Ecological Engineering 103 (2017) 226–235

Contents lists available at ScienceDirect

Ecological Engineering

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

Herbaceous species diversity and soil attributes along a forest-savanna-grassland continuum in a dry tropical region

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ARTICLE INFO

Article history:
Received 23 December 2016
Received in revised form 24 March 2017
Accepted 2 April 2017
Available online 12 April 2017

Keywords:
Community composition
Dry tropics
Plant biomass
Herbaceous diversity
Soil nutrients
Vindhyan forests

ABSTRACT

Dry tropical vegetation is under major pressure of degradation due to various anthropogenic interferences and is characterized by the patches of forest, savanna and grassland systems. These adjacent systems may represent a gradient of various ecological attributes which can be better understood by studying these in a continuum approach to recognise changes at grassroots level. The herbaceous vegetation, a dynamic layer of an ecosystem, acts as an indicator of the environmental changes. The present study is designed to assess the herbaceous plant diversity and soil attributes along the dry deciduous forest-savanna-grassland continuum. A total of nine sites equally distributed in forest, savanna and grassland systems of Vindhyan region were selected. Soil moisture, water holding capacity, carbon, nitrogen, phosphorus and species richness, evenness, diversity and plant biomass were measured at each site. The results showed significant changes in soil attributes and herbaceous species composition, diversity and biomass along the continuum. Forest exhibited higher soil moisture, carbon and nitrogen contents than the savanna and grassland, while the herbaceous species diversity and biomass were higher in grassland vegetation. Savanna revealed intermediate levels of soil water availability, soil nutrients, community composition and species diversity of the herbs. The results showed that the herbaceous diversity was maximum in the grassland followed by savanna and forest. Moreover, a change in community composition and plant functional attributes was also observed. *Evolvulus nummularius-Justicia simplex*, *Justicia simplex-Evolvulus nummularius* and *Cynodon dactylon-Cyperus compressus* communities characterised the forest, savanna and grassland vegetation, respectively. Fabaceae was the most dominant family having the highest number of species in grassland followed by savanna and forest vegetation. Correlation analysis revealed a significant interaction between soil water and nutrient availability with vegetation parameters. Overall, heterogeneity of soil attributes maintaining the community structure and species diversity are essential components for understanding the ecology of herbaceous vegetation in dry tropical ecosystems. The findings of this study may contribute to the holistic understanding and development of ecological management tools for such a continuum.

1. Introduction

Around 42 million km^2 global area is under forest cover, of which ~40% is covered by tropical forests which contribute ~25% and ~33% of total terrestrial carbon store and net primary productivity, respectively (Bonan, 2008). These forests are the most disturbed and the least protected ecosystems on the Earth (Murphy and Lugo, 1986), and considered as the most threatened ecosystems under the changing climate scenario (Maass et al., 2005; Allen et al., 2017). In India, around 38% of the total tropical forest is represented by dry deciduous forest (Singh and Singh, 1988; MoEF, 1999) which is under great pressure due to expanding human population and the increased resource demand, and has degraded into patches of different size (Jha and Singh, 1990; Goparaju et al., 2005; Chaturvedi et al., 2012, 2017). These patches generally exist as forest, savanna and tree-less grassland ecosystems, which are dynamic in space and time (Jha and Singh 1990; Goparaju et al., 2005; Raghubanshi and Tripathi, 2009).

Structurally, savanna vegetation is intermediate between forest and grassland (Singh et al., 1985; Rossatto et al., 2013), and is

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http://dx.doi.org/10.1016/j.ecoleng.2017.04.020
0925-8574/

characterised by a discontinuous tree cover along with a continuous grass layer i.e., mixed tree-grass system (Scholes and Archer, 1997; House et al., 2003; Ratnam et al., 2011). They often occur with forests as a mosaic of patches (Bond and Parr, 2010; Hirota et al., 2011). Asian savannas are mainly represented by three distinct communities, viz., deciduous broadleaf savanna, fine-leafed and spiny savanna, and pine savanna (Ratnam et al., 2016). Among these, deciduous broadleaf savanna are widely distributed in the Asian region and the tree component is mainly dominated by species of *Tectona, Shorea, Dipterocarpus, Anogeissus, Lagerstroemia, Lannea, Hardwickia* and *Terminalia* (Bunyavejchewin et al., 2011; Suresh et al., 2011). They are maintained either by grazing (Singh et al., 1991a) and fire or other long-term human management (Ratnam et al., 2011, 2016). Further degradation of savanna owing to grazing and anthropogenic pressures leads to formation of relatively tree-less grassland.

Grasslands are evolved under varied ecological and climatic-edaphic settings (White et al., 2000). They often occur in areas having lower rainfall (600–1500 mm) and moderate temperatures (Woodward, 1987). Grasslands are dominated by grasses (Poaceae), sedges (Cyperaceae) and rush (Juncaceae), and majorly regulated by grazing and fire. Soil water availability is considered as the major regulatory factor as it provides a platform for other environmental variables favoring the growth and development of herbaceous species (Singh et al., 1998; Li et al., 2004; Sagar et al., 2008a,b; Chaturvedi et al., 2011a,b). In the dry deciduous forest region light intensity, water and nutrients along with canopy cover are reported as the major determinants of the herbaceous communities (Sagar et al., 2008b; Sagar et al., 2012; Verma et al., 2013). Elaboration of factors which regulate the vegetation could lead to tools for the management of the herbaceous vegetation.

