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Commonness and rarity pattern of plant species within *Terai* grassland of northeastern Uttar Pradesh, India

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Abstract

We investigated the frequency of occurrence of plant species in grassy landscapes in northeastern Uttar Pradesh, India. Using random quadrats, field assessment was undertaken at 11 sites to sample an area of 333.75 ha, at an overall sampling density of 0.01%. A total of 287 plant species belonging to 183 genera and 53 families was recorded. Of these, 254 species were commonly distributed and 33 species exhibited localized occurrences; according to the rarity classes of Rabinowitz, the latter were classified as rare. One hundred and sixty-five species had large population sizes and 122 species exhibited small population sizes. The most common species, which exhibited high frequency and abundance, were predominantly from Poaceae, Cyperaceae, Papilionaceae, Asteraceae, Scrophulariaceae and Euphorbiaceae. Some species, which are known to have narrow geographical distributions, were locally abundant. Rare species showed restricted as well as localized distributions and were typically sampled at low population densities. The rare occurrences of once frequent and widespread species probably reflect acute fragmentation and shrinkage of specialized habitats as a result of intense cultural activities. Several species are to be considered as threatened. Studies on the status of rare plant species and the processes threatening their survival are urgently required.

Resumen

En ecosistemas de pastizales nativos en el noreste de Uttar Pradesh, India, se midió la frecuencia de aparición de especies vegetales. Las muestras fueron tomadas utilizando el método de cuadrados al azar en 11 sitios de estudio con 31 sitios de muestreo. El área total muestreada fue de 333.75 ha, con una densidad total de muestreo del 0.01%. En total se registraron 287 especies pertenecientes a 183 géneros y 53 familias. De éstas, 254 especies tenían una distribución común mientras 33 especies aparecían con baja frecuencia y en forma localizada; según las clases de rareza de Rabinowitz; estas últimas fueron clasificadas como raras. En poblaciones grandes ocurrieron 165 especies y en poblaciones pequeñas 122 especies. Las especies más comunes, con alta frecuencia y abundancia, fueron predominantemente de las familias Poaceae, Cyperaceae, Papilionaceae, Asteraceae, Scrophulariaceae y Euphorbiaceae. Algunas especies con una distribución geográfica reducida eran localmente abundantes. Especies clasificadas como raras presentaron tanto distribuciones restringidas como localizadas y en general ocurrían a bajas densidades poblacionales. Las ocurrencias raras de especies que antes eran frecuentes y de distribución amplia, probablemente reflejan una aguda fragmentación y reducción de los hábitats especializados, como consecuencia de intensas actividades agrícolas. Varias especies deben considerarse amenazadas y se sugieren estudios sobre los procesos que amenazan su supervivencia.

Introduction

The structure of plant communities has been conventionally analyzed worldwide (Mueller-Dombois and Ellenberg 1974; Singh and Yadava 1974). The impact of disturbance, described by Pickett and Whyte (1985) as a discrete event along the passage of time that modifies landscape, ecosystem, community and population structure, on the structure and composition of various grassland communities has been observed by various workers (Friedel 1997; Wilsey and Polley 2003), with overexploitation of species and degradation of natural habitats reported to be the major threats to plant species. While excessive removal of plants from the wild, loss of habitat by deforestation and heavy grazing pressure in

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pastures generally threaten the survival of species (Nayar and Sastry 1988), habitat specificity, narrow range of distribution, land use change, introduction of non-native species, habitat fragmentation and degradation of populations, population bottlenecks and genetic drift can also play a part (Weekley and Race 2001; Oostermeijer et al. 2003; Kala 2005).

Many authors have identified and classified the common and rare species of trees and shrubs (Hubbell and Foster 1986; Rabinowitz et al. 1986; Pitman et al. 1999) and emphasized the importance of this process for the conservation of biodiversity in the ecosystem. Information about the frequency of herbaceous plant species, however, is scarce. Daniels et al. (1995) suggested that endemism, elevation, vegetation, habitat and microhabitat specialization influence the relative abundance of plant species, while Pitman et al. (1999) suggest that herbaceous species have smaller geographical ranges than trees. Recently, Magurran and Henderson (2003) and Ulrich and Ollik (2004) proposed the use of composite models to study species abundance to improve ecological understanding of community structuring between common and rare species and predicted high rates of local extinction of rare species.

While a number of workers have studied various phyto-sociological characteristics of grassland communities in different parts of India (Bharucha and Ferreria 1941; Gupta and Sharma 1973) as well as community composition and productivity patterns (Dabadghao and Shankarnarayan 1973; Singh and Yadava 1974; Nautiyal et al. 1997), the so-called *Terai* grasslands of the plains of northeastern Uttar Pradesh (U.P.) have received little attention, especially in terms of diversity patterns and the loss and gain of species in recent times. They are a very important source of fodder for livestock and represent about 1,280 km^2 of the total regional area (Semwal 2005).

The present study was conducted to examine the composition, diversity and frequency patterns of plant species in the regional grassy landscape across the tract between the Sarju River and the foothills of the Himalayas. This region is known to be floristically rich with considerable habitat diversity (Ansari et al. 2006). The empirical relationship between microclimatic conditions of various sites and diversity patterns of respective plant communities was analyzed. The patterns of rarity within the regional flora have been described by using the database of rare species in India as well as the world (Rabinowitz 1981; Rabinowitz et al. 1986; IUCN 2001) in order to emphasize the need to conserve grassland vegetation and their species.

Materials and Methods

Study area

The *Terai* region is a belt of marshy grasslands, savannas, and forests located south of the outer Himalaya foothills, the Siwalik Hills, and north of the Indo-Gangetic Plain. These plains of northeastern Uttar Pradesh (U.P.) cover 14 districts and occupy 45,760 km^2. While the climax vegetation is forest and some patches of forest still remain, most of the area has been subjected to recurrent disturbance in the form of clearing, grazing, trampling and burning, resulting in agricultural fields and grassy landscapes, with many rivers, rivulets, nallahs, lakes and ponds. Abandoned arable land reverts to grassland as a result of secondary succession and tends to be stable under the influence of biotic disturbances such as fire, grazing and cutting practices. The regional plain slopes gently from northwest to southeast, and the landscape presents a mosaic of plant communities with varying amounts of grasses and forbs of contrasting life-forms. Composition of the grasslands, developed and maintained by various cultural practices, varies primarily according to the type of soil and available moisture within the upper layer.

Climate

The climate of the region is typically tropical monsoonal with 3 distinct seasons, viz. summer (March to mid-June), monsoon (mid-June to mid-October) and winter (mid-October to February). Average annual rainfall is about 1,814 mm for the entire study region, with 87% occurring during the wet summer and monsoon seasons. The number of rainy days per annum is 51 ± 3.2 and mean relative humidity is about 87% in the morning and 74% in the evening. The eastern *Terai* plains receive more rainfall over a longer period and possess much richer plant biodiversity than western and southern districts of the state. Mean maximum temperatures during wet summer, winter and dry summer seasons are 35.2, 27.0 and 39.3 ^{o}C and mean minimum temperatures are 26.2, 12.1 and 24.2 ^{o}C, respectively (based on climatic data for 2000–2005).

Soil

The soil of the region is part of the trans-Sarju Plain and comprises Gangetic alluvium brought down by rivers like Ghaghara, Rapti, Rohin and Gandak from the Himalayas in the north. The texture is sandy loam and pH is about neutral. In the northern area there are a few elevat-

ed mounds, locally called *dhus*, which range in size from a few hundred m^2 to 4–5 km^2 and have brown sandy soil.

Vegetation

The growing season extends from mid-June to mid-September, when most species flower and set seed. The general grassland vegetation of northeastern Uttar Pradesh is interspersed with patches of forest, old fields, open pasture, uplands (mounds or *dhus*), lowlands, orchards, playgrounds and human settlements.

Methods

We started this study in June 2011 with a general survey of the vegetation and habitat conditions over a vast stretch of grassy landscape of *Terai* of northeastern Uttar Pradesh, encompassing more than 11 districts and covering about 128,076 ha of a total 36,015 km^2 geographical area (Figure 1). Finally, 31 locations, showing marked differences in habitat conditions, were selected and sampled during August 2011 to March 2014 (Annexes Ia and Ib). Differences in habitat conditions appeared mainly in the degree of light exposure, soil moisture and soil texture as related to topography and disturbance in the form of fire, grazing, cutting and trampling. Twenty 50 x 50 cm quadrats were randomly laid out at each location, giving a total of 620 quadrats across 333 ha of the region.

The population densities of species occupying each quadrat were recorded, and total vegetal area of individuals of each species was measured through the chart-quadrat method. Based on these values, various phyto-sociological and diversity indices were derived through conventional methods (Mueller-Dombois and Ellenberg 1974; Magurran 2004). The simple indices were: frequency, density, vegetative cover, their relative values and *Importance Value Index* (IVI). Several other indices like *Simpson's Dominance Index* ($Cd = \sum p_i^2$), *Shannon's Diversity Index* ($\bar{H} = -\sum p_i \ln p_i$), *Pielou's Evenness Index* ($E = \bar{H}/ln\ S$), *Abundance:Frequency Ratio* (Withford 1948) and *Family Importance Value* (FIV = relative density + relative diversity + relative vegetative cover) were also derived (Mori et al. 1983) (p_i represents the proportional abundance of the *i*th species in the community; S is the species richness; relative diversity of a family is the number of species within the family expressed as a percentage of the total number of species within all families represented in the community). The dominance-diversity curve (species-individual curves or rank-abundance model) was plotted as a log normal distribution model (Magurran 1988).

Figure 1: Map showing the study sites and sampling locations (1−31) in the *Terai* grasslands, northeastern Uttar Pradesh, India.

Identification of common and rare species

Rabinowitz's classification scheme (Rabinowitz 1981; Rabinowitz et al. 1986) was used to categorize each of the threatened taxa into 1 of 7 types. They were defined on the basis of the size of their geographic range (wide vs. narrow), habitat specificity (broad vs. restricted) and population size (large, dominant vs. small, scattered). From the combination of these traits, 8 categories were formed to decide commonness vs. rarity of a given species (Tables 1 and 2). For all species one or more of the following 10 items was allocated as a threat to their survival: 1. urbanization and land development; 2. agricultural activities; 3. logging and associated harvest activities; 4. mining and associated habitat destruction; 5. livestock grazing, especially unsustainable and inappropriate grazing; 6. trampling for recreation, resulting in deleterious changes in community composition; 7. overharvesting for horticultural use; 8. excessive collection for various purposes like medicine; 9. natural disasters such as catastrophic floods and other less-common or miscellaneous threats like fodder, thatch collection etc.; and 10. invasion by alien species (Srivastava et al. 2014).

Results

The grassy landscape of northeastern Uttar Pradesh is represented by contiguous, small to fairly large patches of grassland vegetation ranging from 1 ha to around 80 ha in size.

Composition of taxa

The grassland ground-layer vegetation was comprised of grasses and sedges, collectively referred to as graminoids, and forbs or non-grass herbs. A total of 287 species was recorded, belonging to 183 genera and 53 families; among them, 27 species and 5 families have not yet been identified. Dicotyledons made up 94.5% of families, 74.1% of genera and 69.7% of species, while the remainder were monocotyledons.

Habit groups

The life-span data of different grassland species showed that about 90% of species were annuals and the remainder were perennials. The percentage of plant species in different habit groups was: herbs 87%, climbers 10% and shrubs 3%. Most species (>61%) were erect annuals, 29% were prostrate annuals and the remainder were perennials. Among climbers, 39% were annual twiners, 32% tendril-bearing and 29% perennial twiners. There was fairly high species diversity (H = 3.74) and quite low dominance (Cd = 0.058). The mean number of species per genus was 1.62, with 5.42 per family. The total density was 811.5 individuals/m^2 and evenness was 0.661.

Species richness

Among the 6 dominant families, Poaceae was the most common (17.2% of species), followed by Cyperaceae (11.2%), Papilionaceae (10.5%), Asteraceae (9.8%), Scrophulariaceae (4.9%) and Euphorbiaceae (3.5%). The remaining 44% of species represented 46 families, with 20 families represented by only 1 species, 3 by 2 species, 2 by 3 species, 8 by 4 species, 2 by 5 species, 1 by 6 species, 2 by 7 species, 2 by 9 species and 6 families by more than 10 species. In terms of genera, Poaceae, Asteraceae and Papilionaceae were dominant and were represented by 38, 19 and 16 genera, respectively.

Table 1. Rarity of plant species based on geographic range, habitat specificity and local population size (after Rabinowitz 1981).

Geographic range	Wide		Narrow	
Habitat specificity	Broad	Restricted	Broad	Restricted
Abundance somewhere, large population	Common	Predictable	Unlikely	Endemics
Abundance everywhere, small population	Sparse		Non-existent	

Table 2. Trait combinations for commonness/rarity of regional rare taxa.

