Growth pattern of reed in Caogang Lake, Huanghuaihai Plain, China*

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Abstract—The researches about reed growth were mainly concentrated on seasonal dynamics, investigation of reed resource, and comparison of different ecotypes of reed. By means of fractal geometric theory of non-linear science, the fractal character of growth pattern of reed, for the purpose of quantitatively exploring the mechanism of reed growth was studied. The way to calculate fractal dimension of reed growth is box-dimension (BD) and information dimension (ID). The results showed that the difference between two samplings in May and those among three samplings in June and later were not remarkable for both BD or ID. It was noted that the difference between samplings in and after May is significant. It was demonstrated that the fractal dimension of size distribution of reed ranged from 0.6235 to 0.8761. The distribution pattern could be statistically divided as two significant periods: the size of reed is quite well-distributed at the beginning of reed growth (fractal dimension >0.8), but is irregular in the middle and later growth season (fractal dimension <0.7). These results are benefit to reach the goal of rational use of reed resources and to protect the biodiversity in wetland ecosystem.

Keywords: fractal, pattern, growth, reed, wetland ecosystem.

1 Introduction

Reed (*Phragmites communis*) is a kind of important aquatic plant resource. Not only it is an important industrial raw material, but also it has important functions in typical wetland landscape (marsh, littoral zone of lake, etc.), such as providing the place of living and reproducing for many species, affecting the local climate and so on. So, the study on fractal of the character of growth pattern of reed has important significance to reach the goal of rational use of reed resource and to maintain the biodiversity in wetland ecosystem.

The researches about reed growth were mainly concentrated on seasonal dynamics, investigation of large area resources, and comparison of different ecological forms of reed. The study on size distribution of reed, however, was scarcely reported. By means of fractal geometric theory of non-linear science, we can reasonably analyze the data from the monthly sampling in Fengqiu Experimental Area of the Huanghuaihai Plain and get the fractal character of growth pattern of reed, then the purpose of quantitatively exploring the mechanism of reed growth can be reached.

2 Materials and methods

Because of the short hydrobiological growth season in Fengqiu Experimental Area (FEA), the

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data of the monthly sampling in Caogang Lake (114°E, 35°N) from May to September in 1990 were chosen for analysis.

Caogang Lake, the largest natural lake in this area, is on the north bank of Yellow River, and in the southeast part of FEA. The distance across the water from north to south is longer than that from east to west. The lake is on the site of continental monsoon climate district in the warm temperate zone. The district is dry and has a low rainfall in spring, but hot and rainy in summer. The yearly mean temperature is 13.9℃. The minimum monthly mean temperature occurs in January and is about -1℃. The maximum occurs in July and is approximately 27.2℃. The lake is a riverain lake of Yellow River, and has never been dry. Its water comes from the Yellow River by channel. The bank separates it from Yellow River. The lake has a smooth bottom with a mean depth of 1.5m. The internal and external nutrient of lake is rich. Recently an excess in stocking of Grass Carp (*Ctenopharyngodon idellus*) has converted it from a macrophytic lake to an algae-type lake. There is much cultivated land and residential areas around the lake. Along the shoreline, reeds can be seen here and there, and among them exist some species of hygrophyte. In the north part of lake, some sampling sites are in the littoral zone where reed covers a large area, through these sampling sites the growth dynamics of reeds were monitored.

There are two methods to study the growth pattern of reed: one is to study the seasonal dynamics, which has been reported frequently (as shown in the second paragraph); the other is to study the size distribution of reed, which was scarcely reported. The study on size distribution of reed also has the important meaning to reach the goal of rational use of reed resource.

The classical method of studying size distribution is to draw histogram and then to fit distribution curve. It is well known that the obtained histogram depends strongly on the number of class interval and its correspondent width. The increase the number of class internal leads to the decreasing of its correspondent width and vice versa. The determination of rational number and width of class interval is somewhat arbitrary, since it is made according to analyst's experience. In general, there is a certain similarity among histogram described at different number of class interval and width somehow. It implies that we could use the fractal geometry to analyze the relationship among them, and obtain more reliable conclusion.

The word fractal stemmed from *fractus* (a Latin word, means fractional) and fraction (an English word). It was first used in 1975 by Mandelbrot who is the founder of the fractal geometric theory. It has been used to describe some complex and irregular geometric figures.

People always use the familiar Euclidean geometry to study the regular geometric configuration, such as line segment, circle, cube and so on. The basic problem in geometry is to determine the dimension of object of study. Dimension is the number of independent coordinates that can be used to determine the site of a point in the object of study. Euclidean geometry is apparently powerless to describe the complex and irregular geometrics, such as the cracks on material surface, coastline, cloud, snowflake, the tree of lung's bronchus, network of blood capillary and so on. Mandelbrot once put forward a question: How long is the coast of Britain? The answer to this question is not definite, and it depends on the scale used to measure. If the measure unit was kilometer, the curves whose length is from several to tens' meters would be neglected. If the unit was meter, the measure precision would increase, so did the total length, but the curves less than a centimeter still could not be well described. So, the total length of coastline will increase along with the decreasing of the scale. The decreasing of the measure unit means the enlarging of the object of study, and it is just as same as using a microscope with the magnification increasing to observe the same sample. Curves that the coast displays corresponding to different scales reflect a common character of these irregular geometrics, which is the self-similarity in different levels of scale. Local magnification and its entirety have the similarity in shape, which forms an endless nested self-similarity structure. So, the geometric that have the character mentioned above are called fractal. The dimension of fractal geometry generally is a fraction, which can be called fractal dimension (FD).

