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Article

Diversity and aggregation patterns of plant species in a grass community

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Abstract
Both composition and aggregation patterns of species in a community are the outcome of community self-organizing. In this paper we conducted analysis on species diversity and aggregation patterns of plant species in a grass community, Zhuhai, China. According to the sampling survey, in total of 47 plant species, belonging to 16 families, were found. Compositae had 10 species (21.3%), seconded by Gramineae (9 species, 19.1%), Leguminosae (6 species, 12.8%), Cyperaceae (4 species, 8.5%), and Malvaceae (3 species, 6.4%). The results revealed that the means of aggregation indices I_δ, I and m^*/m were 21.71, 15.71 and 19.89 respectively and thus individuals of most of plant species strongly followed aggregative distribution. Iwao analysis indicated that both individuals of all species and clumps of all individuals of all species followed aggregative distribution. Taylor's power law indicated that individuals of all species followed aggregative distribution and aggregation intensity strengthened as the increase of mean density. We held that the strong aggregation intensity of a species has been resulted from the strong adaptation ability to the environment, the strong interspecific competition ability and the earlier establishment of the species. Fitting goodness of the mean, I, I_δ, m^*/m with probability distributions demonstrated that the mean (density), I, I_δ, and m^*/m over all species followed Weibull distribution rather than normal distribution. *Lophatherum gracile*, *Paederia scandens* (Lour.) Merr., *Eleusine indica*, and *Alternanthera philoxeroides* (Mart.) Griseb. were mostly aggregative, and *Oxalis sp.*, *Eleocharis plantagineiformis*, *Vernonia cinerea* (L.) Less., and *Sapium sebiferum* (L.) Roxb, were mostly uniform in the spatial distribution. Importance values (IV) showed that *Cynodon dactylon* was the most important species, seconded by *Desmodium triflorum* (L.) DC., *Cajanus scarabaeoides* (L.) Benth., *Paspalum scrobiculatum* L., and *Rhynchelytrum repens*. *Oxalis sp.*, *Eleocharis plantagineiformis*, and *Vernonia cinerea* (L.) Less. were the least important species in the community. Summed dominance ratio (SDR2) revealed that *Cynodon dactylon* and *Desmodium triflorum* (L.) DC. were the most dominant species in the community, followed by *Rhynchelytrum repens*, *Paspalum scrobiculatum* L., and *Cajanus scarabaeoides* (L.) Benth.

Keywords grass community; aggregation pattern; importance value; summed dominance ratio.

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1 Introduction

Community succession is a self-organizing process over time and space (Clements, 1916.). Both composition and aggregation patterns of species in a community are the outcome of community self-organizing, and the former in turn affect the community succession. It is important to understand the structure and aggregation patterns of species in the community (Liu and Zhang, 2011). It also plays the fundamental role in the maintainence of biodiversity (Altieri, 1994; IRRI, 1998; Stang et al., 2007; Zhang, 2012; Jayakumar et al., 2011; Ahmad et al., 2013).

In present study, we will conduct analysis on species diversity and aggregation patterns of plant species in a grass community, Zhuhai, China, using various indices and methods, in order to further understand the species composition and spatial structure of the grass community.

2 Materials and Methods

2.1 Sampling survey

Sampling survey was conducted on May 12, 2008 in a grass community of Zhuhai, China (Fig. 1). In total of 100 samples were taken (10 by 10 samples; Fig. 2). Each sample had a size of 1m × 1m. Grass species, frequency (ratio of species presence), cover (area covered/total area) and density (individuals per sample) in each sample were recorded.

Fig. 1 The grassland for sampling survey.

2.2 Methods

2.2.1 Aggregation patterns

For the detection of aggregation patterns of plant species, the following three indices were used

Index of clumping: $I = s^2 / m$

Index of dispersion: $I_\delta = n \Sigma x_j(x_j-1) / (\Sigma x_j(\Sigma x_j-1))$

Index of patchiness (Iwao, 1968): $m^* / m = 1 + (s^2 - m) / m^2$

where m, s^2: mean and variance of number of individuals in a sample, n: number of samples (here n=100), x_j: density of plant individuals in the sample j, j=1,2,…,n. I>1, aggregative distribution; I<1, uniform distribution; I≈1, random distribution. I_δ>1, aggregative distribution; I_δ<1, uniform distribution; I_δ≈1, random distribution; m^*/m >1, aggregative distribution; m^*/m <1, uniform distribution; m^*/m≈1, random distribution.

