphal Airport, Manipur. The warmest month was found in May with a mean maximum temperature of 30.2 °C and the coldest month in January with mean minimum temperature of 4 °C. The mean maximum temperature varied from 22.5 °C (December) to 30.2 °C (May) and the mean minimum temperature ranged from 4.9 °C (January) to 22.9 °C (August). The mean monthly rainfall ranged from 15.4 mm (December) to 200.7 mm (July). Mean annual rainfall was 1313.3 mm. The average relative humidity of air varied between 72.9% (March) to 85.9% (July) across the study sites (Fig. S2).

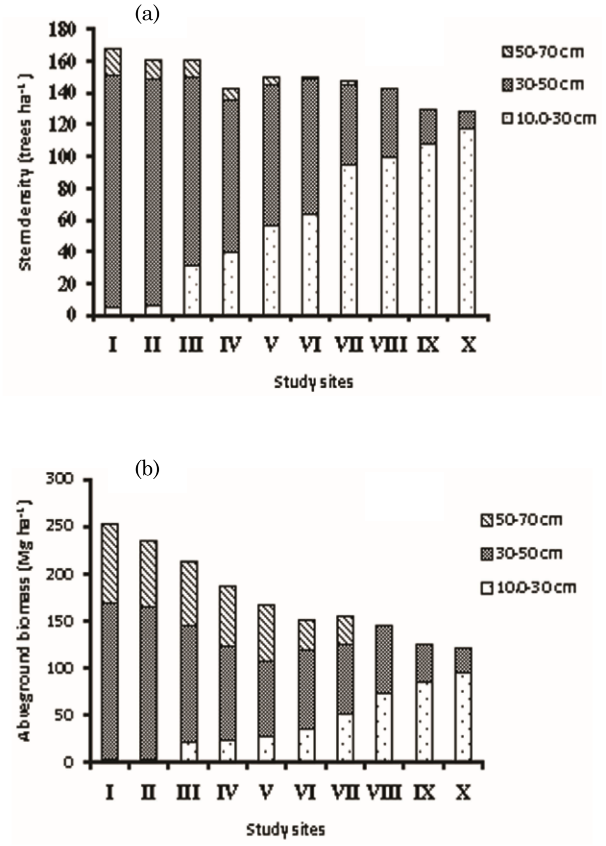

**Fig. 1**. Stand density (a) and tree aboveground biomass, (b) in different girth class and study sites in the forest ecosystem.

### *Soil*

The soil of the study areas is alluvium which consists of variable proportions of clay, sand and silt in different forests. The soil shows a marked variation from sandy to clayey and mostly clay loam in texture and acidic in nature. It is mostly composed of rocks such as siltstone, shale and sandstone.

### *Field Sampling*

A nested two stage sampling approach was adopted to record trees, herbs and shrubs (Fig. S3). In each site, a plot of 250 m × 250 m size was laid down. Four sub plots, each of 31.6 m × 31.6 m (≈ 0.1 ha) size, were laid into each plot in four cardinal directions i.e., NE, NW, SW and SE, respectively. Thus, the total sample size consisted of 10 plots with 40 sub plots. Two quadrats each of 5 m × 5 m size for shrubs and five quadrats each of 1 m × 1 m size for herbs were laid in each sub plot. During the field visits, topographic sheets of India and a GPS device (Garmin GPS 72H, Taiwan) were used to approach the sites.

### *Observation*

In each sub plot, trees with more than 10 cm diameter at breast height (DBH; 1.37 m from the ground) were measured at breast height by using metal measuring tape. Basal area (BA) was calculated to estimate the average area occupied by the tree stems in the forest by using the formula used by Tavankar (2013):

$$BA = 0.785 \times (DBH)^2$$

Species richness was calculated by using Menhinik's index of richness (Whittaker 1977) and was calculated as:

$$\text{Species Richness (SR)} = S/\sqrt{N}$$

where S = number of species, and N = total number of individuals of all species. Species were identified using Botanical Survey of India, Northeastern circle Shillong and specimens were deposited in the herbarium of Life Sciences Department of Manipur University, Imphal. Trees were grouped into three DBH classes i.e., 10–30 cm, 30–50 cm, 50–70 cm to analyse the density and AGB distribution under each DBH class.