1	Wide geographic range, broad habitat specificity, large population size
2	Wide geographic range, broad habitat specificity, small population size
3	Wide geographic range, restricted habitat specificity, large population size
4	Wide geographic range, restricted habitat specificity, small population size
5	Narrow geographic range, broad habitat specificity, large population size
6	Narrow geographic range, broad habitat specificity, small population size
7	Narrow geographic range, restricted habitat specificity, large population size
8	Narrow geographic range, restricted habitat specificity, small population size

The distribution of common and rare plant species among major families (Figure 2) shows that the foremost families in the regional grasslands shared the maximum number of rare plant species. For instance, Papilionaceae had 5 species, followed by Poaceae and Asteraceae (4 species each) and Lamiaceae with 3 species. Scrophulariaceae, Caesalpiniaceae and Boraginaceae families were represented by 2 species each and 12 families by a single species only. The family Apiaceae is economically and medicinally very important but contains the least number of species in the region. Four families, Lobeliaceae, Martyniaceae, Sphenocleaceae and Zygophyllaceae, had only 1 genus each with a single species, viz. *Lobelia alsinoides, Martynia annua, Sphenoclea zeylanica* and *Tribulus terrestris,* respectively. The local extinction of these very rare species would mean that the family would no longer be represented in this region.

Abundance distribution

Abundance is a quantitative indication of patchiness of species. Several common herbaceous species showed hyper-dispersion across grassland vegetation as evident from their density and abundance values. *Lindernia diffusa* had maximum average density and abundance. Species like *Desmodium triflorum, Evolvulus nummularis, Imperata cylindrica, Lindernia ciliata* and *Rungia repens* showed abundance values of >20 (Table 3).

The abundance:frequency (A:F) ratio provides a useful measure to show the degree of clumping or patchiness of species in restricted or localized areas. Table 4 shows the pattern of distribution of grassland species on the basis of A:F ratio, which was highest for erect annual herbs, followed by prostrate annual herbs, with the lowest value for prostrate perennial herbs. The erect annual

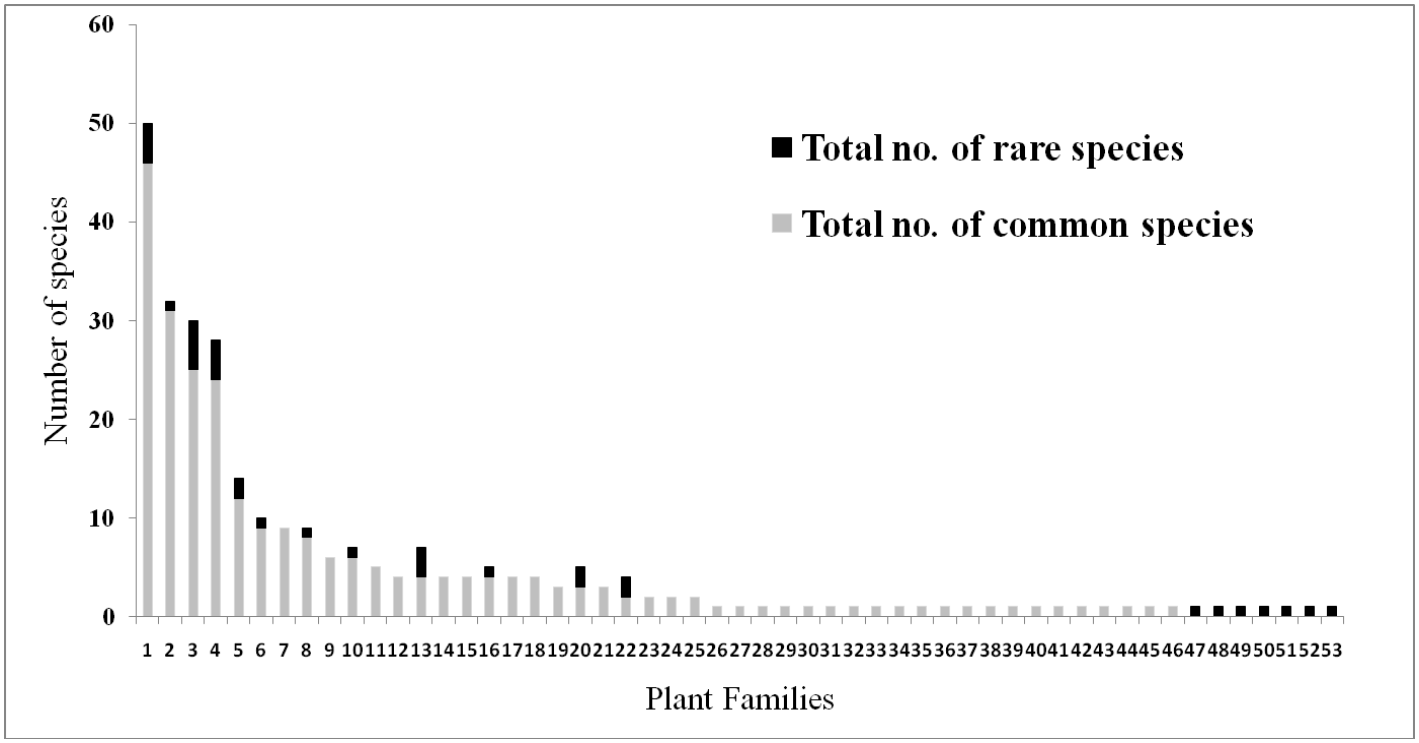

Figure 2. Distribution of plant species among different families of regional grassland vegetation in Uttar Pradesh. The sequence of families is in decreasing order of their species richness. 1. Poaceae, 2. Cyperaceae, 3. Papilionaceae, 4. Asteraceae, 5. Scrophulariaceae, 6. Euphorbiaceae, 7. Malvaceae, 8. Amaranthaceae, 9. Acanthaceae, 10. Convolvulaceae, 11. Unknown, 12. Cucurbitaceae, 13. Lamiaceae, 14. Onagraceae, 15. Polygonaceae, 16. Rubiaceae, 17. Tiliaceae, 18. Verbenaceae, 19. Asclepiadaceae, 20. Caesalpiniaceae, 21. Menispermaceae, 22. Boraginaceae, 23. Cuscutaceae, 24. Lythraceae, 25. Molluginaceae, 26. Aizoaceae, 27. Apocynaceae, 28. Basellaceae, 29. Bignoniaceae, 30. Cannabinaceae, 31. Capparidaceae, 32. Chenopodiaceae, 33. Commelinaceae, 34. Fumariaceae, 35. Moraceae, 36. Nyctanginaceae, 37. Oxalidaceae, 38. Papaveraceae, 39. Polygalaceae, 40. Portulacaceae, 41. Primulaceae, 42. Ranunculaceae, 43. Solanaceae, 44. Sterculiaceae, 45. Urticaceae, 46.Vitaceae, 47. Amaryllidaceae, 48. Apiaceae, 49. Lobeliaceae, 50. Martyniaceae, 51. Sphenocleaceae, 52. Violaceae, 53. Zygophyllaceae.

Table 3. Species showing maximum aggregation and hyper-dispersion (as evident from their density and abundance values) across the grassy landscape of northeastern Uttar Pradesh. (Based on 620 quadrats each of 0.25 m^2 size, laid across 11 districts.)

Species	Density	Abundance
Desmodium triflorum	58.2	20.5
Evolvulus nummularis	50.4	22.2
Imperata cylindrica	19.6	28.9
Lindernia ciliata	56.5	31.7
Lindernia diffusa	143.8	60.7
Rungia repens	62.6	28.8

Table 4. The range of abundance:frequency (A:F) ratio for species in different posture or growth habit groups across the grassy landscape of northeastern Uttar Pradesh.

Posture/Habit	Range of A:F ratio
Herbs	
Erect annuals	18.6–0.05
Prostrate annuals	17.2–0.20
Erect perennials	2.33–0.22
Prostrate perennials	0.90–0.14
Climbers	
Tendril annuals	3.37–0.59
Twining annuals	6.2–0.53
Twining perennials	6.2–0.27
Shrubs	
Erect annuals	2.23–0.16
Erect perennials	1.94–0.18

herbaceous species with A:F>10 were *Hemarthria compressa, Fimbristylis dichotoma, Cynoglossum lanceolatum* and *Zephyranthus citrina.* The lowest A:F ratio was shown by *Euphorbia hirta*.

Dominance-diversity curve

The dominance-diversity curves for the regional grassy landscape as an abstract community showed a log-normal distribution of individuals among constituent species (Figure 3). *Lindernia diffusa, Rungia repens, Desmodium triflorum* and *Lindernia ciliata,* had the highest number of individuals and formed the top end of the curve. On the other hand, the species which formed the tail end of the curve were *Amaranthus spinosus, Crotalaria retusa, Crotalaria pallida, Ludwigia adscendens* and *Solanum virginianum.* The latter species obviously showed rare occurrences.

Population status

Common species have a large range, wide habitat specificity and large populations. However, a few species have a large range and occur in a wide array of habitats, but in chronically small populations, and are considered quite rare (Rabinowitz et al. 1986). In our observations, a number of plant species, which had a large range and wide habitat specificity, apparently showed small populations due to sampling limitations. As these species

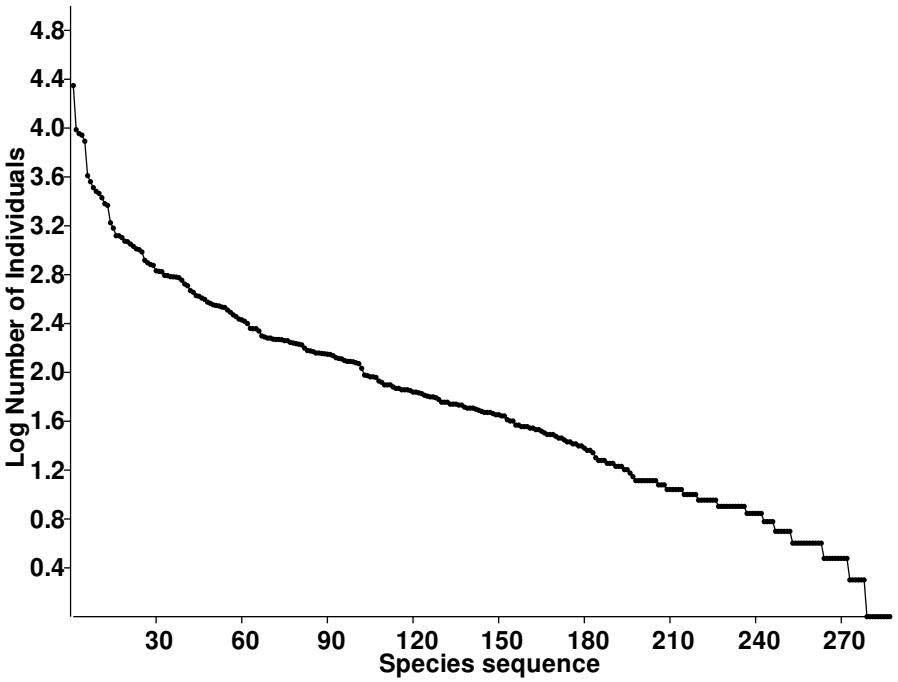

Figure 3. Rank-abundance model (dominance-diversity curve) of the grassy landscape of northeastern Uttar Pradesh.

Table 5. Number and status of rare and common plant species with different trait combinations across the grassy landscape vegetation of northeastern Uttar Pradesh.

Trait combinations	No.	Species	Status
Wide geographic range, broad habitat specificity, large population size	150	*Cynodon dactylon, Desmodium triflorum, Evolvulus nummularis, Imperata cylindrica, Lindernia ciliata, Lindernia diffusa, Rungia repens* and 143 more species	Common
Wide geographic range, broad habitat specificity, small population size	104	*Glinus oppositifolius, Dentella repens, Crotalaria prostrata, Blumea lacera, Ammania baccifera*, *Cissampelos pariera* and 98 more species	Common
Wide geographic range, restricted habitat specificity, large population size	2	*Centella asiatica, Evolvulus alsinoides*	Rare
Wide geographic range, restricted habitat specificity, small population size	2	*Euphorbia thymifolia, Hybanthus linearifolius*	Rare
Narrow geographic range, broad habitat specificity, small population size	2	*Leucas cephalotus, Leucas aspera*	Rare
Narrow geographic range, restricted habitat specificity, small population size	15	*Baccopa monnieri, Chamaecrista absus, Cyperus niveus, Eragrostis capensis, Eragrostis cilianensis, Heliotropium ovalifolium, Lobelia alsinoides, Martynia annua, Cullen corylifolium, Sphenoclea zeylanica, Cajanus scarabaeoides, Teramnus labialis, Tribulus terrestris, Vernonia* sp., *Zephyranthes citrina*	Rare
Narrow geographic range, broad habitat specificity, large population size	1	*Hygrophila auriculata*	Rare
Narrow geographic range, restricted habitat specificity, large population size	11	*Alternanthera pungens, Alysicarpus bupleurifolius, Senna pumila, Chrysanthellum indicum, Crotalaria calycina, Crotalaria pallida, Cynoglossum lanceolatum, Hemarthria compressa, Heteropogon contortus, Perotis indica, Spermacoce pusilla*	Rare

often showed vigorous growth in small patches, distributed across the whole of the range, they could not be considered rare, though their observed traits suggested so. Such an intriguing situation may be common-place in judging the population size of a species as determined by the limitations of method and extent of sampling. Thus, 6 of 8 combinations represent rare and 2 represent common species as evident through this study. Of the total 287 species, 150 showed large range, wide habitat specificity and large populations and 104 species showed large range, wide habitat specificity and small populations (Annex II). Both groups were considered common. The remaining 33 species within 6 different combinations were considered rare (Table 5). Populations of species with habit groups facing a combination of threats have declined within the region (Tables 6 and 7). Thirty-three species showed a maximum of 10 individuals per quadrat and were encountered in <1% of total quadrats observed.