A1	B1	C1	D1	E1	F1	G1	H1	I1	J1
A2	B2	C2	D2	E2	F2	G2	H2	I2	J2
A3	B3	C3	D3	E3	F3	G3	H3	I3	J3
A4	B4	C4	D4	E4	F4	G4	H4	I4	J4
A5	B5	C5	D5	E5	F5	G5	H5	I5	J5
A6	B6	C6	D6	E6	F6	G6	H6	I6	J6
A7	B7	C7	D7	E7	F7	G7	H7	I7	J7
A8	B8	C8	D8	E8	F8	G8	H8	I8	J8
A9	B9	C9	D9	E9	F9	G9	H9	I9	J9
A10	B10	C10	D10	E10	F10	G10	H10	I10	J10

Fig. 2 Sampling design.

Iwao regression (Iwao, 1968) and Taylor's power law are represented by

$$m^* = a + b\,m$$

and $$\log(s^2) = \log(a) + b\log(m)$$

in Iwao regression, $b > 1$, aggregative distribution; $b < 1$, uniform distribution; $b \approx 1$, random distribution. In Taylor's power law, $\log(a) > 0$ and $b \geq 1$, aggregative distribution; $\log(a) = 0$ and $b \approx 1$, random distribution; $\log(a) < 0$ and $b < 1$, uniform distribution.

Negative binomial distribution is expressed as

$$p_r = (k+r-1)!p^r / (r!(k-1)!Q^{k+r}) \qquad r>0$$

where $p = (s^2-m) / m$, $Q = 1+p$, $k = m^2 / (s^2-m)$, p_r: the probability that a sample contains r individuals, m: mean, s^2: variance.

2.2.2 Importance and dominance of species

The importance value (IV) of a plant species is

IV = (relative cover + relative frequency + relative density) / 3

where

Relative cover=area covered / total area covered by all species
Relative frequency= frequency of the species / total frequencies of all species
Relative density= density of the species / total density of all species

The summed dominance ratio for two factors (SDR2) is expressed as

SDR2= (density ratio + relative frequency) / 2 × 100%

2.2.3 Diversity of community

Diversity was measure by two indices

Simpson index: S_p=1 - $\Sigma x_j(x_j-1)$ / ($N(N$-1))
Shannon-wiener index: H'= -$\Sigma(P_j \ln P_j)$

where S: total number of plant species, $P_j= x_j / N$, N: total number of individuals.
2.2.4 One-dimensional cluster analysis
One-dimensional cluster method was used to cluster species into groups without change their natural order (Qi, 2005; Zhang, 2012), for example, the order of importance values from the large to the small.

3 Results

According to the sampling survey, in total of 47 plant species, belonging to 16 families, were found. Compositae has 10 species (21.3%), seconded by Gramineae (9 species, 19.1%), Leguminosae (6 species, 12.8%), Cyperaceae (4 species, 8.5%), Malvaceae (3 species, 6.4%). Convolvulaceae, Amaranthaceae, Oxalidaceae and Euphorbiaceae has 2 species (4.3%) respectively. The remaining 7 families account for 14.9% of total species.

3.1 Aggregation patterns

Aggregation patterns of 47 species are indicated in the Table 1. It can be found from Table 1 that most of the plant species follow aggregative distribution, and a little species follow uniform distribution (or random distribution). *Lophatherum gracile*, *Paederia scandens* (Lour.) Merr., *Eleusine indica*, and *Alternanthera philoxeroides* (Mart.) Griseb. are mostly aggregative, and *Oxalis sp.*, *Eleocharis plantagineiformis*, *Vernonia cinerea* (L.) Less., and *Sapium sebiferum* (L.) Roxb, are mostly uniform in the spatial distribution.

Table 1 Aggregation patterns of 47 species.

