Environmentalist (2012) 32:485–493
DOI 10.1007/s10669-012-9414-5

Composition, species diversity, and biomass of the herbaceous community in dry tropical forest of northern India in relation to soil moisture and light intensity

R. Sagar · A. Pandey · J. S. Singh

Published online: 1 September 2012

Abstract Herb layer contributes substantially to the species diversity of forests and responds relatively quickly to changes in the environment. The objectives of the present study were to understand the relationships among tree canopy cover, soil moisture, light intensity, herbaceous diversity and biomass in a dry tropical forest of India. For this, 20 locations equally distributed in four sites were selected. Four quadrats, each 1 × 1 m in size, were randomly placed for sampling at each location. For each quadrat, tree canopy cover, incident light, soil moisture, herbaceous diversity, and biomass were determined. Results indicated that the selected locations differed in terms of tree canopy cover, soil moisture, light intensity, herbaceous diversity, and biomass. Principal component analysis (PCA), using importance value indices of the component species yielded four groups corresponding to the four communities. PCA axes were related to the tree canopy cover, light intensity, and soil moisture and suggested that these variables had a profound effect on the organization and determination of herbaceous floristic composition and diversity. Positive relationships of tree canopy cover with soil moisture, herbaceous diversity and biomass, and those of soil moisture with herbaceous diversity and biomass suggested that the tree canopies facilitated the herbaceous communities by modifying environmental conditions that ultimately improved the diversity and production. Further, the study showed a linear relationship of herbaceous diversity with biomass, indicating the importance of species diversity for generating primary production in forest herbs.

R. Sagar (✉) · A. Pandey · J. S. Singh
Department of Botany, Banaras Hindu University,
Varanasi 221005, India
e-mail: sagarbhu@gmail.com

Keywords Biomass · Canopy cover · Diversity · Dry tropics · Herb diversity

1 Introduction

Light, nitrogen, and moisture are important limiting factors for the understorey herbaceous vegetation in close-canopied forests (Coomes and Grubb 2000; Gilliam and Roberts 2003; Neufeld and Young 2003). Coomes and Grubb (2000) reviewed literature to conclude that light alone limits plant growth under high moisture/nutrient conditions, while Anderson (2003) showed that N uptake by a variety of herb species increased with N supply, but did so to a greater degree in unshaded than shaded conditions. Creation of openings in the forest canopy due to the death of overstorey trees, i.e., canopy gaps (Bushing and Brokaw 2002), is fundamental to the regeneration ecology of temperate and tropical forests (Bushing and Brokaw 2002; Abe et al. 1995; Denslow et al. 1998; Schnitzer and Carson 2001). These gaps in temperate forests are generally small due to rapid extension of lateral branches of the neighboring canopy trees (Abe et al. 1995; Denslow et al. 1998; Schnitzer and Carson 2001; Runkle 1982). Nevertheless, across a broad gradient of dense to open canopy, light intensity generally increases, and understorey cover increases with it (Anderson et al. 1969). The strength of canopy gaps influences the plant nutrient demand, litter inputs, nutrient availability, soil moisture, light availability (Denslow et al. 1998) and thus, overall resource availability (Bushing and Brokaw 2002). The greater resource availability in tropical forests offers greater opportunities for niche partitioning than in the temperate forest gaps because of steeper sun angles and lower soil fertility in the tropics (Ricklefs 1977). These conditions support a larger amount of diversity in tropical than temperate forests (Bushing and Brokaw 2002; Abe et al. 1995; Denslow et al. 1998; Schnitzer and Carson 2001; Ricklefs 1977).

