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Patterns of plant species diversity across Terai landscape in north-eastern Uttar Pradesh, India

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Abstract: The north-eastern Uttar Pradesh forms a part of *Terai* landscape in north India which is drained by two important tributaries of river Ganga *viz*., Rapti and Gandak. This landscape comprises a mosaic of cultivation, human habitation and natural vegetation that has been heavily used by people. The natural vegetation is broadly divisible into four categories *viz.*, grasslands, secondary scrub, old-fields and forests. Of these, the grasslands were the most species-rich followed by forests, secondary scrub and old-fields. A total of 615 species of angiosperms were recorded within an area of ~10,000 km^2 which represent 389 genera and 94 families. Sampling of forested landscape revealed a sizable number of rare species within frequency range of 0.001- 0.1%. These species showed very low seedling abundance and poor regeneration. The overall, landscape level diversity (γ-diversity) of the forested landscape was 4.035, to which shrubs contributed the most. The scrub vegetation was dominated by woody climbers which frequently formed thickets. Diversity of woody perennials was very low in the plantations. The composition and diversity of various grassland communities have been compared with respect to topography and canopy openings reflecting different light regimes. Suitable measures are suggested for the regeneration and conservation of existing pool of wild flora and those of seral communities across the landscape.

Resumen: El nordeste de Uttar Pradesh forma parte del paisaje Terai en el norte de la India, el cual es drenado por dos tributarios importantes del río Ganges: el Rapti y el Gandak. Este paisaje abarca un mosaico de tierras cultivadas, asentamientos humanos y vegetación natural que ha sido utilizada intensamente por la gente. La vegetación natural se puede dividir de manera gruesa en cuatro categorías: pastizales, matorral secundario, campos agrícola abandonados y bosques. De éstas, el pastizal fue el más rico en especies, seguido de los bosques, el matorral secundario y los cambos abandonados. Se registraron en total 615 especies de angiospermas en un área de ~10,000 km^2, las cuales representan 389 géneros y 94 familias. El muestreo del paisaje forestal reveló un número considerable de especies raras dentro del intervalo de frecuencias de 0.001-0.1%. Estas especies mostraron abundancias de plántulas muy bajas y una regeneración pobre. La diversidad general a nivel de paisaje (diversidad γ) del paisaje forestal fue 4.035, a la cual los arbustos hacen la mayor contribución. La vegetación de matorral estuvo dominada por trepadoras leñosas que con frecuencia formaban matorrales cerrados. La diversidad de plantas perennes leñosas fue muy baja en las plantaciones. La composición y la diversidad de varias comunidades de pastizal fueron comparadas respecto a la topografía y aperturas del dosel que reflejan diferentes regímenes de luz. Se sugieren medidas adecuadas para la regeneración y la conservación del conjunto de la flora local y la de las comunidades serales que están presentes en este paisaje.

Resumo: O nordeste de Uttar Pradesh forma uma parte da paisagem do *Terai* no norte da

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Índia e que é drenada por dois grandes tributários do rio Ganga i.e. o Rapti e o Gandak. Esta paisagem compreende um mosaico de culturas, de habitações humanas e vegetação natural que tem sido fortemente utilizada pela população. A vegetação natural é globalmente dividida em quatro categorias *i.e.*, pastagens, vegetação arbustiva secundária, campos antigos e florestas. Destas, as pastagens eram as mais ricas em espécies, seguidas pelas florestas, vegetação arbustiva secundária e campos antigos. Registaram-se 615 espécies de angiospermas no interior de uma área de ~ 10.000 km² representando 389 géneros e 94 famílias. A amostragem da paisagem florestada revelou um número apreciável de espécies raras com uma frequência que oscilou entre os 0,001 e os 0,1 %. Estas espécies mostraram uma abundância de plântulas muito baixa e uma regeneração pobre. Em geral, o nível de diversidade (diversidade γ) na paisagem foi de 4,035 para os quais a maior contribuição foi dos arbustos. A vegetação arbustiva encontrava-se dominada por trepadeiras lenhosas as quais, frequentemente, formam tufos. A diversidade de perenes lenhosas era muito baixa nas plantações. A composição e diversidade das várias comunidades de pastagens foram comparadas em relação à topografia, e à abertura dos copados reflectindo os diferentes regimes de luz. São sugeridas medidas adequadas para a regeneração e conservação do actual fundo de flora selvagem e daquelas comunidades serais ao longo da paisagem.

Key words: Community features, conservation, grassy and forested landscapes, plant diversity, seral habitats, species richness.

Introduction

The *Terai* landscape of north-eastern Uttar Pradesh (UP) constitutes a mosaic of human habitation, cultivation, natural and semi-natural vegetation comprising grasslands and forests. Most of the natural forests have been replaced by plantation of commercially important trees and agriculture. The areas free from human habitation continue to provide microhabitats for an array of native flora. A number of wild plants including those which occupy human-dominated landscape have been in use for various purposes since antiquity. High human density and resultant pressure on plant resources and habitats have pushed many species towards rarity and local extinction. Maintaining patches of natural vegetation within the human dominated landscape is the only way to conserve native flora (Pimm *et al.* 1995). Therefore, landscape level analysis of vegetation becomes vital for assessing the availability of plant resources, patterns of species diversity, and identification of botanical hot spots (Rosenzweig 1999). In order to conserve maximum range of regional biodiversity better understanding of vegetation dynamics at spatio-temporal scale and successional trends would be required (Adler & Lauenroth 2003; Tilman 1999). So far, very few attempts have been made to analyse the patterns of plant species diversity in the human dominated landscape, especially in relation to time scale (Carey *et al.* 2007; White *et al.* 2006).