The method we use to measure the FD is as follows. Enclose the fractal in a box of side λ and divide the box into $(\lambda/S)^n$ boxes of side S (here, n is the maximum integer dimensions that the fractal may have). Let $N(S)$ be the number of boxes the edge of the fractal enters and plot $\ln N(S)$ against $\ln(1/S)$. If corresponding to small values of S, the graph is almost linear with slope D, then D can be interpreted as the FD. FD also can be called box-dimension (BD) or Hausdorff-dimention. The standard or low-dimension fractal can be treated easily with it; but to actual or high-dimension fractal, it is difficult to conduct. In addition, box of side S sometimes has a point of the fractal, and sometimes has many points, BD cannot really reflect the heterogeneity in the fractal. Giving numbers to the squares, and knowing the possibility fractal enters the box of number i (Pi), according to the definition of Shannon's information entropy, we can calculate entropy by

$$I = -\sum Pi \ln Pi .$$

Plotting I against $\ln(1/S)$, the slope of the graph is the information dimension (ID), which also can be called Renyi-dimension.

The data was treated with self-made and common statistic software on OCTEC PC 486/66 computer.

3 Results and discussion

Because the longest reed occasionally exceeds 400 cm, for the reason of convenience, we define the largest scale $S = 400$ cm. Halving the scale S until it could recognize each individual reed ($S <$ 1 cm), the number of samples fallen in each S and its correspondent entropy at different scales was calculated (Table 1).

Table 1 Basic parameters for estimating fractal dimension of growth pattern of reed

1/S	Value of S, cm	Sampling time (1990)											
		5, May		31, May		27, June		4, August		2, September		2, September*	
		$N(S)$	$-I$	$N(S)$	$-I$	$N(S)$	$-I$	$N(S)$	$-I$	$N(S)$	$-I$	$N(S)$	$-I$
1	400	1	0	1	0	1	0	1	0	1	0	1	0
2	200	1	0	2	0.1164	2	0.6898	2	0.6927	2	0.6626	2	0.4512
4	100	2	0.6327	3	0.7525	3	1.0085	4	0.9529	4	0.8532	3	0.6768
8	50	3	1.0968	5	1.3970	6	1.4955	6	1.5340	6	1.4948	5	1.3013
16	25	6	1.7267	9	2.0233	11	2.1421	11	2.1917	10	2.0621	8	1.8305
32	12.5	12	2.3622	17	2.6777	21	2.7477	20	2.8106	18	2.6657	14	2.4292
64	6.25	23	3.0217	32	3.3316	31	3.2385	33	3.3668	32	3.2746	26	3.0406
128	3.125	44	3.6717	62	3.9704	43	3.6574	44	3.6646	55	3.7950	41	3.5034
256	1.563	73	4.1339	105	4.4743	58	3.9773	49	3.8133	73	4.1340	52	3.8140
512	0.781	98	4.4460	145	4.8198	64	4.0889	56	3.9925	81	4.2605	55	3.8984

* Growth state of the blooming reed

On the basis of the basic parameters, the BD and ID were calculated, simultaneously we had gotten the regressions of estimating fractal dimension of growth pattern of reed at different growth stages. The slope of each regression is the FD (Table 2).

Table 2 Regressions of estimating fractal dimension of growth pattern of reed

	$\ln((N(S))=a+b\ln(1/S)$				$I=a+b\ln(1/S)$			
	a	b	r	p	a	b	r	p
5, May	−0.5579	0.8619	0.9971	<0.00001	−0.5508	0.8351	0.9976	<0.00001
31, May	0.0086	0.8200	0.9978	<0.00001	−0.4181	0.8761	0.9979	<0.00001
27, Jun	0.4053	0.6666	0.9826	<0.00001	0.2337	0.6714	0.9900	<0.00001
4, Aug.	0.5573	0.6235	0.9769	0.00001	0.2896	0.6544	0.9815	<0.00001
2, Sep.	0.3765	0.7000	0.9913	<0.00001	0.0741	0.7225	0.9872	<0.00001
2, Sep.*	0.2943	0.6541	0.9889	<0.00001	0.0740	0.6928	0.9898	<0.00001
Cattail	0.2294	0.6160	0.9735	<0.00001	−0.0079	0.6269	0.9840	<0.00001

* Growth state of the blooming reed

We can learn from Table 2 that the FD of size distribution of reed ranged from 0.6235 to 0.8761. In order to answer whether the difference between FD at any two different growth stages is significant, t-test was carried out to judge if the regressions were parallel. The t-test results are shown in Table 3 and Table 4. The common slope of two regressions, i.e. the common FD of reed at any two growth stages was therefore calculated while the functions are parallel (Table 3 and Table 4).