ID	Plant species	Mean	I	I_δ	m^*/m	Mean of I, I_δ & m^*/m	Spatial distri. pattern
1	*Lophatherum gracile*	0.58	54.06	93.16	92.483	79.901	Aggregative distri.
2	*Paederia scandens* (Lour.) Merr.	0.06	6	100	84.333	63.444	Aggregative distri.
3	*Eleusine indica*	0.04	4	100	76.000	60.000	Aggregative distri.
4	*Alternanthera philoxeroides* (Mart.) Griseb.	0.03	3	100	67.667	56.889	Aggregative distri.
5	*Ischaemum aristatum* L.	5.77	121.3	18.99	21.849	54.046	Aggregative distri.
6	*Eragrostis pilosa* (L.) Beauv	1.02	43.43	42.59	42.598	42.873	Aggregative distri.
7	*Rhus chinensis* Mill.	0.11	6.225	52.72	48.500	35.815	Aggregative distri.
8	*Artemisia indica* Willd.	0.39	15.95	39.95	39.333	31.744	Aggregative distri.
9	*Panicum repens* L.	2.43	45.75	17.05	19.416	27.405	Aggregative distri.
10	*Verbena officinalis* L.	0.31	10.99	33.91	33.226	26.042	Aggregative distri.
11	*Euphorbia hirta* L.	0.08	3.707	39.24	34.838	25.928	Aggregative distri.
12	*Lespedeza bicolor*	0.18	6.664	33.93	32.467	24.354	Aggregative distri.
13	*Paspalum scrobiculatum* L.	9.46	57.99	7.523	7.024	24.179	Aggregative distri.
14	*Kyllinga brevifolia*	0.91	21.12	23.13	23.110	22.453	Aggregative distri.
15	*Chrysopogon aciculatus*	1.18	24.3	20.72	20.746	21.922	Aggregative distri.
16	*Bidens pilosa* L.	2.39	31.25	13.58	13.657	19.496	Aggregative distri.
17	*Aster subulatus* Michx.	0.99	16.82	16.99	16.980	16.930	Aggregative distri.
18	*Oxalis corniculata* L.	0.15	4.226	23.81	22.507	16.848	Aggregative distri.
19	*Moghania philippinensis* (Merr. et	0.09	2.939	25	22.544	16.828	Aggregative distri.

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20	*Cajanus scarabaeoides* (L.) Benth.	9.07	37.28	5.072	5.000	15.784	Aggregative distri.
21	*Desmodium triflorum* (L.) DC.	11.21	37.54	4.223	4.260	15.341	Aggregative distri.
22	*Centella asiatica* (L.) Urb	0.46	8.67	17.79	17.674	14.711	Aggregative distri.
23	*Vetiveria zizanioides* (L.) Vach	0.22	4.461	17.32	16.732	12.838	Aggregative distri.
24	*Rhynchelytrum repens*	4.78	25.41	6.455	6.107	12.657	Aggregative distri.
25	*Ageratum conyzoides*	3.35	22.53	7.499	7.427	12.485	Aggregative distri.
26	*Erigeron acer* L.	0.43	6.12	13.07	12.907	10.699	Aggregative distri.
27	*Cynodon dactylon*	15.87	25.93	2.556	2.571	10.352	Aggregative distri.
28	*Wedelia triloba*	0.75	8.63	11.21	11.173	10.338	Aggregative distri.
29	*Pteris vittata L.*	0.41	5.622	12.41	12.273	10.102	Aggregative distri.
30	*Cayerus exaltatus* Retz.	0.33	4.717	12.51	12.264	9.830	Aggregative distri.
31	*Sesbania cannabina* (Retz.) Poir.	0.39	5.278	12.13	11.969	9.792	Aggregative distri.
32	*Bidens bipinnata* (L.)	0.64	7.201	9.896	10.689	9.262	Aggregative distri.
33	*Sida acuta* Burm. F	0.71	7.406	10.06	10.023	9.163	Aggregative distri.
34	*Ipomoea triloba*	0.22	3.173	11.23	10.877	8.427	Aggregative distri.
35	*Cyperus globosus* All.	1.97	11.85	6.397	6.508	8.252	Aggregative distri.
36	*Alternanthera sessilis* (L.) DC	0.54	5.291	9.012	8.946	7.750	Aggregative distri.
37	*Sida. rhombifolia* L.	1.76	8.92	5.478	5.500	6.633	Aggregative distri.
38	*Emilia sonchifolia* (L.) DC.	0.16	1.919	11.11	6.744	6.591	Aggregative distri.
39	*Mimosa pudica*	0.19	2.2	7.612	7.316	5.709	Aggregative distri.
40	*Syngonium podophyllum*	0.75	4.744	6.222	5.992	5.653	Aggregative distri.
41	*Pharbitis purpurea* L.	0.61	4.236	6.335	6.305	5.625	Aggregative distri.
42	*Ixeris polycephala* Cass	0.18	2.061	7.19	6.894	5.382	Aggregative distri.
43	*Urena lobata*	0.64	3.741	5.32	5.283	4.781	Aggregative distri.
44	*Oxalis sp.*	0.01	1	0	1.000	0.667	Uniform distri.
45	*Eleocharis plantagineiformis*	0.01	1	0	1.000	0.667	Uniform distri.
46	*Vernonia cinerea* (L.) Less.	0.01	1	0	1.000	0.667	Uniform distri.
47	*Sapium sebiferum* (L.) Roxb	0.01	1	0	1.000	0.667	Uniform distri.