### *Estimation of aboveground biomass and carbon stock*

For the present study, a non-destructive sampling method was adopted to estimate AGB and carbon stocks of each tree species and a destructive sampling method for herbs and shrubs was applied following a field manual of Dadhwal *et al.* (2009). All shrubs and herbs occurring in the sub plots were cut at soil level, oven dried and the dry weight was taken. Using DBH as independent variable, tree volume (TV) was calculated by using a unique local volume equation for each tree species (FSI 1996). Specific gravity (SG) of the tree was obtained from species specific gravity datagiven by Rajput *et al.* (1996). The volume equation and species specific gravity used in the present study is listed in Supplementary Table S1. The AGB of each individual tree was calculated by using the equation:

$$\text{Biomass} = TV \times SG$$

Biomass obtained from four sub plots (each of 0.1 ha) in different strata was summed to obtain the total aboveground biomass.

The aboveground biomass carbon stock was calculated by assuming that the carbon content is

**Table 1**. Total aboveground biomass and carbon stock in different study sites (t ha$^{-1}$).

| Study sites | Tree density (stem ha$^{-1}$) | Basal area (m$^2$ ha$^{-1}$) | Trees | | Shrubs | | Herbs | | Total AGB | Total carbon stock |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | AGB | SR | AGB | SR | AGB | SR | | |
| I | 168 | 19.7 | 253.9 | 0.15 | 0.81 | 1.28 | 0.28 | 1.49 | 254.99 | 121.43 |
| II | 160 | 18.5 | 235.1 | 0.24 | 0.79 | 1.44 | 0.3 | 1.6 | 236.19 | 113.56 |
| III | 160 | 16 | 211.69 | 0.24 | 1.93 | 1.53 | 0.37 | 1.8 | 213.99 | 102.18 |
| IV | 158 | 12.9 | 187.43 | 0.32 | 2.76 | 1.58 | 0.41 | 1.88 | 190.6 | 101.04 |
| V | 150 | 11.8 | 166.25 | 0.33 | 2.86 | 1.89 | 0.37 | 1.91 | 169.48 | 81.33 |
| VI | 150 | 10.5 | 157.82 | 0.41 | 2.43 | 1.81 | 0.33 | 1.92 | 160.58 | 77.09 |
| VII | 147 | 7.2 | 154.22 | 0.49 | 1.32 | 1.65 | 0.32 | 2.22 | 155.86 | 74.86 |
| VIII | 143 | 6.2 | 144.76 | 0.50 | 2.73 | 1.75 | 0.34 | 2.03 | 147.83 | 70.93 |
| IX | 129 | 4.2 | 125.28 | 0.70 | 2.86 | 1.83 | 0.75 | 2.63 | 128.89 | 61.75 |
| X | 128 | 3.4 | 121.49 | 0.79 | 2.43 | 2.06 | 0.63 | 3.18 | 124.56 | 60.09 |

AGB = Aboveground Biomass ; SR = Species Richness.

48% of the total above ground biomass (Brown & Lugo 1982; Ravindranath *et al.* 1997).

### *Statistical analysis*

All statistical analyses were performed using STATISTICA 6 and MS Excel 2007. Repeated Analyses of Variance were performed to analyse the relationship between DBH, stand density and biomass of tree species. Linear regression analyses were performed to investigate the relationship of biomass and basal area with altitude.