Analysis of terrestrial vegetation in India was initiated sometimes during 1960's. Misra (1968) revised various methods for the analysis of vegetation and Meher-Homji (1973) analyzed several forest formations. Singh & Yadav (1974) made a comprehensive study on the structure and function of semi-arid grasslands. Ralhan *et al.* (1982) and Singh & Singh (1987) conducted phyto-sociological analysis of forest vegetation in Kumaun Himalaya. Ramakrishnan (1992) compiled most of the studies on the vegetation of agro-ecosystems and natural communities of north-eastern India. Ganesh *et al.* (1996) assessed the plant biodiversity at an undisturbed, mid-elevation evergreen forest of Western Ghats. Despite these attempts, landscape level analysis of vegetation, especially from the Terai region of UP are particularly lacking. A few floristic and community level studies are, however, available from the region (Gupta & Shukla 1991; Pandey & Shukla 1999, 2003, 2005; Tripathi & Shukla 2007; Srivastava 1976). This paper deals with a detailed

analysis of plant species richness, abundance and diversity across different physiognomic units in *Terai* landscape of eastern UP based on qualitative as well as quantitative analysis.

Material and methods

The landscape, climate and vegetation

The study was conducted in the *Terai* landscape of north-eastern UP. This area is characterized by even topography, fine alluvial deposits drained by Rapti and Gandak rivers and high water table. Mean altitude of the study area is 95 m msl. The landscape is frequently intersected by streams and rivulets which run from north-west to south-east direction. Administratively the study area (~10,000 km^2; 27°05' to 27°40' N latitudes and 83°30' to 84°E longitudes) falls in Gorakhpur district of UP state. It is bounded by Nepal in the north and Bihar state of India in the east. The landscape comprises a mosaic of human habitations, agricultural fields, grasslands, commercial plantations and forests. The climate is generally tropical monsoonic with three distinct seasons *viz.*, summer (March to mid June), monsoon (mid June to mid October) and winter (mid October to February). Mean annual rainfall is about 1800 mm, most (> 85%) of which is received during monsoon and rest is distributed sporadically from November to May. Relative humidity ranges between 74 - 87%. The mean minimum and mean maximum temperatures during January and June range between 12 - 27 °C and 24 - 39 °C respectively. The soil of Gorakhpur region is classified as Gangetic alluvium, ranging from clayey to sandy loam in texture with pH ranging from 6.5 to 7.5. In the northern area there are a few elevated mounds, locally called *dhus,* which range in size from a few hundred meters to 4-5 kms and have brown sandy soil.

The natural climax forests of the study area have been classified as Tropical Moist Deciduous