Forest canopies either promote ground vegetation by a mechanism of facilitation or reduce it by competition (Scholes and Archer 1997). Further, they provide shelter for wild flora and fauna (Breshears 2006), influence soil properties and microclimate (Archer 1995) by promoting nutrients, organic matter (Escudero et al. 1985), mineralizable-N, microbial biomass (Weltzin and Coughenour 1990), relative humidity, water-holding capacity, macro porosity and infiltration (Joffre and Rambal 1993), reduce soil temperature, evaporation and wind speed (Ovalle et al. 2006), protect against soil erosion (Gillet et al. 1999), affect herbaceous phenology, production, community composition and species diversity (Gillet et al. 1999; Treydte et al. 2008; Sanchez-Jardon et al. 2010). Herbaceous layer in the forests determines the spatio-temporal distribution and dynamics of woody seedlings through regeneration (Maguire and Forman 1983) and regulates the recruitment of woody plants directly through competition for nutrients, light, and water and indirectly through the addition of macro and micro fuels that sway the intensity and frequency of fire (San Jose and Farinas 1991). Further, understorey grasses also influence nutrient cycling, primary production and energy flow in the forest ecosystems (Das et al. 2008), provide forage for domestic and wild animals, exhibit attraction for many butterflies due to high richness of nectar-bearing flowers (van Swaay 2002) and provide shelter for microbial communities (Singh et al. 2006). Grasses are beneficial in binding soil particles with the help of fibrous root systems, thereby substantially reducing soil erosion and water loss and finally maintaining the soil structure (Sagar et al. 2008a). Thus, the strength of coupling between these strata promotes the structural organization and number of niches (ecosystem complexity) and finally makes the system stable.

Since stability and vulnerability of ecosystems depend on species diversity that is defined by the spatio-temporal alteration in species composition and their distribution (Gillet et al. 1999), and since tree canopies play a critical role in the spatio-temporal build up of herbaceous species diversity and production (Scholes and Archer 1997; Sanchez-Jardon et al. 2010), understanding the composition, distribution, and diversity of herbaceous vegetation is basic to the understanding of dynamics of the forest ecosystem.

Light is generally considered the primary limiting factor for understorey species of closed-canopied forests (Coomes and Grubb 2000 and Neufeld and Young 2003), however, light in the dry tropical forests with broken and sparse canopy cover is seldom limiting. Little or no information is available on the effects of tree canopy on the diversity and productivity of herbaceous communities of dry deciduous forests; however, Sagar et al. (2008a) have reported on the differential effects of planted woody canopies on the species composition and diversity of ground vegetation in the middle Gangetic plains of India.

The objectives of the present study were to analyze the effects of the forest canopy on the composition, diversity, and biomass of the herbaceous layer of the dry tropical forest. Specifically, we addressed the following questions: (1) How does the canopy cover of the dry forest affect the understorey herbaceous diversity and biomass? (2) Do the diversity and biomass of the herbaceous layer respond linearly to the gradient of canopy cover? And finally, (3) Does the diversity of the herbaceous layer influence its biomass accumulation?

2 Materials and methods

2.1 Study area

The study was conducted on four sites (24°18′10″N–24°23′46″N, 83°4′11″E–83°24′44″E); viz: Hathinala, Ranitali, Neruiyadamar, and Gaighat in the Vindhyan dry tropical forest region of India (Sonebhadra district), in February of 2010. The elevation above the mean sea level ranges between 313 and 483 m. The sites were selected on the basis of satellite images and field observations to represent the entire range of canopy cover conditions. The area is known as "Sonaghati" (golden valley due to the richness of its natural resources). Physiographically, the area is characterized by hillocks, escarpments, east–west trending, gorge-like valleys, flat basins, and flat-topped ridges (Sagar et al. 2003a). Hathinala and Neruiyadamar sites are located in the Renukoot Forest Division and the Ranitali and Gaighat sites in Obra Forest Division.

The area experiences a tropical monsoon climate with three seasons in a year; viz: summer (April to mid June), rainy (mid June to September), and winter (November to February). The months of March and October represent transition periods, respectively, between winter and summer, and between rainy and winter seasons. The long-term annual rainfall varies between 850 and 1,300 mm, of which about 86 % is received from the south-west monsoon during June–August. There is an extended dry period of 9 months in the annual cycle (see Sagar and Singh 2004).

Parental rocks are present in between 7.25 and 38.70 cm below the ground surface and are composed of heamatic slates or schists together with banded jaspers and quartzite, hornblende, and limestone. The rock system belongs to the transition system of Bijwar group of rock formation. The soils are Ultisols, sandy loams in texture and reddish to dark gray in color, and are extremely poor in nutrients (Singh et al. 1989).

