Analysis of spatial heterogeneity based on fractal dimension on Nanjing road-region vegetation ecosystem

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***Abstract*—Spatial heterogeneity, by applying the index of fractal dimension, can quantitatively analyze the ecology function and quality of different landscapes in different scales. In this paper, the road-region vegetation ecosystem of Nanjing urban roads was studied by means of semi-variogram analysis, fractal dimension calculation and field survey. The rationality of vegetation arrangement, spatial heterogeneity and ecosystem stability of vegetation were analyzed comparatively in different road-region and slope directions. The result showed that fractal dimension could accurately and quantitatively value the spatial heterogeneity and ecosystem stability of road-region ecosystem. Under different conditions, the road-region with natural vegetation and less artificial disturbance, in southern slopes, and the wide separating vegetation zones were of high spatial heterogeneity, high ecosystem stability and low fractal dimension.**

***Index Terms*—Fractal dimension, spatial heterogeneity, semi-variogram analysis, road-region vegetation**

I. Introduction

Spatial heterogeneity is one of the important concepts in landscape ecology since the 1990s. The variation of ecosystem function and process can be reflected by the spatial heterogeneity changes. Spatial heterogeneity, by applying the index of fractal dimension, can quantitatively analyze the ecology properties of different landscapes, such as forests, wetlands, grasslands and urban landscapes, etc. And accurate results have been drawn out with spatial heterogeneity and fractal analyzing. However, there is no rational method yet to quantitatively analyze the ecological restoration and reconstruction of road region after human disturbance in the urban road construction. In this paper, by applying the method of spatial heterogeneity and fractal theory, the rationality of vegetation arrangement and the ecosystem stability of road-region vegetation were analyzed, aiming to enhance the road-region vegetation ecosystem function.

II. Natural survey

In this paper, the Xuanwu district of Nanjing city was chosen as the study region. The road-region vegetation on the both sides and the separate belt of Huanling Road and Xuanwu Road was taken as the research site.

Nanjing is located in southeast China, at the Yangtze River downstream, between 31°14’ N to 32°37’ N and 118°22’ E to119°14’ E. It belongs to subtropical monsoon climate area, has abundant rainfall with the mean annual precipitation of 1106mm and shows four distinct seasons with a mean annual temperature of 15.4℃. Most planting soil in urban road-region is carry soil with less faction of raw soil and generally contains gravel. The soil pH value is 7.26. The road-region vegetation consists of street trees such as Platanus and Cinnamomum camphora. The separating zones and the traffic islands are covered with shrubs such as Viburnum odoratissimum and Ligustrum X vicaryi, with other ground cover and vine.

III. Method

A. Sampling method

Due to the special environment of road-region, the whole vegetation study region presents slender shape. So the transects were chosen as sample plots and one-dimensional varioaram taken as the calculation method.

Transects were located at Chalukou, Shangwuqi and Qingma of Huanling Road and at the East Coach Station, Yingtie village and Wangjiawan of Xuanwu Road. Nine transects were chosen in each road region, with three on each side of the road (6 transects), one at each side separating belt (2 transects) and one at medial divider (1 transects), as shown in Figure 1. A total of 18 transects were set in the two road regions. Each transect is 50 m by 0.5 m (length by width) and consists of 100 square quadrats, as shown in Figure 2.

