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Spatial distribution of *Tephrosia purpurea* on different habitats in relation to soil, community and site factors

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Abstract
In natural communities, identification of environmental as well as species intrinsic factors associated with its spatial distribution is crucial one for establishing a more resilient community. Spatial paternities of *Tephrosia purpurea* were assessed at three different types of habitat, namely older alluvial plain (OAP), younger alluvial plain (YAP) and Piedmonts located (36 sites) with-in semiarid regions of the Indian Thar desert. Distinctive dispersion indices deals with diverse numerical inborn probabilities were quantified. The result revealed a dominant clumped pattern at OAP habitat, while site-specific patterns (random, uniform and clumped and uniform and random) recorded at YAP and at Piedmont. In totality, community parameters don't demonstrate any noteworthy association with the clumped pattern type of this species at OAP and YAP habitats, further at YAP habitat, site quality elements were additionally non-significant for any example sort. Threshold limits of some exploratory parameters also record that possibly would decide the faith of its distribution type.

Keywords: Alluvial plain, Community dynamics, Grazing and bare surface area, Habitat factors, *Tephrosia purpurea*

Introduction

The horizontal organization of plant communities can be effectively described by explaining their physical arrangement or distribution within the community which in turn can prove to be an utilitarian tool in relation to spatial patterns of a species (Mathur, 2014a). The plant spatial pattern development is the after-effect of distinctive procedure and these can be evaluated by utilizing modules like explanatory models (HilleRisLambers *et al.,* 2001), Markov chains (Beyene *et al.,* 2016) and cellular automata (Bak *et al.,* 1988). The processes that govern spatial pattern of a species operate at multiple levels incorporate topography, soil quality, accessibility of water and nutrients. Seed dispersal (Greig-Smith, 1983; Pacala and Silander, 1985; Schurr *et al.,* 2004), interaction among individuals (Alonso *et al.,* 2002), plant-plant interactions (Mathur, 2014b), environmental heterogeneity and disturbance via grazing (Rayburn and Monaco, 2011) are the major governing factors.
The example of three essential sorts of plant spatial have been perceived: (1) regular (or even, uniform, negatively contagious), where individuals within a population are uniformly spaced; (2) random (or chance) pattern in which all individuals have an equal chance of living anywhere within an area; and (3) clumped (or aggregated, patchy, contagious) in which individual has a higher likelihood of being found in some region than someplace else (Condit *et al.,* 2000). The outcomes are then linked to the ecological processes through which the patterns are conjectured to have formed. Sometimes, observed patterns linked to either positive or negative plant interactions that have the potential to structure local plant neighborhoods (Rayburn and Monaco, 2011). For instance, a regular plant spatial pattern often deciphered as an indication of intense rivalry between individuals for limited resources (Stoll and Bergius, 2005). In contrast, the aggregated pattern (especially inter-specific aggregations) interpreted as evidence of neutral or positive plant interactions (Kéfi *et al.,* 2007). Aggregated plant patterns linked to patchy distributions of the soil assets, especially in shrub-dominated communities (Perry *et al.,* 2008).

Tephrosia purpurea is a leguminous erect short-lived under scrub, prefers dry, gravelly/ rocky and sandy soils. Ecosystem services of this species include regulatory (checks the soil-erosion and nitrogen fixation), provisional (leaves are used as fodder, seeds can be used as a substitute for coffee, broom making) and cultural (medicinal properties) (Padmavathy and Poyyamoli, 2012). Beforehand different ecological aspects of this species have been carried out which related to germination ecology (Sunita *et al.,* 2014), allelopathic

(Yadav and Yadav, 2014), nitrogen fixation capacity (Mohmmaed and Fredan, 2011) and association studies (Mathur and Sundaramoorthy, 2013). The present study was led with two objectives in the perspective of the above points of view, (a) to know the spatial distribution patterns of *Tephrosia purpurea* at different habitats, and (b) how habitat specific biotic (grazing frequency, and community parameters) and abiotic factors (soil parameters and percent availability of bare surface area) influence the spatial pattern's of this species.

