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Assessment of carbon density and accumulation in mono- and multi-specific stands in Teak and Sal forests of a tropical dry region in India

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ABSTRACT

We investigated vegetation characteristics, carbon density (CD) and carbon accumulation (CA) of trees in mono- and multi-specific, *Tectona grandis* (Teak) and *Shorea robusta* (Sal) forest stands in a tropical dry region of India to address the following questions: (i) How are the mono- and multi-specific stands structured in terms of relative basal area of tree species? (ii) What are the levels of CD and CA in the stem component of tree species in the mono- and multi-specific stands? (iii) Which vegetation characteristics strongly account for the variations in CD and CA in the tree species in the mono- and multi-specific stands? We established 15 stands (six mono- and nine multi-specific stands), each having 4 ha area in the forest region. Total number of species across the stands was 46 belonging to 25 families. Average tree density ha^{-1} and stem basal area (BA, m^2 ha^{-1}), across the stands were 522 and 11.1, respectively. Margalef's index of species richness (SR), Whittaker's index of species evenness (Ew) and Shannon–Wiener index (H′) were greater at multi-specific stands compared to mono-specific stands. Average wood specific gravity (WSG) across species for the mono-specific (Teak) was greatest compared to the other categories. Across the mono- and multi-specific stands, WSG among species ranged between 0.47 and 0.79 g cm^{-3}, with 26.2% having WSG $\geqslant$ 0.70 g cm^{-3}. Across the plots in mono- and multi-specific stands, stem density showed positive correlation with BA and aboveground stem biomass (AGB). The associations of SR with Ew and H′, and Ew with H′ were significantly positive. The AGB was positively associated with SR, Ew and BA. Repeated measures ANOVA indicated significant effects of year, stand and species for DBH, height and AGB. Average aboveground CD and CA across the stands were 136 t-C ha^{-1} and 5.3 t-C ha^{-1} yr^{-1}, respectively. Results of step-wise multiple regression indicated that across the stands, CD was influenced by BA and H′, and CA was affected by SR and BA. Principal component analysis exhibited strong association of CA and CD with multi-specific stands compared to mono-specific stands. Teak and Sal trees showed maximum CA per unit BA at multi-specific stand compared to mono-specific stand. These findings can be used by the forest managers to increase the carbon density and accumulation in Teak and Sal forests of India.

1. Introduction

Currently, a major challenge in forestry is adapting forest ecosystems to changes in climatic condition and its consequences, and mixed species stands are being considered to be one of the important strategy for adaptation and risk reduction (Reif et al., 2010; Forrester et al., 2013). The response of species to environmental constraints in a mixture of a large number of species having different functional traits and resource use strategies, might be different in comparison to its response in a pure stand (Kelty, 2006; Ishii and Asano, 2010; Richards et al., 2010; Lebourgeois et al., 2013). It has been emphasized that the facilitative processes and niche complementarity in mixed species stands often lead to greater biomass production, and higher tree growth and carbon sequestration rates compared to pure stands (del Rio and Sterba, 2009; Cavard et al., 2011; Vallet and Pérot, 2011).

Changes in species composition could sharply alter the potential for terrestrial carbon sequestration (Bunker et al., 2005). Particularly, in the regions experiencing similar climatic conditions, composition of the tree species becomes important for the carbon storage (Chen et al., 2011; He et al., 2013). In tropical dry forests, small-scale variations in soil and vegetation characteristics determine the distribution of woody species leading to high

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variation in species composition (Chaturvedi et al., 2011a; Chaturvedi and Raghubanshi, 2014). Due to the patchy distribution of tree assemblages, tropical dry forests generally show uneven distribution of aboveground tree biomass (AGB), carbon density (CD) and carbon accumulation (CA) (Chaturvedi et al., 2011b,c, 2012a). Therefore, identification of the vegetation characteristics governing variations in CD and CA in forest stands having different species composition is important for better implementation of reforestation programmes.

Species composition, structure and stem density of the forest probably affects the growth and development of individual species (Forrester et al., 2013). There are many studies relating the response of the tree species affected by the neighboring species (e.g. Forrester et al., 2013). While many studies compare mixtures with monocultures, very few studies have compared how these interactions change along spatial or temporal gradients in resource availability or climatic conditions (Forrester, 2014). This study compares CD and CA in mono- and multi-specific stands in a tropical dry forest of India. We addressed the following questions: (1) How are the mono- and multi-specific stands structured in terms of relative basal area of tree species? (2) What are the levels of CD and CA in the stem component of tree species in the mono- and multi-specific stands? (3) Which vegetation characteristics strongly account for the variations in CD and CA in the tree species in mono- and multi-specific stands?

2. Materials and methods

2.1. Study region

The study was conducted in the forests of Vindhyan highlands situated in Sonebhadra district of Uttar Pradesh, India (21° 29′–25° 11′ N and 78° 15′–84° 15′ E). The selected study region contains naturally established old-growth forests which experience minimum anthropogenic disturbance. Removal of large logs is prohibited in the study region. *Tectona grandis* L. (Teak) and *Shorea robusta* Roxb. ex Gaertn. f. (Sal) are the dominant tree species in the study region (Table A.1). According to the data collected from the Divisional Forest Office Renukoot, Sonebhadra, 10% of the study region, currently is covered by mono-specific Teak forest, 16% by mono-specific Sal forest, 20% by multi-specific Teak forest without Sal, 30% by multi-specific Sal forest without Teak, 18% by multi-specific forest dominated by Teak as well as Sal, and the remaining 6% dominated by other species but without Teak and Sal trees.