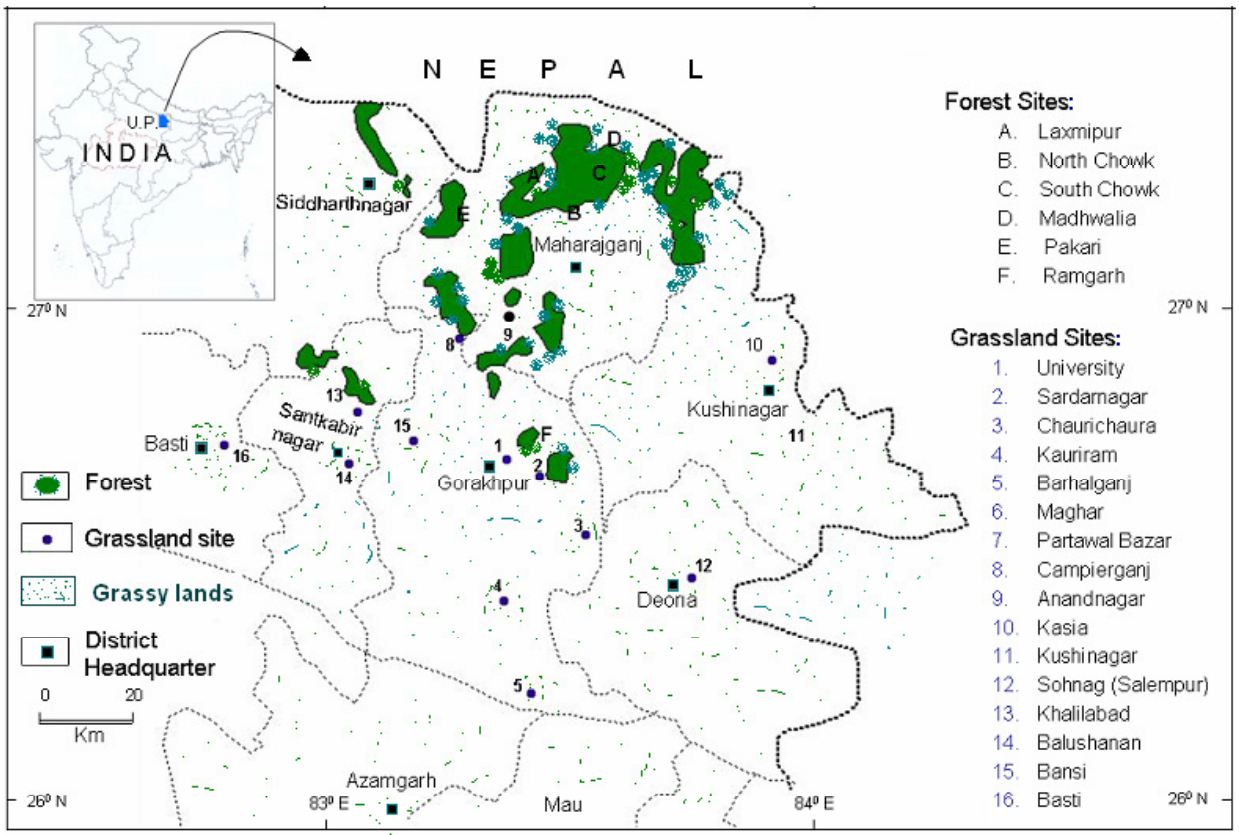

Fig. 1. Vegetation map of north-eastern Uttar Pradesh showing various discrete sites or locations sampled within the forest and grassland vegetations of the region.

and Tropical Semi-evergreen Forests (Champion & Seth 1968). Frequent floods and fire have given rise to a mosaic of early and mid seral stages such as grasslands, secondary scrub and woodlands. Presently, the forest vegetation is confined to the northern ranges (ca. 39,000 ha) only and most of the forests have been converted into agricultural fields, orchards, human habitations and plantations. The older grasslands (*old-fields*) have taken the shape of secondary scrub and woodlands. Most of the plantation forests are dominated by sal (*Shorea robusta*) developed through *taungya* system (Pandey & Shukla 2003), teak (*Tectona grandis*), *Syzygium heyneanum* and *Eucalyptus* species.

Methods

The terrestrial vegetation of the study area was extensively surveyed for more than a decade (1997-2007) to document the patterns of species diversity and characterize various communities at landscape level. Major physiognomic units identified in the area are: forests, woodlands, secondary scrub, grassland, and agricultural fallows (old-fields). Within each physiognomic unit the plant species were enumerated along with their habit, habitat, population size, modes of regeneration and degree of dominance. Grasslands were marked at 16 different sites (Fig. 1) and further stratified into three categories based on moisture regime, *viz.*, dry (xeric), mesic and hydric (hygrophilous). Natural forests and plantations were also stratified according to their maturity (girth class and site history) and degree of anthropogenic disturbance as indicated by cut and damaged trees. The vascular plants in each type were enumerated and identified with the help of local flora (Srivastava 1976). Species were enumerated within random quadrats of 50 x 50 cm for grasslands, 1 x 1 m quadrats for old-fields, and 10 x 10 m for the scrub and forest vegetation. Forested stands (24 in number) were located along the disturbance gradient. Each stand of one ha (100 x 100 m) area was divided into four quarters and each quarter was further subdivided into 25 quadrats of 10 x 10 m (Fig. 2). The trees i.e., individuals ≥ 30 cm girth at breast height (gbh) were enumerated in all the 2400 quadrats but saplings and pole size individuals (< 30 cm gbh) were enumerated in 40 random quadrats within 1 ha stands. The phytosociological parameters such

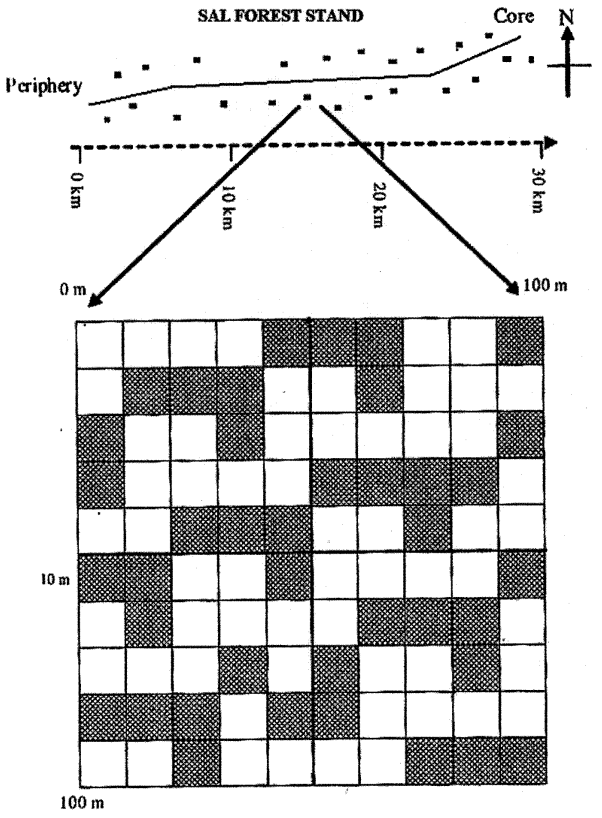

Fig. 2. (above) Detail of the situation of 24 sal stands and 1-ha plots within each stand marked along the side of the transect. (below) 100 grids or quadrats, each of 10 x 10 m^2 within a hectare plot. In each of the four quarters of the plot, which has 25 such grids, 10 random grids or quadrats, identified on the basis of a latin-square design are hatched.