Generally, all parts of the Central Highlands of India are undergoing rapid changes in vegetation; through mining, thermal power generation, and the cement industry, and are bearing a large amount of anthropogenic pressure. The biotic pressure is mainly from human and livestock populations. The human population of Sonebhadra district increased from 683,249 in 1981 to 930,953 in 1991, and the cattle population increased from 132,904 in 1988 to 276,586 in 1997 (Sagar and Singh 2004). The increase in human and livestock populations together with local destruction has exerted tremendous pressure on these forests. The labor population involved in quarrying alone was estimated to use 417 t of fuel wood per month (Singh et al. 1991). Besides illegal tree felling, widespread lopping and extraction of non-timber resources are occurring. A grazing pressure of 0.43 ha per cattle has been estimated (Upadhyay and Srivastava 1980), however the pressure is uneven. The extensive removal of trees for timber, fuel, fodder, and lumber have fragmented the forest canopies and produced degraded savanna and grassland-like ecosystems, which are marginal for crop growth (Champion and Seth 1968).

The potential tree vegetation of the region is dry tropical deciduous forest. *Shorea robusta*, *Terminalia tomentosa*, *Hardwickia binata*, *Boswellia serrata*, *Buchanania lanzan*, *Acacia catechu*, *Diospyros melanoxylon*, *Lannea coromandelica*, etc., are the important tree species. These species exhibited local dominance (Sagar and Singh 2005).

2.2 Sampling

At each of the four sites, five locations were randomly selected to measure the forest canopy cover. The canopy cover was estimated by charting method (Gill et al. 2000) and values were converted to percent. Four quadrats, each 1 × 1 m in size, were randomly placed for sampling. Thus a total of eighty 1 × 1 m quadrats (4 sites × 5 locations × 4 quadrats) were sampled. From each quadrat, total herbaceous vegetation was clipped and number of individuals was recorded by species. The herbage cover of each species in each quadrat was measured by gridding the quadrats into 10 × 10 cm cells and transferring the cover outlines to graph paper (Sagar et al. 2008a).

Incident light (as % of full sunlight), 10 cm above the ground in each quadrat, was determined by using a Lux meter between 11 and 12 h on a cloud-free day. An 80–100 % sunlight level corresponded to 1,600–1,720 mol m^{-2} s^{-1} as measured by LCA-2 portable infrared carbon dioxide analyzer having PAR sensors (filtered selenium photocells) (ADC Scinokem International UK).

Three soil samples (0–10 cm depth) were collected from each quadrat using a 5-cm-diameter corer and these samples were pooled to represent one sample per quadrat. All fine roots were removed from the pooled soil sample carefully. One part of each pooled sample was weighed and oven-dried at 105 °C to determine the gravimetric moisture content.

2.3 Data analysis

The importance value index (IVI) of each species for each location was calculated by summing the relative frequency, relative density, and relative cover of the component species. The species having the highest IVI was identified as the dominant one, and that having the second-highest IVI was defined as the co-dominant species. α-diversity using the Shannon–Wiener index (H'). Species evenness (E) for each location and β-diversity for each site was calculated using the following formulae:

$$H' = -\sum_{i=1}^{s} p_i \ln p_i \text{ (Shannon and Weaver 1949)}$$

$$E = \frac{S}{\ln Ni - \ln Ns} \text{ (Whittaker 1972)}$$

$$\beta = \frac{Sc}{\bar{S}} \text{ (Whittaker 1972).}$$

In the above equations, p_i = proportion of importance value belonging to species 'i', S = number of species, Ni = IVI of the most important species, Ns = IVI of the least important species, Sc = total number of species, $\bar{S}$ = average number of species per sample. Furthermore, the diversity of different sites was compared using a *K*-dominance plot, in which the percentage cumulative importance value is plotted against the log species rank (Platt et al. 1984).

The sampled locations were ordinated by principal component analysis (PCA) option in PC ORD software (McCune and Mefford 1999) using IVI of the component species. Pearson correlation coefficients were calculated to compare explanatory variables (canopy cover, light intensity, and soil moisture) and response variables (PCA axes scores, species diversity, and biomass), using SPSS statistical software package (SPSS 1997).

