RESEARCH ARTICLE

Assessment of Plant Species composition and Diversity indices in Banni Grassland of Kachchh, Gujarat, India

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Abstract

The spatial pattern of plant species diversity signifies the importance of biodiversity in an ecosystem. The landscape heterogeneity configures the aggregation of functionally and physiologically convergent species, increasing species richness. Banni grassland is such a heterogeneous ecosystem, which has wetland, grassland, and dryland habitats. Concurrently, the invasion of *P. juliflora* is slowly converting it to shrubland. Banni is situated in an arid region. As arid grasslands are more fragile, it is important to analyze the plant diversity and its spatial distribution to understand the stability of this ecosystem. The goal of the current study was to investigate how the species composition and distribution vary in Banni grassland. The total plant diversity was examined by Stratified random sampling for 27 grids (10 × 10 Km) in which five quadrats were considered amounting to 135 sampling points. During the present study, 66 plant species were identified which included three trees, 16 sub-shrubs and shrubs, 42 grasses and herbs, and five creepers and climbers. The Kriging interpolation maps for species richness, dominance, evenness, Shannon index, and Simpson index recognized three distinct regions describing the spatial distribution of plant diversity in the Banni grassland. The dominance index in Banni grassland is maximum in west Banni and has a declining trend from west to east Banni. Western Banni, where Chari wetland is located, is dominated by *Sueda nudiflora*, while Central Banni has vernal pools and Eastern Banni has moderate grassland. Central Banni has the highest density and abundance of herbs and grasses, followed by Eastern Banni. The present study concluded that Banni grassland is narrow-niched and ecologically unique. The unique plant composition of Banni grassland requires long-term conservation planning.

Keywords: Banni grassland, Vegetation diversity, Diversity indices, Habitat heterogeneity.

Highlights

- Banni is the largest grassland of India experiences inherent salinity and extreme climatic conditions.
- Plant diversity in Banni grassland is affected by the allelopathic effect of *Prosopis juliflora.*
- Banni grassland has sparse vegetation with xeric and a few halophytic species.
- Plant diversity and richness are comparatively higher in Central Banni.

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Introduction

One of the most vital features of terrestrial ecosystems, plant diversity; is essential for preserving the stability of a region (Cunningham *et al.* 2015). In addition to stabilizing slopes and improving soil, a diverse flora is a reflection of weather events. An ecosystem explains the relationship between vegetation and other biotic components; hence, to understand the ecology it has become important to understand its biodiversity (Givnish 1999; Davis *et al.* 2021). Diversity in plant species is a fundamental structural feature of a natural community that affects several ecosystem processes, including stability and primary productivity (Schläpfer and Schmid, 1999; Spehn *et al.*, 2000). Plant diversity plays a significant role in providing ecosystem services, such as maintaining the safety of watersheds, improving soil health, providing medicine, mitigating weather conditions, and serving as habitats for various wild fauna (Quijas *et al.* 2010). For the maintenance of biodiversity and the structural integrity of these systems that ensures the services drawn from them, understanding them becomes important (Bond, 2008; Bond and Parr, 2010). The dissemination of species diversity in an ecosystem has been attributed to multiple factors, including climate, productivity, biotic interaction, habitat heterogeneity, etc. (Willig *et al.* 2003). Plant species diversity is a crucial structural feature of an ecosystem. Studies have increasingly shown that plant diversity can affect many ecosystem processes, most notably ecosystem stability and productivity (Spehn *et al.* 2000). Studies have also explained the importance of the species abundance and distribution pattern of both real and idealized communities, even though species diversity in the strict sense refers to the number of species (richness) in a community. A study of plant diversity in grasslands of Rajasthan emphasized the need for long-term conservation planning to conserve the plant diversity of arid ecosystems in India (Krishna *et al.*, 2014). In 2021, Ganaie and Reshi studied the species diversity in the

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temperate grassland of Kashmir, India. Later, Joshi *et al*., (2022) studied forest plant diversity in low hills of the Central Himalayas, followed by a similar study for Western Himalayas in 2024.

Grasslands are the largest terrestrial ecosystems on Earth, covering about 40% of the Earth's surface, with tropical grasslands covering 20% of the world's land area (Ramankutty and Foley, 1999). These ecosystems provide many ecosystem services to human society (Hu *et al*. 2014) and have been reported to support the livelihoods of around 30-43 million pastoralists worldwide, who rely mainly on livestock rather than crops, fuel wood, or tourism. Though grasslands support about one-fifth of the human population (Scholes and Archer, 1997), they are degraded the world over. Tropical grasslands are thought to be one of the most vulnerable biomes to future changes in land use and climate (Sala *et al*., 2009; Morgan *et al*., 2011). According to Rawat and Adhikari (2015), in India grasslands occupy 24% of the total land area. However, between 2005 and 2015, this area has shrunk by 31% (Pandey, 2019) making them one of the most endangered ecosystems. In India, less than 5% of grasslands are protected. Nevertheless, the administration is currently attempting to restore these natural grasslands by giving priority to turning them into planted forests (Nerlekar *et al*., 2022).

Banni grassland is the largest grassland in Asia and occupies 50% of the grassland cover in India (Nerlekar *et al*., 2022). Though the rich floral and faunal diversity in Banni has drawn the attention of numerous researchers, the scientific literature regarding the number of plant species in the Banni region and their distribution is limited and records vary. Pandya and Siddha (1982) documented around 41 plant species, encompassing grasses, herbs, shrubs, and trees, from the vicinity of Bhrindiyara village. Later, Bharara and Mathur (1999) identified 30 grass species from Banni. Additionally, GUIDE (1998) reported 23 grass species at the Dhrodo experimental sites in the Banni grassland regeneration project. Later GUIDE (2010) reported 192 species of vascular plants that included herbs, shrubs, trees, and climbers. Therefore, the species diversity studies of Banni grassland, a fragile ecosystem with inherent salinity and extreme climatic conditions, were thought about to enrich the understanding of this system. The objective of the study is to assess the phytosociology of Banni grassland through quantitative ecological methods. Species richness, diversity indices, and distribution of species are considered here.

