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Comportments of arid grazing land plant diversity: a temporal assessment with bottom-up and top-down factors

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Abstract
In the present study, behaviors of arid grazing lands richness (S), evenness (E), Shannon-Wiener diversity (H') and SHE patterns were temporally assessed (pulse, inter-pulse and non-pulse) along with their intra and inter-relationships with soil and habitat factors. Comportments of these diversity variables were also examined in the cumulative data set. Higher average species richness (9.0) and diversity (2.0) were recorded during pulse event while the lowest values for both these parameters (4.0 and 0.9, respectively) were recorded during non-pulse event. Statistically, temporal significant variability's in both these components were exhibited by student t test. Further, both species richness and diversity were positively related with each other during all the sampling period (r^2 = 0.87, 0.64 and 0.73) and in cumulative data set (r^2 = 0.89). A positive relationship (r^2 = 0.77) between diversity and evenness were recorded only during inter-pulse (winter), however, cumulatively both diversity (r^2 = - 0.43) and richness (r^2 = - 0.49) were negatively related with evenness. Log-normal SHE patterns were recorded during pulse and non-pulse periods, while log-series pattern was recorded during inter-pulse period. Partial Least Square (PLS) regression with individual diversity index revealed significant impacts of soil variables (electric conductivity, pH, soil moisture and nitrogen) and per cent bare surface size, while soil organic carbon, botanical composition of climax species along with bare surface size were controlling factors for SHE pattern. Model equations for all the diversity variables and for SHE pattern were prepared with selection of significant predictors with the help of variables importance for the projection (VIPs).

Keywords: Arid region, Evenness, Grazing land, Richness, SHE analysis

Introduction
Biodiversity comprises the expression of life on earth in all its various forms and at all its relevant levels of comp--lexity, in a hierarchy from genes to the biosphere (Bredemeier *et al.,* 2007). There are number of statistically robust techniques for investigating species diversity and most of the classical diversity measures are based on concepts of species richness (S: the number of species) and evenness (E: that measure of how evenly sampled individuals are distributed among species, Magurran, 2004). In addition to these two, compound indices can also be calculated with the relative abundances or with any quantitative data set, and Shannon-Wiener (H') is the most common one that measures uncertainty in the outcome of a diversity sampling process (MacDonald *et al.,* 2017). Inter-relationships among S, H and E have been empirically studied (Buzas and Hayek, 1996; Ma, 2005; Barrante and Sandoval, 2009; Mathur and Sundarmoorthy, 2016). Some studied suggested that species richness and evenness are two independent indices (Smith and Wilson, 1996; Gosselin, 2006), while other concluded that both are negatively related (Stirling and Wilsey; 2001 and Zhang *et al.,* 2015). Such relationships were also studied with reference to their bottom-up and top-down factors like spatial impacts on relationships of species richness and evenness (Zhang *et al.,* 2015), impact of grazing (Manier and Hobbs, 2006), impact of edaphic factor (Ma, 2005), trait based explanation of the relationships between these two parameters (McGill, 2003; Stanley and Tilman, 2006; Shipley, 2006; Kraft *et al.,* 2008), changes in evenness and richness with seed density (Wilsey and Stirling, 2007) and relationships between them was also gauged through their relative abundance distribution (Gosselin, 2006; Su, 2018).

Buzas and Hayek (1998) developed SHE analysis for Bio-zone Identification (SHEBI), in which ln*S* (species richness), *H* (diversity) and *lnE* (evenness) are recalculated as samples are accumulated and the number of specimens N increases. They developed this technique for diversity assessment that allows independent yet simultaneous evaluation of the relative contributions of richness and evenness to community diversity across sampling scales. The basis for SHE is the linear decomposition equation, H = lnS +lnE. This decomposition is derived from the following conditions: (a) maximum H' diversity occurs when all species are equally distributed (H' Max = ln (S), and (b) E is related to H' by the equation [(E) = e^H/S]. Thus the SHE decomposition formula, H = lnS +lnE indicates that H' diversity equals its maximum value, ln (S), less the among of unevenness, ln (E) (subtracted because evenness $\leq$ 1 and ln (E) will be $\leq$ 0 in the sample. It is, therefore, an approach to look at the contribution of species number and accounted for changes in diversity. With reconnaissance of these theoretical and empirical studies, gaps were identified pertaining to diversity dynamics of the Indian arid grazing lands. Hypothesis related to this study was based on the fact that in the Indian arid region where the resources are released in different form of pulses and such resource fluctuations have the capability to mold the diversity dynamics of arid grazing lands. Thus to examine this, richness, evenness, and diversity (H') along with SHE patterns were temporally assessed at twelve arid grazing lands. Impacts of the pulse (rain), inter-pulse (winter) and non-pulse (summer) were gauged through the various predictors related to soil and with habitat quality.