Analysis of variance (ANOVA) procedure of SPSS software package (1997) was used to see the effect of sites on the number of species, Shannon–Wiener index and biomass using five locations on each site as replicates. A Tukey's HSD test was used to determine the significance of differences for mean number of species, diversity indices, and biomass among the sites.

3 Results

Percent tree canopy, light intensity, and soil moisture at the four sites are presented in Table 1. Tree canopy cover and

Table 1 Percent tree canopy cover, light intensity, and soil moisture at four sites in Vindhyan dry tropical forest of northern India

Sites	Tree canopy cover (%)	Light intensity (%)	Soil moisture (%)
Hathinala	55 (7)[a]	74 (5)[a]	4.08 (1.59)[a]
Ranitali	43 (5)[b]	83 (4)[b]	1.39 (0.50)[b]
Neruiyadamar	46 (7)[ab]	82 (6)[b]	2.74 (1.20)[ab]
Gaighat	48 (3)[ab]	77 (4)[b]	2.89 (0.81)[ab]

Values in parentheses are ±1 SD. *Different superscript letters within column* are significantly different at $p = \leq 0.05$

soil moisture were highest at the Hathinala site and lowest at the Ranitali site. The ground flora of Ranitali site received the greatest light intensity followed by Neuraiyadamar, Gaighat, and Hathinala sites (Table 1). ANOVA (analysis of variance) revealed that the percentage tree canopy ($F_{3,16} = 4.50$, $p = 0.02$), soil moisture ($F_{3,16} = 4.96$, $p = 0.01$) and light intensity ($F_{3,16} = 18.79$, $p = 0.00$) varied significantly due to site.

A total of 28 species was recorded from the four sites covering 80-m^2 areas. The total number of species per site varied from six (Neraiyadamar) to 11 (Hathinala). Similarly, the number of unique species per site also differed from three to seven. The values were highest for the Hathinala and lowest for the Neraiyadamar site (Table 2).

On the basis of IVI, the four sites differed in the combination of dominant and co-dominant species (Table 2). The Hathinala site represented *Cyperus–Heteropogon* community, Ranitali site; *Atylosia–Hyptis* community, Neruiyadamar site; *Ludwigia–Desmodium* community, and Gaighat site; *Desmostachya–Convolvus* community (Table 2). The PCA ordination of 20 locations on the basis of IVI of component species is presented in Fig. 1. The PCA axis-1 accounted for 38 % variation in species composition, while PCA axis-2 accounted for 23 % variation. The PCA axis-1 scores were related with tree canopy cover ($r = -0.63$, $p = 0.00$), soil moisture ($r = -0.58$, $p = 0.01$), light intensity ($r = -0.49$, $p = 0.03$), and the PCA axis-2 represented only the gradient of light intensity ($r = -0.86$, $p = 0.00$).

The average number of herbaceous species, evenness, Shannon–Wiener index, β-diversity and biomass per site/community varied from four to six, 2.01 to 3.29, 1.12 to 1.51, 1.20 to 2.40, and 9.21 to 34.97, respectively (Table 3). ANOVA indicated that number of species ($F_{3,16} = 3.51$, $p = 0.04$), Shannon–Wiener index ($F_{3,16} = 3.47$, $p = 0.04$), and biomass ($F_{2,16} = 24.61$, $p = 0.00$) varied significantly due to site. The species evenness did not vary due to site, but it was positively and significantly related to soil moisture ($r = 0.60$, $p = 0.01$). Figure 2 shows the *K*-dominance of species rank plot. The bottom curve (Hathinala, *Cyperus–Heteropogon* community) represented the highest diversity, while the uppermost curve (Neruiyadamar, *Ludwigia–Desmodium* community) represented the lowest diversity.

The forest canopy cover and soil moisture were positively and linearly coupled with each other, and these variables were also related to species richness, Shannon index, and biomass of the ground flora (Fig. 3). Further, the relationships of herbaceous biomass with α-diversity and its component, species richness, exhibited significantly fit with linear and non-linear models used in the analysis; but the linear model exhibited a better fit to the data compared to non-linear models (Table 4).