as frequency, density, abundance, canopy cover, basal area and Importance Value Index (IVI) were computed and derived through conventional methods described in Pandey & Shukla (1999, 2001, 2003, 2005). IVI was taken as the sum of relative frequency, relative density and relative basal cover (relative ground cover in case of herbs) where the relative values of frequency, density and cover were derived as the value for a species, expressed as percentage of the sum of the values for all the species of a community (Mueller-Dombois & Ellenberg 1974). The dominance was determined as Simpson's index ($Cd = \Sigma\ pi^2$) and diversity as Shannon's index ($H' = -\ \Sigma\ pi\ ln\ pi$), where, pi represents the proportional abundance of i^{th} species in the community. The degree of Evenness was calculated by Pielou's index (E = H'/

ln S), where, S is the total species richness of the community. Similarly, Beta diversity (β_w), a measure of species turnover with change in habitat (forest community in this case), was computed using the formula $\beta_w = \gamma/\alpha$, where, γ (gamma) = number of species in all the sites, and α (alpha) is the number of species per site or plot (Magurran 1988).

Results

Plant species composition and richness

Four broad physiognomic units of vegetation *viz.*, grasslands, old-fields, secondary scrub and forests varied considerably in terms of species composition and richness. Highest number of angiosperms were recorded in grasslands (375) followed by forests (281), secondary scrub (175) and old-fields (113). In all, 615 species of flowering plants were recorded from the survey area. Detailed break up of growth habits and dominant families across major physiognomic units has been given in Table 1. Species composition in various physiognomic units are given below:

(a) Grasslands

The xeric, mesic and hydric grasslands varied considerably in terms of structure and composition (Table 2). The xeric grasslands are divisible into two types: (i) grassland communities on the mounds and (ii) grasslands in upland plains. The mounds, locally called *dhus,* are characterized by *Brachiaria ramosa, Desmodium triflorum, Gomphrena globosa, Hyptis suaveolens, Saccharum spontaneum* and *Tridax procumbens.* The upland plains are generally used as pasture which abound in leguminous forbs such as species of *Alysicarpus, Desmodium, Indigofera* and *Zornia* along with non-leguminous species e.g., *Boerhaavia diffusa*, *Canscora foetida, Euphorbia hirta, Evolvulus numularis*, *Gomphrena globosa, Polygala chinensis* and *Tridax procumbens.* Among grasses, the more ubiquitous ones were the species of *Bothriochloa, Chrysopogon, Cynodon, Dichanthium, Eragrostis* and *Paspalum.*

The mesic grasslands are broadly divisible into two types: (i) communities in open areas and (ii) shaded communities. The characteristic species of open areas include *Alternanthera sessilis, Bulbostylis barbata, Borreria stricta, Biophytum sensitivum, Caesulia axillaris, Cyperus globosus, Cyperus alulatus, Echinochloa crus-galli, Eclipta prostrata, Polygonum plebjum* and *Rungia pectinata.* Grassland communities in partial or full shade, were dominated by *Oplismenus burmanii* and *Pouzolzia zeylanica* but other species such as *Centella asiatica, Commelina benghalensis, Fleurya interrupta* and *Peperomia pellucida* were less common. A number of common but miniature, ephemeral annual herbs which occupied partially shaded communities were *Lindernia bracheata, L. ciliata, Majus pumilus, Oldenlandia affinis* and *Phyllanthus amarus.*

Table 1. Habitat wise species richness and dominant families across major physiognomic units in north-eastern U.P.

Physiognomic unit	Species richness	HABIT				No. of families represented	Dominant families
		Herbs	Shrubs	Trees	Climbers/lianas		
Grassland	375	311	37	-	27	66	*Poaceae Asteraceae Fabaceae*
Old-fields	113	57	32	-	24	36	*Malvaceae Poaceae Fabaceae*
Secondary scrub	175	46	54	29	46	52	*Fabaceae Euphorbiaceae Poaceae*
Forests	281	39	62	199	65	73	*Fabaceae Euphorbiaceae Rubiaceae*
Total species in the region	615						

Table 2. Sampling effort, number of species and characteristic species across xeric, mesic and hydric grasslands in North-eastern UP.

