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FRACTAL ANALYSIS APPLIED TO SPATIAL STRUCTURE OF CHINA'S VEGETATION

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ABSTRACT: Based on the fractal theory, the spatial structure of China's vegetation has been analyzed quantitatively in this paper. Some conclusions are drawn as the following. 1) The relationships between size and frequency of patch area and patch shape index exist objectively for China's vegetation. 2) The relationships between perimeter and area exist objectively for China's vegetation. 3) The fractal dimension of evergreen needleleaf forests on mountains in subtropical and tropical zones is the largest, while the smallest for deciduous broadleaf and evergreen needleleaf mixed forests in temperate zone, reflecting the most complex spatial structure for evergreen needleleaf forests on mountains in subtropical and tropical zones and the simplest for deciduous broadleaf and evergreen needleleaf mixed forests in temperate zone. 4) The fractal dimensions of China's vegetation types tend to decrease from the subtropics to both sides. 5) The stability of spatial structure of deciduous broadleaf and evergreen needleleaf mixed forests in temperate zone is the largest, while the smallest for double-cropping rice, or double-cropping rice and temperate-like grain, and tropical evergreen economic tree plantations and orchards, reflecting the steadiest for deciduous broadleaf and evergreen needleleaf mixed forests in temperate zone and the most unstable for double-cropping rice, or double-cropping rice and temperate-like grain, and tropical evergreen economic tree plantations and orchards in spatial structure. 6) The stability of spatial structure of China's vegetation tends to decrease from the temperate zone to both sides. It is significantly pertinent to understand the formation, evolution, dynamics and complexity rule of ecosystem of vegetation.
KEY WORDS: vegetation; spatial structure; fractal; fractal dimension; China

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1 INTRODUCTION

Mandelbrot stated the uncertainty of the length of a coastline in his paper "How long is the coast of Britain? Statistical self-similarity and fractional dimension" published in Science in 1967 (MANDELBROT, 1967). The concepts of fractal and fractal dimension were presented for the first time in that paper and have been applied to quantitatively describing the difference of crooked coastlines of British and South Africa. Compared with the Euclidean geometry with more than two thousand years of history, fractal and fractal dimension are fitter for describing various complicated objects in nature.

The fractal theory has been applied in many fields. At present it has become a field with vast potential for its applications in many disciplines. It has been applied extensively in botany too. For instance, MORSE et al., (1985) studied the relationship between fractal dimension of vegetation and distribution of anthropod body lengths. ZEIDE and PFEIFER (1991) designed a method for estimation of fractal dimension of tree crowns. LOEHLE et al., (1996) applied the fractal theory to indicating the forest spread and phase transitions at forest-prairie ecotones in Kansas, USA. XIN et al., (1999) analyzed the fractal characteristic of grass patches under grazing and flood disturbance in alkaline grassland of the Songnen Plain, China. MA and ZU (2000) studied the fractal properties of vegetation pattern. LIU and CAMERON (2001) analyzed the landscape fractal patterns in coastal wetlands of Galveston Bay, Texas, USA. PERRY et al. (2001) described a spatially explicit, landscape-level model developed to investigate the vegetation pattern on Mont Do, New Caledonia. DESPLAND (2003) evaluated box-counting dimension as a quantita-

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tive clumping index for discontinuous plant cover, and applied it to studies of both small- and large-scale ecological processes in desert locust swarming. ALADOS et al. (2003) studied the effect of grazing on the degree of regression of successional vegetation dynamics in a semi-arid Mediterranean matorral, and quantified the spatial distribution patterns of the vegetation by fractal analyses. Although related studies have been done, the references on spatial fractal structure of vegetation on larger scale have not been seen until now. Different types of vegetation display patches with different magnitude and distribution of odds in space that implies that there might occur significant variability in the spatial distribution of different types of vegetation. Based on the fractal theory, it is significant to study the character of spatial distribution of different types of vegetation to systematically understand the formation, evolvement and commonness rule of ecosystem of vegetation.