4 Discussion

Phytosociological analysis of the herbaceous vegetation indicated that the dry forest can harbor a variety of herbaceous communities in response to the changes in canopy cover and the related availabilities of light and moisture. In our study, the four sites represented different communities with different species combinations of dominants and co-dominants. Evidently, each site represented a unique combination of environmental factors including canopy cover, light intensity, soil moisture, and other growth conditions. PCA ordination based on the IVI values of component species also yielded four distinct groups. Significant relationships among PCA axis-1, canopy cover, light intensity and soil moisture, and between PCA axis-2 and light intensity indicated that soil moisture and light intensity played a significant role in the determination of ground vegetation. Canopy cover evidently facilitated relatively high soil moisture condition and moderated the heating effect of the light intensity. Thus, the study suggests that the forest canopy profoundly determines the constitution and distribution of herbaceous communities in the Vindhyan dry tropical forest of India by favoring the water regime and therefore a range of herbaceous communities can be expected to occur along the gradient of canopy cover.

In this study, forest canopy reduced the light intensity and enhanced the soil moisture. Joshi et al. (2001) have also reported more soil moisture in shaded area than in the open. The possible mechanism through which trees facilitate the below canopy environment for ground vegetation is interception of direct solar heat, which could reduce soil temperatures and evaporation, thus increasing the below-canopy soil moisture (Vetaas 1992). The improved soil moisture could provide a platform for other environmental variables which favor the growth and development of herbaceous species and finally improve the α-diversity and species richness of the ground flora. Pausas and Austin

Table 2 Important value index (IVI) of herbaceous species at four sites in Vindhyan dry tropical forest of northern India

Species	Hathinala	Ranitali	Neruiyadamar	Gayghat
Aeschynomene aspera L.	0.00	12.00	0.00	0.00
Aeschynomene indica L.	0.00	0.00	0.00	11.03
Alysicarpus vaginalis L.	11.82	0.00	0.00	0.00
Alysicarpus bupleurifolius L.	0.00	0.00	30.83	16.17
Alysicarpus monilifer L.	0.00	0.00	0.00	13.63
Atylosia cajanifolia Haines	4.95	76.46	0.00	0.00
Cenchrus ciliaris L.	0.00	0.00	0.00	10.94
Chrysopogon zizanioides L.	3.91	0.00	0.00	0.00
Convolvulus pluricaulis Chois	0.00	0.00	0.00	60.53
Cyperus compressus L.	0.00	63.27	0.00	0.00
Cyperus niveus Retz	125.35	0.00	0.00	0.00
Cyperus rotandus L.	2.75	0.00	0.00	0.00
Desmodium gangeticum L.	0.00	0.00	84.32	5.52
Desmostachya bipinnata L.	0.00	0.00	0.00	147.95
Evolvulus nummularius L.	0.00	16.98	0.00	0.00
Heteropogon contortus L.	74.59	0.00	0.00	0.00
Hyptis suveolens L.	15.38	115.19	0.00	0.00
Imperata cylindrica L.	20.85	0.00	0.00	0.00
Ludwigia adscendens L.	0.00	0.00	156.83	0.00
Mimosa pudica L.	0.00	0.00	13.33	0.00
Mollugo pentaphylla L.	18.08	0.00	0.00	0.00
Oldenlandia corymbosa L.	0.00	0.00	0.00	3.32
Phyllanthus urinaria L.	0.00	0.00	8.52	0.00
Rungia pectinata Nees.	7.91	0.00	6.14	0.00
Sida acuta Burm.f.	0.00	5.26	0.00	0.00
Sida cordifolia L.	0.00	0.00	0.00	7.40
Triumfetta pentandra A.Rich.	14.35	0.00	0.00	23.45
Urena lobata L.	0.00	10.83	0.00	0.00