Materials and Methods

For empirical evidences of our hypothesis, temporal observations on community, soil and on habitat qualities were taken from previous study (12 open grazing lands during 2006) and the collected data's were reanalysized with present hypothesis and SHE concept in 2018. Studied grazing lands were located within 16 km radius of the Jodhpur district of Rajasthan, India. These lands were lying between 26° 11' 33.4" to 26° 18' 47" Latitude and 72° 56' 5.9" to 73° 60' 35.1" Longitude and these lands were sampled during pulse (rainy season), inter-pulse (winter) and non-pulse (summer) events.

Species sampling and diversity: At each grazing land 10 quadrats of 5 m x 5 m were placed during every seasonal event (thus 120 plots were studied during every sampling period) and the data were analyzed for relative importance value (RIV) of each species and for various diversity parameters like Shannon-Wiener Index (H'), evenness (E) and species richness (Ludwig and Reynolds, 1988). SHE analysis was carried out with the help of RIV values of the species recorded at different grazing lands during three seasonal events. This was done with the help of PAST software (Hammer *et al.,* 2001). Both diversity (S, E, and H') and SHE analysis were also examined in cumulative/pooled data set and this was done with the aim to figure out the holistic pattern operates at a broader level.

Allogenic factors: Soil samples were collected from upto 30 cm depth at all grassland during all the sampling events. All the soil parameters were quantified in triplicate. Soil moisture (%) was estimated in non-dried soil through gravimetric method (Black, 1965). While other physical and chemical parameters were estimated in well air-dried and sieved (2 mm) soil samples (Pandeya *et al.,* 1968). Electrical conductivity (mS/m) and soil pH were measured in water-soil suspension (5:1) by respective digital meters. Organic carbon was determined by modified Walkley and Black's method (Jackson, 1973). Total nitrogen in soil was estimated by Microkjeldahl method as described by (Jackson, 1973). Available phosphorus estimation was based on the development of molybdenum blue colour as described by Allen *et al.* (1976).

Habitat assessment: Habitat conditions were quantified as per parameters developed by Kumar (1992). Parameters include botanical species composition of climax species, percent biomass contribution of climax species and grazing intensity. These parameters were ranked from 1 (mild or low) to 5 (heavy or severe) score (Kumar, 1992). Modified Bare Patch Index (BPI_{Modif}) was quantified by using the mean size of bare patches (B_{Mean}), the total bare soil (B) and total transect length (L = 100 m). This mathematical expression has a multiplication factor of connectivity of bare patch where 1 was used for inter-connected bare patches and 0.5 for their non-connectivity (Mathur and Sundarmoorthy, 2018) and equated as:

$$BPI_{Modif} = B_{Mean} \times \left(\frac{B}{L}\right) \times \text{Connectivity of Bare Patch \{i.e. 1 for yes and 0.5 for no\}}$$

Multivariate analysis: Student t-test was conducted to identify the significant variability's in S, H' and E among different seasonal events. Further temporal relationships among S, H and E were established by canonical correlation analysis (CCorA). Two step partial least square (PLS) regression was conducted to establish predictor (allogenic, habitat factors)- dependent (community attributes *i.e.* S, H and E) relationships. In the first step, significant predictors were firstly identified with the help of variable importance for the projection (VIPs) and then PLS bi-plot and model equation for dependent variable with significant VIPs predictors were prepared. Similar two steps PLS were also utilized for

SHE analysis with studied predictors. The uses of such multivariate techniques for diversity pattern analysis were advocated by Barrante and Sandoval (2009).