Table 3 Test of box-dimension between different sampling time (lower triangle show t value, upper common dimension)

	5, May	31, May	27, Jun	4, Aug.	2, Sep.	2, Sep*
5, May		0.8410				
31, May	1.2925					
27, Jun	3.6319	2.9496		0.6450	0.6833	0.6603
4, Aug.	4.1680	3.5380	0.6146		0.6617	0.6388
2, Sep.	3.7627	2.9412	0.5638	1.2274		0.6770
2, Sep*	4.6533	3.9023	0.2077	0.4819	0.8991	

* Growth state of the blooming reed

Table 4 Test of information-dimension between different sampling time (lower triangle show t value, upper common dimension)

	5, May	31, May	27, Jun	4, Aug.	2, Sep.	2, Sep*
5, May		0.8556				
31, May	1.3250					
27, Jun	3.8647	4.8591		0.6629	0.6969	0.6821
4, Aug.	3.4090	4.1966	0.2819		0.6884	0.6736
2, Sep.	2.6654	3.6549	1.0002	1.1307		0.7077
2, Sep*	3.2592	4.2197	0.4106	0.6282	0.5683	

* Growth state of the blooming reed

The results showed that the difference between two samplings in May and those among three samplings in June and later were not remarkable for both BD and ID. It was noted that the difference between sampling in and after May is significant. Then dividing the data into two parts, we calculated the BD and ID respectively. Regressions are given by:

BD	May	$\ln N(S) = -0.2747 + 0.8410 \ln(1/S)$	$r = 0.9875$	$p < 0.00001$
	June and later	$\ln N(S) = 0.4464 + 0.6634 \ln(1/S)$	$r = 0.9824$	$p < 0.00001$
ID	May	$I = -0.4845 + 0.8556 \ln(1/S)$	$r = 0.9935$	$p < 0.00001$
	June and later	$I = -0.1992 + 0.6828 \ln(1/S)$	$r = 0.9870$	$p < 0.00001$

So the distributing pattern could be statistically divided as two significant periods: the size of reed is quite well-distributed at the beginning of reed growth (fractal dimension > 0.8), but is irregular in the middle and later growth season (fractal dimension < 0.7). The florescence of reed begins in the end of June every year.

Using the same way to analyze the data of Cattail (*Typha angustifolia*) sampled in September, the regressions are given by:

BD	$\ln N(S) = 0.2294 + 0.6160 \ln(1/S)$	$r = 0.9735$	$p = 0.00001$
ID	$I = -0.0079 + 0.6269 \ln(1/S)$	$r = 0.9840$	$p < 0.00001$

Compared with the FD of reed samplings in September, neither BD nor ID of cattail is larger than that of reed. The difference between the two species is not remarkable ($t_{BD} = 1.2910$ and $t_{FD} = 1.7059$).

4 Conclusion

The researches about reed (*Phragmites communis*) growth were mainly concentrated on seasonal dynamics, investigation of large area resource, and comparison of different ecological forms of reed. The study on size distribution of reed, however, was scarcely reported. By means of fractal geometric theory of non-linear science, we studied the fractal character of growth pattern of reed, for the purpose of quantitatively exploring the mechanism of reed growth. The classical method of studying size distribution is to draw histogram and then to fit distribution curve. It is well known, however, that the obtained histogram depends strongly on the number of class interval and its correspondent width. The determination of rational number and width of class interval is somewhat arbitrary, since it is made according to analyst's experience. In general, there are a certain similarity among histograms described at different class number of class interval and width somehow. It implies that we could use the fractal geometry to analyze the relationship among them, and obtain more reliable conclusion.

The data we used in our analyses are from the monthly sampling in Caogang Lake (114°E, 35°N), an emergent macrophyte dominated lake in Fengqiu Experimental Area of the Huanghuaihai Plain, Henan Province, China. The way to calculate fractal dimension (FD) of reed growth is box-dimension (BD) and information dimension (ID). Because the longest reed occasionally exceeds 400 cm, for the reason of convenience, we define the largest scale $S = 400$ cm. Halving the scale S until it could recognize each individual reed ($S < 1$ cm), the relationship between different scale S and the number of samples fallen in each S and their correspondent entropy were calculated, respectively (Table 1 and 2). The slope of each regression is the FD at different growth stages. In order to answer whether the difference between FD at any two different growth stages is significant, t-test was carried out to judge if the regressions are parallel. The common slope of two regressions, i.e., the common FD of reed at any two growth stages was therefore calculated while the functions are parallel (Table 3 and 4). The results show that the difference between two samplings in May and those among three samplings in June and later were not remarkable for both BD or ID. It was noted, however, that the difference between samplings in and after May is significant. It was demonstrated that the fractal dimension of size distribution of reed ranged from 0.6235 to 0.8761. The distribution pattern could be statistically divided as two significant periods: the size of reed is quite well-distributed at the beginning of reed growth (fractal dimension >0.8), but is irregular in the middle and later growth season (fractal dimension <0.7). These results are benefit to reach the goal of rational use of reed resources and to protect the biodiversity in wetland ecosystem.

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