Grassland type	Sub-types	No. of sites sampled*	Total species encountered	Five characteristic species
Xeric	Xeric-plain (No water-logging)	21	93	*Alysicarpus monolifer* *Gomphrena globosa* *Chrysopogon aciculatus* *Tridax procumbens* *Desmodium triflorum*
	Mound(Dhus)(Nil water-logging)	18	59	*Convolvulus alsinoides* *Perotis indica* *Cyperus* sp. (white spike) *Sida ovata* *Heliotropium strigosum*
Mesic	Open condition (Short water-logging)	44	126	*Alternanthera sessilis* *Eclipta prostrata* *Bulbostylis barbata* *Rungia pectinata* *Echinocloa crusgalii*
	Shaded condition (Short water-logging)	12	77	*Centella asiatica* *Oplismenus burmanii* *Commelina benghalensis* *Pouzolzia zeylanica* *Fleurya interrupta*
	Long water-logging	20	114	*Cyperus iria* *Rumex dentatus* *Plygonum glabrum* *Veronica anagallis-aquatica* *Ranunculus scleratus*
Hydric	Flood Plain (Ephemeral sps.)	20	61	*Companula colorata* *Seseli diffusum* *Cythocline purprrea* *Wahlenbergia marginata* *Potentilla supina*
	Flood Plain (Grass-dominated)	15	59	*Desmostachya bipinnata* *Lippia nodiflora* *Hachelocloa granularis* *Saccharum spontaneum* *Hemarthria compressus*

* 10 quadrats of 1x1 m at each site

The hydric grasslands are further divisible into (i) ephemeral, forb - dominated and (ii) grass-dominated communities. The ephemeral communities develop mostly on freshly deposited sandy soil after receding of floods. Characteristic species include *Cotula anthemoides, Campanula colorata, Cyathocline purpurea, Wahlenbergia marginata, Centipeda minima, Dentella repens, Grangea maderaspatana, Gnaphalium pulvinatum, Polycarpon prostratum* and *Potentilla supina*. The grass-dominated communities, formed along periodically flooded river banks, were characterized by *Desmostachya bipinnata, Hemarthria compressa, Saccharum benghalense* and *Sorghum halepense*. Other angiosperms associated with these grasses were *Ipomoea fistulosa, Lippia nodiflora, Oxystelma secamone* and *Phyla nodosa*.

(b) Old-fields and secondary scrub

The old - fields represent the transitional phase between the grasslands and forests. They are limited in extent. Based on soil moisture they are divisible into two categories i.e., mesic and marshy old-fields. The mesic sites were dominated by a number of herbaceous climbers such as *Antigonon leptopus, Cayratia trifolia, Cissampelos pariera, Ipomoea pes-tigridis, I. nil, I. obscura,*

Trichosanthes cucumerina and a few ruderals, *viz*., *Achyranthes aspera*, *Anisomeles ovata, Cassia tora, C. absus, C. occidentalis, Calotropis procera, Clerodendron viscosum, Croton bonplandianum, Cynoglossum lanceolatum, Datura stramonium, Hyptis suaveolens, Peristrophe bicalyculata, Sida acuta, S. rhombifolia, Triumfetta pentandra* and *Urena lobata.* The characteristic species in the marshy areas were *Ipomoea fistulosa, Phyllanthus reticurlotus, Oxystelma secamone, Phragmites karka*, *Solanum nigrum* and *Vetiveria zizanioides.*

Areas heavily used by the people for fuel wood collection and livestock grazing are dominated by scrub vegetation. The characteristic species are *Croton bonplandianum, Cassia occidentalis, Sida acuta, Leonotis nepetaefolia, Clerodendrum viscosum, Lantana camara, Solanum torvum, Triumfetta pentandra* and *Urena lobata* along with a number of shrubs and undershrubs such as *Barleria cristata, Adhatoda vesica, Alangium suaveolens, Zizyphus mauritiana, Z. oenoplia* and *Flacourtia indica.* A few robust lianas which add to the complexity of scrub vegetation are *Tinospora cordifolia, Teramnus labialis, Thunbergia grandiflora* and *Operculina turpethum*. Species of this habitat which commonly share with old-fields are *Antigonon leptopus, Clitoria ternata, Passiflora foetida, Basella rubra* and *Ipomoea quamoclit*.

(c) The forest formations

The forest formations in the study area are divisible into natural forests and plantations. The natural forests are confined to small patches in remote areas of Pakari, Madhaulia and Nichlaul Ranges. Based on the moisture regime they are further divisible into upland, seasonally inundated and swamp forests. Within 24 ha area a total of 246 species of angiosperms were recorded which include 51 species of trees, 116 species of shrubs including saplings, 15 lianas and 64 herbs and herbaceous climbers (Table 3). Papilionaceae (23 species), Euphorbiaceae (13 species) and Caesalpiniaceae (11 species) contributed maximum to the species richness in the area. Climax forest is dominated by *Shorea robusta* (Dipterocarpaceae) which had highest density and basal area. In the upland forests characteristic species are *Alstonia scholaris, Bischofia javanica, Cordia dichotoma, Careya arborea, Lagerstroemia parviflora*, *Mangifera indica, Pterocarpus marsupium, Sterculia alata, Terminalia alata* and *Terminalia bellerica.* The characteristic species of seasonally inundated forests are *Acacia catechu, Aegle marmelos, Bauhinia malabarica, Ficus* spp., *Grewia asiatica, Kydia calycina, Mallotus philippensis, Morus indica* and *Semicarpus anacardium.* The swamp forests face perpetual water-logging and get dominated by *Barringtonia acutangula, Syzygium heyneanum* and *Trewia nudiflora* and climbers such as *Smilax macrophylla, S. prolifera, Rosa involucrata* and a rattan (*Calamus tenuis*).