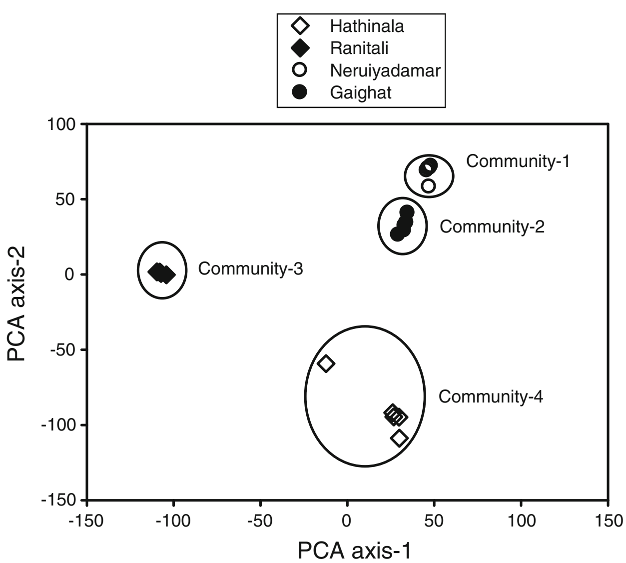

Fig. 1 PCA ordination of sites on the basis of IVI of the component herbaceous species, revealing four communities

(2001) advocated that a decrease in radiation is often associated with an increase in water availability, resulting in increased species richness under the canopies of trees. Sheltering effect could be another possible mechanism for greater herbaceous diversity beneath the tree canopies, because in the absence of tree, survival of many species is hindered, influencing the species diversity (Treydte et al. 2008; Sanchez-Jardon et al. 2010). Tree canopies improve soil water conditions (Gindel 1964), soil nutrients, soil organic matter (Escudero et al. 1985), and mineralizable-N (Weltzin and Coughenour 1990). Further, studies have shown that soils developing under the tree canopy have greater water-holding capacity and a macro porosity favorable to infiltration and redistribution of soil water (Joffre and Rambal 1993).

In contrast to tree biomass, herbaceous biomass is intimately related to annual production and thus is an easily measured substitute for productivity (Johnson et al. 1996; White et al. 1999). Studies indicated that increased herbaceous production beneath the tree canopy was associated with greater resources compared to those of adjacent

Table 3 Species diversity and biomass of the herbaceous vegetation at four sites in Vindhyan dry tropical forest of northern India

Sites	Species number (ha^{-2})	Evenness	Shannon index	β-diversity	Biomass (g^{-2})
Hathinala	4.6^{ab}	3.29^{a}	1.31^{ab}	2.40	15.39^{a}
	(1.52)	(1.53)	(0.30)		(8.35)
Ranitali	6.00^{a}	2.94^{a}	1.51^{a}	1.20	34.97^{b}
	(0.71)	(0.73)	(0.12)		(7.35)
Neruiyadamar	4.00^{b}	2.10^{a}	1.12^{b}	1.50	4.33^{c}
	(0.71)	(0.43)	(0.13)		(1.26)
Gaighat	4.60^{ab}	2.54^{a}	1.23^{ab}	2.20	9.21^{ca}
	(0.89)	(0.82)	(0.18)		(4.63)

Values in parentheses are ±1 SD. *Different superscript letters within column* are significantly different at $p = \leq 0.05$

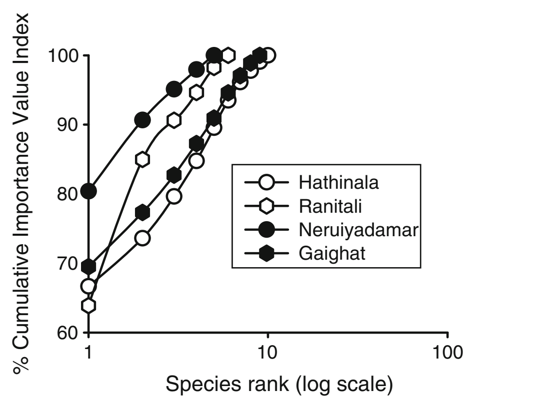

Fig. 2 *K*-dominance plot, in which percentage cumulative importance value is plotted against log species rank for each site

grassland away from tree canopies (Weltzin and Coughenour 1990). Scholes and Archer (1997) reviewed the effects of tree canopy on herbaceous production and reported greater herbaceous production at optimum levels of tree canopies. Similarly, Sanchez-Jardon et al. (2010) also reported higher herbaceous productivity in areas of scattered trees or medium-density forests than open area. A greater productivity with increased tree cover has been reported in different degraded ecosystems (Scholes and Archer 1997).