Vegetation types of China are abundant, most types being distributed in China. Therefore, China with an area of $9.6\times10^6 km^2$ is a region suitable for studying the spatial fractal structure of vegetation. This paper focused on four problems. Firstly, the relationship between size and frequency of patches of vegetation types of China; secondly, the relationship between perimeter and area of patches of vegetation types of China; thirdly, the fractal dimensions of spatial structure of vegetation types in China; and fourthly, the stability of spatial structure of vegetation types of China.

2 METHODS AND MATERIALS

According to the fractal theory, the relationships between size and frequency of patches of vegetation types of China were established. The basic fractal formula of size-frequency is as follows (TURCOTTE, 1986):

$$N(>r)=\frac{c}{r^d} \quad (1)$$

where r is size, N(>r) is frequency above size r, c is a constant, d is fractal dimension.

In this paper, r in formula (1) is defined as patch area and patch shape index respectively. N in formula (1) is defined as the number of vegetation patches above size r.

Formula of patch shape index contrasted with square is expressed as (WU, 2002):

$$S=\frac{0.25\times P}{\sqrt{A}} \quad (2)$$

where S is patch shape index, P is patch perimeter and A is patch area.

The relationship between perimeter and area of patches is established by fractal formula (3) (LOREJOY, 1982; MANDELBROT et al., 1984).

$$A=kP^{2/D} \quad (3)$$

where A is patch area, P is patch perimeter, D is fractal dimension, k is a constant. Formula (3) may be transformed by logP against logA, then

$$\log A=\frac{2}{D}\log P+C \quad (4)$$

Fractal dimension of spatial structure of vegetation can be calculated by formula (4). The slope of the regression line of series of logP against logA is 2/D. Larger the value of D, more complex is the spatial structure. When D is equal to 1.5, spatial structure is most unstable, because it is in a random condition of Brownian movement (XU, 2002). When D is closer to 1.5, spatial structure is unstable. The stability index of spatial structure of vegetation is established as (XU, 2002):

$$SK=|1.5-D| \quad (5)$$

Larger the value of SK, steadier is the spatial structure of soil.

The data used are from "Resources and Environment Database of China (1∶4 000 000)" prepared by the State Key Laboratory of Resources & Environment Information System of Chinese Academy of Sciences in 1996. Vegetation data of the database are from "China's Vegetation Map (1∶4 000 000)" (Institute of Botany, Chinese Academy of Sciences, 1979). China's Vegetation Map in this database was vectorized through Arc/info, popular GIS software, and data capacity reached 16 936 965 bytes. In this database, information of perimeters and areas of patches of different types of vegetation can be read and then calculated on the basis of formulas (1) - (5) through Excel software. Based on formulas (1) and (4), linear regressions of double logarithms were done, and then significance tests were done using the critical value of correlation coefficient (YUAN and ZHOU, 2003). The vegetation types in this database are classified as natural vegetation, cultivated vegetation, land without vegetation, and lake.