Teak and Sal are the most important timber-yielding plants in India. According to a report by Forest Survey of India (F.S.I., 1998), 29% of the total forest area of the country is dominated by Teak and 37% by Sal. Teakwood is moderately hard, easily worked and extremely durable, whereas, Sal is known for its heavy, hard and tough wood. Teak is a deciduous tree reaching its large dimensions in western and southern India (Champion and Seth, 1968). Its northern limit is western Aravallis and eastward through central India. Sal is a semi-evergreen or deciduous tree widely distributed in tropical regions of India (Champion and Seth, 1968). The species occurs either gregariously or mixed with other trees in Himalayan foothills and central Indian belts. The requirements of the two species differ, Sal seeking more hygroscopic soils, and Teak seeking good subsoil drainage combined with a fair rainfall, however, in central India the two species occasionally occur mixed (Troup, 1986). In tropical dry deciduous forest, Teak is commonly associated with *Terminalia tomentosa* Roxb., *Terminalia belerica* Roxb., *Lagerstroemia parviflora* Roxb., *Ougeinia oogeinsis* (Roxb.) Hochr., *Anogeissus latifolia* (Roxb. ex DC.) Wallich ex Beddome, etc., while, Sal is mostly accompanied with *Buchanania lanzan* Spreng., *Terminalia tomentosa* Roxb., *Diospyros melanoxylon* Bakh., *Acacia catechu* (L.f.) Willd., *Dalbergia sisoo* Roxb. ex DC., etc.

2.2. Climate

The area experiences tropical monsoon climate. The year is divisible into four seasons: hot pre-monsoon (April–June), monsoon/rainy (July–September), early post-monsoon with gradually decreasing temperature (October–December) and late post-monsoon with gradually increasing temperature (January-March). About 85% of the annual rainfall occurs during the monsoon season from the south-west monsoon, and the remaining from the few showers in December and in May–June. There is an extended dry period of about 9 months in the annual cycle (Jha and Singh, 1990). According to the data collected from the meteorological stations of the state forest department for 1980–2010, the mean annual rainfall in the study region is 1215 mm. The maximum monthly temperature varies from 20 °C in January to 46 °C in June, and the mean minimum monthly temperature reaches 12 °C in January and 31 °C in May. The monthly rainfall varies from 8 mm in April to 383 mm in August.

2.3. Study design and field methods

We established 15 stands (six mono- and nine multi-specific stands), each spanning 4 ha (200 m × 200 m) area in the forest region. Distance between the nearest two stands was 2 km s. The selected stands were sufficiently uniform in tree size and age. On the basis of the dominant tree species on the stand, the selected stands were classified into five categories, each containing three stands; (i) mono-specific (Teak), (ii) mono-specific (Sal), (iii) multi-specific (Teak), (iv) multi-specific (Sal) and (v) multi-specific (Teak + Sal) (Table A.1). In categories (i), (iii) and (v) Teak was the dominant species, whereas, in categories (ii) and (iv), Sal was the dominant species (Table A.1). The multi-specific stands in categories (iii) and (iv) did not contain Sal and Teak, respectively, whereas, the multi-specific stands in the category (v) contained both Teak and Sal, mixed with the other associated tree species (Table A.1). The average relative basal area of Teak and Sal across stands in categories (i) and (ii) were 94% and 90%, respectively (Fig. 1). At the multi-specific stands, relative basal area of the individual species in the stands was <90% (Fig. 1). In each stand, three

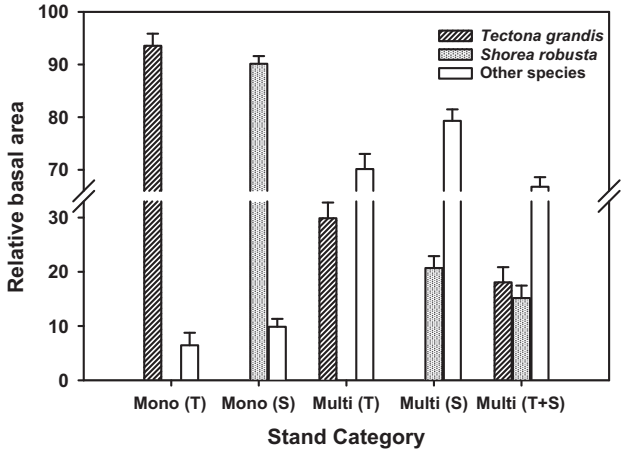

Fig. 1. Relative basal area of Teak, Sal and other trees in the mono- and multi-specific stands. Mono (T), mono-specific (Teak); Mono (S), mono-specific (Sal); Multi (T), multi-specific (Teak); Multi (S), multi-specific (Sal); Multi (T + S), multi-specific (Teak + Sal).