Results and Discussion

Community and diversity dynamics: The natural vegetation of Indian hot, arid and semi arid areas is classed as northern tropical thorn forest (Champion and Seth, 1968), occurring in small clumps scattered more or less openly and composed of trees, shrubs and herbs. According to Mathur and Pandey (2016) *Cenchrus ciliaris, C. setigerus, Cynodon dactylon, Dichanthium annulatum, Lasiurus sindicus, Cymbopogon jwarancusa, Dactyloctenium sindicum, Sporobolus marginatus, Sehima nervosum, Hetropogon contortus, Bothriochloa pertusa* are the major species of grazing lands. Among them, the dominance of *Cenchrus biflorus, Aristida funiculata*, and *Dactyloctenium aegypticum* represented the sub-climax stage of the plant community (Mathur and Sundarmoorthy, 2016).

In the present study *Eragrostis ciliaris, Tribulus terristris, Tephrosia purpurea* and *Dactyloctenium aegyptium* were recorded as the most dominant species during the pulse period, while *Dactyloctenium sindicum, Heliotropium subulatum, Mimosa indica, Convovulus microphyllus, Lasiurus sindicus* and *Justicia simplex* were recorded as rare species. During the inter-pulse period *Eragrostis ciliaris* and *Tephrosia purpurea* along with *Corchorus depressus* exhibited their dominance. During this sampling period, *Citrullus collocynthis, Indigofera cordifolia, Mimosa indica, Chenopodium album, Cynodon dactylon, Heliotropium subulatum* and *Lasiurus sindicus* were the rare species. However, during non-pulse period, the dominance of *Tephrosia purpurea* and *Corchorus depressus* were shared with *Cyperus rotundus, Blepharis sindica* and *Indigofera cordifolia,* while *Cenchrus biflorus, Cleome viscosa, Chloris virgata, Dactyloctenium aegyptium, Lasiurus sindicus, Convolvulus microphyllus, Euphorbia caducifolia* were rare in nature. Thus this study revealed temporal variabilities in grazing land communities wherein dominance of indicator grasses like *Cenchrus biflorus, Aristida funiculata* and *Dactyloctenium aegypticum* were decreased from pulse to inter-pulse and were least during non-pulse period. Reverse to above trend, species with high ecosystem services values (provisional and regulating) like *Tephrosia purpurea* and *Corchorus depressus* showed their dominance during non-pulse event.

Mean of richness (S), diversity (H'), evenness and allogenic parameters (organic carbon, nitrogen, phosphorus, soil pH and electric conductivity) were recorded (Table 1). The scoring range of habitat condition parameters (*viz.,* botanical species composition of climax species, biomass contribution of climax species and grazing intensity) along with number of sites having such range for these parameters during the three sampling periods were also recorded (Table 2). Relative Importance Values (∑ Relative density +Relative frequency +Relative abundance/3) of different species recorded during different seasonal events were also considered. Species diversity could be divided into two main components: 'richness', which represents the number of species in a given area, and 'evenness', which represents the variability in species abundances (Magurran, 2004). In this study, higher richness and diversity (H') were recorded during pulse event followed by inter-pulse and least during non-pulse. On the contrary, bare surface size (%) followed reverse trend recorded higher during non-pulse event. Student t-test suggested significant temporal variability's in richness and diversity (Table 3). However, non-significant differences were recorded for evenness between pulse and inter-pulse periods. Thus temporal impacts were more pronounced on species richness and diversity compared to evenness.

For a better understanding of how diversity components are related, field based studies should be in priority so that dynamics of community attributes and their underlying ecological principles could be explored (Buzas and Hayek, 1996; Stirling and Wilsey, 2001; Mouillot *et al.,* 2013). Some theoretical studies suggested that there is always a direct positive relationship between species evenness and species richness (Farmilo *et al.,* 2014), while empirical studies revealed that the relationship between species richness and evenness is not always positive (Stirling and Wilsey, 2001; Manier and Hobbs, 2006). Species evenness and richness also differed in their responses to local habitat factors (Lundhlom and Larson, 2003; Ma, 2005; Wilsey and Stirling, 2007), suggesting that the two diversity components might vary independently and be influenced by different ecological processes.