Natural vegetation is classified as 43 types, whose names and codes are as follows: deciduous needleleaf forests on mountains in cold-temperate and temperate zones (1101), evergreen needleleaf forests on mountains in temperate zone (1102), evergreen needleleaf woodland on sandy land in steppe in temperate zone (1103), evergreen needleleaf forests in temperate zone (1104), evergreen needleleaf forests in subtropical and tropical zones (1105), evergreen needleleaf forests on mountains in subtropical and tropical zones (1106), deciduous broadleaf and evergreen needleleaf mixed forests in temperate zone (1207), deciduous broadleaf forests in temperate and subtropical zones (1208), microphyllous de ciduous forests on mountains in temperate and subtropical zones (1209), microphyllous deciduous woodland in temperate zone (1210), broadleaf deciduous and evergreen mixed forests on calcareous soil in subtropical zone (1211), broadleaf evergreen and deciduous mixed forests on mountainous acid yellow soil in subtropical zone (1212), evergreen broadleaf forests in subtropical zone (1213), evergreen broadleaf forests with characters of tropical rain forests (1214), sclerophyllus evergreen broadleaf forests in subtropical zone (1215), bamboo forests in subtropical zone (1216), semi-evergreen broadleaf monsoon forests and second birth vegetation in tropical zone (1217), evergreen broadleaf rain forests and second birth vegetation in tropical zone (1218), deciduous scrubs and dwarf forests in temperate and subtropical zones (1319), broadleaf evergreen and deciduous scrubs and dwarf forests and tufted-grass on acid soil in subtropical and tropical zones (1320), evergreen and deciduous scrubs and dwarf forests with many sorts of lianes (1321), sclerophyllus broadleaf evergreen scrub and dwarf forests on seaside areas in tropical zone (1322), broadleaf evergreen succulent scrub and dwarf forests on coral islands in tropical zone (1323), alpine and subalpine sclerophylla evergreen scrubes in subtropical zone (1324), subalpine deciduous scrubs in temperate and subtropical zones (1325), alpine tundra with dwarf scrubes in temperate zone (1326), alpine cushion dwarf semi-shrub in temperate and subtropical zones (1327), dwarf semi-shrub deserts in temperate zone (1428), succulent halophytic dwarf semi-shrub deserts in temperate zone (1429), shrub and semi-shrub deserts in temperate zone (1430), semi-arboreous deserts in temperate zone (1431), high-cold cushion dwarf semi-shrub deserts in temperate zone (1432), temperate grass, forb steppes (1533), temperate tufted grass steppes (1534), temperate tufted grass steppes on mountains (1535), temperate tufted low grass, dwarf semi-shrub steppes (1536), temperate low grass, dwarf semi-shrub steppes on mountains (1537), high-cold steppes in temperate and subtropical zones (1538), sparse shrub steppes in tropical and subtropical zones (1539), temperate meadows (1640), high-cold meadows in temperate and subtropical zones (1641), temperate herbage marsh (1642), temperate high-cold herbage marsh(1643).

Cultivated vegetation is classified as 5 types, whose names and codes are as follows: one year one ripe grain and cold-tolerant economic crop (2100), one year two ripes or two year three ripes grain (rice locally) and deciduous orchards, economic tree platations in warm-temperate zone (2200), one year two ripes (grain and rice) and subtropical evergreen, deciduous economic tree plantations and orchards (2300), Single (double)-cropping rice and cool-like grain, or one year three ripes (2400), double-cropping rice, or double-cropping rice and temperate-like grain, and tropical evergreen economic tree plantations and orchards (2500).

The vegetation types and patch number of China are listed in Table 1.

Table 1 Vegetation type and patch number of China

Vegetation type	Patch number	Vegetation type	Patch number	Vegetation type	Patch number	Vegetation type	Patch number
1101	145	1213	212	1325	18	1537	41
1102	184	1214	50	1326	11	1538	81
1103	5	1215	19	1327	230	1539	48
1104	81	1216	51	1428	93	1640	240
1105	818	1217	35	1429	33	1641	152
1106	115	1218	19	1430	102	1642	57
1207	30	1319	345	1431	36	1643	6
1208	497	1320	178	1432	14	2100	316
1209	110	1321	167	1533	220	2200	152
1210	58	1322	3	1534	86	2300	114
1211	107	1323	0	1535	27	2400	168
1212	101	1324	47	1536	46	2500	120

3 RESULTS

3.1 Relationship of Size-frequency of Patch Area

Size r in formula (1) is defined as patch area here. The result of size-frequency of patch areas of the whole China's vegetation types are listed in Table 2, and those of different vegetation types of China are listed in Table 3. Some of vegetation types are not listed in Table 3 because the patch number is not enough.

Table 2 shows that the patch number of the whole China's vegetation types is 5466 pieces above size 50km^2, and it is 27 pieces above size 50 000km^2.

Plot of logN(>r) against logr of patch areas of the whole China's vegetation types is shown in Fig. 1.