Materials and Methods

Study area

Banni, largest residual grassland in India is situated on the northern edge of the Bhuj taluka (23^0 19′ to 23^0 52′ N latitude and 68^0 56′ to 70^0 32′ E longitude) of the Kachchh district (Fig. 1), in Gujarat separating the Greater Rann of Kachchh from central part of Kachchh district and covers an area of 3,847 km^2 (Pillai *et al*. 2018).

Comprising 8.4% of the total area of the Kachchh Desert, the Banni grassland is a stretch of the world's largest hypersaline marshlands, with a zone of Tectonic activity that has uplifted this land, resulting in the mudflat being elevated at a height of around 4 to 20 meters above the Great Rann (Kar, 2011). The

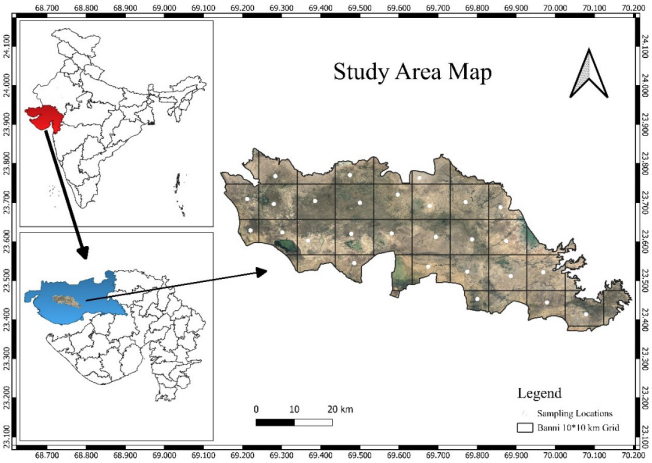

Fig. 1: Banni grassland, Kachchh district, Gujarat, India

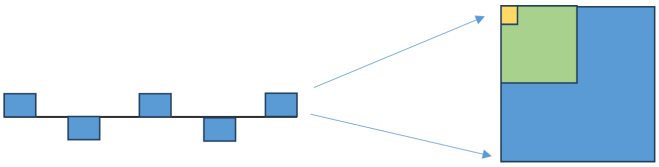

Fig. 2: Transect for plant species analysis

north-flowing river system of the Khari, Chhari, and Kaila rivers brought the sediments to the Banni area from the Mesozoic sedimentary strata of the northern Kachchh Mainland (Maurya 1973). The sediments of Banni grassland are of fluvial origin with layered silt and clay textures (Singh and Kar 2001).

The Banni region is primarily flat where flooding is common during the wet season. According to Mehta *et al*. (2014), Banni is a dual ecosystem that is made up of a dry environment during the pre-monsoon and a seasonal wetland during the monsoon. The sparse vegetation in Banni is primarily reliant on variations in the monsoon over the years. After the first rain that occurs in June-July, the grasses begin to grow and endure until December-January. Banni grassland vegetation is primarily composed of halophilic forbs and graminoids, with occasional shrubs and tree cover. Banni was proclaimed as a reserved grassland traditionally known as "Rakhal" a reserved grassland. In this reserved grassland, human settlement was restricted and only grazing of milch cattle was allowed. Later, other livestock were also allowed to graze, but specific fees were charged. Presently, these grazing policies have come to an end and livestock from other regions of the state also move to Banni for grazing during the monsoon and post-monsoon periods, as there is enough fodder during this period (Joshi and Kiran 2021).

Methodology

The study was conducted from December 2021 to May 2022. The Banni grassland was divided into 27 grids of 10 Km^2 each (Fig. 1). Vegetation sampling was carried out in 5 quadrates along a transect line of 1 km (Fig. 2) in all 27 grids, amounting to a total of 135 quadrates. The trees planted near villages were not considered. The size of quadrats varied for each vegetation type as 1m^2 for herbs and grasses, 5 m^2 for shrubs and subshrubs, and

10 m^2 for trees, creepers, and climbers (Fig. 2). During analysis, all data were converted to 10 m^2. All the plants were identified from their key vegetative and reproductive features based on the literature available on regional floras *viz*. Flora of Gujarat State (Shah, 1978), Flora of the Indian desert (Bhandari 1990), and Indian biodiversity portal (https://indiabiodiversity.org/species/show/252920). To find spatial species composition, the Shannon Wiener, Simpson, and Evenness indices were calculated for each grid using PAST Software (version 4.03), while density, frequency, and abundance were calculated for each vegetation type separately using MS Excel. Species richness for each site was calculated as described by Aggemyr *et al*., (2018). Further, the mean plant species diversity indices were calculated for all three geographical locations.

The formulas used for these indices are as follows:

$$\text{Density} = \frac{\text{Total number of individuals of a species in all quadrats}}{\text{Total number of quadrats studied}}$$

$$\text{Frequency (\%)} = \frac{\text{Number of quadrats in which the species occurred}}{\text{Total number of quadrats studied}} \times 100$$

$$\text{Abundance} = \frac{\text{Total number of individuals of a species in all quadrats}}{\text{Total number of quadrats in which the species occurred}}$$

Banni covers a vast area, so to predict the attribute values of unsampled locations, Kriging interpolation maps were prepared using QGIS software version 10.7. for species richness, Shannon index, evenness, species dominance, and abundance calculated for each grid. Kriging interpolation calculates each interpolated value to minimum error values. These maps gave three distinct regions: western, central, and eastern; hence, the data collected was segregated into these three regions to understand the spatial distribution of the species.