Chrysanthellum indicum, Evolvulus alsinoides and *Spermacoce pusilla*, however, were recorded at only 1 of the 11 sites but there were numerous individuals at this site. Almost all species were exposed to the threats of urbanization and land development, habitat destruction, intense agricultural practices, unmanaged livestock grazing, trampling and other miscellaneous threats. The populations of some of the highly medicinal plants, such as *Hygrophila auriculata, Bacopa monnieri, Centella asiatica, Chrysanthellum indicum, Hybanthus linearifolius, Euphorbia thymifolia, Evolvulus alsinoides, Leucas aspera, L. cephalotus, Vernonia* sp. and *Tribulus*

Table 6. Types of threat reducing populations of various plant species to rarity and local extinction across grassy landscapes of northeastern Uttar Pradesh.

No.	Threat type
1	Urbanization and land development
2	Agricultural activities
3	Logging and associated harvest activities
4	Mining and associated habitat destruction
5	Livestock grazing, especially unsustainable and inappropriate grazing
6	Trampling by stock and humans
7	Over-harvesting for horticultural use
8	Excessive collection for various purposes like medicine and fodder
9	Natural disasters such as catastrophic floods and other miscellaneous threats
10	Invasion by alien plants

Table 7. Species by habit group facing combinations of threats (numbered as above) which have declined to the level of rarity within the regional grassy landscape in northeastern Uttar Pradesh.

Species	Habit	Combination of threats
Alternanthera pungens	Annual herb	1+4+6+8
Sphenoclea zeylanica	Annual herb	1+4+5+6
Alysicarpus bupleurifolius	Annual herb	1+4+5+6+8
Hygrophila auriculata	Perennial herb	1+2+4+8
Centella asiatica	Perennial herb	1+2+4+7+8+10
Tribulus terrestris	Annual herb	1+2+4+6+7+8+9
Eragrostis capensis, Eragrostis cilianensis, Hemarthria compressa, Zephyranthes citrina	Annual herb	1+2+4+5+6+8+9
Heliotropium ovalifolium, Lobelia alsinoides	Annual herb	1+2+4+5+6+8
Bacopa monnieri	Perennial herb	1+2+4+5+7+8+10
Leucas aspera, Leucas cephalotus	Annual herb	1+2+6+8+9
Chamaecrista absus	Annual herb	1+2+5+6+9
Euphorbia thymifolia	Annual herb	1+2+4+8+9
Vernonia sp.	Annual herb	1+2+3+4+5+8+9
Cajanus scarabaeoides, Crotalaria calycina, Crotalaria pallida, Cullen corylifolium, Cynoglossum lanceolatum, Cyperus niveus, Martynia annua, Perotis indica, Senna pumila, Spermacoce pusilla	Annual herb	1+2+4+5+8+9+10
Heteropogon contortus	Perennial herb	1+2+4+5+8+9+10
Teramnus labialis	Annual herb	1+2+4+5+8+9+10
Chrysanthellum indicum, Evolvulus alsinoides, Hybanthus linearifolius	Annual herb	1+2+3+4+6+7+8+9

terrestris have suffered seriously owing to voracious harvesting from the wild by untrained people. Some rare species of annual upland legumes, such as *Alysicarpus bupleurifolius, Alysicarpus longifolius, Senna pumila, Crotalaria calycina, Crotalaria pallida* and *Cullen corylifolium,* require a relatively longer time to produce seeds to complete their annual life cycle as compared with several non-legumes. The period of peak seed fall is often closely followed by high rainfall and moderate water-logging for about a week, and long submergence of fresh seeds may destroy the embryos, rendering them non-viable. On the other hand, the very rare and poor occurrences of some lowland therophytes, such as *Cyperus niveus, Lindernia pyxidaria, Lobelia alsinoides* and *Sphenoclea zeylanica*, may be attributed to severe overgrazing just before full blooming and the seed-setting stage. The second most important threat was invasive alien species. *Centella asiatica, Baccopa monnieri* and *Hygrophila auriculata* showed very poor populations under these conditions despite efficient modes of non-seed regeneration (Table 8), as invaders have a competitive advantage and readily suppress and replace the native species under stressful environments. Table 9 shows the specific habitats for rare plant species.

Table 8. Mode of regeneration and sprouting efficiency of different rare and most common (with asterisk) plant species of grassy landscapes of northeastern Uttar Pradesh.

Mode of regeneration	Species
Seed only	*Alysicarpus bupleurifolius, Chrysanthellum indicum*, *Crotalaria calycina*, *Crotalaria pallida, Cullen corylifolium*, *Cynoglossum lanceolatum, Cyperus niveus, Eragrostis capensis, Eragrostis cilianensis*, *Euphorbia thymifolia, Hemarthria compressa, Hybanthus linearifolius*, *Leucas aspera, Leucas cephalotus, Lindernia ciliata*, Lindernia diffusa*, Lobelia alsinoides*, *Martynia annua, Perotis indica, Rungia repens*, Senna pumila, Spermacoce pusilla, Sphenoclea zeylanica*, *Teramnus labialis, Tribulus terrestris*
Seed + Sprout	*Alternanthera pungens, Cajanus scarabaeoides, Heliotropium ovalifolium, Hygrophila auriculata*
Seed + Ramet	*Bacopa monnieri, Centella asiatica*, *Cynodon dactylon*, Evolvulus nummularis**
Seed + Rhizome + Storage roots	*Heteropogon contortus, Imperata cylindrica*, Zephyranthes citrina*
Seed + Sprout + Ramet	*Desmodium triflorum**

Table 9. Habitat specificity of rare plant species across the regional grassland vegetation of northeastern Uttar Pradesh. *Light:* O = Open, PS = Partial shade; *Soil moisture*: HM = High moisture, LM = Low moisture, AM = Average moisture; and *Soil texture*: S = Sandy, G = Gravel, C = Clay, CL = Clay-loam, SL = Sandy loam.

No.	Species	Family	Habitat specificity factors		
			Light	Soil moisture	Soil texture
1	*Alternanthera pungens*	Amaranthaceae	O	LM	G
2	*Alysicarpus bupleurifolius*	Papilionaceae	O	AM	C/CL
3	*Baccopa monnieri*	Scrophulariaceae	O	HM	C
4	*Cajanus scarabaeoides*	Papilionaceae	O	AM	CL
5	*Centella asiatica*	Apiaceae	O	HM	C
6	*Chamaecrista absus*	Caesalpiniaceae	PS	AM	CL
7	*Chrysanthellum indicum*	Asteraceae	O	AM	S/SL
8	*Crotalaria calycina*	Papilionaceae	O	LM	SL
9	*Crotalaria pallida*	Papilionaceae	O	LM	SL
10	*Cullen corylifolium*	Papilionaceae	PS	AM	SL
11	*Cynoglossum lanceolatum*	Boraginaceae	O	LM	SL
12	*Cyperus niveus*	Cyperaceae	O	AM	SL
13	*Eragrostis capensis*	Poaceae	O	AM	SL
14	*Eragrostis cilianensis*	Poaceae	O	AM	C/CL
15	*Euphorbia thymifolia*	Euphorbiaceae	O	LM	SL/G
16	*Evolvulus alsinoides*	Convolvulaceae	O	AM	SL/S
17	*Heliotropium ovalifolium*	Boraginaceae	O	HM	C
18	*Hemarthria compressa*	Poaceae	O	HM	C
19	*Heteropogon contortus*	Poaceae	O	LM	SL
20	*Hybanthus linearifolius*	Violaceae	O/PS	AM	SL/CL
21	*Hygrophila auriculata*	Lamiaceae	O	HM	C
22	*Leucas aspera*	Lamiaceae	O	LM	SL
23	*Leucas cephalotus*	Lamiaceae	O	AM	SL
24	*Lobelia alsinoides*	Lobeliaceae	PS	HM	CL
25	*Martynia annua*	Martyniaceae	O	LM	CL
26	*Perotis indica*	Poaceae	O	LM/AM	SL
27	*Senna pumila*	Caesalpiniaceae	PS	AM	CL
28	*Spermacoce pusilla*	Rubiaceae	O	AM	SL
29	*Sphenoclea zeylanica*	Sphenocleaceae	O	HM	C
30	*Teramnus labialis*	Papilionaceae	PS	AM	G
31	*Tribulus terrestris*	Zygophyllaceae	O	LM	S
32	*Vernonia* sp.	Asteraceae	O	LM	SL
33	*Zephyranthes citrina*	Amaryllidaceae	O/PS	AM	G & C

Discussion

Community structure and diversity pattern

This study shows that the *Terai* landscape contains very diverse assemblages and associations relative to semi-arid grasslands in other parts of India (Pandeya 1964; Dabadghao and Shankaranarayan 1973), but owing to continued alteration of the habitats through anthropogenic disturbance, the resulting landscape is gradually losing a number of plant species, which can flourish only in a narrow habitat range. The very little similarity and drastic differences among grassland patches, in terms of species richness and abundance, are probably due to the severity of a range of factors, including clipping, grazing, trampling, habitat fragmentation, water-logging, mining and transportation of soil. Singh and Joshi (1979) considered that high numbers of associations in hygrophilous grasslands could be due to different intensities of anthropogenic disturbance plus local variations in topography and soil depth. Locations found on elevated mounds or *'dhus'* supported a diverse assemblage of

grasses and palatable herbs despite regular livestock grazing.

The grasslands in the study area showed much higher species richness than other vegetation types of the region, i.e. almost 3 times higher than that in adjacent forests (Pandey and Shukla 2003). Similar observations have been made in the protected grassland of Dudhwa National Park in *Terai* of Uttar Pradesh (Mathur et al. 2003). The reason for higher species diversity could be the variation in micro-habitat features and occurrence of a number of associations of grass species in the *Terai* grasslands (Shukla 2009).

Our analysis showed that annual herbs contributed most towards different phyto-sociological indices. While most herbaceous plant species can readily establish themselves, quickly produce herbage cover and improve soil fertility (Graham 1941), those which regenerate from seeds are less likely to persist in communities facing recurrent grazing and trampling, although forbs respond positively to disturbance (Belsky 1986). Prostrate perennial species, like *Cynodon dactylon, Desmodium triflorum, Evolvulus nummularis* and *Rungia repens,* showed marked dominance (density and IVI) across the region. They readily occupied the horizontal space created by disturbance through grazing and clipping, and often showed high seed production as well as ramet proliferation, even at sites facing regular disturbance. Multiple types of reproductive strategy can result in the dominance of species over an area (Harper and White 1974; Patrica et al. 2002). Moderate grazing also promotes rapid colonization of newly available space by these species, mainly through vegetative means.

The higher the abundance:frequency (A:F) ratio, the greater will be the tendency of species to clump, and vice-versa. Low values of both the abundance and frequency indicate rare occurrence of species, while very high values indicate dominance of species. A:F ratios of the most common prostrate perennial herbs like *Desmodium triflorum* and *Evolvulus nummularis,* were not high because both the abundance and frequency values of these species were quite high. The pattern of species abundance has been related to both growth pattern and habitat factors (Varghese and Menon 1999). Diversity is often considered to be a synthetic measure of a combination of structure, complexity and stability of a community (Hubbell and Foster 1983). Species distribution in a community is often non-random with dominant species being widely distributed, while subordinate species are generally locally distributed (Kolasa 1989). A moderate level of disturbance is, therefore, compatible with the maintenance of high biodiversity in the landscape. On the other hand, more severe disturbance through regular clipping causes greater dominance and low diversity, and the species of prostrate habit dominate the local communities (Gentry 1991).