## Results and Discussion

### *Vegetation structure: stand density and basal area*

The stand density varied from 128 to 168 trees ha$^{-1}$ and the basal area varied from 3.4 to 19.7 m$^2$ha$^{-1}$in differentforest sites (Table 1). The stand density and basal area were recorded to be largest at the highest altitude within a *Terminlia myriocarpa-Phoebe lanceolata* community. The lowest stand density and basal area were measured at the lowest altitude within a *Schima wallichii–Castanopsis hystrix* community. The linear regression analysis indicates a significant positive relationship between stand density and altitude ($r^2 = 0.84$; $P < 0.01$). The repeated measures analysis of variance revealed that thestand density was found to be highest in the 10–30 cm DBH class in site VII, VIII, IX and X, whereas in site I, II, III, IV, V and VI stand density was highest in the 30–50 cm girth class. The density of trees within the 50–70 cm DBH class were found to be highest in site I and II, however, the density steadily decreased towards lower altitudes. Compared to the stand density of other classes, the density of 50–70 cm is low (Fig. 1a). Our results indicate that the size of trees and basal area decreased from high to low altitudes.

The increase of tree density and basal area with increasing altitude reflects the magnitude of anthropogenic disturbances as it gets more and more difficult to log trees at higher altitudes. A similar observation was also reported by Zhou *et al.* (2009). The stand density of trees with large DBH was also higher at higher altitudes, which resulted in the increase of basal area in higher altitude. Low density of trees with large stem diameters (i.e., 50–60 cm and 60–70 cm) in site IX and X resulted in low basal area owing to selective logging. At low altitudes, local people use an old traditional practice of slash and burn agriculture where a patch of forest is cleared for cultivation of crops forseveral years and then abandoned, while shifting to another forest patch. This is also known as shifting cultivation prevalent in the Northeast part of India (FSI 2013).

Stand density has been used as index of level of disturbances and based on this, our results show that the anthropogenic disturbance was highest in site IX and X and lowest in site I and II, whereas other sites were moderately disturbed. A similar pattern was observed in the dry tropical forest region of India (Sagar *et al.* 2003), where stand density and basal area were reported to be highest in the least disturbed site and lowest at highly disturbed sites.

### *Species richness, aboveground biomass and carbon stock*

The species richness of tree species decreased with increasing altitude, with the highest richness in site X (0.79) and the lowest richness in sites I (0.15). The same pattern between species richness and altitude was observed for shrubs and herbs, with the highest species richness at the lowest altitude (2.06 for shrubs, 3.18 for herbs ) and the lowest species richness at the highest altitude (1.3 for shrubs, 1.49 for herbs; Table 1). Species richness of trees, shrubs and herbs was negatively correlated ($r^2 = 0.92$; $r^2 = 0.89$; $r^2 = 0.79$; $P<0.05$) with altitude.

Our study revealed that maximum species richness of tree species, shrubs and herbs was highest at low altitudes, where disturbance levels are high. Disturbance creates more opportunities for other species to propagate through the creation of ecological niches and microhabitats, hence leading to the increase of species richness. Similar findings were reported in several studies in the forest of Central Himalaya (Kumar & Ram 2005; Rawal *et al.* 1991; Singh *et al.* 1994). This suggests that plant species richness of forests in Northeast India is not suited as an indicator for the conservation status of a forest but rather an indicator of its disturbance.

The maximum total aboveground biomass was recorded in site I (255 t $ha^{-1}$) and the minimum biomass in site X (124.6 t $ha^{-1}$). Repeated measures analysis of variance also showed that the biomass of tree species was found to be greatest in the 30–50 cm DBH classes for sites I, II, III, IV, V, VI, and VII whereas at lower altitudes (sites VIII, IX and X) the highest biomass was recorded in the girth classes10–30 (Fig. 1b).

Aboveground biomass varied from site to site because of varying plant community structures, variation in plant species and the succession stage of the forest. In addition, wood collected by local villagers and shifting cultivation have led to the destruction of forests and thus the reduction of biomass in some of the sites situated at the lower altitude. At some sites (IV, V, VI, VII) the tree density was high but biomass was low due to small tree sizes compared to sites at higher altitudes. Results of the present study indicate that it is not the tree density but the basal area of the trees that determine aboveground biomass.