Materials and Methods

Habitat and site selection : Three dominant habitats namely older alluvial plain (OAP), younger alluvial plain (YAP) and Piedmonts within arid regions of the Indian Thar desert were selected to evaluate their potential impacts on the spatial distribution patterns of this species. Under each habitat category, twelve different sites were selected (total 36 sites). The geographical extent of these habitats ranged from (N) 26^0 11' 33.4" and 26^0 21' 54.5" to (E) 72^0 56' 5.9" and 73^0 60' 35.1". To study population dynamics of this species, 10 quadrats (10 x 10 m) were laid down (2003 - 2006 and reanalysis in 2014) at each site (Kent and Cooker, 1992). Vegetation community parameters were quantified and interpreted by following Ludwig and Reynolds (1988). Site qualities were assessed through Kumar (1992). Soil samples were collected from the soil layer up to 30 centimetres. Soil moisture, electric conductivity (mS/m) and pH were estimated through following Pandeya *et al.* (1968). The particle size, organic carbon and total nitrogen were quantified by Jackson (1973) while, available phosphorus quantified by the development of molybdenum blue color method (Allen *et al.,* 1976).

Dispersion indices : The dispersion indices of four different types, namely Lloyd's, Morisita, Moran's I and Smith and Wilson were quantified. The indices were selected based on their mathematical inheritance that deals with mean crowding, degree of aggregation, covariance with the neighborhood and variance in abundance, respectively. These were quantified according to Ludwig and Reynolds (1988) and Sawada (1999). Value of the Lloyd's index 0 or <1 indicates uniform; 1 = random and >1 clumped (Mathur, 2014b), while index value of the Morisita's index equal to 1 indicates random, more than one indicates aggregated, and less than one uniform distribution (Kristensen *et al.,* 2006). Similarly, values of Moran's index ranges from approximately -1 to 1(Boots and Getis, 1988). A significant positive value indicates an aggregated pattern; a significant negative value indicates a regular spatial pattern, whereas non-significant values indicate a random distribution. The threshold of 1.96 applied to test the significance level of Z (Mathur, 2014a). Smith and Wilson index is basically based on the variance in the abundance of the species. Exploratory factor analysis (Principal component analysis, PCA) carried out as a data reduction technique. The main objective of PCA analysis was to find out underlying factors associated with distribution patterns of *T. purpurea*. Analysis of variance carried out with two-way strip plot design (Deb *et al*., 2016). Appropriate regression equations were selected with the help of a significance probability level and higher R^2 value (* 5% and ** 1% significance). This path analysis carried out by Curve Expert software (2001).

Results and Discussion

Habitat and site parameters **:** Range of various soils, community and site quality parameters are depicted in Table 1. Higher woody perennial richness and overall diversity (Shannon and Weaver index) recorded at OAP followed by YAP and piedmonts habitats. Similarly, evenness index at 12 sites of OAP indicated them to be more homogenous compared to sites of YAP and piedmont sites. Analysis of variance revealed significant variations in community parameters (richness, Shannon and Weaver index and Simpson index of dominance) brought only by a habitat factor while both habitat and site factors were non-significant for evenness. ANOVA analysis suggested that habitat factor brought significant variation in these chemical and physical soil properties. Among the site quality parameters, grazing intensity and percent bare surface area ranged from 1-3 at OAP and YAP, however, these parameters at piedmonts ranged from 1-4 (Table 1). Their ANOVA analysis divulges that variations in both these parameters brought by both sites as well as by habitat factors. Thus, these two parameters considerably varied between the sites belonging to the same habitat.

Spatial indices **:** Dispersal indices were looked to maintain a strategic distance from the reiteration in translation, with reference to habitat. According to interpretation criteria of different indices and with the use of their significant analysis tool, four different spatial patterns were recognized, namely, (a) the clumped (b)