The commonness between any two adjacent patches is proportional to the extent of their contact or boundary length (Cole and Hobbs 1994). Most of the adjacent patches of grassy landscape showed a number of common species, under genera like *Lindernia, Phyllanthus, Oldenlandia* and *Heliotropium*. The distribution of grassland species was largely random but several were also found locally aggregated on different spatial scales. A number of erect, prostrate and climber species showed aggregation in the form of compact to loose patches. Aggregation occurred due to either localized seed fall or vigorous vegetative proliferation through ramets. Pacala (1997) also reported that local or intra-specific aggregation is generated by limited seed dispersal, clonal growth and patchy environments.

The resource sharing and niche occupancy of species is frequently expressed by dominance-diversity curves (Whittaker 1975). Conditions like moderate grazing and reduced clipping and trampling allowed relatively greater numbers of species to share community resources, thus reducing the degree of dominance at the community level. A less steep and more flattened curve has also been reported by Raizada et al. (1998). However, some species depicted as rare by the curve, through quadrat sampling, were actually not so rare. They occurred in small patches but only on specified habitats with respect to soil moisture.

Disturbance may have positive effects on some species as reported earlier (Sundriyal et al. 1987) and that caused by herbivores may reduce the effect of competition (Grace and Jutila 1999). In comparison with other species in exposed communities, erect herbaceous species were dominant in terms of RD, RVC and IVI, especially in situations with low moisture and moderate disturbance. *Lindernia diffusa* occurred frequently and its dominance across the region may be due to frequent clipping and grazing. The periodic clipping inhibited the establishment of most of the upper strata species and promoted dominance of only a few prostrate species like *Rungia repens* and *Desmodium triflorum.*

Commonness of plant species

Forbs produce numerous fruits and seeds per plant. The seeds are usually small and often possess very hard seed coats, which can easily escape damage from trampling and digestion within the guts of birds, cattle and other animals. *Evolvulus nummularis* and *Desmodium triflorum* also regenerated efficiently through ramets and

sprouts in addition to seeds. A few species like *Mukia maderaspatana, Ranunculus scleratus, Ruellia tuberosa* and *Soliva anthemifolia* were found in small loose patches with a good number of prostrate neighbors. Other species like *Boerhavia diffusa* and *Clerodendrum indicum* could directly build up a large phytomass from their root-stock and rhizome systems. Their dense vegetative cover suppresses the subordinate species and thus promotes the homogeneity of the community (Armesto and Pickett 1985).

Trampling had significant effects on the occurrence of some species. *Croton bonplandianum, Parthenium hysterophorus* and *Acalypha indica* were more common in areas facing frequent trampling, while species like *Tridax procumbens*, *Cyanthillium cinereum, Alysicarpus monilifer* and *Murdannia nudiflora* occurred when clipping and trampling were only occasional. With increased frequency of trampling and clipping, the occurrence of *Achyranthes aspera, Amaranthus viridis, Ruellia tuberosa* and *Gomphrena globosa* markedly increased. The combination of heavy trampling, grazing and clipping provided extreme conditions of biotic disturbance. Grasses, notably *Setaria glauca, Eragrostis amabilis* and *Cyperus rotundus*, and a few leguminous forbs, e.g. *Desmodium triflorum* and *Alysicarpus monilifer,* coped with such composite disturbance. About 10% of the common species showed ramet proliferation, while others displayed mass seed germination at suitable sites. Some prostrate species aggregated to form compact mats, which allowed few associates and low species richness of local communities. Erect species, on the other hand, allowed significant numbers of species among their aggregations. A number of new entrants produced propagules irrespective of their vitality level to the community. The dense vegetal cover of *Hyptis suaveolens* and *Parthenium hysterophorus* suppressed the growth of other species as evident at locality 8 (Marimata campus). Since these species were unpalatable and faced no clipping and little trampling owing to their height, they showed significant local dominance (Tripathi and Shukla 2007).

Rarity of plant species

A number of species, which showed low tolerance of disturbance and were totally absent from such sites (Table 6), occurred only in few localities and preferred sandy to loamy soils. Species such as *Centella asiatica* and *Hygrophila auriculata*, earlier frequent in or near water-logged areas, have also become quite rare during recent decades. On the other hand, a sizable number of species, which occupy quite specialized habitats, showed small population sizes within narrow distributional ranges (Table 6). Chiefly because of their medicinal importance, they have been over-exploited and are on the verge of local extinction. The population density of *Chamaecrista absus*, *Cyperus niveus*, *Leucas cephalotus*, *Leucas aspera, Lobelia alsinoides, Martynia annua* and *Cullen corylifolium* has declined markedly during the last few years. This indicates their specialized habitat requirements (Tripathi 1999). The land-use changes plus mining and transportation of soil for filling and construction purposes appear to be important threats. Voracious and unmanaged harvesting presents a major threat to the persistence of several valuable plant species of the region (Shukla 2009). Hubbell and Foster (1986) found that most rare species are specialists in terms of habitat or appropriate niches for regeneration. The fast expansion of townships and associated disturbances during the current era have caused major reduction in availability of specialized niches in the region.

The spread of viable seeds from parent plants can be restricted due to the absence of dispersal vectors, especially grazers. Several authors have highlighted the importance of migrating sheep and cattle for plant dispersal (Fischer et al. 1996; Poschlod et al. 1998). Although the fruits of *Tribulus terrestris* are dispersed far and wide through a hooking device, which attaches to the skin of cattle, the population of this species has shrunk rapidly during the last decade. A contributing factor could be the unavailability of suitable micro-sites for germination and growth of seeds. *Crotalaria calycina* and *Hybanthus linearifolius* are examples of species now classified as rare, as their population size has declined significantly during the last decade, despite production of sufficient viable seeds/fruits. These species prefer shaded and damp habitats around orchards, and availability of such habitats has declined markedly, mainly through increased urbanization and agricultural expansion. Metzger (2000) suggests that shade-tolerant species are more sensitive to habitat fragmentation than shade-intolerant species.

Species like *Hygrophila auriculata, Bacopa monnieri, Centella asiatica* and *Heliotropium ovalifolium* grow mostly on clayey soil subjected to some degree of water-logging. Currently, they have become infrequent across water-logged or lowland sites, despite their two-pronged regeneration strategy, i.e. through seeds as well as sprouts and ramets. With improvement of technologies and population explosion, humans have a major role in escalating extinction rates (Hopping et al. 2004). Species populations which are small in size and with restricted habitat requirements are more prone to extinction (Menges 1998; Butaye et al. 2005).

It was quite striking that some very rare species in the regional grassland were the only representatives of a particular genus, which, in turn, represented a single family. For example, Lobeliaceae, Martyniaceae, Sphenocleaceae and Zygophyllaceae were represented by *Lobelia alsinoides, Martynia annua, Sphenoclea zeylanica* and *Tribulus terrestris,* respectively. The loss of these single species would mean the loss or non-representation of a whole family. These species may be passing through their lag time, as often there is a lag time between when the species habitat is lost and when the species actually becomes extinct (Hopping et al. 2004). A great amount of evolutionary history and biological distinctiveness is lost when the last species of an entire genus or family becomes extinct (Kareiva and Marvier 2003). Levin and Levin (2004) strongly suggest concentrating efforts on saving such families and higher levels of taxonomic groups.

The survival and growth of several plant species into large populations indicated that habitat quality was not always worse for all species, especially invaders, which form one of the major threats to the survival and growth of several native species (Sekar 2012). The invaders colonize and successfully out-compete the native species, especially in open habitats with reduced competition, often created by grazing and man-made disturbance (Wu et al. 2004; Huang et al. 2009). The introduction and spread of invasive aliens may be facilitated by floods, changes in land-use pattern and environmental conditions caused by livestock grazing, timber harvest, agriculture and ornamental purposes (Srivastava et al. 2015). These alien species have the potential to damage or eliminate already feeble populations of rare taxa (Menges 1991).

Conservation strategy of grasses

Availability of viable seed is important for conservation of biodiversity and may determine the composition, structure and dynamics of present and future vegetation in different ecosystems. Grazing pressure in the *Terai* region is very intense and much of the seed-bearing parts of plants are removed. Further, developmental activities often create severe soil disturbance, and compaction and erosion have adverse impacts on the survival of grassland species (Godefroid and Koeda 2004a; 2004b). Disturbance complicates the relationship and may increase species richness by lowering dominance and presenting opportunities for some species to spread rapidly (Whitmore 1996; Gusson et al. 2009). The management of biodiversity at landscape levels involves the twin objectives of preservation and sustainable use of natural habitats.

Conclusion

The present data on abundance distribution and diversity pattern of plant species suggest that the acute fragmentation of the natural habitat of northeastern *Terai* has resulted in limited distribution of once very common and widely spread species. Fast shrinkage of grassland habitats due to urbanization, agricultural expansion, grazing, trampling, fire and the mining and transportation of soil for the brick industry and site filling have pushed many less-common but valuable plant species towards rarity and several of them face local extinction. It appears that many valuable species will be lost from these grasslands, if the current practices in the community are allowed to continue unchecked. The present observations emphasize the urgent need for studies on the status of existing rare plant species and identification of the most detrimental cultural practices threatening their survival before some important species are lost from these plant communities.

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References

Ansari AA; Singh SK; Srivastava RC. 2006. Flora and vegetation of Madhaulia forest (U.P.). Oriental Enterprises, Dehradun, Uttarakhand, India.

Armesto JJ; Pickett STA. 1985. Experiments on disturbance in old-field plant communities: Impact on species richness and abundance. Ecology 66:230–240. DOI: 10.2307/1941323

Belsky AJ. 1986. Revegetation of artificial disturbances in grasslands of the Serengeti National Park, Tanzania: II. Five years of successional change. Journal of Ecology 74:937–951. DOI: 10.2307/2260225

Bharucha FR; Ferreria DB. 1941. The biological spectra of the Matheran and Mahabaleshwar flora. Journal of the Indian Botanical Society 20:195–211.

Butaye J; Adriaens D; Honnay O. 2005. Conservation and restoration of calcareous grasslands: A concise review of the effects of fragmentation and management on plant species. Biotechnology, Agronomy, Society and Environment 9:111–118. http://goo.gl/vulcsa

Cole PG; Hobbs RJ. 1994. Landscape heterogeneity indices: Problems of scale and applicability, with particular reference to animal habitat description. Pacific Conservation Biology 1:183–193. DOI: 10.1071/PC940183

Dabadghao PM; Shankarnarayan KA. 1973. The grass cover of India. Indian Council of Agricultural Research, New Delhi, India.

Daniels RJ; Kumar AN; Jayanthi M. 1995. Endemic, rare and threatened flowering plants of South India. Current Science 68:493–495. http://goo.gl/1siFnz

Fischer SF; Poschlod P; Beinlich B. 1996. Experimental studies on the dispersal of plants and animals on sheep in calcareous grasslands. Journal of Applied Ecology 33:1206–1222. DOI: 10.2307/2404699

Friedel MH. 1997. Discontinuous change in arid woodland and grassland vegetation along gradients of cattle grazing in central Australia. Journal of Arid Environment 37:145–164. DOI: 10.1006/jare.1997.0260

Gentry AH. 1991. The distribution and evolution of climbing plants. In: Putz FE; Mooney HA, eds. The biology of vines. Cambridge University Press, Cambridge, UK. p. 3–42.

Godefroid S; Koeda MN. 2004a. Interspecific variation in soil compaction sensitivity among forest floor species. Biological Conservation 119:207–217. DOI: 10.1016/j.biocon.2003.11.009

Godefroid S; Koeda MN. 2004b. The impact of forest paths upon adjacent vegetation: Effects of the path surfacing material on the species composition and soil compaction. Biological Conservation 119:405–419. DOI: 10.1016/j.biocon.2004.01.003

Grace JB; Jutila H. 1999. The relationship between species density and community biomass in grazed and ungrazed coastal meadows. Oikos 85:398–408. DOI: 10.2307/3546689

Graham EH. 1941. Legumes for erosion control and wildlife. USDA Miscellaneous Publication 412, US Department of Agriculture, Washington, DC, USA.

Grime JP. 1979. Plant strategies and vegetation processes. John Wiley & Sons Ltd., Chichester, UK.

Gupta RK; Sharma SK. 1973. Phytosociological changes in an enclosed area of Jodhpur. Journal of the Indian Botanical Society 52:1–11.

Gusson AE; Lopes SF; Dias Neto OC; Vale VS do; Oliveira AP de; Schiavini I. 2009. Características químicas do solo e estrutura de um fragmento de floresta estacional semidecidual em Ipiaçu, Minas Gerais, Brasil. Rodriguésia 60:403–414. http://www.jstor.org/stable/23499997

Harper JL; White J. 1974. The demography of plants. Annual Review of Ecology and Systematics 5:419–463. DOI: 10.1146/annurev.es.05.110174.002223

Hopping I; Mackro D; Delson L. 2004. Human effects on terrestrial biodiversity. The Traprock 3:1–5.