Table 1. Mean and standard deviation of community, allogenic parameters and bare surface size (%)

Parameters	Pulse events	Inter-pulse events	Non-pulse events
Richness	9.0±1.9	6.0±1.17	4.0±1.49
Shannon Wiener Index (H')	2.0±0.3	1.61±0.27	0.9±0.39
Evenness	0.8±0.2	0.88±0.22	1.7±0.47
Organic carbon (mg/100g)	54.1±45.0	166.4±79.4	153.5±124.5
Nitrogen (mg/100g)	40.3±17.5	76.9±27.3	90.9±57.9
Phosphorus (mg/100g)	37.0±10.6	24.5±12.1	11.4±6.8
Electrical conductivity (mS/m)	0.3±0.1	0.2±0.05	0.2±0.1
pH	8.6±0.7	7.5±0.6	7.8±0.5
Moisture (%)	7.2±2.8	1.8±1.0	0.9±0.4
Bare surface size (%)	5.93±5.7	16.54±8.6	21.69±11.4

Table 2. Range of different habitat assessment parameters and number of sites during sampling season

Botanical species composition of climax species				Biomass contribution of climax species (%)				Grazing intensity			
Range of parameter	Number of sites with a range			Range of parameter	Number of sites with a range			Range of parameter	Number of sites with a range		
	I	II	III		I	II	III		I	II	III
25-40	1	0	0	Over 50	0	0	1	Light	3	3	3
10-<25	10	7	6	25-<50	8	6	4	Moderate	9	6	6
1-<10	-	4	5	10-<25	4	5	6	Heavy	0	3	3
<1	1	1	1	5-<10	0	0	0	Very heavy	0	0	0
-	-	-		<1	0	1	1	-	0	0	0

I = Pulse; II = Inter-pulse and III = Non-pulse events

Table 3. Student t-test for various community parameters among different seasonal events

	Richness		Shannon and Wiener Index		Evenness	
	Pulse	Inter-pulse	Pulse	Inter-pulse	Pulse	Inter-pulse
Inter-pulse	6.23**	-	3.61**	-	0.05^{NS}	-
Non-pulse	13.42**	4.73**	9.99**	4.32**	6.33**	5.31**

Degree of freedom = 11; t Critical one-tail = 1.79*; t Critical two-tail = 2.20**

Canonical correlations among diversity variables during various seasonal events were derived (Table 4). Result revealed positive correlation between richness and diversity (H') during all the sampling period and in cumulative data set of pulse (r^2 = 0.87, P<0.01), inter-pulse (r^2 = 0.64, P<0.01), non-pulse (r^2 = 0.73, P<0.01) and cumulative (r^2 = 0.89, P<0.01). During inter-pulse, positive relationship between diversity and evenness (r^2 = 0.77, P<0.01) was also recorded. However, both richness (r^2 = - 0.49 P<0.01) and diversity (r^2 = - 0.43 P<0.01) exhibited significant negative relationships with evenness in pooled data set. No relationships were recorded between species richness and evenness during three sampling periods. Thus within this part of the world, the relationships among diversity attributes not only changed temporally, but also exhibited different patterns when examined in a holistic manner.

SHE analysis: With SHE analysis three patterns are expected, a broken stick, log normal and log series model In the present study, during the pulse event, species richness and Shannon-Wiener index showed the increasing trend from initial (Fig 1). However, the richness was stabilized while the diversity showed a little bit drop. The evenness line throughout showed a downward trend. Such pattern reflected the dominant log-normal pattern during this seasonal event. With the log sampling site, richness continuously increased from 2 to 2.5, however, the diversity by and large showed a similar trend across the sampling site. Increasing trends in richness and diversity and decreasing trends in evenness during the inter-pulse period, suggested the log-series pattern (Fig 2). During non-pulse event evenness still showed the decreasing trend, but the diversity index (H') after initial growth showed a downward trend while richness showed a static trend after initial increase. Such pattern suggested the log-normal model (Fig 3). Log normal pattern (changes in all three components of biodiversity) was also recorded when all the community parameters were analyzed in combined irrespective to their seasonal

Table 4. Canonical correlation of community variables during various seasonal events and in the combined data set

Variables	Pulse		Inter-pulse		Non-pulse		Cumulative data	
	Richness	**H'**	**Richness**	**H'**	**Richness**	**H'**	**Richness**	**H'**
Richness	-	-	-	-	-	-	-	-
Diversity (H')	**0.87**	-	**0.64**	-	**0.73**	-	**0.89**	-
Evenness	0.52	0.46	0.03	**0.77**	0.02	0.40	**-0.49**	**-0.43**

Degree of freedom during a particular sampling period 10; P = 0.70 (99%) and 0.57 (95%); Degree of freedom in the cumulative data set 34; P = 0.42 (99%) and 0.32 (95%); Bold numbers represent the significant relationships

event (Fig 4). Such pattern stipulated increasing in richness and diversity and decreasing in evenness.