Results

A total of 68 plant species were recorded from 135 sampling points. Among these, only 3 were tree species, two creepers, and three climbers, while 42 species were grasses and herbs, and 19 shrubs and sub-shrub.

The species richness represents the number of species found. The species richness was calculated for each of the 27 grids in Banni grassland, which ranged between 29 to 60 and, when plotted on Kriging interpolation (Fig. 3), shows that species richness is higher in central Banni with occasional spikes while it is lower in eastern Banni and lowest in western Banni.

Similarly, the dominance index of plant species from each 27 grids, which ranged between 0.06 to 0.28, is plotted on the Kriging interpolation map (Fig. 4a). Dominance value showed an increasing trend from east to west Banni, with small patches of very high dominance in the west. The evenness index ranges between 0.3 to 0.8 (Fig. 4b), which shows an opposite trend with higher values in the east and lower in the west with few spikes in each area.

As shown in Figs 5a and 5b, the spatial distribution of Shannon-Wiener Index (H) and Simpson's index (D), the measures of biodiversity richness and abundance of the species, both exhibited similar trends with higher values in eastern Banni with decreasing trend towards the west. The values of Simpson diversity and Shannon diversity index ranged between 0.63 to 0.96 and 1.76 to 3.65, respectively, in Banni grassland representing low to moderate diversity. Based on the interpolation maps, to understand the spatial distribution, the data analyzed is divided into three regions- east, central, and west. Further, the mean plant species diversity indices were calculated for all three geographical locations (Table 1), while

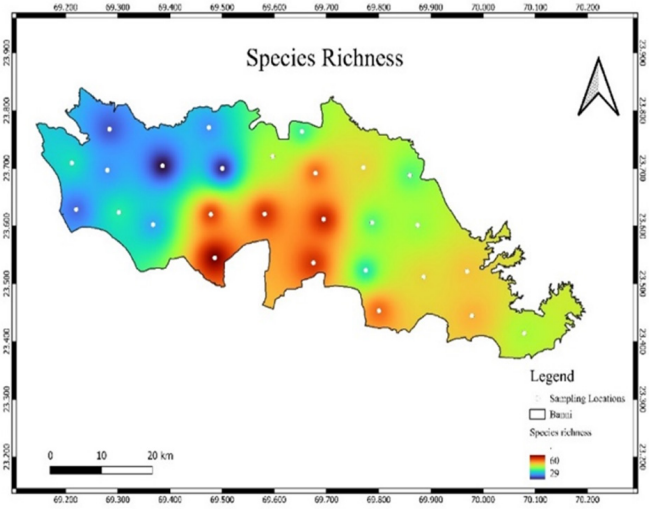

Fig. 3: Spatial distribution of species richness in Banni Grassland

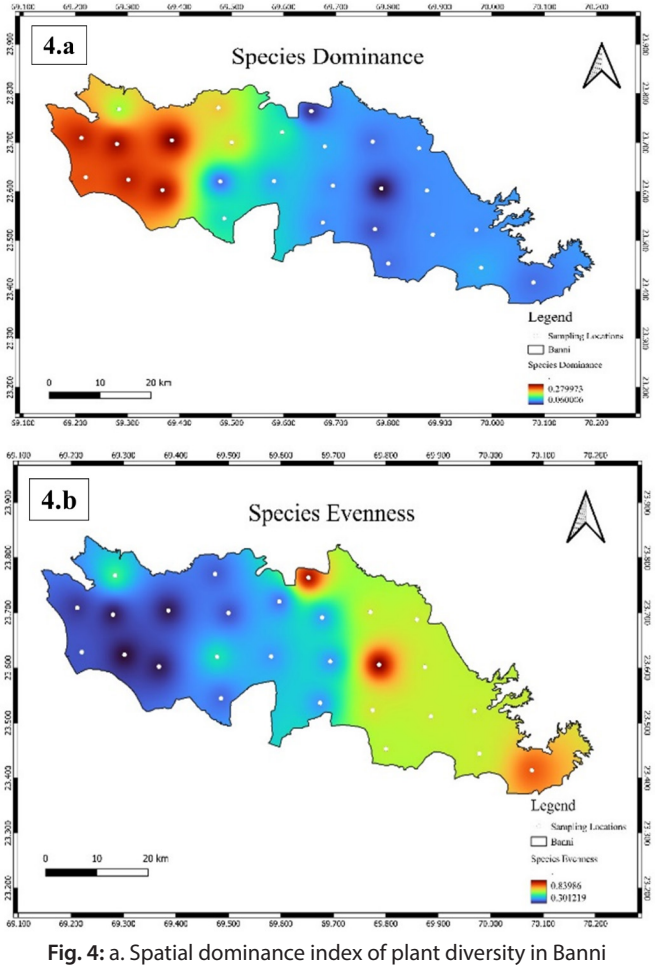

Fig. 4: a. Spatial dominance index of plant diversity in Banni grassland; b. Spatial Evenness index of plant diversity in Banni grassland

Table 1: Diversity indices of different geographical locations of Banni grassland

Diversity indices	*Taxa_S*	*Individuals*	*Dominance_D*	*Simpson_1-D*	*Shannon_H*	*Evenness_e^H/S*
West	23.4	186.03	0.21	0.79	2.13	0.37
Central	41.5	259.8	0.13	0.87	2.82	0.43
East	26.6	143.46	0.09	0.91	2.79	0.62

Table 2: Tree Species composition and diversity indices in Banni Grassland

Location	*Plant species*	*Veg. type*	*Density*	*Frequency*	*Abundance*
	Acacia nilotica (L.) Del.	tree	0.26	25.71	1
West	*Acacia Senegal*	tree	0.17	17.14	1
	Azadirachta indica	tree	0.14	17.14	0.83
	Acacia nilotica (L.) Del.	tree	0.24	24	1
Central	*Acacia Senegal*	tree	0.06	6	1
	Azadirachta indica	tree	0.16	16	1
	Acacia nilotica (L.) Del.	tree	0.3	26	1.15
East	*Acacia Senegal*	tree	0.12	12	1
	Azadirachta indica	tree	0.24	24	1