Mean=number of individuals/sample.

The means of I_δ, I and m^*/m are 21.71, 15.71 and 19.89 respectively, and the variances of I_δ, I and m^*/m are 700.63, 469.01, 480.09 respectively. There is a strong correlation between I_δ and m^*/m (R^2=0.969). The correlations between I and I_δ (R^2=0.002) and m^*/m (R^2=0.012) are not significant.

Iwao regression of 47 species is: m^* = 8.638+ 4.49 m, R^2=0.396, p<0.00001. This means that both individuals of all species and clumps of individuals of all species follow aggregative distribution.

Taylor's power law: log(s^2) = 2.529 + 1.542 log (m), R^2=0.956, p<0.00001. It means that individuals of all species follow aggregative distribution, and aggregation intensity will strengthen with the increase of the mean density. Logically, it is obvious that increased aggregation intensity leads to the increase of the mean density. We thus hold that the strong aggregation intensity of a species has been resulted from the strong adaptation ability to the environment, the strong competition ability and the earlier establishment of the species.

Fitting goodness of mean, I, I_δ, m^*/m with normal distribution and Weibull distribution, calculated by

Matlab functions, are illustrated in Fig. 3. Linear relationship between probability and data means that the mean and three indices follow Weibull distribution.

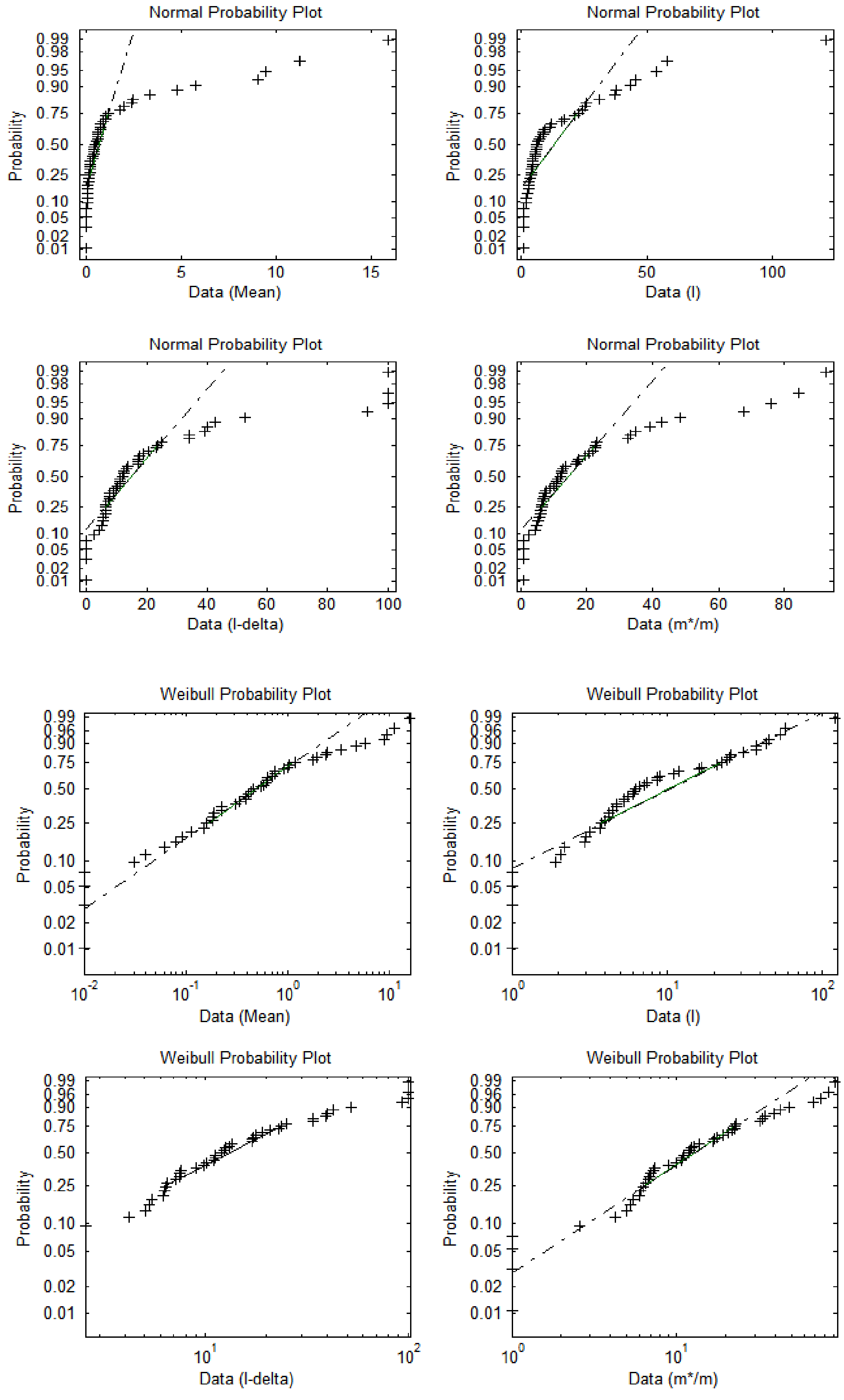

Fig. 3 Fitting goodness of the mean, *I*, I_δ, m^*/m with normal distribution and Weibull distribution. Linear relationship between probability and data means that the mean and three indices follow Weibull distribution rather than normal distribution.

One-dimensional cluster tree, calculated from the mean of I, I_δ and m^*/m in Table 1, is indicated in Fig. 4.

As an example, we give the spatial distribution (individuals per sample) of *Cynodon dactylon* as the following

0	0	2	3	0	5	0	0	0	0
0	0	0	11	0	17	0	0	6	18
0	39	22	24	22	10	5	0	11	16
9	26	34	37	25	26	22	19	19	18
8	0	3	27	26	34	9	44	10	8
0	0	0	1	6	54	35	10	7	10
18	13	14	17	20	93	82	45	0	107
35	32	19	4	9	3	16	20	20	3
69	50	43	18	0	22	35	30	0	0
0	12	0	0	0	0	0	0	0	0

For *Cynodon dactylon*, m= 15.9, s^2= 407.373. Thus p= (s^2-m) / m= 24.669, Q= 1+ p =25.669, k= 1.372, and

$$p_r = (1.372+r-1)!\ 24.669^r/(r!(\ 1.372-1)!\ 25.66938^{1.371545+r})$$

χ^2=925<$\chi_{0.05}{}^2$, therefore *Cynodon dactylon* follows negative binomial distribution in the community.