According to the least square method, the relationship between size and frequency of patch areas of the whole

Table 2 Result of size-frequency of whole China's vegetation type

Size (km^2)	Frequency (piece)	Size (km^2)	Frequency (piece)	Size (km^2)	Frequency (piece)	Size (km^2)	Frequency (piece)
>50	5466	>500	1765	>2000	589	>20000	63
>100	4808	>600	1517	>3000	425	>30000	42
>200	3572	>700	1348	>4000	320	>40000	34
>300	2654	>800	1228	>5000	251	>50000	27
>400	2095	>1000	1026	>10000	133		

Table 3 Result of size-frequency of patch area of China's vegetation type

Vegetation type	Frequency (piece)										
	>50*	>100	>200	>300	>400	>500	>600	>700	>800	>1000	>2000
1101	127	110	70	46	39	33	32	29	28	21	-
1102	152	96	43	29	15	-	-	-	-	-	-
1105	796	732	500	324	208	152	124	91	78	57	17
1106	115	111	94	78	62	44	37	34	30	28	19
1208	456	334	213	127	97	75	60	51	43	31	-
1209	97	75	44	27	17	-	-	-	-	-	-
1211	102	93	47	22	10	-	-	-	-	-	-
1213	210	201	137	83	56	42	29	24	22	-	-
1319	325	300	249	203	163	139	124	113	107	93	54
1320	144	135	118	102	89	77	63	59	48	40	27
1321	161	146	128	104	87	73	61	49	45	35	14
1327	221	202	158	122	98	87	75	67	62	54	29
1428	91	88	84	76	71	67	59	55	50	47	38
1430	100	99	97	92	80	73	68	60	51	39	100
1533	202	183	163	133	109	101	85	80	73	60	29
1640	231	207	173	137	111	97	81	73	71	59	25
1641	148	143	128	108	93	83	80	74	64	62	40
2100	297	245	158	113	81	70	60	56	49	37	23
2200	145	112	63	39	28	24	21	19	-	-	-
2300	109	103	77	45	31	18	-	-	-	-	-
2400	156	145	114	83	70	58	51	44	32	21	-
2500	112	106	81	62	48	45	33	28	26	23	-
Natural vegetation	4633	4087	3069	2303	1828	1541	1329	1181	1085	913	523
Cultivated vegetation	819	711	493	342	258	215	179	159	136	106	60

Notes: "- " means no data; * All data in this row are size (km^2)

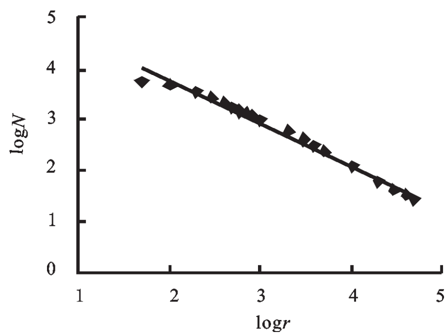

Fig. 1 Plot of logN (>r) against logr of patch area of whole China's vegetation type

China's vegetation types is established by linear regression as follows:

$$\log N=5.4383-0.832\log r \quad (6)$$

Similarly, the relationship of size-frequency of each vegetation type may be established. The results are listed in Table 4.

The relationships of size-frequency of all vegetation types can pass the R test ($R_{0.05} \geq 0.8783$), which ascertains the significance of relationships of size-frequency of China's vegetation types.

3.2 Relationship of Size-frequency of Patch Shape Index

Size r in formula (1) is defined as patch shape index here. Size-frequency relationship has been computed using formula (1). The results are listed in Table 5 and Table 6.

Plot of logN (>r) against logr of patch shape index of the whole China's vegetation types is shown in Fig. 2.

The relationship between size and frequency of the whole China's vegetation types is established through linear regression as:

$$\log N=3.6912-2.6029\log r \quad (7)$$

Relationship of size-frequency of each vegetation type can be established by the same method. The results are listed in Table 7.

The relationships of size-frequency of patch shape index of China's vegetation types can pass the R test-