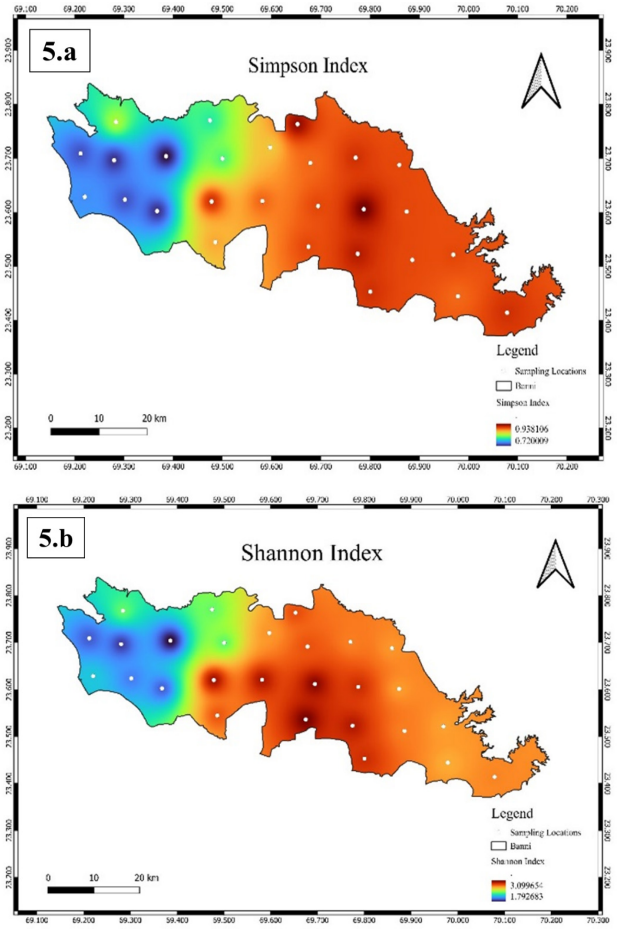

Fig. 5: a. Spatial Shannon diversity index of plant diversity in Banni, grassland; b. Spatial Simpson diversity index of plant diversity in Banni, grassland

density, frequency, and abundance are considered for trees (Table 2), Herbs and grass (Table 3), shrubs and subshrubs (Table 4) and creepers and climbers (Table 5).

As noted in Table 1, the mean taxa value (species richness) was found to be highest in Central Banni (41.5) followed by Eastern Banni (26.6) and Western (23.4). Similarly, mean values of individuals of different plant species were also highest in Central Banni (259.8) and lowest in Eastern Banni (143). Even though in East Banni mean dominance was minimum (0.09) it was maximum in Western Banni. The Evenness index followed a reverse pattern with maximum mean values (0.62) in Eastern Banni and lowest in Western Banni (0.37). Similarly, mean Simpson diversity was found to be highest in Eastern Banni, which declines from east to west with values - 0.91, 0.87, and 0.79, respectively. Central Banni experiences the highest values of the Shannon diversity index (2.82), while Western Banni experiences the lowest (0.79).

In Banni only three species of trees were identified. Trees like Banyan (*Ficus benghalensis*), Pipal (*Ficus religiosa*), Mango (*Mangifera indica)*, *Eucalyptus sp.*, and other introduced plantation species were mainly observed near villages and not considered here. The Density of *Acacia nilotica* was highest in the east region with 0.3 m^2 followed by 0.26 m^2 in the west region and 0.24 m^2 in the central region (Table 2). *Azadiracta indica* had maximum density in the east (0.24) and minimum density in the west region (0.14 m^2), which was almost maintained in the central (0.16 m^2). *Acacia senegal* has the lowest values with a decreasing trend from west to east. All three tree species occurred all over Banni grassland. Comparatively, Central Banni supported lesser density and abundance of all the three tree species (Table 2).

A total of 42 species of herbs and shrubs were identified in Banni grassland during the study. When relative density and relative abundance of herbs and grasses are considered (Table 3) 4 species of Herbs and grasses emerged to dominate the 3 regions identified. *Cressa cretica* L. emerged to top the List, followed by *Cyperus rotundus* L and *Corchorus depressus* (L.) Stocks in west and central Banni while *C. depressus* (L.) Stocks and *C. rotundus,* respectively in east Banni. However, *Aeluropus lagopoides* (L.) Trin. ex Thw. was abundant in the east. *C. depressus* (L.) Stocks, *Cressa cretica* L., and *C. rotundus* L. are the dominating herb species in eastern Banni.

Fourteen species of herbs and grasses were not recorded from western Banni. These are *Aristida histricula* Edgew, *Blumea eriantha* DC, *Brachiaria ramosas* (L.) Stapf, *Cyperus haspan* L., *Digera muricata* (L.) Mart, *Echinochloa colonum* (L.) Link, *Eclipta prostrata* (L.) L. Mant, *Eleusine indica* (L.) Gaertn, *Eragrostis japonica, Heliotropium marifolium* Koen.ex Retz. *Indigofera linifolia* Retz. *I. linnaei* Ali. *Launaea procumbens* Roxb and *Mollugo cerviana* Ser. Highest densities of *Aeluropus lagopoides* (L.) Trin.