Table 1. Range of different parameters

Parameters	OAP	YAP	Piedmonts
Richness	7- 12	4 -8	2 - 7
Simpson	0.0-0.19	0.1-0.2	0.2-0.6
Shannon Index	1.7-2.3	1.3-2.0	0.5-1.7
Evenness	0.8-1.2	0.8-1.0	0.7-1.0
Clay (%)	17.2-35.2	10.2-23.4	10.2-30.1
Silt (%)	7.5-18.8	24.8-34.2	8.2-17.61
Sand (%)	38.2-63.9	28.4-47.5	20.2-34.2
Gravel (%)	8.0-13.4	15.5-21.0	30.2-48.4
Soil organic carbon (mg/100g)	62.8-384.1	19.5-432.0	19.1-187.8
Soil Phosphorus (mg/100g)	31.2-74.0	10.3-44.8	4.7-25.3
Soil Nitrogen (mg/100g)	18.9-112.6	16.8-255	19.1-76.2
C/N ratio	0.7-10.5	0.29-6.2	0.5-5.3
pH	6.1-9.1	6.2-7.9	6.3-8.1
Electric Conductivity (mS/m)	0.1-0.5	0.1-0.2	0.1-0.2
Soil moisture (%)	3.8-12.4	9.3-18.7	3.6-10.2
Removal of plant parts	1- 3	1 – 3	1-4
Bare surface area (%)	1- 3	1 – 3	1-4

OAP : Older alluvial plain; YAP: Younger alluvial plain

the random (c) the uniform and random and (d) the uniform and clumped. Among these four patterns, clumped pattern transcendentally showed by all the indices ascertained for sites belongs to OAP. At this habitat positive significant value of Moran's I index indicates a clumped pattern (Table 2) while for rest two habitats Moran's index values were non-significant that speak to the irregular pattern. Similarly, at OAP, Morisita index value more than one indicates clumped pattern with high *chi-square* values, anyway for YAP habitat some sites either show a value equal to one (random pattern) or less than one (uniform pattern) and also for piedmont, some sites had more than one value (clumped) and few sites having less than one index (uniform). Analysis of Variance indicates that significant variation for these indices brought by habitat factor only. In principal ordination (Figure 1a, b, c) as to the cumulative percentage, the first four axes together accounted for 70.19, 69.01 and 75.50% of variability in the data sets related to OAP, YAP and Piedmont habitats, respectively, and in all these three cases the first two axes *i.e.* F1 and F2 showed the maximum variance.

***Factors influencing the spatial distribution* :** Regression analysis between different exploratory factors (soil, community and site quality) and dependent factors (different spatial indices) were carried out to determine the underlying factors for observed spatial patterns *viz.,* clumped, random, uniform and random and uniform and clumped. Results revealed that among the soil factors silt, clay and gravel content, soil organic carbon, pH, electric conductivity, the soil phosphorus and the C/N ratio significantly affects the patterns at different habitats, however soil nitrogen and moisture component were non-significant. Similarly, among the community parameters woody perennial richness, Shannon and Weaver index and Simpson index affect the patterns at piedmont (uniform and clumped) and at YAP (uniform and random patterns) habitats, respectively. Evenness factor doesn't show any relationship with any patterns. In contrast, site status parameters, i.e. grazing intensity and bare surface area (%) affect only the clumped pattern of this species at OAP and Piedmont habitats.

Clumped pattern and their exploratory factors : At OAP the clumped pattern was indicated by all four indices, however; at piedmont this pattern was indicated Lloyd's and Smith and Wilson indexes and at YAP only Lloyd's index showed such pattern. Among the soil factors, soil pH showed a quadratic relationship with Moran's I at OAP (R^2 = 0.62*) linear relationships with Lloyd's (R^2 = 0.71**) and Smith and Wilson index (R^2 = 0.74**) at OAP and Piedmont, respectively. Thus, the majority of sites relates to OAP and Piedmont habitats, slightly alkaline condition (8-9.09) negatively affects the degree of clumped pattern. Soil electrical conductivity linearly governs the clumped pattern (Lloyd's index) of this species at Piedmont (R^2 = 0. 65*) and at OAP habitat (R^2 = 0. 63*) while quadratic relationships were found with Smith and Wilson index at OAP (R^2 = 0. 60*). The quadratic impact of the C/N ratio (with Smith and Wilson index) as well as soil P (Lloyd's

