Ecological Engineering 99 (2017) 513–524

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng

Aboveground biomass and carbon stock assessment in Indian tropical deciduous forest and relationship with stand structural attributes

Soumit K. Behera[a,c,*], Nayan Sahu[a], Ashish K. Mishra[a], Surendra S. Bargali[b], Mukunda D. Behera[c], Rakesh Tuli[a,d]

[a] Plant Ecology and Environmental Science Division, CSIR – National Botanical Research Institute, Rana Pratap Marg, Lucknow, India
[b] Department of Botany, Kumaun University, Nainital, Uttarakhand, India
[c] Centre for Oceans, Rivers, Atmosphere and Land Sciences, Indian Institute of Technology, Kharagpur, India
[d] UIET, Panjab University, Sector 25, Chandigarh, India

ARTICLE INFO

Article history:
Received 20 April 2016
Received in revised form 7 November 2016
Accepted 13 November 2016
Available online 23 December 2016

Keywords:
Tropical deciduous forest
Above ground biomass
Carbon sequestration
Plant functional type
Litter fall

ABSTRACT

Indian tropical deciduous forest due to higher species richness, irregular stem densities and stem cover, multistoried canopy and microclimate, offers dynamism to the understanding of the spatial patters in aboveground biomass (AGB) and carbon (AGBC) within different plant functional types (PFTs). Field-based AGB and AGBC estimates are vital for carbon cycle study and provide inputs for data-deficit regional and global carbon and climate models.

In this paper we generated the primary baseline data on tree composition, species richness (SR), AGB and AGBC gathered from nine 10,000 m^2 long-term ecological research (LTER) plots in three distinct PFTs {dry mixed (DM), sal mixed (SM) and teak plantation (TP)} within an Indian tropical deciduous forest along Himalayan foothills during 2009–2012. The functional relationship of PFT structural attributes i.e. SR, density, basal cover, leaf area index and litter fall on AGB was investigated. PCA was applied to study the relationship between PFT microclimate, structural attributes and diversity vs. AGB.

A total of 22, 22 and 6 tree species were found in DM, SM and TP PFT, respectively. Shannon's diversity index was highest (2.46) in DM, whereas Simpson's dominance index was maximum (0.85) in TP. AGB (Mg ha^{-1}) ranged from 290.82–455.99 among all PFTs. AGBC (Mg ha^{-1}) ranged between 207.52–220.34, 215.58–228.87, and 125.94–141.18 in DM, SM and TP respectively. AGB observed strong positive correlation with tree density and cover. PCA revealed humidity and air temperature as the major microclimatic variables, leading to higher AGB.

1. Introduction

Tropical forests are important carbon pools, comprising approximately 40% of terrestrial carbon storage (Dixon et al., 1994). The tropical forests are among the most productive ecosystems on the earth, estimated to account for above one-third of global net primary productivity (NPP) (Gaston et al., 1998; Field et al., 1998), but have been relatively under-sampled compared with their importance. Tropical deciduous forests are forests occurring in tropical regions characterized by pronounced seasonality in rainfall distribution, with few months of drought period.

The aboveground biomass (AGB) of a forest ecosystem is one of the fundamental parameters describing its functioning. Studies on biomass of forest vegetation are essential for determining storage of the carbon in the dominant tree component and computing the carbon cycling at regional as well as global level. Measurement of AGB of dominant tree species in different forest communities/plant functional types is of great importance because the dominant tree species greatly influence the magnitude and pattern of energy flow that is stored in trunks, branches, leaves and roots in the form of various organic substances and material remained in continuous circulation between biotic and abiotic components of the ecosystem. The quantity of AGB in a forest is the result of the difference between production through photosynthesis and consumption through respiration, mortality, harvest, and herbivory.

Estimation of AGB is an essential aspect of studies of carbon stocks and global carbon balance (Ketterings et al., 2001). Estimating AGB is a useful measure for comparing structural and functional

* Corresponding author at: Plant Ecology and Environmental Science Division, CSIR – National Botanical Research Institute, Rana Pratap Marg, Lucknow, India.
E-mail addresses: soumitkbehera@gmail.com, soumitbehera@nbri.res.in (S.K. Behera).

http://dx.doi.org/10.1016/j.ecoleng.2016.11.046
0925-8574/

attributes of forest ecosystems across a wide range of environmental conditions (Brown et al., 1999). Permanent sampling plots have long been used in ecological studies for assessing how much biomass is held in ecosystem (Brown, 2002; Fearnside, 1996). Tree AGB is strongly correlated with trunk diameter (Brown and Lugo, 1992; Brown, 1997) and it is therefore possible to use forest inventory data to estimate the stocks and changes in AGB in those inventories. So far different studies have been conducted to estimate AGB and they have mostly used diameter and height (Chave et al., 2001; Clark et al., 2001; Cummings et al., 2002; DeWalt and Chave, 2004; Malhi et al., 2004; Nascimento and Laurance, 2004; Segura and Kanninen, 2005). Variations in environmental factors such as topography, hydrology and edaphic characteristics (e.g soil nutrient availability) may also complicate attempts to generalize stand density and AGB over regional or landscape scale (Clark and Clark, 2000). AGB is thus of direct applied importance for estimating ecosystem carbon storage and fluxes (Brown, 1997; Baker et al., 2004; Fearnside, 1997; Nelson et al., 1999). Biomass fluctuation with time and space involving stand dynamics can be estimated by repeated tree census, so that changes due to growth and mortality of trees can be followed in a given area (Chave et al., 2003).