Table 4 Relationship of size-frequency of each vegetation type

Vegetation type	Relationship of size-frequency	Correlation coefficient	Vegetation type	Relationship of size-frequency	Correlation coefficient
1101	logN=3.2199- 0.6204logr	0.9886	1430	logN=2.5345- 0.2610logr	0.9084
1102	logN=3.8219- 0.9470logr	0.9934	1533	logN=3.2815- 0.4969logr	0.9391
1105	logN=4.9745- 1.0597logr	0.9590	1640	logN=3.4784- 0.5727logr	0.9491
1106	logN=3.1372- 0.5523logr	0.9551	1641	logN=2.8712- 0.3586logr	0.9573
1208	logN=4.3305- 0.9175logr	0.9858	2100	logN=3.8175- 0.7334logr	0.9902
1209	logN=3.4539- 0.8216logr	0.9696	2200	logN=3.6486- 0.8329logr	0.9901
1211	logN=4.0001- 1.0839logr	0.9282	2300	logN=3.4294- 0.7432logr	0.9118
1213	logN=4.0340- 0.8998logr	0.9548	2400	logN=3.4009- 0.6280logr	0.9336
1319	logN=3.4643- 0.4958logr	0.9694	2500	logN=3.1485- 0.5783logr	0.9609
1320	logN=3.0891- 0.4716logr	0.9420	Natural vegetation	logN=4.8219- 0.6137logr	0.9811
1321	logN=3.4619- 0.6280logr	0.9234	Cultivated vegetation	logN=4.3191- 0.7475logr	0.9822
1327	logN=3.4073- 0.5568logr	0.9734	Total vegetation	logN=5.4383- 0.8320logr	0.9919
1428	logN=2.4546- 0.2500logr	0.9380			

Table 5 Result of size-frequency of patch shape index of whole China's vegetation patches

Size	Frequency (piece)	Size	Frequency (piece)	Size	Frequency (piece)
>1	5336	>1.8	1057	>5.0	77
>1.2	2970	>2.0	796	>6.0	45
>1.4	1930	>3.0	283	>7.0	31
>1.6	1384	>4.0	147	>8.0	21

($R_{0.05} \geq 0.8783$), which means the significance of relationships of size-frequency of patch shape index.

3.3 Relationship of Perimeter and Area of Patch

The plot of logP against logA of patches of the whole China's vegetation types is shown in Fig. 3. The number of patches of 1322 and 1323 is less than 2 respectively. Therefore, their relationships of perimeter and area of patches cannot be established.

Table 6 Result of size-frequency of patch shape index of each vegetation type

Size	1101	1105	1106	1208	1213	1319	1320	1321	1327	1428
>1	120	721	107	379	193	312	174	159	218	89
>1.2	61	316	70	115	104	196	110	116	129	68
>1.4	37	162	47	53	62	131	70	84	94	55
>1.6	28	107	39	30	36	96	52	53	72	46
>1.8	22	80	29	22	20	65	43	40	59	35
>2	-	50	24	-	-	53	32	29	45	27

Size	1430	1533	1640	1641	2100	2200	2400	2500	Natural vegetation	Cultivated vegetation
>1	97	194	214	149	287	134	165	111	4353	807
>1.2	72	117	143	109	151	62	116	79	2361	469
>1.4	57	71	109	92	91	36	80	55	1547	295
>1.6	46	48	83	78	64	29	49	40	1123	198
>1.8	33	38	65	64	41	22	34	31	870	137
>2	23	30	53	49	35	14	24	24	651	103

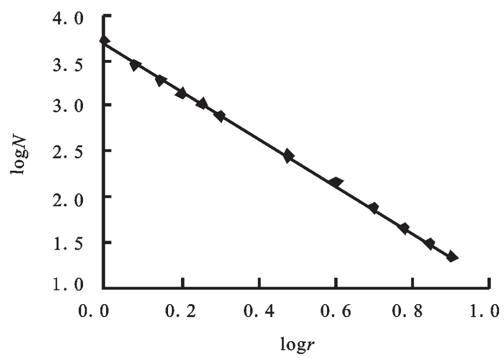

Fig. 2 Plot of logN (>r) against logr of patch shape index of whole China's vegetation types

The relationship between perimeter and area of the whole China's vegetation types is established through linear regression analysis as

$$\log A=1.5358\log P+0.8197 \quad (8)$$

Table 8 shows the relationship of perimeter and area of patches of vegetation types of China.

The relationships of perimeter and area of patches of vegetation types can all pass the R test. Fractal characteristics exist for the spatial structure of China's vegetation.