Table 3: Herb and grass species composition and diversity indices in Banni Grassland

S. No.	Plant species	Veg. type	West			Central			East		
			Density	Frequency	Abundance	Density	Frequency	Abundance	Density	Frequency	Abundance
1	*Achyranthes aspera* L.	herbs	0.08	8	1	1.3	60	2.17	0.6	28.57	2.1
2	*Aeluropus lagopoides* (L.) Trin. ex Thw.	grass	10.32	80	12.9	10.92	100	10.92	7.57	85.71	8.83
3	*Ammannia baccifera* L.	herbs	4.54	100	4.54	2.5	80	3.13	0.51	25.71	2
4	*Aristida histricula* Edgew.	grass	0	0	0	2.66	90	2.96	1.11	22.86	4.88
5	*Bacopa monnieri (*L.) Pennell	herbs	1.9	100	1.9	0.08	6	1.33	0.17	8.57	2
6	*Blumea eriantha* DC	herbs	0	0	0	1.08	46	2.35	1.29	65.71	1.96
7	*Brachiaria ramosa* (L.) Stapf	grass	0	0	0	7.1	86	8.26	1.2	60	2
8	*Chloris barbata Sw.*	grass	5.14	100	5.14	13.2	78	16.92	4.4	54.29	8.11
9	*Convolvulus microphyllus* (Roth) Sieb. ex Spr	herbs	1.6	80	2	1.02	42	2.43	1.23	51.43	2.39
10	*Corchorus depressus* (L.) Stocks	herbs	11.1	80	13.88	22.74	80	28.43	21.8	45.71	47.69
11	*Corchorus olitorius* L.	herbs	0.44	22	2	2.04	88	2.32	0.46	28.57	1.6
12	*Cressa cretica* L.	herbs	23.34	78	29.92	53.72	86	62.47	57.8	97.14	59.5
13	*Cyperus glomeratus*	grass	4.06	78	5.21	5.64	100	5.64	0.74	31.43	2.36
14	*Cyperus haspan* L.	grass	0	0	0	1.48	84	1.76	0.17	5.71	3
15	*Cyperus rotundus* L.	grass	6.14	20	30.7	37.88	86	44.05	31.11	62.86	49.5
16	*Dactyloctenium aegypticum* (L.) P. B.	grass	0.74	18	4.11	6.02	66	9.12	1.09	40	2.71
17	*Dactyloctenium sindicum* Boiss.	grass	0.18	8	2.25	1.06	56	1.89	0.23	22.86	1
18	*Dichanthium annulatum* (Forak.) Stapf	grass	0.04	0	0	3.86	86	4.49	0.57	28.57	2
19	*Digera muricata* (L.) Mart.	herbs	0	0	0	1.02	34	3	0.14	14.29	1
20	*Echinochloa colonum* (L.) Link	grass	0	0	0	5.04	88	5.73	0.97	51.43	1.89
21	*Eclipta prostrata* (L.) L. Mant.	herbs	0	0	0	4.3	88	4.89	0.8	28.57	2.8
22	*Eleusine indica* (L.) Gaertn.	grass	0	0	0	3.72	30	12.4	0.37	17.14	2.17
23	*Eragrostis ciliaris* (L.)	grass	2.9	80	3.63	4.72	50	9.44	1	40	2.5
24	*Eragrostis japonica*	grass	0	0	0	6.44	94	6.85	0.29	20	1.43
25	*Eragrostis tremula Hochst.*	grass	2.48	96	2.58	0.66	40	1.65	0	0	0
26	*Euphorbia hirta* L.	herbs	2.02	80	2.53	1.08	58	1.86	0.74	42.86	1.73
27	*Euphorbia thymifolia* L.	herbs	0.46	20	2.3	1.84	84	2.19	0	0	0
28	*Evolvulus alsinoides* (L.)	herbs	2.74	80	3.43	2.62	86	3.05	0.29	14.29	2
29	*Frimbristylis millicea* (L.)	grass	1.34	20	6.7	0.54	20	2.71	2.42	94	2.57
30	*Goniogyna hirta* (Willd.) Ali	herbs	0.6	20	3	0.43	20	2.14	2.88	70	4.11
31	*Heliotropium marifolium* Koen.ex Retz.	herbs	0	0	0	0.43	17.14	2.5	1.7	78	2.18

32	*Indigofera linifolia* Retz.	herbs	0	0	0	0.37	22.86	1.63	2.12	84	2.52
33	*Indigofera linnaei* Ali.	herbs	0	0	0	0.2	14.29	1.4	1.9	90	2.11
34	*Launaea procumbens* Roxb	herbs	0	0	0	0.74	42.86	1.73	0.6	38	1.58
35	*Leucas aspera* (Willd.) Spr.	herbs	0.84	30	2.8	0.26	17.14	1.5	1.26	56	2.25
36	*Mollugo cerviana* Ser.	herbs	0	0	0	0.23	17.14	1.33	1.68	84	2
37	*Mukia maderespatensis* (L.) M. Roem.	herbs	1.3	50	2.6	0.69	37.14	1.85	1.5	72	2.08
38	*Pavonia arabica* Steud	herbs	1.38	70	1.97	0.74	40	1.86	1.74	84	2.07
39	*Physalis minima* L.	herbs	2.52	100	2.52	1.03	48.57	2.12	1.2	62	1.94
40	*Portulaca meridiana* L.	herbs	0.54	28	1.93	0.74	37.14	2	1.08	42	2.57
41	*Sporobolus helvolus* (Trin.) Th. Dur. et Sch	grass	1.66	92	1.8	0.97	57.14	1.7	0.8	44	1.82
42	*Vernonia cinerea* (L.) Less.	herbs	0.94	48	1.96	0.6	40	1.5	0.3	12	2.5

Table 4: Species composition and diversity indices of shrubs/sub-shrubs in Banni grassland