Table 2. Spatial distribution indices at various habitats

Sites	OAP				YAP				Hill and Piedmont			
	1	2	3	4	1	2	3	4	1	2	3	4
1	0.80	1.16	9.52	0.70	-0.17	1.01	4.88	1.2	0.01	0.89	3.24	0.79
2	0.71	1.14	5.39	0.70	0.02	1.05	3.99	1.4	0.52	0.86	3.44	0.70
3	0.63	1.20	6.45	0.70	0.73	0.89	3.37	1.2	0.21	0.94	3.44	0.72
4	0.74	1.12	4.96	0.71	0.30	0.91	3.58	1.2	0.31	0.95	3.51	0.70
5	0.61	1.14	5.89	0.70	0.27	1.04	5.06	1.1	-0.21	1.18	5.25	0.73
6	0.75	1.16	9.51	0.77	0.09	1.09	4.16	1.1	-0.19	1.21	3.90	0.72
7	0.72	1.51	5.73	0.70	-0.04	0.93	3.82	0.70	0.10	1.14	4.34	0.75
8	0.69	1.12	8.68	0.72	0.50	1.00	3.18	0.70	-0.49	1.25	4.43	0.70
9	0.81	1.61	6.21	0.71	-0.14	0.87	3.82	1.1	-0.45	1.20	4.79	0.71
10	0.67	1.20	8.68	0.74	0.09	0.92	3.99	0.99	0.11	1.28	3.82	0.71
11	0.59	1.19	7.00	0.71	0.02	1.04	4.70	0.70	-0.24	1.24	4.43	0.70
12	0.71	1.19	4.44	0.77	-0.05	0.85	3.24	0.72	-0.25	0.90	3.58	0.70

1= Moran's index; 2= Morisita index; 3= Index of mean crowding and 4 = Smith and Wilson index

index) on clumped distribution pattern was observed at OAP (R^2 = 0.78**) and YAP (R^2 = 0.62*), respectively. Thus, both these soil parameters facilitate the degree of clumping at different habitats, respectively.

Entertainingly, impacts of soil textures on clumped pattern recorded only at piedmont, where, both clay (R^2 = 0.81**) and gravel content (R^2 = 0.78**) governed such pattern in quadratic but in opposite fashion *i.e.* lower clay content (16.2-20.2) or higher gravel content (30.6 to 50). Among the habitat factors, bare surface area (%), linearly affects the clumped pattern of this species both at OAP (R^2 = 0.62*) and at Piedmont (R^2 = 0.64*), grazing intensity at OAP habitat also affecting this pattern type in a quadratic fashion (R^2 = 0.66*). For explaining the dominate clumped pattern at various habitats, particularly on OAP, Quets *et al.* (2014) approaches of seed limitation (SL) and habitat patchiness (HP) can be employed. Seed limitation has two components, *i.e.* distance seed limitation and density. Seed limitation occurs when seed can't potentially reach all landscapes locations and the seed are restricted to parent plant surroundings (*i.e.* seed store within seed shadow). For *T. purpurea,* this approach can also utilize to explain clumped pattern that can be supported by another finding related to its vivipary habitat (Mishra and Sen, 1984). This habit limits its dispersal ability, particularly at OAP where herbivore and wind velocity is lesser than compared to YAP or Piedmont.

Suzuki *et al.* (2005) have reported that both vegetative as well as reproductive phases of *Lysimachia rubida* showed aggregation within small-gravel areas, which became intensified with growth stages. Their outcomes proposed that patches of smaller gravel are suitable for survival of both vegetative and reproductive plants. Impacts of soil particle and chemical properties in relation to spatial patterns of *Haloxylon ammodendrvon, Ammoipotanthus mongolicus* and *Peganum harmala* have been evaluated by Li *et al.* (2007), Jia *et al.* (2009) and Abadou *et al.* (2013), respectively. Lower or moderate grazing intensity and clumping pattern (Morans's I index) at OPA, can be explained by the findings of Baraza *et al.* (2006) and Wang *et al.* (2010) suggested that the sheep consummation rate of higher preferred species occurs with the situation under low preferred species (non-palatability of *T. purpurea* in the present case) followed a clumped pattern. The clumped distributions of less preferred species are always beneficial for herbivore to search and consume favored one, thus, higher grazing activity at site/habitat indicate clumped pattern of non-preferred or non-palatable species. Hence, the clumped pattern at OAP in relation to grazing frequency may be the resultant action of patchy grazing (i.e. selection of palatable and avoid unpalatable species). The present study attempted to fill the gap related to such prediction and in this case, habitat-intra-specific relationships between grazing frequency and spatial pattern achieved. Hence, the accompanying elements can be viewed as biological pointers for the development of the clumped pattern: (a) Community parameters not affecting the clumped distribution of this species at habitats like OAP, YAP and the piedmont, (b) At YAP habitat, only soil phosphors can be designated as a controlling indicator for the clumped pattern (Figure 1b), (c) at OAP and piedmont soil electric conductivity supports it's shifting from the clumped to uniform distribution, and (d), the soil texture, particularly gravel and clay contents at piedmont are the indicator factor (Fig. 1c).