3.4 Fractal Dimension of China's Vegetation Type

The fractal dimensions of spatial structure of vegetation

Table 7 Relationship of size-frequency of patch shape index of each vegetation type of China

Vegetation type	Relationship of size-frequency	Correlation coefficient	Vegetation type	Relationship of size-frequency	Correlation coefficient
1101	logN=2.0395- 2.8844logr	0.9909	1533	logN=2.2740- 2.7376logr	0.9971
1105	logN=2.8142- 3.7400logr	0.9954	1640	logN=2.3248- 1.9981logr	0.9996
1106	logN=2.0164- 2.1487logr	0.9976	1641	logN=2.1751- 1.5093logr	0.9923
1208	logN=2.5037- 4.8716logr	0.9891	2100	logN=2.4340- 3.0892logr	0.9968
1213	logN=2.3105- 3.7975logr	0.9965	2200	logN=2.0738- 3.0598logr	0.9900
1319	logN=2.4963- 2.5919logr	0.9991	2400	logN=2.2641- 2.8383logr	0.9935
1320	logN=2.2273- 2.4167logr	0.9974	2500	logN=2.0595- 2.2320logr	0.9991
1321	logN=2.2407- 2.5013logr	0.9936	Natural vegetation	logN=3.6076- 2.6792logr	0.9970
1327	logN=2.3110- 2.1937logr	0.9964	Cultivated vegetation	logN=2.9066- 2.9881logr	0.9999
1428	logN=1.9677- 1.6695logr	0.9915	Total vegetation	logN=3.6912- 2.6029logr	0.9996
1430	logN=2.0178- 1.9923logr	0.9849			

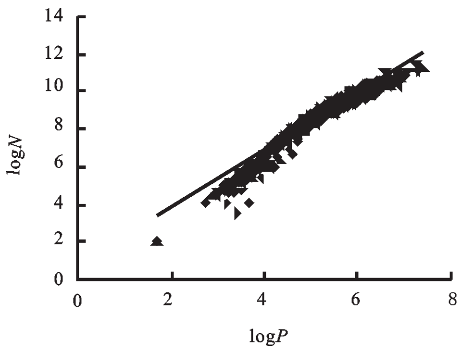

Fig. 3 Plot of logP against logA of patches of whole China's vegetation types

types of China (D) have been calculated by incorporating the area and perimeter values from Table 8 into the e quation (4) and the results obtained are presented in Table 9.

Table 9 shows that the fractal dimension of evergreen needleleaf forests on mountains in subtropical and tropical zones (1106) is the largest, while smallest for deciduous broadleaf and evergreen needleleaf mixed forests in temperate zone (1207), implying that the spatial structure of 1106 is the most complex while that of 1207 is the simplest. Based on this inference, fractal dimension could be considered as a vital parameter to describe the spatial structure of China's vegetation. The complexity