S. No.	*Plant species*	*West*			*Central*			*East*		
		Density	*Frequency*	*Abundance*	*Density*	*Frequency*	*Abundance*	*Density*	*Frequency*	*Abundance*
1	Alhagi maurorum	0.54	28.57	1.9	1.12	52	2.15	0.68	30	2.27
2	Atriplex stocksii	0.54	28.57	1.9	1.66	56	2.96	1.64	48	3.42
3	Cadaba fruticose	0.31	8.57	3.67	1.06	48	2.21	1.2	34	3.53
4	*Calotropis procera* (Ait.) R. Br.	0.8	26	3.08	1.4	52	2.69	2.6	85	3.06
5	*Capparis decidua* (Forsk.) Edgew.	1.03	42.86	2.4	1	44	2.27	1.56	70	2.23
6	Euphorbia caducifolia	0.03	2.86	1	1	48	2.08	0.54	20	2.7
7	Lycium barbarum	0.8	34.29	2.33	1.08	52	2.08	0.94	36	2.61
8	Maerua oblongifolia	0.54	28.57	1.9	1	50	2	0.9	38	2.37
9	Prosopis cineraria	0.91	48.57	1.88	0.56	46	1.22	0.16	16	1
10	*Prosopis juliflora* (Sw) DC.	2.51	82.86	3.03	3.92	96	4.08	2.92	86	3.4
11	Salvadora oleoides	0.69	45.71	1.5	0.54	38	1.42	0.42	20	2.1
12	*Salvadora persica* L.	0.97	57.14	1.7	2.3	64	3.59	1.38	78	1.77
13	*Suaeda fruticosa* (L.) Forsk. ex Gmel.	0.4	20	2	1.7	64	2.66	2.22	78	2.85
14	*Suaeda nudiflora* (Willd.) Moq.	3.57	82.86	3.97	2.46	70	3.51	1.7	60	2.83
15	Tamarix sp	2.25	37.14	6.07	0.38	40	0.95	0	0	0
16	Ziziphus numularia	0.66	48.57	1.35	0.78	56	1.39	0.52	34	1.53

ex Thw., *Brachiaria ramosa* (L.) Stapf, *Chloris barbata* Sw., *C. depressus* (L.) *Stocks, C. rotundus* L. and *C. rotundus* L. were found in in Central Banni. *Eragrostis tremula* Hochst. and *Euphorbia thymifolia* L. were not found in eastern Banni.

When frequency is considered in the western region *Ammannia baccifera* L.*n, Bacopa monnieri* (L.) Pennell*, Chloris barbata* Sw., *Eragrostis tremula* Hochst., *Physalis minima* L. *and Sporobolus helvolus* (Trin.) Th. Dur. et Sch exhibited 90 to 100% frequency in the west while *Aeluropus lagopoides* (L.) Trin. ex Thw., *Aristida histricula* Edgew., *C. glomeratus, and Eragrostis japonica* had maximum frequency in Central Banni, and only *Cressa cretica* L. had high frequency in East Banni. Rest all species ranged between 0 to 89%.

When abundance is considered, again *Cressa cretica* L emerged at the top with a maximum abundance of 62.47% in Central Banni followed by 59.5% in Eastern Banni and 29.92% in the west. Other species with high abundance in decreasing order are *C. rotundus* L. (44.05%), *C. depressus* (L.) Stocks (28.43%),

Table 5: Creepers/climbers species composition and diversity indices in Banni grassland

Locations	*S. No.*	*Plant species*	*Veg. type*	*Density*	*Frequency.*	*Abundance*
	1	*Corallocarpus epigaeus*	Climber	1.02	32.00	3.19
	2	*Cucumis callosus*	Creeper	0.82	30.00	2.73
East	3	*Cucumis prophetarum*	Creeper	0.54	20.00	2.70
	4	*Momordica balsamina*	Climber	0.68	28.00	2.43
	5	*Pentatropis spiralis*	Climber	0.60	24.00	2.50
	1	*Corallocarpus epigaeus*	Climber	1.20	46.00	2.61
	2	*Cucumis callosus*	Creeper	1.08	50.00	2.16
Central	3	*Cucumis prophetarum*	Creeper	1.22	56.00	2.18
	4	*Momordica balsamina*	Climber	1.12	54.00	2.07
	5	*Pentatropis spiralis*	Climber	1.70	56.00	3.04
	1	*Corallocarpus epigaeus*	Climber	0.91	31.43	2.91
	2	*Cucumis callosus*	Creeper	0.97	37.14	2.62
West	3	*Cucumis prophetarum*	Creeper	0.09	5.71	1.50
	4	*Momordica balsamina*	Climber	0.74	20.00	3.71
	5	*Pentatropis spiralis*	Climber	0.80	34.29	2.33

Chloris barbata Sw. (16.92%), *Eleusine indica* (L.) Gaertn. (12.4%), and *Aeluropus lagopoides* (L.) Trin. ex Thw. (10.92%) in Central Banni. In western Banni there were *C. glomeratus* (15.7%), *C. depressus* (L.) *Stocks* (13.88%) and *Aeluropus lagopoides* (L.) Trin. ex Thw. (12.9%), while in the east, there were *C. rotundus* L. (49.5%), and *C. depressus* (L.) *Stocks* (47.69%). Rest all species had lower abundance.

Around 18 species of shrubs and subshrubs are recorded in Banni grassland during the present study (Table 4). *Prosopis juliflora* (Sw) DC has the highest density in Central Banni (3.92 /5 m^2) followed by Eastern Banni (2.92/5 m^2) and Western Banni (2.51/5m^2). Halophyte *Suaeda nudiflora* (Willd.) Moq has the highest density in western Banni. *Tamarix sp.* is a wetland plant and the highest density of this species is noted near Chari wetland in western Banni. *Calotropis procera* (Ait.) R. Br is highly abundant (3.06) and dense (2.60) in Eastern Banni.