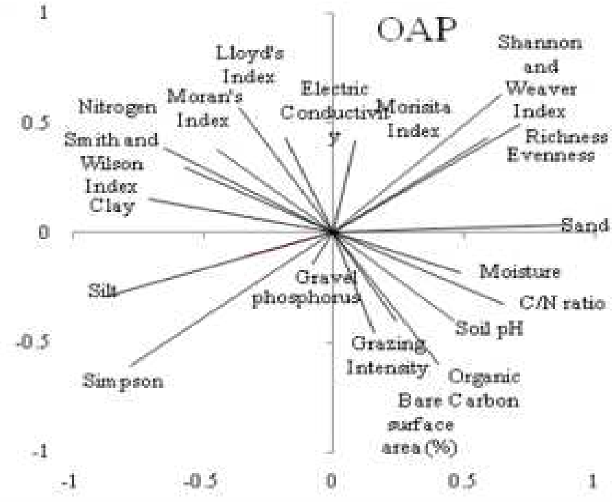

Fig 1a. PCA at OAP

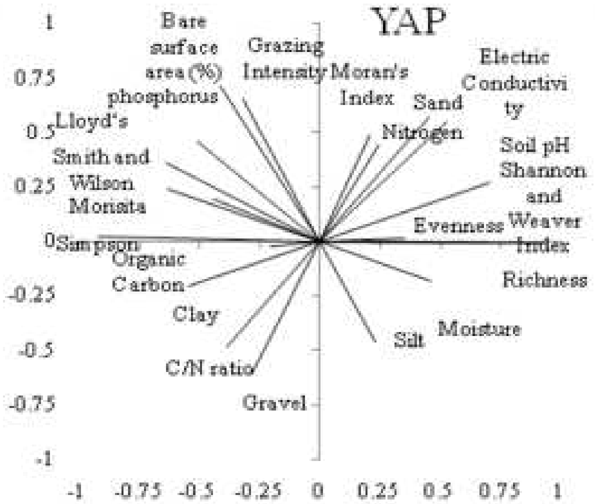

Fig 1b. PCA at YAP

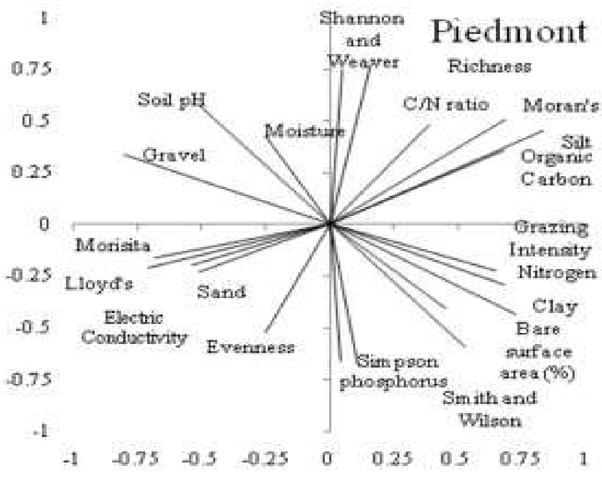

Fig 1c. PCA at Piedmont

Random pattern and piedmont and their exploratory factors : Non-significant Moran's I index at YAP and at Piedmont, representing the random distribution. Soil, community as well as site quality parameters were statistically non significant with random pattern at YAP. However, at Piedmont, silt content (R^2 = 0.71*), soil organic carbon (R^2 = 0.66*) and C/N ratio (R^2 = 0.58*) identified as indicator factors that controls the random type distribution pattern in linear fashion but their controlling mechanisms are site specific *i.e.* they have contrasting relationships with Moran index that changed site by site. Thus, for random pattern at piedmont these types of factors are not the best indicators.