The plantation forests mainly include plantations of sal and teak. The sal plantations have been developed through *taungya* system over much larger area covering slightly inundated to upland sites. Teak plantations cover relatively smaller areas and have been planted exclusively on the upland sites. Their understorey is often depauperate in terms of species richness and vegetal cover. Other species planted in the region are jamun (*Syzygium heyneanum*), kadamb *(Anthocephalus cadamba),* shisham *(Dalbergia sissoo),* arjun (*Terminalia arjuna),* bhelar (*Trewia nudiflora)* and eucalyptus (*Eucalyptus globulus).*

Table 3. Sum of the values of different phytosociological indices for species under different habit groups of regional forest and for the whole of the abstract community of regional forested landscape.

Habit Groups	Species Richness	Relative Density	No. of individuals ha^{-1}	Basal Area ($m^2 ha^{-1}$)	IVI
Trees (> 30 cm gbh)	51	1.3	624	35.45	113.5
Shrubby individuals (< 30 cm gbh)	116	59.0	28,291	0.87	119.0
Woody climbers	15	5.0	2,400	0.05	28.0
Herbs and herbaceous climbers	64	34.7	16,641	0.03	39.5
Regional forested Landscape	246	100	47,956	36.40	300

Species diversity and abundance

Of the nine forest communities, natural sal and mixed forest had highest species diversity (H'= 3.36 and 3.16 respectively). *Eucalyptus* plantation was poorest in species diversity (H'=2.28). Diversity of trees, shrubs, climbers and herbs across various forest communities, total diversity within and across the communities have been compared in Table 4. Shrubs contributed maximum to the values of H' for mixed forest followed by sal stands. Lianas also showed quite high diversity in sal stands and mixed forest communities as compared to minor plantation forests. The H' for the regional forested landscape was calculated to be 4.035. β-diversity, a measure of species turnover, showed a pattern inverse to that of α-diversity.

Within grasslands highest richness was exhibited by erect herbaceous annuals. Climbers contributed the least to the overall species richness, density, diversity and dominance. The grasslands as a whole showed high diversity (H' = 4.0) with maximum contribution of erect annual herbs. Majority of grassland species fell under the frequency range of 0.1-10%. Species showing fortuitous occurrence, however, were much more in number as compared to the species of common occurrence. While *Perotis indica*, *Evolvulus alsinoides, Alysicarpus monilifer* and *Desmodium triflorum* occurred only in upland habitats, *Eclipta prostrata, Rungia pectinata* and *Alternanthera sessilis*, were present mainly in exposed mesic habitats. *Centella asiatica, Fleurya interrupta* and *Oplismenus burmanii* occurred only in shaded mesic habitats. The sum values of frequency, density, percent vegetal cover and IVI were more evenly distributed among species which occupied the grazed or natural grassland patches as compared to regularly clipped or managed patches. The contribution of rare species to the above values was, however, quite comparable between the two types of patches.

Patterns of Rarity and Regeneration

Careya arborea, Oroxylum indicum, Clerodendrum indicum, Gloriosa superba, Careya herbacea, Combretum nanum, Cleome rutidosperma and *Potentilla supina* were adjudged as most rare species (Table 5). Some of the tree species commonly found in protected areas of terai *viz*., *Diospyros melanoxylon, Kydia calycina, Ougenia oojeinensis, Pterocarpus marsupium, Pterospermun acerifolium,* and *Bombax cieba* had very low frequency (<1%) in this area. *Rauvolfia serpentina* and *Withania somnifera,* the two high value medicinal shrubs were also encountered only once. *Clerodendrum viscosum, Croton oblongifolius* and *Mallotus philippensis* were common in the disturbed forests due to their efficient sprouting and capacity to produce ramets rapidly. Species of *Asparagus, Costus, Curculigo, Elephantopus, Leea* and *Typhonium* perpetuated even in highly stochastic environment as they have deep underground storage. As expected, patterns of rarity and regeneration among various species are indicative of their ability to reproduce and

Table 4. Sum of pi ln pi for species under different habit groups contributing to the Shanon's diversity index (H') of different concrete communities (α-diversity) as well to the γ-diversity of the regional forest landscape. Beta-diversity for different stands has also been given.

Forest communities	Sum of *pi ln pi* for different habit groups contributing to H' value of different forest communities				α-diversity	β-diversity
	Trees	Shrubs	Lianas	Herbs		
Mixed - Forest	0.049	1.745	0.274	1.099	3.167	1.274
Sal - stand	0.193	1.594	0.328	1.245	3.360	1.201
Teak - stand	0.322	0.531	0.083	1.830	2.766	1.459
Sal + Teak stand	0.071	1.731	0.147	1.085	3.034	1.330
Eugenia- stand	0.013	0.742	0.077	2.355	3.187	1.266
Anthocephalus - stand	0.091	0.713	0.038	1.656	2.498	1.615
Eucalyptus - stand	0.124	1.572	0.015	0.573	2.284	1.767
Trewia - stand	0.051	0.355	0.019	1.927	2.352	1.716
Terminalia - stand	0.028	0.404	0.098	2.396	2.926	1.379
Regional forested landscape	0.106	1.725	0.280	1.924	4.035 (γ-diversity)	

establish efficiently in frequently disturbed environment. A comparison of modes of non-seed regeneration among the perennial species in the area shows that 123 species were low sprouters, 41 were moderate sprouters (producing up to 5 sprouts per plant) and only a few species were highly efficient in terms of sprout / coppice production. Sixteen species had storage roots while 22 species regenerated through ramets. As many as 45.5% of total individuals in the forest were of ramet origin but belonged only to 10.6% species of the forest (Fig. 3).