Since the forest, savanna and grassland patches occur throughout the dry forest region, we can consider these as components of a forest-savanna-grassland continuum. This consideration provides a simple framework for studying various ecosystems within the continuum as gradients of coverage by woody plants (Belsky and Canham, 1994; Martens et al., 2000; House et al., 2003). The forest-savanna-grassland continuum encompasses several types of ecological gradients including a climatic gradient, in which soil moisture, temperature and biogeochemistry vary among sites (Kerkhoff et al., 2004; Breshears, 2006). The amount of canopy coverage, as well as the associated stature and spatial patterns of tree species are a fundamental determinant of many key ecosystem processes and associated abiotic patterns (Scholes and Archer, 1997; Martens et al., 2000). Such systems and transitions between them are expected to face major changes under future climate change scenario (Baudena et al., 2015). General understanding of ecological properties along the forest-savanna-grassland continuum has been hampered by the narrow scope of most field studies, which usually have focussed on a single site (House et al., 2003). We feel that a study encompassing the soil moisture, nutrient availability, herbaceous diversity and biomass at multiple sites in a forest-savanna-grassland continuum would be of vital importance for understanding the ground layer (herbaceous vegetation) dynamics in the dry deciduous vegetation.

In this study we examined whether the different ecosystems in the forest-savanna-grassland continuum are characterized by distinct herbaceous communities and represent specific soil features. It is known that the ground vegetation of the dry forest and savanna systems exhibits a high herbaceous diversity (Pandey and Singh, 1992) and has the potential to act as an early indicator of environmental change (Sagar et al., 2012). The lack of a comparative account of herbaceous vegetation and soil features in the various components of the forest-savanna-grassland continuum has prompted this study. Maass et al. (2005) assume that the more forest that is transformed, the more agricultural and pastoral goods are obtained. However, the patchy distribution of communities and species means that as the area of the dry tropical forest diminishes a rapid species loss could occur and consequently the delivery of regulating services, such as bio-regulation, and even cultural services, could decline (Maass et al., 2005). Thus, an ecological understanding of the herbaceous vegetation in this region could contribute to the formulation of management strategies for sustainable development of the system and associated human population. The objective of the study was to assess the soil and vegetation attributes and to elucidate the association between the key edaphic factors and the differential species composition of the herbaceous vegetation in the forest-savanna-grassland continuum of the dry tropical region. Soil moisture, water holding capacity, soil carbon, nitrogen and phosphorus, and herbaceous species distribution, community composition and species diversity are the major attributes examined in this study.

2. Material and methods

2.1. Study area

On the basis of reconnaissance survey and field observations in order to represent the entire range of vegetations, nine sites viz., Naugarh, Vinayakpur, Devari Kalan, Amritpur, Chandraprabha, Ahraura Vanashthali, Lakhania Dari, Hathinala and Ranitali distributed over the forest-savanna-grassland continuum in the Vindhyan dry tropical region (24°16′N–24°59′N, 83°01′E–83°15′E, 110–320 m a.s.l.) of India were selected in January–February, 2011. The study sites are located in three districts of Uttar Pradesh, viz., Chanduali (Naugarh, Vinayakpur, Devari Kalan, Amritpur and Chandraprabha sites), Mirzapur (Ahraura Vanashthali and Lakhania Dari sites), and Sonebhadra (Hathinala and Ranitali sites). These nine sites were equally categorised into three vegetation types (Forests, Savanna and Grassland) on the basis of homogeneity in vegetation composition. Among these sites; Naugarh, Hathinala and Ranitali were studied for the forest vegetation. Vinayakpur (Naugarh), Chandraprabha (Rajdari) and Lakhania Dari were examined for the savanna component. The grassland sites were Devari Kalan (Naugarh), Amritpur and Ahraura. The locational attributes of the sites are summarized in Supplementary Table 1. One hectare area, visually homogeneous, was selected at each site for the study.

The area experiences a tropical monsoon climate with three distinct seasons in a year, viz., summer (April to June), rainy (mid-June to September) and winter (November to February). March and October constitute transition periods, respectively between winter and summer, and between rainy and winter seasons (Sagar et al., 2012; Chaturvedi et al., 2017). The long term annual rainfall varies between 850 and 1300 mm, of which about 86% is received from the south-west monsoon during June-August. There is an extended dry period of nine months in the annual cycle (Jha and Singh, 1990; Chaturvedi et al., 2011c). Soils are Ultisol, sandy loam in texture and reddish to dark grey in colour, and are extremely poor in nutrients (Singh et al., 1989).

The region is undergoing rapid changes due to various anthropogenic forces such as mining, thermal power generation, cement industry, etc. (Jha and Singh, 1990). The area is inhabited by a large human and cattle population. The expanding human and livestock population have led to illegal tree felling, lopping, and increased extraction of non-timber forest products (Sagar and Singh, 2005; Chaturvedi et al., 2017). The forest is managed by the Uttar Pradesh Forest Department through selective felling (Upadhyay and Srivastava, 1980; Harikant and Ghildiyal, 1982).

The forest component of the studied continuum is dominated by *Acacia catechu, Anogeissus latifolia, Boswellia serrata, Bridelia retusa, Buchanania lanzan, Diospyros melanoxylon, Hardwickia binata, Lan-*