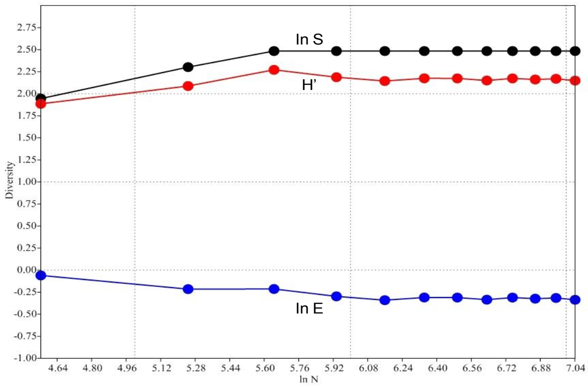

Fig 1. SHE analysis during pulse events

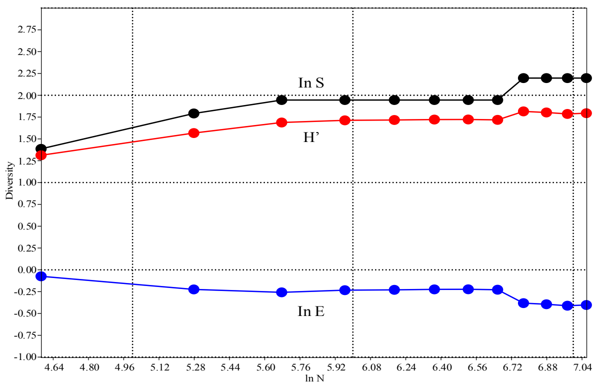

Fig 2. SHE analysis during inter-pulse events

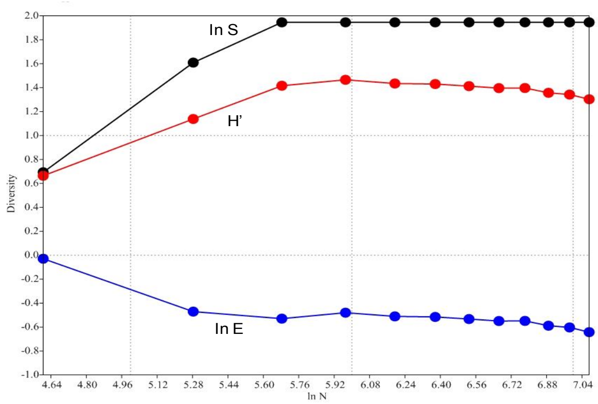

Fig 3. SHE analysis during non-pulse events

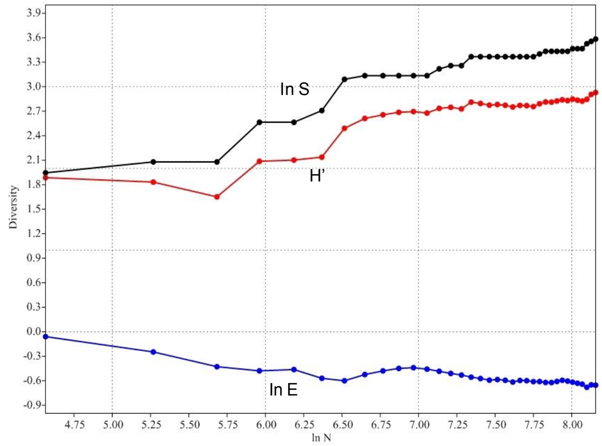

Fig 4. SHE analysis combined

With SHE analysis, Buzas and Hayek (2005) proposed and justified the use of the log-series distribution (with regression on the information decomposition equation) as a null model for determination of community structure. Baghani *et al.* (2009) utilized this tool for defining species diversity components of mountain rangelands (ZIARAT Basin, Gorgan) and they found that role of evenness was much more important than species richness in defining diversity at species and family levels. While Javed (2016) used SHE to examine the relationships among diversity measures from a single quadrat (micro-scale) to cumulative measure of community (macro-scale) across all vegetation units pertaining to alpine grassland at Bandipora, Kashmir. From conservation and management point of view, Salarian *et al.* (2015) suggested that this technique is very useful for planning of future trend of the rangeland ecosystem. In this study the log series pattern was observed during the inter-pulse period and this result indicated the possible role of significant positive relationship between diversity and evenness.

PLS model quality indexes and variable importance in the projection (VIPs) with cumulative data set for S, H' and E and for SHE were also assessed (Table 5). The Q^2 cumulated index measures the global goodness of fit and in the present study, the Q^2 for individual commu-

-nity parameter remained low, even with fourth components (ideally it should be close to 1). This suggested that quality of fit varied a lot on the dependent variables. However, with SHE analysis the Q^2 index was 0.99 suggested high model quality. The cumulated R^2Y and R^2X corresponded to the correlation between the exploratory (X) and dependent (Y) variables with the component close to 1 with 4th component generated by PLS summarized well both by X_S and the Y_S for the studied parameters.

Table 5. PLS model quality indexes and variable importance in the projection (VIP) of different predictors for various dependent variables