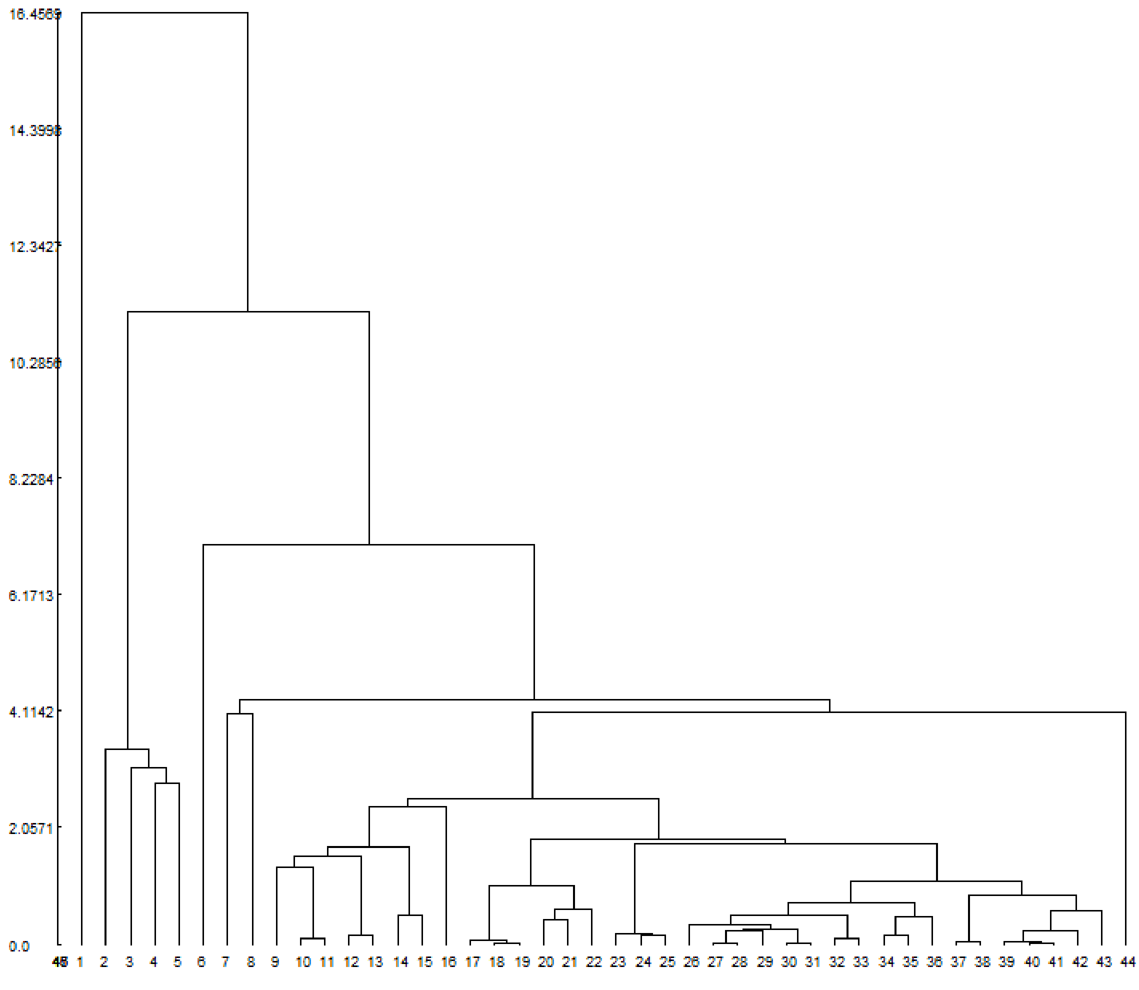

Fig. 4 One-dimensional cluster tree of species based on their similarity in aggregation degree (the mean of I, I_δ and m^*/m) in Table 1. Species for ID number 1 to 47 are listed in Table 1.

3.2 Importance values of plant species

Importance values of 47 species are indicated in the Table 2.

Table 2 Importance values of 47 species.

ID	Plant species	Relative cover	Relative frequency	Relative density	Importance value (IV)
1	*Cynodon dactylon*	0.31	0.68	0.1944	0.3948
2	*Desmodium triflorum* (L.) DC.	0.1381	0.49	0.1373	0.2552
3	*Cajanus scarabaeoides* (L.) Benth.	0.0569	0.41	0.1111	0.1927
4	*Paspalum scrobiculatum* L.	0.0925	0.35	0.1061	0.1829
5	*Rhynchelytrum repens*	0.0423	0.44	0.0544	0.1789
6	*Ageratum conyzoides*	0.0444	0.29	0.0403	0.1249
7	*Sida rhombifolia* L.	0.0276	0.3	0.0216	0.1164
8	*Bidens pilosa* L.	0.0186	0.26	0.0268	0.1018
9	*Urena lobata*	0.0081	0.25	0.0078	0.0887
10	*Syngonium podophyllum*	0.0092	0.24	0.0088	0.086
11	*Ischaemum aristatum* L.	0.046	0.13	0.0812	0.0858
12	*Cyperus globosus* All.	0.0322	0.16	0.0245	0.0722
13	*Pharbitis purpurea* L.	0.005	0.2	0.0075	0.0708
14	*Aster subulatus* Michx.	0.0072	0.18	0.0121	0.0664
15	*Bidens bipinnata* (L.)	0.0083	0.17	0.0086	0.0623
16	*Chrysopogon aciculatus*	0.0114	0.16	0.0145	0.0619
17	*Panicum repens* L.	0.0345	0.11	0.0339	0.0595
18	*Alternanthera sessilis* (L.) DC	0.0091	0.16	0.0066	0.0586
19	*Sida acuta* Burm. F	0.0104	0.13	0.0087	0.0497
20	*Wedelia triloba*	0.008	0.12	0.0092	0.0457