Huang QQ; Wu JM; Bai YY; Zhou L; Wang GX. 2009. Identifying the most noxious invasive plants in China: Role of geographical origin, life form and means of introduction. Biodiversity and Conservation 18:305–316. DOI: 10.1007/s10531-008-9485-2

Hubbell SP; Foster RB. 1983. Diversity of canopy trees in neo-tropical forest and implications to conservation. In: Sutton L; Whitmore TC; Chadwick C, eds. Tropical rain forest: Ecology and management. Blackwell Scientific Publications, Oxford, UK. p. 25–41.

Hubbell SP; Foster RB. 1986. Commonness and rarity in a neotropical rain forest: Implications for tropical tree conservation. In: Soulé ME, ed. Conservation Biology: The science of scarcity and diversity. Sinauer Associates, Sunderland, MA, USA. p. 205–231.

IUCN. 2001. IUCN Red List categories and criteria: Version 3.1. IUCN Species Survival Commission. International Union for Conservation of Nature, Gland, Switzerland and Cambridge, UK.

Kala CP. 2005. Indigenous uses, population density, and conservation of threatened medicinal plants in protected areas of the Indian Himalayas. Conservation Biology 19:368–378. DOI: 10.1111/j.1523-1739.2005.00602.x

Kareiva P; Marvier M. 2003. Conserving biodiversity cold spots. American Scientist 91:344–351. DOI: 10.1511/2003.4.344

Kolasa J. 1989. Ecological systems in hierarchical perspective: Breaks in community structure and other consequences. Ecology 70:36–47. DOI: 10.2307/1938410

Levin PS; Levin DA. 2004. The real biodiversity crisis. American Scientist 90:6–8. DOI: 10.1511/2002.1.6

Magurran AE. 1988. Ecological diversity and its measurement. University Press, Cambridge, UK.

Magurran AE. 2004. Measuring biological diversity. Blackwell Publishing, Oxford, UK.

Magurran AE; Henderson PA. 2003. Explaining the excess of rare species in natural species abundance distributions. Nature 422:714–716. DOI: 10.1038/nature01547

Mathur PK; Kumar H; Lehmkuhl JF. 2003. Terai grassland diversity, management and conservation perspectives. ENVIS Bulletin Grassland, Ecosystems and Agroforestry 1:1–28.

Menges ES. 1991. The application of minimum viable population theory to plants. In: Falk DA; Holsinger KE, eds. Genetics and conservation of rare plants. Oxford University Press, Oxford, UK. p. 47–61.

Menges ES. 1998. Evaluating extinction risks in plant populations. In: Fiedler PL; Kareiva PM, eds. Conservation biology for the coming decade. Chapman and Hall, New York, USA and London, UK. p. 49–65.

Metzger JP. 2000. Tree functional group richness and landscape structure in a Brazilian tropical fragmented landscape. Ecological Applications 10:1147–1161. DOI: 10.1890/1051-0761(2000)010%5B1147:tfgral%5D2.0.co;2

Mori SA; Boom BM; Carvalino AM de; Santos TS dos. 1983. Ecological importance of Myrtaceae in an eastern Brazilian wet forest. Biotropica 15:68–70. DOI: 10.2307/2388002

Mueller-Dombois D; Ellenberg H. 1974. Aims and methods of vegetation ecology. John Wiley & Sons Ltd., New York, USA.

Nautiyal BP; Pandey N; Bhatt AB. 1997. Analysis of vegetation pattern in an alpine zone in North West Himalaya: A case study of Garhwal Himalaya with reference to diversity and distribution patterns. International Journal of Ecology and Environmental Science 23:49–65.

Nayar MP; Sastry ARK, eds. 1988. Red data book of Indian plants. Botanical Survey of India, Calcutta, India.

Oostermeijer JGB; Luijten SH; den Nijs JCM. 2003. Integrating demographic and genetic approaches in plant conservation. Biological Conservation 113:389–398. DOI: 10.1016/s0006-3207(03)00127-7

Pacala SW. 1997. Dynamics of plant communities. In: Crawley MJ, ed. Plant ecology. Blackwell Scientific, Oxford, UK. p. 532–555.

Pandeya SC. 1964. Ecology of grassland of Sagar, Madhya Pradesh: IIb. Composition of the associations open to grazing or occupying special habitat. Journal of the Indian Botanical Society 43:606–639.

Pandey SK; Shukla RP. 2003. Plant diversity in managed sal (*Shorea robusta* Gaertn.) forests of Gorakhpur, India: Species composition, regeneration and conservation. Biodiversity and Conservation 12:2295–2319. DOI: 10.1023/A:1024589230554

Patrica B; Emily L; Gerardo S; Christina S; Angeles I. 2002. Patterns of β-diversity in a Mexican tropical dry forest. Journal of Vegetation Science 13:145–158. DOI: 10.1111/j.1654-1103.2002.tb02034.x

Pickett STA; White PS, eds. 1985. The ecology of natural disturbance and patch dynamics. Academic Press, New York, USA.

Pitman NCA; Terborgh J; Silman MR; Nuñez PV. 1999. Tree species distributions in an upper Amazonian forest. Ecology 80:2651–2661. DOI: 10.1890/0012-9658(1999)080[2651:TSDIAU]2.0.CO;2

Poschlod P; Kiefer S; Tränke U; Fischer S; Bonn S. 1998. Plant species richness in calcareous grasslands as affected by dispersability in space and time. Applied Vegetation Science 1:75–91. DOI: 10.2307/1479087

Rabinowitz D. 1981. Seven forms of rarity. In: Synge H, ed. The biological aspects of rare plant conservation. John Wiley & Sons Ltd., New York, USA. p. 205–217.

Rabinowitz D; Cairns S; Dillon T. 1986. Seven forms of rarity and their frequency in the flora of the British Isles. In: Soulé ME, ed. Conservation biology: The science of scarcity and diversity. Sinauer, Sunderland, MA, USA. p. 182–204.

Raizada A; Joshi SP; Srivastava MM. 1998. Composition and vegetation diversity in an alpine grassland in the Garhwal Himalayas. Tropical Ecology 39:133–144.

Sekar KC. 2012. Invasive alien plants of Indian Himalayan region − diversity and implication. American Journal of Plant Sciences 3:177–184. DOI: 10.4236/ajps.2012.32021

Semwal RL. 2005. The Terai arc landscape in India: Securing protected areas in the face of global change. World Wide Fund for Nature (WWF)-India, New Delhi, India.

Shukla RP. 2009. Patterns of plant species diversity across Terai landscape in north-eastern Uttar Pradesh, India. Tropical Ecology 50:111–123.

Singh JS; Yadava PS. 1974. Seasonal variation in composition, plant biomass and net primary productivity of tropical grassland of Kurukshetra, India. Ecological Monographs 94:371–376. DOI: 10.2307/2937034

Singh JS; Joshi MC. 1979. Primary production. In: Coupland RT, ed. Analysis of grassland and their uses. International Biological Programme (IBP) Synthesis Series, Cambridge University Press, London, UK.

Srivastava S; Dvivedi A; Shukla RP. 2014. Invasive alien species of terrestrial vegetation of north-eastern Uttar Pradesh. International Journal of Forestry Research Volume 2014, ID 959875, 9 pages. DOI: 10.1155/2014/959875

Srivastava S; Dvivedi A; Shukla RP. 2015. *Solanum sisymbriifolium* Lam. (Solanaceae): A new invasive undershrub of the old-fields of northeastern Uttar Pradesh**.** Checklist: The Journal of Biodiversity Data. Volume 11, number 3, article 1643, 4 pages. DOI: 10.15560/11.3.1643

Sundriyal RC; Joshi AP; Dhasmana R. 1987. Phenology of high altitude plants at Tungnath in the Garhwal Himalaya. Tropical Ecology 28:289–299.

Tripathi SL. 1999. Plant diversity of grasslands of north-eastern U.P. with emphasis on populations of *Parthenium hysterophorus* L. Ph.D. Thesis. D.D.U. Gorakhpur University, Gorakhpur, India.

Tripathi SL; Shukla RP. 2007. Effect of clipping and grazing on various vegetational parameters of grassland communities of Gorakhpur, Uttar Pradesh. Tropical Ecology 48:61–70.

Ulrich W; Ollik M. 2004. Frequent and occasional species and the shape of relative-abundance distributions. Diversity and Distribution 10:263–269. DOI: 10.1111/j.1366-9516.2004.00082.x

Varghese AO; Menon ARR. 1999. Ecological niches and amplitudes of rare threatened and endemic trees of Peppara Wildlife Sanctuary. Current Science 76:1204–1208.

Weekley CW; Race T. 2001. The breeding system of *Zizyphus celata* Judd & D.W. Hall (Rhamnaceae), a rare, endemic plant of the Lake Wales Ridge, Florida, USA: Implications for recovery. Conservation Biology 100:207–213. DOI: 10.1016/S0006-3207%2801%2900024-6

Whitmore C. 1996. A review of some aspects of tropical rain forest seedling ecology with suggestions for further enquiry. In: Swaine MD, ed. The ecology of tropical forest seedlings. Man and the Biosphere Series Vol. 17, UNESCO, Paris, France and Parthenon Publishing Group, Inc. New York, USA. p. 3−39.

Whittaker RH. 1975. Communities and Ecosystems. MacMillan Publishing Co., Inc., New York, USA.

Wilsey BJ; Polley HW. 2003. Effects of seed additions and grazing history on diversity and productivity of subhumid grasslands. Ecology 84:920–931. DOI: 10.1890/0012-9658(2003)084%5B0920:eosaag%5D2.0.co;2

Withford PB. 1948. Distribution of woodland plants in relation to succession and clonal growth. Ecology 30:199–208. DOI: 10.2307/1931186

Wu SH; Hsieh CF; Rejmánek M. 2004. Catalogue of the naturalized flora of Taiwan. Taiwania 49:16–31. http://ntur.lib.ntu.edu.tw/retrieve/168216/05.pdf

Annex Ia

Names and sampling areas of locations at the 11 study sites (districts). The habitat characteristics (see Annex Ib) at locations are expressed in terms of ***light regime*** (O - open, PS - partial shade); ***soil moisture*** (HM - high moisture, AM - average moisture, LM - low moisture); ***soil texture*** (SS - sandy soil, LS - loam soil, CL - clay soil, SLS - sandy-loam soil, CLS - clay-loam soil and GS - gravel soil); and ***disturbance regime*** (HD - high disturbance, MD - medium disturbance, LD - low disturbance).

Study site	Location	Habitat characteristics	Area (ha) of sampling sites
Bahraich	Acholaya (Stadium)	O,LM,SLS,LD	10.12
	Acholaya I	O,AM,SLS,MD	10.12
	Acholaya II	PS,HM,SLS,HD	11.33
	Acholaya III	O,LM,SLS,HD	14.17
	Acholaya Dhus	O,AM,SLS,MD	4.05
	Basahiya	O,LM,SS,MD	9.71
	Tikora (Parag Dairy)	O,HM,HD,CS	36.42
	Tikora (Mari Mata)	PS,AM,CLS,MD	2.02
Balrampur	Neel Palace	PS,AM,GS,LD	1.21
	Ranjeetpur	O,HM,CS,HD	8.09
	Hanuman Mandir	O,HM,CS,LD	2.83
	Rani Talab	O,LM,CLS,MD	1.21
Gonda	Sarayya Mafi	O,LM,LS,HD	80.94
Shravasti	Mahaet	O,LM,GS,LD	12.14
Basti	Ramauli	PS,AM,CLS,MD	3.24
Sant Kabir Nagar	Maghar	O,HM,CS,HD	11.33
Siddharth Nagar	Piperahawa	O,AM,CS,MD	38.45
Maharajganj	Chhapwa I	O,AM,CLS,MD	2.43
	Chhapwa II	PS,LM,SLS,LD	2.05
Gorakhpur	University Campus	O,AM,CLS,MD	6.07
	Airforce I	PS,AM,CLS,HD	7.29
	Airforce II	O,LM,CLS,MD	7.29
	Airforce III	PS,HM,CLS,HD	8.09
	Jagatbella	O,HM,CS,MD	12.14
Kushi Nagar	Sirshya I	O,LM,SLS,LD	4.86
	Sirshya II	O,LM,SLS,MD	2.43
	Sirshya III	PS,AM,SLS,HD	2.02
Deoria	Deoghat I	PS,LM,SLS,MD	6.07
	Deoghat II	PS,AM,SLS,HD	2.02
	Uska	PS,HM,CLS,MD	5.67
	Singahi	PS,HM,CLS,HD	5.20

Annex Ib

Habitat identification

The habitats of plant species were determined on the basis of characteristics that increase the heterogeneity of terrestrial vegetation: change in local topography; light regime; soil moisture; soil texture; and degree and type of anthropogenic disturbances.

Light regime: The degree of exposure was measured by an illuminometer (Kyoritsu-5200) at 10 random and nearly equi-distant points on the floor of the vegetation during sunny days of November at mid-day. The light regime of open communities ranged from 70,000 to 75,000 lux and that of partially shaded communities was below 10,000 lux.