The frequency of shrubs and sub-shrubs was found to range between 0-96%. *Prosopis juliflora* in Central Banni exhibited 96% frequency while in eastern Banni and western Banni, it was 86 and 82.86%, respectively. Another species with a higher frequency percentage was *Calotropis procera* (Ait.) R. Br. mainly in the eastern Banni (85%). Its frequency decreased as we moved from central to western Banni (52 and 26%, respectively). Other species with more than 70% frequency were *Salvadora persica* L. and *Suaeda fruticosa* (L.) Forsk. ex Gmel with 78% each and *Capparis decidua* (Forsk.) Edgew with 70% in east Banni while *Suaeda nudiflora* (Willd.) Moq. with 70% in central Banni. The other species showed a very low percentage of frequency.

The abundance of shrubs and sub-shrubs in the 3 regions studied ranged between 0-8 with *Tamarix spp.* having maximum abundance in the west (8), very low in the central, and absent in the east. The next in abundance was *Prosopis juliflora* (Sw) DC. with 4.08 abundance in Centre, 3.4 in East, and 3.03 in West Banni. Among other species, *Cadaba fruticosa* had 3.67 abundance in west, 3.53 in east, and 2.21 in central Banni. The abundance of *Calotropis procera (*Ait.) R. Br was around 3 in all the 3 regions, whereas the abundance of *Atriplex stocksii* was 3.42, which decreased to 2.96 in central Banni and 1.90 in the west. *Salvadora persica* L. was next in abundance to *Prosopis juliflora* (Sw) DC in central Banni but low in the other two regions, while *Suaeda nudiflora* (Willd.) Moq had 3.97 abundance in the west, which declined to 3.91 in the Central and 2.83 in the east. Rest all species had lower than 3 abundances in all the regions.

Two species of climber and 3 creepers were recorded in Banni grassland (Table 5). All the creeper and climber species have the highest density in central Banni. Here, the densities of *Corallocarpus epigaeus, Cucumis callosus, Cucumis prophetarum, Momordica balsamina,* and *Pentatropis spiralis* are 1.20/10 m^2, 1.08/10 m^2, 1.22/10 m^2, 1.12/10 m^2 and 1.70/10 m^2, respectively. The creepers and climber species in Banni are recorded in post-monsoon season and subsist for a few months only. The frequency of occurrence for all the creepers and climbers ranged between 20 to 56% except for *Cucumis prophetarum,* which occurred at a low frequency of 5.71%. In general, in central Banni, creepers and climbers occurred at a higher frequency of around 50%. When abundance is considered, each region had only one but different species of climber with higher than 3 values. These are *Corallocarpus epigaeus* in estern Banni, *Pentatropis spiralis* in central Banni, and *Momordica balsamina* in western Banni. All other species had abundance values below 3.

Discussion

It has been reported that desert and arid plant communities have simple structures and a low species diversity, with small xeric, halophilic, hyper-xeric shrubs and perennial herbage plants predominating. These plants are adapted to the harsh and variable environmental conditions of the region. Hence, in the dry ecosystem, due to their tolerance for environmental

volatility, dwarf half-shrubs and small shrubs predominate (Zhang *et al*., 2017). In arid lands, the majority of the herb species contain perennial herbs, with annual herbs falling into different tiers (Zhang *et al*., 2017). In Banni grassland vegetation depends on seasonal rainfall, which is scanty and irregular. This results in sparse vegetation.

Based on 5 Kriging interpolation maps (Figs 3, 4 and 5), for species richness, dominance, evenness, Shannon index, and Simpson index, three distinct regions emerged as far as the spatial distribution of plant diversity of Banni grassland is deliberated. The central region has higher species richness, density as well as diversity. The species richness and number of individuals counted were also higher in the Central region with a comparatively higher Shannon index. In central Banni several vernal pools (seasonal wetlands) created during monsoon retain moisture in the soil for a longer duration, supporting a higher diversity of species in the region. This region supports more herbs and grass populations too (Table 3). The saline wetlands of Kachchh are, although known to sustain low biodiversity, the biodiversity here is highly distinctive (Chauhan and Gopal, 2016). Most species in central Banni are the species of tropic or subtropics as well as those depending on dry climatic conditions. The shrubs in central Banni are mainly adapted to arid conditions. Due to the presence of seasonal wetlands, central Banni supports a maximum number of species. *Prosopis juliflora*, the invasive species is found to occupy mainly Central Banni with dense patches. Central Banni has maximum density and abundance of herbs and grasses too. It is noted here that central Banni, with vernal pools, is also a habitat for the majority of grassland species (Table 3). A larger habitat with several microhabitats is a driver for species diversity at spatial scales (Lengyel *et al*., 2016). The central Banni, with vernal wetland patches, grassland and scrub, has similar conditions and has shown the presence of maximum species and diversity of plants.

As far as habitats created are concerned, Central Banni shows the presence of vernal wetlands, grasslands, and scrubland, as well as some saline land near Rann of Kachchh. Alsterberg *et al*. (2017) have discussed the relationship of habitat diversity and multifunctionality, stating that diversity of habitat within an ecosystem can complement species diversity. Further, Gastauer *et al*. (2021) discuss that the increase in ecological niches available influences the landscape heterogeneity while configurational land aggregate functionally and physiologically convergent species increasing species richness. However, Ben-Hur and Kadmon (2020) report that area heterogeneity trades off on species richness depending on deterministic and stochastic drivers of extinction and may have a negative influence on species richness.

The Chari Dhand wetland in the west mainly supports wetland species that are not considered in the present study. However, some of the species with higher density in west are water-dependent too. In western Banni, the evenness of plant species distribution is minimal due to the dominancy of a few species, which also negatively affects the species richness. Higher dominance of a few species negatively influences the evenness of species (Akatov *et al.,* 2018). In the Western Banni, the dominating plant species are *Sueda nudiflora* and *Tamarix*. *Sueda spp* is a halophyte and has maximum survival in saline soil, while *Tamarix spp*. is a facultative halophyte wetland species. Western Banni with highly saline wetland- Chari dhand, supported highest density of both *Tamarix spp* and *Sueda spp*. These are the species that grow well in saline soils (Wungrampha *et al.,* 2019). These species were also recorded in grids closer to Rann of Kachchh where flooding occurs in monsoon. The few species of shrubs present in western Banni with higher density are halophytes depending on saline soils.