21	*Sesbania cannabina* (Retz.) Poir.	0.0042	0.11	0.0048	0.0397
22	*Cayerus exaltatus* Retz.	0.0019	0.11	0.004	0.0387
23	*Mimosa pudica*	0.0118	0.1	0.0023	0.038
24	*Ixeris polycephala* Cass	0.0035	0.1	0.0022	0.0352
25	*Erigeron acer* L.	0.0056	0.09	0.0053	0.0336
26	*Ipomoea triloba*	0.0031	0.09	0.0027	0.0319
27	*Centella asiatica* (L.) Urb	0.0046	0.08	0.0056	0.0301
28	*Pteris vittata L.*	0.0037	0.08	0.005	0.0296
29	*Kyllinga brevifolia*	0.0051	0.07	0.0111	0.0288
30	*Verbena officinalis* L.	0.0064	0.06	0.0038	0.0234
31	*Emilia sonchifolia* (L.) DC.	0.0023	0.06	0.001	0.0211
32	*Artemisia indica* Willd.	0.0026	0.05	0.0048	0.0191
33	*Vetiveria zizanioides* (L.) Vach	0.0022	0.05	0.0027	0.0183
34	*Lespedeza bicolor*	0.0019	0.05	0.0022	0.018
35	*Eragrostis pilosa* (L.) Beauv	0.0072	0.03	0.0125	0.0166
36	*Moghania philippinensis* (Merr. et Rolfe) Li	0.0034	0.04	0.0011	0.0148
37	*Oxalis corniculata* L.	0.0004	0.04	0.0018	0.0141
38	*Lophatherum gracile*	0.0039	0.03	0.0071	0.0137
39	*Rhus chinensis* Mill.	0.0027	0.03	0.0013	0.0114
40	*Euphorbia hirta* L.	0.0004	0.03	0.001	0.0105
41	*Paederia scandens* (Lour.) Merr.	0.0014	0.01	0.0007	0.004
42	*Sapium sebiferum* (L.) Roxb	0.0009	0.01	0.0001	0.0037
43	*Eleusine indica*	0.0003	0.01	0.0005	0.0036
44	*Alternanthera philoxeroides* (Mart.) Griseb.	0.0003	0.01	0.0004	0.0035
45	*Oxalis sp.*	0.0001	0.01	0.0001	0.0034
46	*Eleocharis plantagineiformis*	0.0001	0.01	0.0001	0.0034
47	*Vernonia cinerea* (L.) Less.	0.0001	0.01	0.0001	0.0034