Soil moisture regime: The moisture content within the top 10 cm of soil was measured gravimetrically. More than 40% of soil moisture was treated as high moisture (HM), 20−40% as average moisture (AM) and <20% as low moisture (LM).

Soil texture: Soil texture refers to particle size composition and according to the proportions of sand, silt and clay, soils are classified, in general, as sandy, clayey, loamy, sandy-loam, silty-loam, clayey-loam and silty-clay soils. The physical characterization of soil at the study sites is based on analysis by the Agricultural Research Center, Bahraich (U.P.), India (Table A below). The silty-loam and silty-clay soils were termed as gravelly soil as they contained significant proportions of gravels and pebbles.

Disturbance: The anthropogenic disturbance factors (see also Table B below) operating at each sampling location were recorded. The intensity of each factor was scaled in the classes: 1 (absent or very little); 2 (occasional); and 3 (recurrent) (see Table C below).

Table A. Soil physical characteristics at the study locations within 11 districts across grassy landscapes of northeastern Uttar Pradesh.

Study site (district)	Sample no.	Location	Composition (%)				Texture
			Sand		Silt	Clay	
			Fine	Coarse			
Bahraich	1	Acholaya (Stadium)	40.2	31.2	16.8	11.8	Sandy-loam
	2	Acholaya I	42.0	30.6	16.2	11.2	Sandy-loam
	3	Acholaya II	40.4	30.2	17.0	12.4	Sandy-loam
	4	Acholaya III	40.4	32.0	16.8	10.8	Sandy-loam
	5	Acholaya Dhus	41.2	30.4	17.2	11.2	Sandy-loam
	6	Basahiya	44.7	35.8	8.3	11.2	Sandy
	7	Tikora (Parag Dairy)	4.0	2.8	9.8	83.4	Clay
	8	Tikora (Mari Mata)	18.2	3.6	43.8	34.4	Clay-loam
Balrampur	9	Neel Palace	14.2	26.2*	45.6	28.2	Gravel
	10	Ranjeetpur	2.8	2.0	9.0	86.2	Clay
	11	Hanuman Mandir	3.2	2.3	8.9	85.6	Clay
	12	Rani Talab	14.8	2.0	46.4	36.8	Clay-loam
Gonda	13	Sarayya Mafi	4.6	3.2	64.8	27.4	Loam
Shravasti	14	Mahaet	14..4	26*	45.6	28.2	Gravel
Basti	15	Ramauli	24.2	7.0	32.4	36.4	Clay-loam
Sant Kabir Nagar	16	Maghar	2.6	2.2	7.8	87.4	Clay
Siddharth Nagar	17	Piperahawa	3.8	2.5	9.9	83.8	Clay
Maharajganj	18	Chhapwa I	23.2	8.0	33.6	35.2	Clay-loam
	19	Chhapwa II	41.4	29.2	18.0	11.4	Sandy-loam
Gorakhpur	20	University Campus	19.6	2.0	44.8	33.6	Clay-loam
	21	Airforce I	19.2	2.4	44.4	34.0	Clay-loam
	22	Airforce II	18.6	2.2	42.8	36.4	Clay-loam
	23	Airforce III	13.8	3.0	46.8	36.4	Clay-loam
	24	Jagatbella	3.2	3.1	9.2	84.5	Clay
Kushinagar	25	Sirshya I	41.8	31.2	16.2	10.8	Sandy-loam
	26	Sirshya II	42.2	31.6	15.2	11.0	Sandy-loam
	27	Sirshya III	42.4	31.2	16.0	10.4	Sandy-loam
Deoria	28	Deoghat I	42.8	32.0	15.4	9.8	Sandy-loam
	29	Deoghat II	42.4	32.7	15.6	9.3	Sandy-loam
	30	Uska	23.2	8.0	30.4	38.4	Clay-loam
	31	Singahi	23.2	8.0	33.6	35.2	Clay-loam

*The coarse sand fraction also included gravels and pebbles.

Table B. Different types of disturbance classes at the study sites and their weightage score across grassy landscapes of north-eastern Uttar Pradesh.

Disturbance factor	Very little	Occasional	Recurrent
Agricultural practices	1	2	3
Fire	1	2	3
Forage removal	1	2	3
Fuel wood collection	1	2	3
Grazing	1	2	3
Habitat destruction	1	2	3
Horticulture	1	2	3
Invasion	1	2	3
Litter collection	1	2	3
Mining of soil	1	2	3
Root collection	1	2	3
Trampling	1	2	3
Flood	1	2	3

Table C. Disturbance levels based on weightage scores of various disturbances.

Disturbance level	Weightage score
Low	1 or 2 or 3
Medium	1 and 2 or 1 and 3
High	1 and 2 and 3

Annex II

Commonness and rarity of species of grassland vegetation across northeastern Uttar Pradesh. [Nomenclature according to The Plant List database (http://www.theplantlist.org)]. Habit: H = herb; C = climber; S = shrub; Posture: EA = erect annual; PA = prostrate annual; PerTw = perennial twiner; PPer = prostrate perennial; ATw = annual twiner; EPer = erect perennial; ATn = annual tendril.

Plant species	Family	Habit	Posture	Total no. individuals	Density (/m^2)	Population size	Habitat specialization	Geographical range
Acalypha ciliata Forssk.	Euphorbiaceae	H	EA	10	0.07	Large	Broad	Wide
Acalypha indica L.	Euphorbiaceae	H	EA	6	0.04	Large	Broad	Wide
Achyranthes aspera L.	Amaranthaceae	H	EA	63	0.41	Large	Broad	Wide
Aerva lanata (L.) Juss.	Amaranthaceae	H	EA	34	0.30	Small	Broad	Wide
Aeschynomene aspera L.	Papilionaceae	H	EA	7	0.05	Large	Broad	Wide
Aeschynomene indica L.	Papilionaceae	H	EA	3	0.02	Large	Broad	Wide
Ageratum conyzoides (L.) L.	Asteraceae	H	EA	32	0.21	Large	Broad	Wide
Ageratum houstonianum Mill.	Asteraceae	H	EA	357	2.30	Large	Broad	Wide
Alternanthera paronychioides A.St.-Hil.	Amaranthaceae	H	PA	148	0.95	Large	Broad	Wide
Alternanthera pungens Kunth	Amaranthaceae	H	PA	9	0.06	Large	Narrow	Narrow
Alternanthera sessilis (L.) R.Br. ex DC.	Amaranthaceae	H	PA	187	1.21	Large	Broad	Wide
Alysicarpus bupleurifolius (L.) DC.	Papilionaceae	H	EA	33	0.21	Large	Narrow	Narrow
Alysicarpus longifolius (Spreng.) Wight & Arn.	Papilionaceae	H	EA	14	0.09	Small	Broad	Wide
Alysicarpus monilifer (L.) DC.	Papilionaceae	H	PA	324	2.09	Large	Broad	Wide
Alysicarpus ovalifolius (Schum.) Leonard	Papilionaceae	H	EA	26	0.17	Small	Broad	Wide
Alysicarpus vaginalis (L.) DC.	Papilionaceae	H	PA	667	4.30	Large	Broad	Wide
Amaranthus spinosus L.	Amaranthaceae	H	EA	1	0.01	Large	Broad	Wide
Amaranthus viridis L.	Amaranthaceae	H	EA	57	0.37	Large	Broad	Wide
Ammannia auriculata Willd.	Lythraceae	H	EA	48	0.41	Small	Broad	Wide
Ammannia baccifera L.	Lythraceae	H	EA	72	0.46	Small	Broad	Wide
Anagallis arvensis L.	Primulaceae	H	EA	71	0.46	Large	Broad	Wide
Apluda mutica L.	Poaceae	H	EA	46	0.30	Small	Broad	Wide
Argemone mexicana L.	Papaveraceae	H	EA	7	0.05	Large	Broad	Wide
Bacopa monnieri (L.) Wettst.	Scrophulariaceae	H	EA	8	0.05	Small	Narrow	Narrow
Basella alba L.	Basellaceae	C	PerTw	3	0.02	Small	Broad	Wide
Blumea axillaris (Lam.) DC.	Asteraceae	H	EA	8	0.05	Large	Broad	Wide
Blumea eriantha DC.	Asteraceae	H	EA	35	0.23	Large	Broad	Wide
Blumea lacera (Burm.f.) DC.	Asteraceae	H	EA	8	0.05	Small	Broad	Wide
Blumea laciniata (Wall. ex Roxb.) DC.	Asteraceae	H	EA	26	0.17	Small	Broad	Wide
Boerhavia diffusa L.	Nyctaginaceae	H	PPer	120	0.77	Large	Broad	Wide
Bolboschoenus glaucus (Lam.) S.G.Sm.	Cyperaceae	H	EA	23	0.15	Small	Broad	Wide
Cajanus scarabaeoides (L.) Thouars	Papilionaceae	C	ATw	27	0.17	Small	Narrow	Narrow
Calotropis procera (Aiton) Druand.	Asclepiadaceae	S	EPer	36	0.23	Large	Broad	Wide
Cannabis sativa L.	Cannabinaceae	H	EA	1	0.01	Large	Broad	Wide

Continued

Plant species	Family	Habit	Posture	Total no. individuals	Density (/m^2)	Population size	Habitat specialization	Geographical range
Carex fedia Nees	Cyperaceae	H	EA	186	1.20	Large	Broad	Wide
Cayratia trifolia (L.) Domin	Vitaceae	C	ATn	16	0.10	Large	Broad	Wide
Ceesulia axillaris Roxb.	Asteraceae	H	EA	143	0.92	Large	Broad	Wide
Cenchrus biflorus Roxb.	Poaceae	H	EA	11	0.07	Large	Broad	Wide
Centella asiatica (L.) Urb.	Apiaceae	H	PA	17	0.11	large	Narrow	Wide
Chamaecrista absus (L.) H.S.Irwin & Barneby	Caesalpiniaceae	H	EA	7	0.05	Small	Narrow	Narrow
Chenopodium album L.	Chenopodiaceae	H	EA	24	0.15	Large	Broad	Wide
Chloris barbata Sw.	Poaceae	H	EA	467	3.01	Small	Broad	Wide
Chrysanthellum indicum DC.	Asteraceae	H	PA	595	3.84	Large	Narrow	Narrow
Chrysopogon aciculatus (Retz.) Trin.	Poaceae	H	EA	790	5.10	Large	Broad	Wide
Cissampelos pareira L.	Menispermaceae	C	PerTw	8	0.05	Small	Broad	Wide
Cleome viscosa L.	Capparidaceae	H	EA	7	0.05	Large	Broad	Wide
Clerodendrum indicum (L.) Kuntze	Verbenaceae	S	EPer	55	0.35	Small	Broad	Wide
Coccinia grandis (L.) Voigt	Cucurbitaceae	C	ATn	9	0.06	Large	Broad	Wide
Commelina benghalensis L.	Commelinaceae	H	PA	27	0.17	Large	Broad	Wide
Commelina diffusa Burm.f.	Commelinaceae	H	PA	45	0.29	Small	Broad	Wide
Corchorus aestuans L.	Tiliaceae	H	PA	83	0.54	Large	Broad	Wide
Corchorus fascicularis Lam.	Tiliaceae	H	EA	57	0.37	Large	Broad	Wide
Crotalaria calycina Schrank	Papilionaceae	H	EA	15	0.10	Large	Narrow	Narrow
Crotalaria medicaginea Lam.	Papilionaceae	H	EA	123	0.79	Large	Broad	Wide
Crotalaria pallida Aiton	Papilionaceae	H	PA	1	0.01	Small	Broad	Wide
Crotalaria prostrata Willd.	Papilionaceae	H	EA	512	3.30	Large	Narrow	Narrow
Crotalaria retusa L.	Papilionaceae	H	PA	1	0.01	Small	Broad	Wide
Crotalaria sp.	Papilionaceae	H	PA	79	0.51	Small	Broad	Wide
Croton bonplandianus Baill.	Euphorbiaceae	H	EA	69	0.45	Large	Broad	Wide
Cucumis melo L.	Cucurbitaceae	C	ATn	9	0.06	Large	Broad	Wide
Cullen corylifolium (L.) Medik.	Papilionaceae	H	EA	191	1.23	Small	Narrow	Narrow
Cuscuta chinensis Lam.	Cuscutaceae	C	ATw	1	0.01	Large	Broad	Wide
Cuscuta sp.	Cuscutaceae	C	ATw	50	0.32	Large	Broad	Wide
Cyanotis axillaris (L.) D.Don ex Sweet	Commelinaceae	H	EA	137	0.88	Small	Broad	Wide
Cyanthillium cinereum (L.) H.Rob.	Asteraceae	H	EA	1,077	6.95	Large	Broad	Wide
Cynodon dactylon (L.) Pers.	Poaceae	H	PPer	3,644	23.51	Large	Broad	Wide
Cynoglossum lanceolatum Forssk.	Boraginaceae	H	EA	123	0.79	Large	Narrow	Narrow
Cyperus alopecuroides Rottb.	Cyperaceae	H	EA	262	1.69	Large	Broad	Wide
Cyperus alulatus J.Kern	Cyperaceae	H	EA	47	0.30	Small	Broad	Wide
Cyperus capitatus Vand.	Cyperaceae	H	EA	568	3.66	Large	Broad	Wide
Cyperus castaneus Willd.	Cyperaceae	H	EA	130	0.84	Small	Broad	Wide
Cyperus compressus L.	Cyperaceae	H	EA	31	0.20	Large	Broad	Wide
Cyperus difformis L.	Cyperaceae	H	EA	51	0.33	Small	Broad	Wide