Discussion

The grasslands in the study area have much higher species richness as comparted to the forests. One of the reasons for higher species

Table 5. List of some most rare and most common plant species within the regional forested landscape.

Species showing most rare occurrence[1]	Species showing most common occurrence[2]
Trees	
Careya arborea Roxb.	*Adina cordifolia* Roxb.
Dillenia indica Roxb.	*Alstonia scholaris* Linn.
Ehretia laevis Linn.	*Bridelia retusa* Hook.f.
Ougenia dalbergioides Benth.	*Cassia nodosa* Buchnan
Oroxylum indicum	*Cordia dichotoma* Forst.f.
Pterospermum acerifolium Wild.	*Mallotus philippensis* Muell.Arg.
Pterocarpus marsupium Roxb.	*Mitragyna parviflora* Roxb.
Sterculia alata	*Semicarpus anacardium* Linn.
Stereospermum suaveolens DC.	*Terminalia alata* W&A
Terminalia chebula Retz.	
Shrubs/Undershrubs	
Clerodendrum indicum Kuntz.	*Carissa spinarum* Linn.
Desmodium triangulare Retz.	*Clerodendrum viscosum* Auct.
Desmodium latifolium DC.	*Desmodium gangaticum* (L) DC.
Helectres isora	*Desmodium pulchellum* (L.) Benth.
Leea macrophylla Roxb.	*Moghania chappar* Ham. Ex. Kutze.
Woody Climbers	
Aristolochia indica Linn.	*Ampelocissus latifolia* Roxb.
Butea parviflora Roxb.	*Cayratia trifolia*
Dioscorea pentaphylla	*Cissampelos pareira* Linn.
Entada sp.	*Dioscorea bulbifera*
Gloriosa superba Linn.	*Dioscorea oppositifolia* Linn.
Narvelia zeylanica DC	*Hemidesmus indicus* Linn.
Stephania japonica Thunb.	*Ichnocarpus frutescens* Prb.
Perennial Herbs	
Bacopa monerii Linn.	*Aerva lanata* Linn.
Careya herbacea	*Centella asiatica* Linn.
Knoxia corymbosa	*Costus speciosus* Smith.
Trichodesma sedgwikianum Rbr.	*Curculigo orchioides*
Sejusbeckia sp.	*Elephantopus scaber* Linn.

[1]The species which occurred only in one or two quadrats

[2]The species which occurred in most of the quadrats, laid within the forest vegetation.

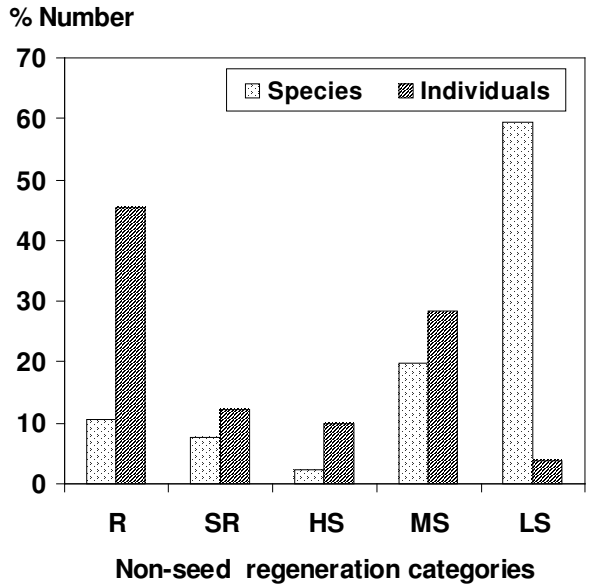

Fig. 3. Bar-diagrams showing the proportion of species and proportion of individuals grouped under three different modes of non-seed regeneration, R- ramet producing roots; SR- storage roots; HS- high sprouting; MS- moderate sprouting; LS- least-sprouting.