We may find from Table 2 that *Cynodon dactylon* is relatively the most important species, seconded by *Desmodium triflorum* (L.) DC., *Cajanus scarabaeoides* (L.) Benth., *Paspalum scrobiculatum* L., and *Rhynchelytrum repens*. *Oxalis corniculata* L., *Eleocharis plantagineiformis*, and *Vernonia cinerea* (L.) Less. are the least important species in the community.

One-dimensional cluster tree, calculated from importance values in Table 2, is indicated in Fig. 5.

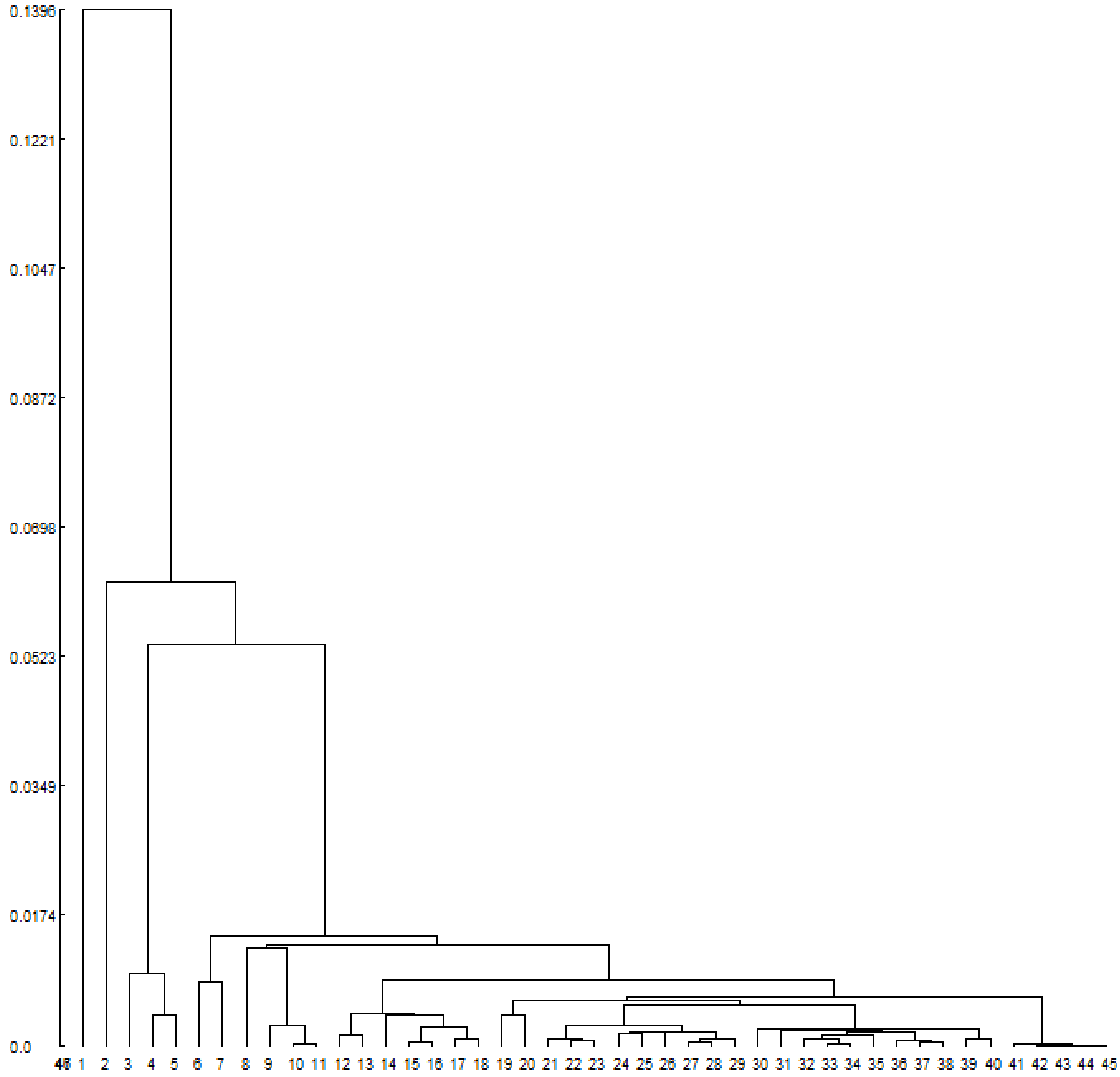

Fig. 5 One-dimensional cluster tree of species based on their similarity in species importance in Table 2. Species for ID number 1 to 47 are listed in Table 2.

Table 3 indicates that *Cynodon dactylon* and *Desmodium triflorum* (L.) DC. are the most dominant species in the community, followed by *Rhynchelytrum repens*, *Paspalum scrobiculatum* L., and *Cajanus scarabaeoides* (L.) Benth.

3.3 Diversity of plant species

Simpson index and Shannon-wiener index of the community is 0.903 and 2.788 respectively. Thus the community is relatively diverse.

Table 3 Summed dominance ratio for two factors (SDR2) for 47 species.

Plant species	SDR2(%)	Plant species	SDR2(%)
Cynodon dactylon	100.00	*Centella asiatica* (L.) Urb	22.50
Desmodium triflorum (L.) *DC.*	80.00	*Chrysopogon aciculatus*	22.50
Rhynchelytrum repens	65.00	*Kyllinga brevifolia*	17.50
Paspalum scrobiculatum L.	65.00	*Sida acuta* Burm. F	17.50
Cajanus scarabaeoides (L.) Benth.	62.50	*Artemisia indica* Willd.	15.00
Bidens pilosa L.	52.50	*Ageratum conyzoides*	15.00
Sida rhombifolia L.	50.00	*Vetiveria zizanioides* (L.) Vach	15.00