Continued

Plant species	Family	Habit	Posture	Total no. individuals	Density (/m^2)	Population size	Habitat specialization	Geographical range
Cyperus dubius Rottb.	Cyperaceae	H	EA	150	0.97	Large	Broad	Wide
Cyperus exaltatus Retz.	Cyperaceae	H	EA	13	0.08	Small	Broad	Wide
Cyperus michelianus (L.) Delile	Cyperaceae	H	PA	13	0.08	Large	Broad	Wide
Cyperus niveus Retz.	Cyperaceae	H	EA	2	0.01	Small	Narrow	Narrow
Cyperus rotundus L.	Cyperaceae	H	EA	44	0.28	Large	Broad	Wide
Cyperus sp. 1	Cyperaceae	H	EA	68	0.44	Large	Broad	Wide
Cyperus sp. 2	Cyperaceae	H	EA	269	1.74	Small	Broad	Wide
Cyperus sp. 3	Cyperaceae	H	EA	74	0.48	Large	Broad	Wide
Cyperus sp. 4	Cyperaceae	H	EA	28	0.18	Small	Broad	Wide
Cyperus trachysanthos Hook. & Arn.	Cyperaceae	H	EA	353	2.28	Large	Broad	Wide
Dactyloctenium aegyptium (L.) Willd.	Poaceae	H	EA	622	4.01	Large	Broad	Wide
Dentella repens (L.) R.Forst. & G.Forst.	Rubiaceae	H	PA	251	1.62	Small	Broad	Wide
Desmodium gangeticum (L.) DC.	Papilionaceae	H	EPer	52	0.34	Large	Broad	Wide
Desmodium triflorum (L.) DC.	Papilionaceae	H	PPer	9,015	58.16	Large	Broad	Wide
Desmostachya bipinnata (L.) Stapf	Poaceae	H	EPer	140	0.90	Large	Broad	Wide
Dichanthium annulatum (Forssk.) Stapf	Poaceae	H	EA	1,028	6.63	Large	Broad	Wide
Digera muricata (L.) Mart.	Amaranthaceae	H	EA	3	0.02	Small	Broad	Wide
Digitaria ciliaris (Retz.) Koeler	Poaceae	H	EA	218	1.41	Small	Broad	Wide
Echinochloa colona (L.) Link	Poaceae	H	EA	65	0.42	Large	Broad	Wide
Eclipta prostrata (L.) L.	Asteraceae	H	EA	49	0.32	Large	Broad	Wide
Elephantopus scaber L.	Asteraceae	H	PA	132	0.85	Large	Broad	Wide
Emilia sonchifolia (L.) DC. ex DC.	Asteraceae	H	EA	273	1.76	Small	Broad	Wide
Eragrostis amabilis (L.) Wight & Arn.	Poaceae	H	EA	2,330	15.03	Large	Broad	Wide
Eragrostis capensis (Thunb.) Trin.	Poaceae	H	EA	45	0.29	Small	Narrow	Narrow
Eragrostis cilianensis (All.) Janch.	Poaceae	H	EA	29	0.19	Small	Narrow	Narrow
Eragrostis minor Host	Poaceae	H	EA	420	2.71	Large	Broad	Wide
Eragrostis pilosa (L.) P.Beauv.	Poaceae	H	EA	92	0.59	Small	Broad	Wide
Eragrostis unioloides (Retz.) Nees ex Steud.	Poaceae	H	EA	969	6.25	Large	Broad	Wide
Erigeron bonariensis L.	Asteraceae	H	EA	12	0.08	Large	Broad	Wide
Euphorbia hirta L.	Euphorbiaceae	H	EA	54	0.35	Large	Broad	Wide
Euphorbia hypericifolia L.	Euphorbiaceae	H	EA	54	0.35	Large	Broad	Wide
Euphorbia thymifolia L.	Euphorbiaceae	H	PA	29	0.19	Small	Narrow	Wide
Evolvulus alsinoides (L.) L.	Convolvulaceae	H	PPer	763	4.92	large	Narrow	Wide
Evolvulus nummularius (L.) L.	Convolvulaceae	H	PPer	7,805	50.36	Large	Broad	Wide
Ficus heterophylla L.f.	Moraceae	S	EPer	5	0.03	Large	Broad	Wide
Fimbristylis aestivalis Vahl	Cyperaceae	H	EA	144	0.93	Large	Broad	Wide
Fimbristylis bisumbellata (Forssk.) Bubani	Cyperaceae	H	EA	2,406	15.52	Large	Broad	Wide
Fimbristylis cymosa R.Br.	Cyperaceae	H	EA	228	1.47	Small	Broad	Wide
Fimbristylis dichotoma (L.) Vahl	Cyperaceae	H	EA	3	0.02	Small	Broad	Wide

Continued

Plant species	Family	Habit	Posture	Total no. individuals	Density (/m^2)	Population size	Habitat specialization	Geographical range
Fimbristylis falcata (Vahl) Kunth	Cyperaceae	H	EA	406	2.62	Small	Broad	Wide
Fimbristylis ovata (Burm.f.) J.Kern	Cyperaceae	H	EA	1,187	7.66	Large	Broad	Wide
Fimbristylis quinquangularis (Vahl) Kunth	Cyperaceae	H	EA	608	3.92	Large	Broad	Wide
Fimbristylis schoenoides (Retz.) Vahl	Cyperaceae	H	EA	367	2.37	Large	Broad	Wide
Fimbristylis sp.	Cyperaceae	H	EA	60	0.39	Small	Broad	Wide
Fumaria indica (Hausskn.) Pugsley	Fumariaceae	H	EA	1	0.01	Large	Broad	Wide
Glinus lotoides L.	Molluginaceae	H	PA	16	0.10	Small	Broad	Wide
Glinus oppositifolius (L.) Aug.DC.	Molluginaceae	H	PA	37	0.24	Small	Broad	Wide
Gnaphalium polycaulon Pers.	Asteraceae	H	EA	142	0.95	Small	Broad	Wide
Gomphrena celosioides Mart.	Amaranthaceae	H	EA	40	0.26	Large	Broad	Wide
Grangea maderaspatana (L.) Poir.	Asteraceae	H	PA	72	0.46	Large	Broad	Wide
Heliotropium indicum L.	Boraginaceae	H	EA	13	0.08	Small	Broad	Wide
Heliotropium ovalifolium Forssk.	Boraginaceae	H	EA	12	0.08	Small	Narrow	Narrow
Heliotropium strigosum Willd.	Boraginaceae	H	PPer	2,917	18.82	Small	Broad	Wide
Hemarthria compressa (L.f.) R.Br.	Poaceae	H	EA	47	0.30	Large	Narrow	Narrow
Hemidesmus indicus (L.) R.Br. ex Schult.	Asclepiadaceae	C	PerTw	51	0.33	Small	Broad	Wide
Hemigraphis hirta (Vahl) T.Anderson	Acanthaceae	H	PA	229	1.48	Large	Broad	Wide
Heteropogon contortus (L.) P.Beauv. ex Roem. & Schult.	Poaceae	H	EPer	25	0.16	Large	Narrow	Narrow
Hybanthus linearifolius (Vahl) Urb.	Violaceae	H	EA	122	0.79	Small	Narrow	Wide
Hygrophila auriculata (Schumach.) Heine	Lamiaceae	H	EA	13	0.08	Large	Broad	Narrow
Hygrophila difformis Blume	Acanthaceae	H	EA	12	0.08	Small	Broad	Wide
Hyptis suaveolens (L.) Poit.	Lamiaceae	H	EA	186	1.20	Large	Broad	Wide
Ichnocarpus frutescens (L.) W.T.Aiton	Apocynaceae	C	PerTw	62	0.40	Large	Broad	Wide
Imperata cylindrica (L.) Raeusch.	Poaceae	H	EA	3,035	19.58	Large	Broad	Wide
Indigofera linifolia (L.f.) Retz.	Papilionaceae	H	PPer	376	2.43	Large	Broad	Wide
Indigofera linnaei Ali	Papilionaceae	H	PPer	47	0.30	Small	Broad	Wide
Ipomoea aquatica Forssk.	Convolvulaceae	C	ATw	2	0.01	Large	Broad	Wide
Ipomoea pes-tigridis L.	Convolvulaceae	C	ATw	5	0.03	Small	Broad	Wide
Ipomoea sp.	Convolvulaceae	C	ATw	4	0.03	Small	Broad	Wide
Jatropha curcas L.	Euphorbiaceae	S	Eper	11	0.07	Small	Broad	Wide
Kylinga brevifolia Rottb.	Cyperaceae	H	EA	1,012	6.53	Large	Broad	Wide
Lantana camara L.	Verbenaceae	S	EPer	5	0.03	Large	Broad	Wide
Laphangium luteoalbum (L.) Tzvelev	Asteraceae	H	EA	752	4.85	Small	Broad	Wide
Lathyrus aphaca L.	Papilionaceae	C	ATn	37	0.24	Small	Broad	Wide
Lathyrus odoratus L.	Papilionaceae	C	ATn	44	0.28	Small	Broad	Wide
Lathyrus sativus L.	Papilionaceae	C	ATn	13	0.08	Small	Broad	Wide
Launaea aspleniifolia (Willd.) Hook.f.	Asteraceae	H	EA	396	2.55	Small	Broad	Wide
Launaea nudicaulis (L.) Hook.f.	Asteraceae	H	EA	4	0.03	Small	Broad	Wide
Launaea procumbens (Roxb.) Ramayya & Rajagopal	Asteraceae	H	EA	6	0.04	Small	Broad	Wide

Continued

Plant species	Family	Habit	Posture	Total no. individuals	Density (/m^2)	Population size	Habitat specialization	Geographical range
Leucas aspera (Willd.) Link	Lamiaceae	H	EA	19	0.12	Small	Broad	Narrow
Leucas cephalotes (Roth) Spreng.	Lamiaceae	H	EA	51	0.33	Small	Broad	Narrow
Limnophylla sp. 1	Scrophulariaceae	H	EA	4	0.03	Small	Broad	Wide
Limnophylla sp. 2	Scrophulariaceae	H	EA	11	0.07	Small	Broad	Wide
Limnophylla sp. 3	Scrophulariaceae	H	EA	40	0.26	Small	Broad	Wide
Lindernia antipoda (L.) Alston	Scrophulariaceae	H	EA	182	1.17	Small	Broad	Wide
Lindernia brachiata (Link & Otto) Biswas	Scrophulariaceae	H	EA	22	0.14	Large	Broad	Wide
Lindernia ciliata (Colsm.) Pennell	Scrophulariaceae	H	EA	8,761	56.52	Large	Broad	Wide
Lindernia crustacea (L.) F.Muell.	Scrophulariaceae	H	EA	228	1.47	Small	Broad	Wide
Lindernia diffusa (L.) Wettst.	Scrophulariaceae	H	EA	22,288	143.79	Large	Broad	Wide
Lindernia procumbens (Krock.) Philcox	Scrophulariaceae	H	PA	108	0.70	Large	Broad	Wide
Lindernia pyxidaria All.	Scrophulariaceae	H	EA	158	1.02	Large	Narrow	Narrow
Lippia alba (Mill.) N.E.Br. ex Britton & P.Wilson	Verbenaceae	S	EA	9	0.06	Small	Broad	Wide
Lobelia alsinoides Lam.	Lobeliaceae	H	EA	141	0.91	Small	Narrow	Narrow
Ludwigia adscendens (L.) H.Hara	Onagraceae	H	PA	1	0.01	Small	Broad	Wide
Ludwigia octovalvis (Jacq.) P.Raven	Onagraceae	H	EA	10	0.06	Small	Broad	Wide
Ludwigia perennis L.	Onagraceae	H	EA	176	1.14	Small	Broad	Wide
Ludwigia prostrata Roxb.	Onagraceae	H	EA	9	0.06	Small	Broad	Wide
Malvastrum coromandelianum (L.) Garcke	Malvaceae	H	EA	34	0.30	Small	Broad	Wide
Martynia annua L.	Martyniaceae	H	EA	10	0.06	Small	Narrow	Narrow
Mazus pumilus (Burm.f.) Steenis	Scrophulariaceae	H	EA	129	0.83	Large	Broad	Wide
Mecardonia procumbens (Mill.) Small	Scrophulariaceae	H	EA	168	1.08	Small	Broad	Wide
Medicago polymorpha L.	Papilionaceae	H	EA	453	2.92	Small	Broad	Wide
Melochia corchorifolia L.	Sterculiaceae	H	EA	118	0.76	Large	Broad	Wide
Merremia sp.	Convolvulaceae	H	PA	17	0.11	Small	Broad	Wide
Momordica dioica Roxb. ex Willd.	Cucurbitaceae	C	ATn	3	0.02	Small	Broad	Wide
Mukia maderaspatana (L.) Roem.	Cucurbitaceae	C	ATn	4	0.03	Small	Broad	Wide
Murdannia nudiflora (L.) Brenan	Commelinaceae	H	PA	1,516	9.78	Large	Broad	Wide
Ocimum americanum L.	Lamiaceae	H	EA	55	0.35	Large	Broad	Wide
Oldenlandia biflora L.	Rubiaceae	H	PA	63	0.41	Large	Broad	Wide
Oldenlandia corymbosa L.	Rubiaceae	H	PA	1,315	8.48	Large	Broad	Wide
Oldenlandia tenelliflora (Blume) Kuntze	Rubiaceae	H	EA	827	5.35	Small	Broad	Wide
Operculina turpethum (L.) Silva Manso	Convolvulaceae	C	PerTw	8	0.05	Large	Broad	Wide
Oplismenus burmanni (Retz.) P.Beauv.	Poaceae	H	PA	529	3.41	Large	Broad	Wide
Oxalis corniculata L.	Oxalidaceae	H	PA	92	0.59	Large	Broad	Wide
Oxystelma secamone H.Karst.	Asclepiadaceae	C	ATw	2	0.01	Small	Broad	Wide
Panicum sumatrense Roth	Poaceae	H	EA	20	0.13	Small	Broad	Wide
Panicum antidotale Retz.	Poaceae	H	EA	74	0.48	Large	Broad	Wide
Panicum sp. 1	Poaceae	H	PA	125	0.81	Large	Broad	Wide