Indian forests are a major tropical forest ecosystem constituting nearly 701,673 sq. km (70.17 million ha), 21.34% of the geographical area of country (State of forest report (SFR), 2015). Indian tropical deciduous forest are species rich with associates of varied phenophases having irregular distribution of stem densities and basal cover. Additionally, Indian deciduous forests have multistoried canopy with different microclimate which makes it complex for understanding the patters of AGB within and among different plant functional types (PFTs) over space and time (Blackburn and Gaston, 1996; Behera et al., 2012). There remains much uncertainty how tropical forests will respond to future climate changes (Gaston et al., 1998). Information on AGB and AGBC at PFT class level in Indian tropical deciduous forests is needed for real-time assessment of national carbon stock and further global carbon crediting. Studying the AGB patterns in different PFT class will help to understand the response of climatic changes on these ecosystems and future scenarios. Detailed species level AGB measurements in different PFT classes will help to identify the keystone species sequestering higher AGB, for sustainable carbon stock management and biodiversity conservation. PFT class wise AGB assessment will also help to validate the projections of global carbon model output with ground data. Estimating the biomass stock of tropical deciduous forests and understanding their role in regulating the cycling of carbon and nutrients is on high priority (Cairns et al., 1997). Although few past studies including remote sensing approach attempted to estimate the AGB and biomass carbon in Terai regions including Doon valley, no detailed study exist investigating the patters of AGB and biomass carbon at PFT level from Indian tropical deciduous forests (Kumar, 2009; Pandey et al., 2010; Mandal and Joshi, 2014; Mohommad and Joshi, 2015). Considering the above research gaps, the presents study was undertaken in Katerniaghat Wildlife Sanctuary at Terai region of Uttar Pradesh, India. The main objective of present study were (1) to estimate the species level AGB and AGBC in PFTs i.e. dry mixed (DM), sal mixed (SM) and teak plantation (TP) using annual DBH inventory records from long term ecological research permanent plots (LTER) and (2) to analyze the relation between AGB with community, as well as structural and functional variables such as species richness, basal cover, stem density, litter fall and leaf area index (LAI) in three PFTs having distinct tree species composition, different edaphic factors and microclimate conditions within a tropical moist deciduous forest ecosystem. Additionally, we attempted to establish relationship between PFT microclimate, community structural variables and diversity indices with stand AGB by having principal component analysis (PCA). We also explored the relationship between PFT AGB and annual litter fall.

2. Material and methods

2.1. Study area

The present study was undertaken at Katerniaghat Wildlife Sanctuary (KWLS), a tropical moist deciduous forest in the upper Gangetic plains adjoining Himalayan foothills in Uttar Pradesh state, India (Fig. 1). The KWLS is situated between 27° 41′ and 27° 56′ N latitude; and 81° 48′ and 81° 56′ E longitude, with elevation ranges from 116 to 165 m along the southern border of Nepal. The site experiences climatic variation, typical of northern India with extremes of heat and cold; and winter nights are very cold and foggy and heavy dew falls regularly. Heavy monsoon rain is experienced from June end to September, and along with the winter rainfall having an average annual rainfall of about 1300 mm (Behera et al., 2012).

2.2. Long term ecological study

Nine 1-ha long term ecological research (LTER) permanent plots (100 m × 100 m) were established (in triplicate) in three PFTs i.e. DM, SM and TP under Council of Scientific and Industrial Research (CSIR), New Delhi network project (NWP-020). Each of the 1-ha LTER plots was sub gridded into ten 0.1-ha quadrate (10 m × 100 m) for further tree numbering and annual inventory. Each of the 0.1 ha sub grids in all LTER plots were further inventoried for ecological and biomass monitoring. All the trees having diameter at breast height (DBH) ≥ 5 cm were considered as tree and therefore labeled and numbered for further inventory. Forests of KWLS falls under moist deciduous forest, which are two to three storied having distinct understory and top storey stratification, which experience about 3–5 dry months in a year, harbour largely deciduous species with a few semi-evergreen and evergreen species and also a considerable diversity and density of lianas. Phenophases of all tress also varies throughout the year, major deciduous species having leaf fall during March–April in the year.

2.3. Field survey

2.3.1. Forest phytosociology analysis

Phytosociological attributes of each tree species (≥5 cm DBH) were studied in LTER plots during 2008–2009 in all PFTs. Frequency, density and basal area and importance value index (IVI) for individual tree were calculated following Misra (Misra, 1968). The DBH of all stems/trees having ≥5 cm were measured at 1.37 m from ground level within each LTER. Tree species richness (SR) in each sampled stand was computed (Misra, 1968). Shannon's diversity index (H′) (Cootam and Curtis, 1956), Simpson's dominance index (C) (Simpson, 1949), and Hill diversity numbers N1 and N2 (Hill, 1973) were computed for each PFT.

2.3.2. DBH class and tree height

Tree censuses were carried out in all 9 LTER plots to determine the growth rate of forest stands. Only trees ≥5 cm DBH were included in the census. Annual tree census and DBH increment in all the stems having DBH ≥ 5 cm were measured during March-May in each year from 2009 to 2012. Tree height was measured with laser rangefinder (Nikon Laser 550AS) and per tree average height per PFT were considered for further analysis.

2.3.3. Biomass and biomass carbon

We determined the AGB using multiple censuses data of LTER plots. Annual DBH measurements of each tree were subsequently