Table 8 Relationship of perimeter-area of patches of China's vegetation types

Vegetation type	Relationship of perimeter-area	Correlation coefficient	Vegetation type	Relationship of perimeter-area	Correlation coefficient
1101	logA=1.5063logP+0.9796	0.9572	1428	logA=1.3783 logP+1.6690	0.9718
1102	logA=1.7672 logP- 0.2043	0.9714	1429	logA=1.4586 logP+1.3400	0.9646
1103	logA=1.5761 logP+0.7255	0.9889	1430	logA=1.4482 logP+1.3558	0.9670
1104	logA=1.7517 logP- 0.1255	0.9705	1431	logA=1.2848 logP+2.2533	0.9737
1105	logA=1.3873 logP+1.6143	0.9511	1432	logA=1.1686 logP+2.8485	0.9899
1106	logA=1.1436 logP+2.8388	0.9751	1533	logA=1.5139 logP+0.9924	0.9749
1207	logA=1.7826 logP- 0.4251	0.9723	1534	logA=1.4930 logP+1.1118	0.9807
1208	logA=1.5688 logP+0.7481	0.9728	1535	logA=1.2370 logP+2.3979	0.9844
1209	logA=1.5184 logP+0.9547	0.9716	1536	logA=1.5233 logP+0.9499	0.9900
1210	logA=1.2827 logP+2.1230	0.9613	1537	logA=1.4407 logP+1.2481	0.9664
1211	logA=1.2692 logP+2.1643	0.9371	1538	logA=1.2975 logP+2.0023	0.9736
1212	logA=1.2709 logP+2.0949	0.9643	1539	logA=1.3526 logP+1.4906	0.9827
1213	logA=1.3665 logP+1.7036	0.9516	1640	logA=1.4283 logP+1.3230	0.9502
1214	logA=1.4660 logP+1.1185	0.9595	1641	logA=1.2681 logP+2.1476	0.9589
1215	logA=1.2021 logP+2.5309	0.9821	1642	logA=1.2687 logP+2.2198	0.9686
1216	logA=1.4371 logP+1.3816	0.9548	1643	logA=1.6107 logP+0.5252	0.9918
1217	logA=1.3713 logP+1.6752	0.9698	2100	logA=1.3916 logP+1.5422	0.9752
1218	logA=1.4480 logP+1.2086	0.9818	2200	logA=1.3743 logP+1.6311	0.9837
1319	logA=1.4191 logP+1.4358	0.9706	2300	logA=1.5823 logP+0.6280	0.9740
1320	logA=1.4550 logP+1.1708	0.9676	2400	logA=1.4627 logP+1.1619	0.9722
1321	logA=1.2992 logP+2.0101	0.9778	2500	logA=1.3301 logP+1.8359	0.9712
1324	logA=1.1617 logP+2.6734	0.9517	Natural vegetation	logA=1.4043 logP+1.4982	0.9658
1325	logA=1.1454 logP+2.8320	0.9853	Cultivated vegetation	logA=1.4106 logP+1.4453	0.9742
1326	logA=1.6215 logP+0.5148	0.9937	Total vegetation	logA=1.5358 logP+0.8197	0.9617
1327	logA=1.3843 logP+1.5580	0.9608			

Table 9 Fractal dimension of China's vegetation type

Vegetation type	D	Vegetation type	D	Vegetation type	D
1101	1.3278	1218	1.3812	1535	1.6168
1102	1.1317	1319	1.4093	1536	1.3129
1103	1.2690	1320	1.3746	1537	1.3882
1104	1.1417	1321	1.5394	1538	1.5414
1105	1.4416	1322	-	1539	1.4786
1106	1.7489	1323	-	1640	1.4003
1207	1.1220	1324	1.7216	1641	1.5772
1208	1.2749	1325	1.7461	1642	1.5764
1209	1.3172	1326	1.2334	1643	1.2417
1210	1.5592	1327	1.4448	2100	1.4372
1211	1.5758	1428	1.4511	2200	1.4553
1212	1.5737	1429	1.3712	2300	1.2640
1213	1.4636	1430	1.3810	2400	1.3673
1214	1.3643	1431	1.5567	2500	1.5036
1215	1.6638	1432	1.7115	Natural vegetation	1.4242
1216	1.3917	1533	1.3211	Cultivated vegetation	1.4178
1217	1.4585	1534	1.3396	Total vegetation	1.3023

of spatial structure of China's vegetation types is arranged as follows:

1106>1325>1324>1432>1215>1535>1641>1642>1211>1212>1210>1431>1538>1321>2500>1539>1213>1217>2200>1428>1327>1105>2100>1319>1640>1216>1537>1218>1430>1320>1429>2400>1214>1534>1101>1533>1209>1536>1208>1103>2300>1643>1326>1104>1102>1207.

The spatial variability of formation and evolvement of China's vegetation is apparent. Table 10 lists the average fractal dimensions of vegetation types in different climatic zones in China.

Table 10 shows that the average fractal dimension of the subtropical vegetation types is the largest, reflecting the most complex spatial structure associated with the subtropical vegetation types, and it tends to decrease towards its both sides.

Table 10 Average fractal dimensions of vegetation types in different climatic zones

Climatic zone	Vegetation type	Average fractal dimension
Transition zone between cold and temperate zones	1101	1.3278
Temperate zone	1102, 1103, 1104, 1207, 1210, 1326, 1428, 1429, 1430, 1431, 1432, 1533, 1534, 1535, 1536, 1537, 1640, 1642, 1643	1.3750
Transition zone between temperate and subtropical zones	1208, 1209, 1319, 1325, 1327, 1538, 1641	1.4730
Subtropical zone	1211, 1212, 1213, 1215, 1216, 1324	1.5650
Transition zone between subtropical and tropical zones	1105, 1106, 1320, 1321, 1539	1.5166
Tropical zone	1214, 1217, 1218, 1322, 1323	1.4013

3.5 Stability Index of Spatial Structure of China's Vegetation Type

Using the fractal values from Table 9 in equation (5), sta bility indexes SK of spatial structure of vegetation types of China are calculated and listed in Table 11.