diversity in the grasslands could be variation in micro-habitat features and occurrence of several associations. Based on the dominance of species as many as 9 distinct associations of grasses were discernible within the grasslands of the study area. These are: *Cynodon-Paspalum, Bothriochloa -Dichanthium, Cynodon-Bothriochloa-Dichanthium, Chrysopogon-Eragrostis, Heteropogon-Sporobolus, Dichanthium-Arundo donax, Desmostachya-Saccharum spontaneum, Themeda-Coix* and *Phragmites-Saccharum-Imperata.* The first four associations represent short grasslands with maximum herbage in prostrate forms. The *Heteropogon-Sporobolus* and *Dichanthium-Arundo* associations showed some vertical growth in the form of long and linear inflorescences. The last three associations of tall grasses occupied significant aerial environment due to their elaborate foliage and long culms. Mathur *et al.* (2003) also reported similar trends in the protected grasslands of Dudhwa National Park in *Terai* area of UP. These authors reported that the richness of herbaceous species in the grasslands of *Terai* was almost three times higher than that of forests. In a similar study in the grasslands of Chitawan National Park, Lehmkuhl (1989) identified ten grassland associations which correspond more or less with the associations identified in the present study. Thus, the *Terai* landscapes represent much diverse assemblages and associations as compared to semi-arid and other tracts of India (Dabadghao & Shankarnarayan 1973; Pandeya 1964). Singh & Joshi (1979) opined that higher number of grassland associations in hygrophilous grasslands can be due to different intensities of anthropogenic disturbances and local variations in topography and soil depth. Communities found on elevated mounds or *'dhus*' represent unique features in the present study. Such areas, despite heavy livestock grazing, support much diverse assemblages of grasses and palatable herbs (forbs). Forbs have been reported to respond more positively to disturbance (Belsky 1992) and the multiple reproductive strategy is a known prerequisite for the dominance of a species over an area (Harper & White 1974; Patrica *et al.* 2002).

The forests and grasslands had very little similarity in terms of species (< 40%) which is attributed to drastic differences in habitat conditions. However, forests and scrub had much higher commonality. The occurrence of true forest elements in the secondary scrub or old-field vegetation may be due to ability of certain shrubs to coppice and persist through root suckers after clearing of forests. Examples of such species include *Croton oblongifolia, Holarrhena antidysenterica* and *Kirganelia reticulata.* Unlike Western UP and semi-arid regions of India, an alien invasive species *Lantana camara* has not dominated the landscape so far, though it has started replacing *Clerodendrum viscosum* and *Parthenium hysterophorus* at some sites.

The old–fields were marked by richness of woody perennials similar to several other tropical grasslands (Brown 1997). In essence, they are unmanaged pastures, inviting a number of wild herbivores and adding diversity to the landscape. Such communities harbour a number of large shrubs and undershrubs belonging to Acanthaceae, Lamiaceae and Malvaceae which provide certain degree of protection to minor palatable herbs and facilitate the emergence of seedlings of several tall woody perennials. In tropical pastures, new trees may emerge from residual seed bank or from seed dispersal and/or from sprouts arising from roots and stems (Archer 1995). Moderately disturbed stands adjacent to

forests had higher proportion of woody elements and low abundance of herbs. Such sites represented transition phase between old-field and mature forest and resembled young forest physiognomically in terms of preponderance of a few fast growing herbs, shrubs, tree saplings and climbers. This type of composition was quite common in scrub vegetation which abounded in shade-intolerant elements including lianas. Their vigorous growth resulted into an entangled mass of vegetation (thicket) under which some of the rare species could be found. Such thickets, however, were more common at moist sites and play significant role in species conservation (Pandey & Shukla 2003).

The forest vegetation in the region also showed a considerable plant diversity. A number of factors including available moisture, soil-type, exposure and disturbance are known to influence the relative abundance of species in the forested habitat (Archer 1995; Walker 1992). Hubbell (1979) showed through simulation that a more mature and balanced forest community with a log-normal type of dominance-diversity relation is driven back to geometric type through repeated disturbance. Many of the models which explain the patterns of diversity change agree that intermediate disturbance levels maintain diversity. While the moderate disturbance promotes a non-equilibrium species-rich system, the high disturbance interferes with the proper vegetative growth, successful flowering and fruiting of the species, thus pushing them towards rarity (Pandey & Shukla 1999). Tiwari & Shukla (1995) have attempted to document the neighbourhood interaction and community structure in the region. Patterns of rarity and abundance among several species in this landscape are also reflective of autogenic as well as allogenic changes. For example, a few grassland and old-field species such as *Cassia absus, C. pumila, Tribulus terrestris* and *Martynia annua* have been replaced completely in many localities due to successional changes. *Basella rubra, Ipomoea nil, Operculina turpethum* and *Thunbergia grandiflora* which were quite frequent in scrub vegetation during 1997-98, have now been taken over by other woody elements. This landscape continues to harbour as many as 20 species of medicinal plants which have been listed in the high conservation priority species by the National Medicinal Plants Board (Haridasan 2006). This study underlines the significance of long term monitoring of habitats and population dynamics of various species including those which had very low frequency (< 0.001%) such as *Careya herbacea, Clerodendrum indicum, Combretum nanum, Gmelina asiatica* and *Pterocarpus marsupium.*

Conclusions

Extensive eco-floristic studies conducted in the *Terai* landscape of eastern UP during past 10 years have resulted in the analysis of regional floral diversity and documentation of vegetation structure and composition across major physiognomic types. The study reveals that grasslands had much higher species diversity as compared to forests. Natural sal and mixed forests had higher species diversity than plantations and other forest types. Most of the rare and threatened species were confined to forest edges and scrub vegetation. Continued monitoring of various physiognomic units and quantitative information on the response of threatened species to autogenic as well as allogenic changes are required to understand the ecology of this ecosystem.

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