Palmer (1994) listed more than 100 hypotheses to elucidate the patterns of species diversity along various environmental gradients, in which productivity is one of them. In the present study, all the studied models (quadratic, logarithmic, power, and linear) gave highly significantly fits but the linear relationships of herbaceous productivity with species richness and α-diversity exhibited a lower standard error of estimate and a higher coefficient of determination compared to the non-linear models. The standard error of estimate is a measure of the accuracy of predictions because it represents the spread of real data points around the fitted regression curve. A model yielding the lowest standard error of estimate provides better results compared to those with larger standard error of estimate (Sagar et al. 2003b, 2008b). Linear relationship between productivity and diversity was also found in several other studies (Abrams 1995 and Bai et al. 2007). On the other hand, several studies (see White et al. 1999) have reported a humped relationship between herbaceous species richness and biomass, and suggested that at low levels of biomass the site is too unsympathetic for many species to stay alive, whereas at high levels, the site is sympathetic and one or few species dominate through competitive segregation (Safi and Yarranton 1973).

The relationship between biodiversity and ecosystem function has been a hot debate among ecologists (Johnson et al. 1996; White et al. 1999; Bai et al. 2007). Four prevalent hypotheses (diversity-stability, rivet-popper, redundancy, and idiosyncratic response) were advocated by scientists under the umbrella of diversity and ecosystem function concept. The productivity–diversity relationship has important implications for ecosystem management (Bai et al. 2007). In the present study, the linear relationship between diversity and productivity supported the diversity–stability hypothesis of Elton (1958). It has been argued that species richness is a function of ecosystem stability (Bai et al. 2007), which represents the greater degree of ecosystem complexity; i.e., structural organization, and number of niches (Gillet et al. 1999). Stability has been reported to increase with species diversity (Safi and Yarranton 1973). Therefore, dry tropical forest tree canopies can potentially lead to an increase in stability and complexity of the ecosystems.

4.1 Ecological implications

The populations of many tree species in the dry tropical forest of India are depleting and many locations are facing high threats of species loss because of biotic perturbations (Sagar and Singh 2004). This decline in tree species populations would certainly influence the herbaceous diversity, productivity, and their relationship, because growth and development of many herbaceous species are facilitated by tree canopies (Scholes and Archer 1997) through improvement in moisture regimes (Joffre and Rambal 1993) and soil nutrients (Archer 1995; Escudero et al.