The eastern Banni has mostly grassland habitat where the maximum species of grasses occurred (Table 3), with *Cressa cretica* as the dominant herb species. In the neighboring state of Rajasthan also, this species has been reported as one of the top five species of saline grassland (Krishna *et al*., 2014). Banni being closer to Rann of Kachchh, salinity is higher in the soil. A small number of halophytes are found in the east. In Eastern Banni the herbs and shrubs with higher density are either adapted to dry, dry deciduous, grassland habitats or tropical habitats. Here comparatively, the tree densities noted are also higher (Table 2). A mixed type of vegetation predominates in this area. In Eastern Banni the densities of *Prosopis* and *Sueda nudiflora* are moderate and the distribution is uniform.

The evenness index describes the number of individuals of each species within the community. In other words, the degree of equity/equality in the distribution of individuals among species is known as the evenness of species. The ecology is better balanced if individuals from different species occur equally in a habitat. The value of the evenness index are known to span between 0 and 1, towards 0 when one particular species is in abundance, and towards 1 when numbers of individuals of all species in a population are somewhat comparable (Jost, 2010; Duncan *et al*. 2014). In Banni Grassland mean evenness of plant species is comparatively low with only the eastern region having moderate mean evenness. The evenness index has an inversely proportional relation with the dominance index (Jost 2010; Akatov *et al*. 2018), which is also noted in Banni grassland where eastern region has higher species richness while dominance is low compared to the western region. Rest of Banni has a moderate to low evenness index, which implies that Banni grassland is a moderately stable ecosystem.

In Banni shrub groups are crucial to plant assemblages. This region has a lower species diversity, a simpler community structure, and a sparser species makeup. Our study's findings demonstrated the moderate variations in species variety seen in Banni's semi-arid zone. Numerous local environmental elements, including soil, water, microclimate, grazing, and others, have an impact on it (Deák *et al*. 2021). Salinity was one of the factors for restricting species diversity. *Sueda nudiflora* is the dominant species in the west where salinity is expected to be high (Dayal *et al*. 2023).

As far as *Sueda nudiflora* is concerned one more region emerges, that is Northern Banni region, which is expected to be under the influence of Rann of Kachchh, the largest salt-encrusted land in the summer, where we measured the low species diversity too. This species is well-recognized for having a high degree of salinity adaptability. Although these plants can indicate the land's salinity, each species' ability to adapt to salinity varies (Zhao *et al*., 2020). The distribution pattern of species decides the species diversity of the landscape (Li, *et al*.,

2018). The *Sueda nudiflora* show a stratified distribution, while in Central Banni, the dominant species is *Prosopis juliflora,* which shows patchy distribution.

Both biotic and abiotic factors influence the distribution patterns of plant communities. Changes in environmental factors, including soil moisture, salt content, and soil stability, frequently take place at the same time, creating complex relationships between plant communities and their surroundings (Zhu *et al*. 2012). Bai *et al*. (2021) have shown a positive correlation between temperature, precipitation, and plant diversity in inner Mongolian grasslands. In Banni, grassland temperature is high and precipitation is very low and only during monsoon. Consequently, the vegetation diversity is maximum only in the post-monsoon season. In Arid ecosystems where soil moisture content is lower, plant species can flourish side by side without directly competing with one another for resources (Abrams, 1995). The dominance index of Banni ranges from 0.09 to 0.2. Banni grassland is a hypersaline area and experiences high temperatures with seasonal rainfall and thus is defunct for low plant diversity comprising halophytic, xeric shrubs and both annual and perennial herbs. Thus, Banni grassland, because of higher salinity, can be narrow-niched and ecologically unique, as described by Krishna *et al*. (2014) for Grasslands in the neighboring state of Rajasthan.

Conclusion

The current study discusses the phytosociological features of the Banni grassland by examining the diversity of plant species. The Banni grassland displays a varied landscape, with wetlands in the west, vernal pools in central Banni, and grasslands in eastern Banni. These diverse habitats supported diverse plant species with maximum vegetation diversity. Central Banni has maximum density and abundance of herbs and grasses, followed by Eastern Banni. Grassland habitat is present in Eastern Banni while Chari wetland in western Banni and vernal pools in Central Banni. Grassland and agricultural fields mainly occupy Eastern Banni. The present vegetation study recorded 66 species (3 trees, 16 sub-shrubs and shrubs, 42 grasses and herbs, and 5 creepers and climbers) in the study area. In conclusion, this article examined the species diversity in plant communities and the spatial distribution of vegetation within the Banni grassland ecosystem. The majority of species are saline-alkaline and xerophytic-tolerant plants. The plant diversity in Banni grassland is moderate to low. *Calotropis procera (Ait.) R. Br.* is dense in Eastern Banni. However, it is sparsely distributed in Central Banni, where more spots of *Prosopis juliflora* exist. It is crucial to comprehend the impact of continued climatic and human-induced stress on the diversity of species in grasslands to develop sustainable conservation strategies. This research establishes foundational data to shape management policies and conservation measures for vegetation in dry and saline environments.

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Contribution of Authors

All the authors provided crucial feedback and contributed to shaping the research, analysis, and manuscript. Asha Sharma wrote the manuscript with support and comments from Dr. Arun Kumar Roy Mahato, while Prof. Geeta Padate critically evaluated and edited the manuscript and contributed to the final version.

Conflict of Interest

All co-authors confirm that the submission is original work and agree with the contents of the manuscript. We declare that there are no conflicts of interest to report.

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