Table 11 shows that the stability of spatial structure of 1207 (deciduous broadleaf and evergreen needleleaf mixed forests in temperate zone) is the largest, while smallest for 2500 (double-cropping rice, or double-cropping rice and temperate-like grain, and tropical evergreen economic tree plantations and orchards). The sta bility structure of China's vegetation types is arranged as follows:

1207>1102>1104>1326>1643>1106>1325>2300>1103>1208>1324>1432>1536>1209>1533>1101>1215>1534>1214>2400>1429>1320>1430>1218>1535>1537>1216>1640>1319>1641>1642>1211>1212>2100>1210>1105>1431>1327>1428>2200>1217>1538>1321>1213>1539>2500.

Table 12 lists the average stability indexes of vegetation types in different climatic zones in China.

Table 11 shows that the average stability index of temperate zone's vegetation types is the largest, reflecting the steadiest spatial structure for temperate zone's vegetation types, and it tends to decrease towards both sides.

4 CONCLUSIONS

Quantitative analyses of the spatial distribution of vegetation types of China were performed. Not only the quantitative relationship between the perimeter and area of patches of various types of vegetation was established, but also the fractal dimension and stability indexes of different types of vegetation were further estimated. They are the characteristic parameters for quantitatively describing the ecosystem of vegetation types of China. Vegetation system is an outcome of long-term evolution and combined action of nature and human factors. This process led to the formation of complex natural cum human-induced fractal objects within the vegetation pattern that can be characterized by thorough understanding of the fractal dimension and its variability in relation to the climatic conditions and seasonal variations. It is significantly pertinent to understand the formation, evolution, dynamics and comple-

Table 11 Stability index of spatial structure of China's vegetation type

Vegetation type	SK	Vegetation type	SK	Vegetation type	SK
1101	0.1722	1218	0.1188	1535	0.1168
1102	0.3683	1319	0.0907	1536	0.1871
1103	0.2310	1320	0.1254	1537	0.1118
1104	0.3583	1321	0.0394	1538	0.0414
1105	0.0584	1322	-	1539	0.0214
1106	0.2489	1323	-	1640	0.0997
1207	0.3780	1324	0.2216	1641	0.0772
1208	0.2251	1325	0.2461	1642	0.0764
1209	0.1828	1326	0.2666	1643	0.2583
1210	0.0592	1327	0.0552	2100	0.0628
1211	0.0758	1428	0.0489	2200	0.0447
1212	0.0737	1429	0.1288	2300	0.2360
1213	0.0364	1430	0.1190	2400	0.1327
1214	0.1357	1431	0.0567	2500	0.0036
1215	0.1638	1432	0.2115	Natural vegetation	0.0758
1216	0.1083	1533	0.1789	Cultivated vegetation	0.0822
1217	0.0415	1534	0.1604	Total vegetation	0.1977

Table 12 Average stability indexes of vegetation types in different climatic zones

Climatic zone	Vegetation type	Average stability index
Transition zone between cold and temperate zones	1101	0.1722
Temperate zone	1102, 1103, 1104, 1207, 1210, 1326, 1428, 1429, 1430, 1431, 1432, 1533, 1534, 1535, 1536, 1537, 1640, 1642, 1643	0.1798
Transition zone between temperate and subtropical zones	1208, 1209, 1319, 1325, 1327, 1538, 1641	0.1312
Subtropical zone	1211, 1212, 1213, 1215, 1216, 1324	0.1133
Transition zone between subtropical and tropical zones	1105, 1106, 1320, 1321, 1539	0.0987
Tropical zone	1214, 1217, 1218, 1322, 1323	0.0987

xity rule of ecosystem of vegetation.

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