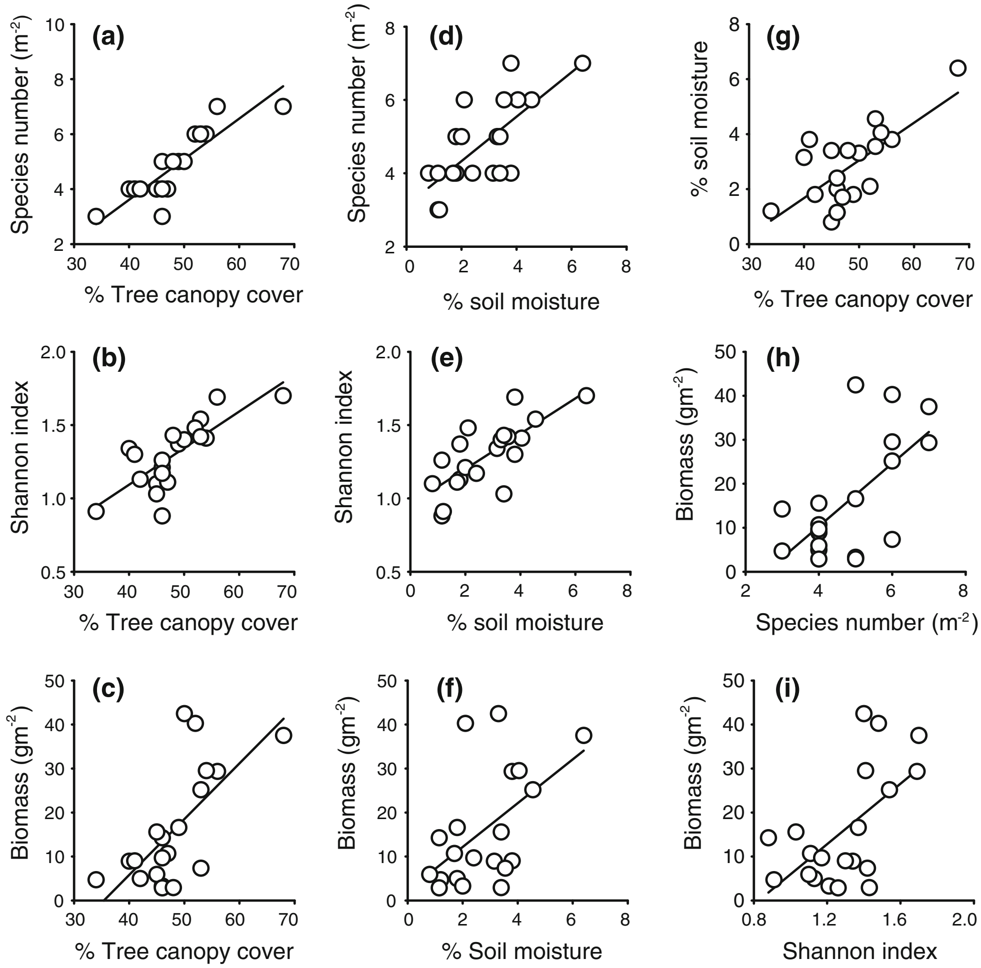

Fig. 3 **a** Relationship between tree canopy cover (C) and number of species (S), according to $S = -2.28 + 0.15C$; $R^2 = 0.76$, $p = \leq 0.001$. **b** Relationship between tree canopy cover (C) and Shannon index (H'), according to $H' = 0.10 + 0.03C$; $R^2 = 0.59$, $p = \leq 0.001$. **c** Relationship between tree canopy cover (C) and biomass (B), according to $B = -44.89 + 1.27C$; $R^2 = 0.46$, $p = \leq 0.001$. **d** Relationship between soil moisture (M) and number of species (S), according to $S = 3.11 + 0.61M$; $R^2 = 0.51$, $p = \leq 0.001$. **e** Relationship between soil moisture (M) and Shannon index (H'), according to $H' = 0.96 + 0.12M$; $R^2 = 0.55$, $p = \leq 0.001$. **f** Relationship between soil moisture (M) and biomass (B), according to $B = 2.22 + 4.95B$; $R^2 = 0.28$, $p = \leq 0.01$. **g** Relationship between tree canopy cover (C) and soil moisture (M), according to $M = -3.80 + 0.14C$; $R^2 = 0.47$, $p = \leq 0.001$. **h** Relationship between number of species (S) and biomass (B), according to $B = -18.31 + 7.15S$; $R^2 = 0.44$, $p = \leq 0.001$. **i** Relationship between Shannon index (H') and biomass (B), according to $B = -28.45 + 34.37H'$; $R^2 = 0.37$, $p = \leq 0.01$

Table 4 Relationships of herbaceous biomass with α-diversity (Shannon index) and its component (species richness) in dry tropical forests of India

Regression models	R^2	Standard error of estimate ($S\hat{y}$)	p
Relationships between species richness (X) and biomass (Y)			
Quadratic	0.44	10.38	0.007
Logarithmic	0.39	10.58	0.003
Power	0.44	10.12	0.001
Linear	0.44	0.93	0.001
Relationships between Shannon index (X) and biomass (Y)			
Quadratic	0.36	10.43	0.007
Logarithmic	0.27	11.19	0.009
Power	0.37	10.37	0.002
Linear	0.37	0.19	0.002

1985; Weltzin and Coughenour 1990). A decline in tree density would reduce the canopy cover and increase the xericness of the habitat. Therefore, strong regulatory measures and protection are required for re-establishment of the depleted tree populations to augment and maintain forest herbs. Apart from protection, seed sowing and planting of field-collected or nursery-raised tree seedlings through aggressive forestry will be required, particularly in the case of severely depleted populations. Systematic fuelwood plantation of fast-growing trees on the village commons for raising high-density short-rotation fuelwood plantation can be a practicable approach to ease the anthropogenic pressure on natural forests (Sagar et al. 2008a; Sagar and Singh 2004, 2005).

Acknowledgments The Ministry of Environment and Forests, Government of India, is acknowledged for financial support. JSS is supported by NASI Senior Scientist Scheme.

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