Exploratory variables	Cumulative data set with individual community variable (S, H' and E)	Cumulative data set with SHE analysis
Q² cumulative	0.41	0.99
R²Y cumulative	0.50	0.99
R²X cumulative	0.66	0.96
Bare surface size (%)	1.52	1.05
Soil moisture	1.52	-
Soil pH	1.26	-
Soil EC	1.08	-
Soil N	1.03	-
Soil organic carbon	-	1.03
Botanical species composition of climax species	-	1.04

In SHE analysis, log normal is a consequence of the central limit theorem (Magurran, 2004) which states that when large number of factors acts to determine the amount of a variable, random variation in those factors will result in the variables being normally distributed. This effect becomes more pronounced as the number of determining factors increase. In this study, soil variables (EC, pH, moisture and nitrogen) as well as bare patch size significantly influenced the SHE pattern particularly during pulse and non-pulse event, however, such predictor had the lesser impacts compared to community intrinsic variables *i.e.* significant relationships of evenness with diversity during this period and thus leads to log-series pattern.

Multivariate analysis: PLS bi-plot of cumulative data set with individual community variables was recorded (Fig 5) and it suggested that the richness (r^2 = 0.64, P<0.01) and diversity (r^2 = 0.52, P<0.01) were positively linked with soil moisture and with soil pH (r^2 = 0.56, P<0.01 and r^2 = 0.33, P<0.01, respectively). Diversity also showed a positive link with electrical conductivity (r^2 = 0.34, P<0.01). However, both these parameters negatively related to soil nitrogen (r^2 = - 0.51, P<0.01 and r^2 = - 0.33, P<0.01) and with bare surface size (r^2 = - 0.64, P<0.01 and r^2 = - 0.56, P<0.01). On the other hand evenness showed negative relationships with electrical conductivity (r^2 = - 0.55, P<0.01) and with soil pH (r^2 = - 0.33, P<0.01). Habitat variables like grazing intensity, biomass contribution of climax species and botanical species composition of climax species were found non-significant for any diversity variable. The significance of such exploratory variable for model quality was assessed with variable importance for the projection (VIPs).

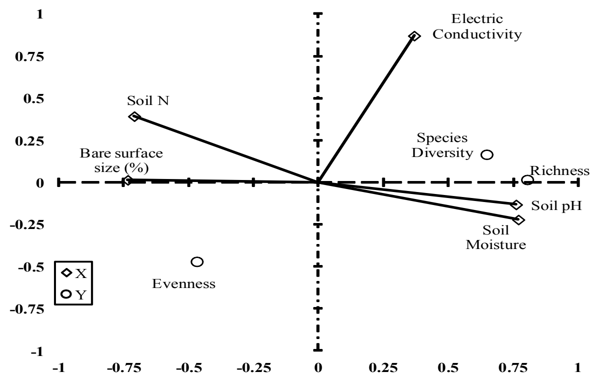

Fig 5. PLS bi-plot showing the relationships of community variables with significant predictors