Urena lobata	47.50	*Moghania philippinensis* (Merr. et Rolfe) Li	15.00
Alternanthera sessilis (L.) DC	47.50	*Lespedeza bicolor*	15.00
Pharbitis purpurea (L.)	47.50	*Cyperus globosus* All.	15.00
Oxalis corniculata L.	47.50	*Euphorbia hirta* L.	15.00
Syngonium podophyllum	47.50	*Rhus chinensis* Mill.	15.00
Bidens bipinnata (L.)	42.50	*Pteris vittata L.*	12.50
Ixeris polycephala Cass	40.00	*Verbena officinalis* L.	10.00
Aster subulatus Michx.	37.50	*Eragrostis pilosa* (L.) Beauv	7.50
Ischaemum aristatum L.	37.50	*Lophatherum gracile*	7.50
Sesbania cannabina (Retz.) Poir.	30.00	*Vernonia cinerea* (L.) Less.	5.00
Wedelia triloba	27.50	*Eleusine indica*	5.00
Emilia sonchifolia (L.)DC.	25.00	*Eleocharis plantagineiformis*	5.00
Mimosa pudica	25.00	*Sapium sebiferum* (L.) Roxb.	5.00
Cayerus exaltatus Retz.	25.00	*Alternanthera philoxeroides* (Mart.) Griseb.	5.00
Ipomoea triloba	25.00	*Oxalis sp.*	5.00
Erigeron acer L.	22.50	*Paederia scandens* (Lour.) Merr.	5.00
Panicum repens L.	22.50		

4 Discussion and Main Conclusion

Individuals of most of plant species follow aggregative distribution. In addition, clumps of all individuals of most species follow aggregative distribution. The plant density, the aggregation indices I, I_δ, and m^*/m over all species follow Weibull distribution, rather than normal distribution. We guess that most of the indices over multiple species used in ecological studies might follow Weibull distribution. This should be further validated in the future studies.

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