***Uniform and clumped pattern at piedmont* :** With Morisita index, 58% (7 sites) and 42% (5 sites) showed clumped and uniform pattern, respectively. The sites with the clumped pattern may have marked with five noteworthy ecological processes that can govern such pattern includes, evidence of neutral or positive plant interaction, sketchy dissemination of the soil assets, the size deviated, the niche segregation and dispersal limitation (Fig. 1c) and similar sites with uniform pattern can be under the intense competition between the plants for limited resources.

Regression analysis, suggested that the community parameters like the woody perennial richness affects such two types of patterns at different sites belongs to same habitat (R^2 =0.57*), Simpson index (R^2 = 0.65*) and Shannon and Waver diversity index (R^2 =0.74**) in quadratic fashion. For answering the uniform and the clumped patterns, findings of Eriksson (1994) can be utilized that suggested that inconsistent seed dispersal near the mother plants clarifies the total of seedlings around regenerative plants. If seeds frequently dispersed beyond a patch within a habitat, the plants would occupy most of the suitable patches (*i.e.* uniform pattern will generate). On the other hands, if the dispersal of seeds happens just around reproductive plants within a patch, the plants would aggregate within the 'home' patch and a number of suitable patches may remain unoccupied by plants. In this manner, the spatial scale and the degree of aggregated patterns of a local population would depend on the sizes of suitable patches and the capability of the plants to disperse their seeds and the capability of plants to persevere inside patches (Rand, 2000).

As per Schurr *et al.* (2004) "It is exceptionally hard to distinguish which variables create aggregated patterns of the local population in a patchy habitat, because those different factors can potentially generate the same aggregated patterns of the plants", thus, to patch the existing knowledge gap it can be concluded that 3 to 5 woody perennial richness emerged as a threshold level at which pattern will be clumped and either 2 or between 5 to 7 supports its uniform distribution. Similarly, diversity parameters (Shannon and Weaver index) from 1.05 to 1.35 are the threshold level for the clumped pattern while 0.56 to 0.69 and 1.37 to 1.71 is the predictor for uniform pattern. The Simpson index showed that dominance from 0.27-0.35 supports clumped distribution type while 0.21-0.28 and 0.38 to 0.49 uniform pattern. Thus, from present study the above mentioned threshold limits of diversity parameters can be utilized as an indicator for such pattern analysis.

Uniform and random pattern at YAP : At YAP habitat, Morisita index revealed the uniform (50% sites) and random (remaining 50% sites) patterns, and similar to piedmont these patterns also controlled by community parameters like the woody perennial richness, linearly (R^2 =0.62*) and with Simpson (R^2 =0.68*) and Shannon and Weaver (R^2 =0.67*) index in quadratic fashions. The woody perennial richness from 4 to 6 has emerged as the threshold level on which pattern will be random and 6 to 8 richness supports uniform distribution. Similarly, diversity parameters (Shannon and Weaver index) from 1.3 to 1.69 are the threshold level for random pattern while 1.63 to 2.03 is the predictor for uniform pattern. The Simpson index showed that dominance from 0.191 to 0.27 supports the random distribution type while the 0.12 to 0.21 for uniform pattern.

Conclusion

In totality the community parameters are not responsible for clumped pattern type of this species at OAP and YAP habitats, further, particularly at YAP habitat, the site quality factors were also non-significant for any pattern. Threshold limits of various exploratory parameters suggested the faith of its distribution. At OAP and Piedmont habitats vivipary habit of this species commanding its clumped pattern and in such setting, after germination conditions like acidic soil, high C/N ratio and availability of the bare surface area would be the promising factor for its further pattern types. Similarly electric conductivity will be the most crucial factors for post germination establishment at OAP and Piedmont. Additionally, after germination conditions, particularly community dynamics like woody perennial richness diversity and concentration of dominance would be key controlling factors for its clumped pattern at Piedmont and YAP further, in either side oscillation of these factors from a threshold level would facilitate its uniform pattern at both habitats.

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