Continued

Plant species	Family	Habit	Posture	Total no. individuals	Density (/m^2)	Population size	Habitat specialization	Geographical range
Panicum maximum Jacq.	Poaceae	H	EA	296	1.91	Large	Broad	Wide
Panicum virgatum L.	Poaceae	H	EA	343	2.21	Small	Broad	Wide
Parthenium hysterophorus L.	Asteraceae	H	EA	350	2.26	Large	Broad	Wide
Paspalidium flavidum (Retz.) A.Camus	Poaceae	H	PA	1,311	8.46	Large	Broad	Wide
Paspalum distichum L.	Poaceae	H	EPer	672	4.34	Small	Broad	Wide
Paspalum scrobiculatum L.	Poaceae	H	EA	1,679	10.83	Large	Broad	Wide
Pennisetum glaucum (L.) R.Br.	Poaceae	H	EA	1,123	7.25	Large	Broad	Wide
Peristrophe bicalyculata (Retz.) Nees	Acanthaceae	H	EA	41	0.26	Large	Broad	Wide
Perotis indica (L.) Kuntze	Poaceae	H	PA	174	1.12	Large	Narrow	Narrow
Persicaria glabra (Willd.) M.Gómez	Polygonaceae	H	EA	8	0.05	Large	Broad	Wide
Persicaria lapathifolia (L.) Delarbre	Polygonaceae	H	EA	10	0.06	Large	Broad	Wide
Phyla nodiflora (L.) Greene	Verbenaceae	H	EA	85	0.55	Large	Broad	Wide
Phyllanthus niruri L.	Euphorbiaceae	H	EA	69	0.45	Large	Broad	Wide
Phyllanthus urinaria L.	Euphorbiaceae	H	EA	2,690	17.36	Small	Broad	Wide
Phyllanthus virgatus G.Forst.	Euphorbiaceae	H	EPer	1,173	7.57	Large	Broad	Wide
Physalis minima L.	Solanaceae	H	EA	7	0.05	Small	Broad	Wide
Physalis peruviana L.	Solanaceae	H	EA	3	0.02	Small	Broad	Wide
Polygala chinensis L.	Polygalaceae	H	EA	94	0.61	Small	Broad	Wide
Polygonum plebeium R.Br.	Polygonaceae	H	PA	286	1.85	Large	Broad	Wide
Portulaca oleracea L.	Portulacaceae	H	PA	64	0.41	Large	Broad	Wide
Pouzolzia zeylanica (L.) Benn.	Urticaceae	H	EA	19	0.12	Large	Broad	Wide
Pycreus pumilus (L.) Nees	Cyperaceae	H	EA	30	0.19	Small	Broad	Wide
Ranunculus sceleratus L.	Ranunculaceae	H	EA	4	0.03	Large	Broad	Wide
Rhynchospora colorata (L.) H.Pfeiff.	Cyperaceae	H	EA	55	0.35	Small	Broad	Wide
Ruellia tuberosa L.	Acanthaceae	H	EA	4	0.03	Large	Broad	Wide
Rumex hastatus D.Don.	Polygonaceae	H	EA	199	1.28	Large	Broad	Wide
Rungia repens (L.) Nees	Acanthaceae	H	PA	9,701	62.59	Large	Broad	Wide
Saccharum sp.	Poaceae	H	EA	425	2.74	Large	Broad	Wide
Saccharum spontaneum L.	Poaceae	H	EPer	76	0.49	Large	Broad	Wide
Sacciolepis indica (L.) Chase	Poaceae	H	EA	144	0.93	Large	Broad	Wide
Sacciolepis myosuroides (R.Br.) A.Camus	Poaceae	H	EA	79	0.51	Large	Broad	Wide
Salvia plebeia R.Br.	Lamiaceae	H	EA	11	0.07	Small	Broad	Wide
Salvia reptans Jacq.	Lamiaceae	H	EA	6	0.04	Small	Broad	Wide
Schoenoplectiella lateriflora (J.F.Gmel.) Lye	Cyperaceae	H	PA	13	0.08	Small	Broad	Wide
Schoenoplectiella mucronata (L.) J.Jung & H.K.Choi	Cyperaceae	H	EA	13	0.08	Small	Broad	Wide
Scoparia dulcis L.	Scrophulariaceae	H	EA	172	1.11	Large	Broad	Wide
Senna obtusifolia (L.) H.S. Irwin &Barneby	Caesalpiniaceae	H	EA	606	3.91	Large	Broad	Wide
Senna occidentalis (L.) Link	Caesalpiniaceae	H	EA	91	0.59	Large	Broad	Wide
Senna pumila (Lam.) K.Larsen	Caesalpiniaceae	H	PA	13	0.08	Large	Narrow	Narrow

Continued

Plant species	Family	Habit	Posture	Total no. individuals	Density (/m^2)	Population size	Habitat specialization	Geographical range
Senna tora (L.) Roxb.	Caesalpiniaceae	H	EA	4	0.03	Large	Broad	Wide
Sida acuta Burm.f.	Malvaceae	H	EA	191	1.23	Large	Broad	Wide
Sida cordata (Burm.f.) Borss.Waalk.	Malvaceae	H	EA	185	1.19	Large	Broad	Wide
Sida cordifolia L.	Malvaceae	H	EA	182	1.17	Large	Broad	Wide
Sida ovata Forssk.	Malvaceae	H	EA	7	0.05	Large	Broad	Wide
Sida rhombifolia L.	Malvaceae	H	EA	195	1.26	Large	Broad	Wide
Sida spinosa L.	Malvaceae	H	EA	18	0.12	Small	Broad	Wide
Solanum americanum Mill.	Solanaceae	H	EA	23	0.15	Large	Broad	Wide
Solanum virginianum L.	Solanaceae	H	EA	1	0.01	Large	Broad	Wide
Soliva anthemifolia (Juss.) Sweet	Asteraceae	H	PA	4	0.03	Small	Broad	Wide
Sonchus asper (L.) Hill	Asteraceae	H	EA	11	0.07	Large	Broad	Wide
Sonchus oleraceus (L.) L.	Asteraceae	H	EA	3	0.02	Small	Broad	Wide
Spermacoce pusilla Wall.	Rubiaceae	H	EA	4,076	26.30	Large	Narrow	Narrow
Sphenoclea zeylanica Gaertn.	Sphenocleaceae	H	EA	10	0.06	Small	Narrow	Narrow
Spilanthes acmella (L.) L.	Asteraceae	H	PA	31	0.20	Large	Broad	Wide
Tecoma capensis (Thunb.) Lindl.	Bignoniaceae	C	PerTw	3	0.02	Small	Broad	Wide
Tephrosia purpurea (L.) Pers.	Papilionaceae	H	EPer	6	0.04	Large	Broad	Wide
Teramnus labialis (L.f.) Spreng.	Papilionaceae	C	PerTw	8	0.05	Small	Narrow	Narrow
Tiliacora racemosa Colebr.	Menispermaceae	C	PerTw	1	0.01	Large	Broad	Wide
Tinospora sinensis (Lour.) Merr.	Menispermaceae	C	PerTw	9	0.06	Large	Broad	Wide
Trianthema portulacastrum L.	Aizoaceae	H	PA	8	0.05	Small	Broad	Wide
Tribulus terrestris L.	Zygophyllaceae	H	PA	5	0.03	Small	Narrow	Narrow
Tridax procumbens (L.) L.	Asteraceae	H	EA	603	3.89	Large	Broad	Wide
Triumfetta pentranda A.Rich.	Malvaceae	H	EA	31	0.20	Large	Broad	Wide
Triumfetta rhomboidea Jacq.	Malvaceae	S	EA	18	0.12	Large	Broad	Wide
Urena lobata L.	Malvaceae	S	EA	5	0.03	Large	Broad	Wide
Urena repanda Roxb. ex Sm.	Malvaceae	H	EA	35	0.23	Large	Broad	Wide
Vernonia sp.	Asteraceae	H	EA	9	0.06	Small	Narrow	Narrow
Xanthium strumarium L.	Asteraceae	S	EA	79	0.51	Large	Broad	Wide
Zephyranthes citrina Baker	Amaryllidaceae	H	EA	8	0.05	Small	Narrow	Narrow
Zornia gibbosa Span.	Papilionaceae	H	PA	3,255	21.00	Small	Broad	Wide
Samples in process of species identification:								
Unknown 3	Poaceae	H	EA	679	4.38	Small	Broad	Wide
Unknown 4	Poaceae	H	EA	1,270	8.19	Large	Broad	Wide
Unknown 5	Poaceae	H	EA	620	4	Large	Broad	Wide
Unknown 6	Poaceae	H	EA	36	0.23	Small	Broad	Wide
Unknown 7	Poaceae	H	EA	170	1.07	Small	Broad	Wide
Unknown 8	Poaceae	H	EA	57	0.37	Large	Broad	Wide
Unknown 9	Poaceae	H	EA	311	2.01	Small	Broad	Wide

Continued

Plant species	Family	Habit	Posture	Total no. individuals	Density (/m^2)	Population size	Habitat specialization	Geographical range
Unknown 10	Poaceae	H	EA	18	0.12	Small	Broad	Wide
Unknown 11	Poaceae	H	EA	340	2.19	Small	Broad	Wide
Unknown 12	Poaceae	H	EA	67	0.43	Large	Broad	Wide
Unknown 13	Poaceae	H	EA	11	0.07	Large	Broad	Wide
Unknown 14	Poaceae	H	EA	95	0.61	Small	Broad	Wide
Unknown 15	Poaceae	H	EA	19	0.12	Small	Broad	Wide
Unknown 16	Poaceae	H	EA	72	0.46	Large	Broad	Wide
Unknown 17	Poaceae	H	EA	36	0.23	Large	Broad	Wide
Unknown 18	Poaceae	H	EA	151	0.97	Large	Broad	Wide
Unknown 19	Unknown	H	EA	3	0.02	Small	Broad	Wide
Unknown 20	Papilionaceae	H	PA	25	0.16	Small	Broad	Wide
Unknown 21	Unknown	C	ATw	4	0.03	Small	Broad	Wide
Unknown 22	Papilionaceae	C	ATw	2	0.01	Small	Broad	Wide
Unknown 23	Papilionaceae	C	ATw	8	0.05	Large	Broad	Wide
Unknown 24	Asteraceae	H	EA	4	0.03	Large	Broad	Wide
Unknown 25	Papilionaceae	C	ATw	2	0.01	Large	Broad	Wide
Unknown 27	Acanthaceae	H	EA	17	0.11	Small	Broad	Wide
Unknown 28	Unknown	H	EA	5	0.03	Large	Broad	Wide
Unknown 29	Unknown	H	PA	4	0.03	Small	Broad	Wide
Unknown 30	Unknown	H	EA	2	0.01	Small	Broad	Wide

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