Wilsey and Stirling (2007) based on their experiment at prairie microcosm communities suggested that evenness and richness could be influenced by different processes, richness was more influenced by the number of emerging seedlings and evenness more by species interactions like competition. These results suggested that both diversity components need to be measured in plant diversity studies whenever it is possible. Additionally, they showed that while species richness might be influenced by the availability of seed sources in the surroundings, species evenness is more likely to be affected by the abiotic and biotic properties of local habitats. Several other studies also concluded that species evenness might show a stronger association (than species richness) with ecosystem stability and function (Wilsey and Potvin, 2000; Mattingly *et al.,* 2007). Dorji *et al.* (2014) concluded that changes in plant species richness, evenness, and composition were mainly associated with open habitat patches, associated with elevation, surface roughness and soil moisture. Ma (2005) found that richness and evenness were correlated with different edaphic factors in a field study; richness was negatively correlated with soil P, whereas evenness was negatively correlated with soil organic C: N ratio. In this study it was noticed that patterns of biodiversity components were not static and they changed according to various bottom-up and to-down factors. The present study showed that the richness and diversity positively linked with soil moisture and soil pH. However, both these were negatively linked with soil nitrogen. Soil electrical conductivity and pH showed the negative impacts on evenness while this soil factor was found to be conducive for diversity (H').

Richness and diversity both were negatively related with bare patch size in the cumulative data set. With PLS, this predictor was also found significant for individual diversity attributes (S, H' and E) in the cumulative data set as well as in SHE analysis. Such relationships between species diversity and bare patch were reported earlier by many researchers like Hobbs (1988), Honnay *et al.* (1999), Arroyo-Rodriguez *et al.* (2009), Miguel *et al.* (2014), Farmilo *et al.* (2014) and Huang *et al.* (2016) from forest area and by Bisigato and Bertiller (1997), Tracy and Sanderson (2000) and Briggler *et al.* (2017) from grasslands. No such study was documented from arid grazing lands of India. The present study revealed that the available species were not in position to occupy the available bare area and this might be linked with dispersal and germination behaviors of species and soil factors.

VIPs for each exploratory variable with different data types were recorded (Table 5). This method allowed to identify which exploratory variable contributed most to the model. Any independent variable with a VIP value greater than 1 was considered as a highly important predictor (Onderka *et al.,* 2012). Among the studied soil parameter, pH, EC, nitrogen and moisture were identified as significant predictors (VIPs>1.0) for pooled data set, while for SHE analysis, soil organic carbon and botanical species composition of climax species were the significant predictor. Bare surface size (%) was the significant predictor for both. After eliminating non significant predictors the model equations for individual diversity parameter were as follows; richness = -1.08+2.80*EC+0.14*soil moisture+0.61*soil pH-0.007*soil N-0.065*bare surface size (r^2 = 0.64, P<0.01); species diversity = 0.14+0.84*EC+0.02489*soil moisture+0.09*soil pH-0.003*soil N-0.01*bare surface size (r^2 = 0.44, P<0.01); evenness = 2.55-1.53*EC-0.019*soil moisture-0.061*soil pH-0.001*soil N+0.009*bare surface size (r^2 = 0.44, P<0.01). With SHE analysis the model equation was as follows: SHE analysis = 2.38-0.01*bare surface area -0.47*Bot. sp. composition of climax species + 0.002*soil organic carbon. Thus partial least square (PLS) regression with individual diversity index suggested the significant impact of soil variables (electrical conductivity, pH, and soil moisture and soil nitrogen) and per cent bare surface size. However, soil organic carbon, botanical composition of climax species and bare surface size were the controlling factors for SHE analysis.

Conclusion

It was concluded that plant species richness (S) and evenness (E) were temporally not related with each other in arid grazing-lands of India, but when assessed cumulatively, both S and diversity (H') showed negative relationships with E. Grazing intensity and biomass contribution of climax species were identified as non-significant predictors for SHE pattern and also for S, H' and E. The importance of per cent bare surface size was addressed and found that in addition to soil moisture, this habitat factor was also important for shaping the arid grazing land diversity.

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