The tree biomass contributed 121.5–253.9 t $ha^{-1}$ to the total aboveground biomass among the different sites followed by shrub (0.81–2.86 t $ha^{-1}$) and herb (0.28–0.75 t $ha^{-1}$). Tree aboveground biomass was positively correlated with altitude ($r^2 = 0.82$) while shrubs and herbs biomass was negatively correlated with altitude ($r^2 = 0.63$; $r^2 = 0.59$; $P < 0.05$). Thus shrub and herbaceous biomass was inversely related to woody biomass a pattern that seems largely due to reduced light availability under closed canopies, which reduces the growth rate and leads to lower biomass at the herb and shrub level. Aboveground biomass of tree species increased with increasing altitude because of the dominance of mature, large trees at higher altitudes in comparison to lower altitudes. Similar findings were also reported for the high altitude forests of Central Himalaya (Adhikari *et al.* 1995), for the tropical Atlantic moist forests of Brazil (Alves *et al.* 2010), and for temperate valley slopes of Garhwal Himalaya (Gairola *et al.* 2011). However, our result were contradictory with the studies reported by Moser *et al.* (2007) and Leuschner *et al.* (2007) where AGB decreased with increasing altitude because mainly small trees occurred at high altitude. Our results support the overall assumption, that stand density and aboveground biomass strongly vary by altitude.

The tree layer contributed the majority, between 97.5% to 99.6%, of the total aboveground biomass (tree + shrub + herb layer) across the study sites. Thereby, the percentage of herb and shrub layer to the total aboveground biomass increased with decreasing altitude. Only 1–3% of the biomass is contributed by the shrub and herb biomass. Our results are in accordance with a prior study (Brown 1997), which reported that understory can contribute up to 3% of the biomass of total ecosystem. The present value of shrub biomass (0.79 t $ha^{-1}$ to 3.18 t $ha^{-1}$) is comparable with the value of 0.59 t $ha^{-1}$ to 1.95 t $ha^{-1}$ reported by Devagiri *et al.* (2013), in moist deciduous forest, Karnataka but is lower than that reported by Zheng *et al.* (2006) in tropical seasonal rainforest in China (4.135 to 5.243 t $ha^{-1}$) and Zhang *et al.* (2013) in different forest ecosystems of China (4.8 to 16.7 t $ha^{-1}$).

The carbon stock in the aboveground tree layer varied from 60.09 to 121.43 t C $ha^{-1}$ across the study sites (Table 1) with the highest carbon stocks in sites I and II and lowest carbon stocks in sites IX and X (Table 1). The forest at higher altitudes is mature natural stand comprising higher diameter classes which could accumulate more biomass and lead to the higher carbon stock. Similar patterns have been reported for tropical Atlantic moist forests (Alves *et al.* 2010), Garhwal Himalayas (Gairola *et al.* 2011) and Central Himalayan forest (Sharma *et al.* 2010). Thus, our reusults support the growing evidence that forest ecosystems growing at higher altitudes store higher amounts of carbon than low altitude forest ecosystems, regardless of the dominant vegetation,

Our study provides relevant information on aboveground biomass and carbon stock along an altitudinal gradient of different forest ecosystems of Manipur. Our data also highlights the effect of anthropogenic disturbance on stand density and species diversity of forests along an altitudinal gradient. The natural forest at higher altitudes and low disturbance levels comprised higher densities of large trees while the lowland forest are affected by harvesting and logging of trees and wild fires by local villager, which contribute to low stand densities and thus inhibit large accumulations of carbon stocks. Joint efforts should be taken to enhance the speed and efficiency of tree growth and regeneration in disturbed natural forest to improve and restore natural stand dynamics of forest ecosystems degraded by human activities. Sustainable forest management practises such as reduced logging intensity and conservation efforts could be first steps to increase carbon sequestration in the plant soil system and to mitigate climate change.

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## Supporting Information

Additional Supporting Information may be found in the online version of this article.

**Table S1.** Volume equation and wood specific gravity used in the present study.