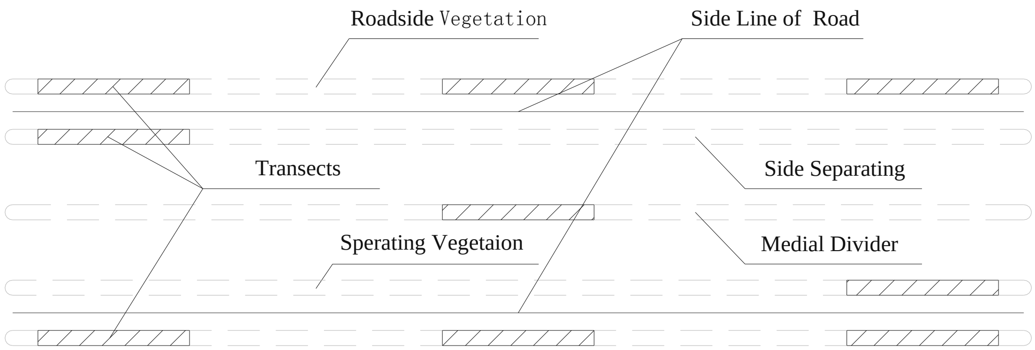

Fig. 1. Map of transects distribution

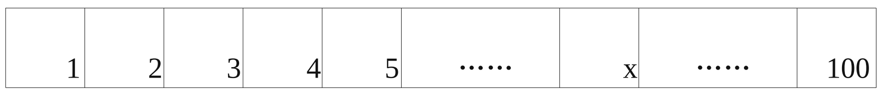

Fig. 2. Map of quadrats in transect

The specific name, site, plant height, diameter and crow width in each quadrat were recorded and specimens were collected and numbered. The position and slope direction of each transect were recorded and numbered as well. The survey was taken between July 1 and July 25 in 2012, which was the peak season of plant growth.

B. Analysis method

The species richness and sampling scale were taken as the main index, combining with the other survey data for statistical analysis. The model of variation function was founded, and the fractal dimension (D) was employed as index to quantitatively describe the spatial heterogeneity, vegetation arrangement rationality and ecosystem stability of different road-region ecosystem.

- Variogram

Variogram is the unique and fundamental tool in geo-statistics. In one-dimensional conditions, the mathematical expression is Formula (1):

$$\gamma(h) = \frac{1}{2N(h)} E[Z(x) - Z(x+h)]^2 \tag{1}$$

In Formula (1), $\gamma(h)$ is variogram; $Z(x)$ and $Z(x+h)$ are the value of point x_i and $x_i + h$, which are the species richness (the number of vegetation species) in Quadrat i and Quadrat i+1 respectively in this paper; $N(h)$ is the pair number of samples apart with a distance h; h is the spatial distance; namely the sampling scale.

- Semi-variogram double logarithmic coordinate graph

Semi-variogram consists of variograms corresponding to different sampling scales. The semi-variogram double logarithmic coordinate graph is obtained after logarithmic transformation of the scale h and corresponding semi-variogram. The semi-variogram double logarithmic coordinate graph reveals the self-similar relationship of the vegetation spatial heterogeneity in different scales by fractal dimension (D). Using the semi-variogram as variable, the calculation formula of fractal dimension is Formula (2):

$$2\gamma(h) = h^{(4-2D)} \tag{2}$$

After logarithmic transformation, Formula (2) can be transformed to Formula (3):

$$D = (4-m)/2 \tag{3}$$

In Formula (3), m is the slope of semi-variogram double logarithmic coordinate graph; D is the fractal dimension.

- Fractal dimension

By analysis, the geometric meaning of fractal dimension can be regarded as the complication level of vegetation structure in different scales — the characterization of heterogeneity. Fractal dimension reveals the variation characteristic of vegetation spatial heterogeneity scale. It is independent of scale and it is a generality of species number of community in different scales.

When D =2, the slope m =0, the straight line fitted is horizontal in the semi-variogram double logarithmic coordinate graph, which means the difference of scales is small, the spatial heterogeneity is low and the vegetation of quadrats is homogeneous. When D is far away from (less than) 2, the slope m is large and the straight line fitted is steep, which means the difference of scales is great and the spatial heterogeneity is high. Therefore, the fractal dimension (D) reveals the variation characteristic of the spatial heterogeneity in different scales.

IV. Results

A. Data analysis

The data of 18 transects in Huanling Road and Xuanwu Road was analyzed. Nine transects in each road region was divided into southern slope, northern slope and separating zone according to slope direction and road-region. The slope m and fractal dimension D were obtained after the scale and corresponding variogram fitted in the semi-variogram double logarithmic coordinate graph, as shown in Figure 3. The average of 3 fractal dimensions was taken and comparatively analyzed with the conditions of same slope direction and different road and vegetation arrangement.

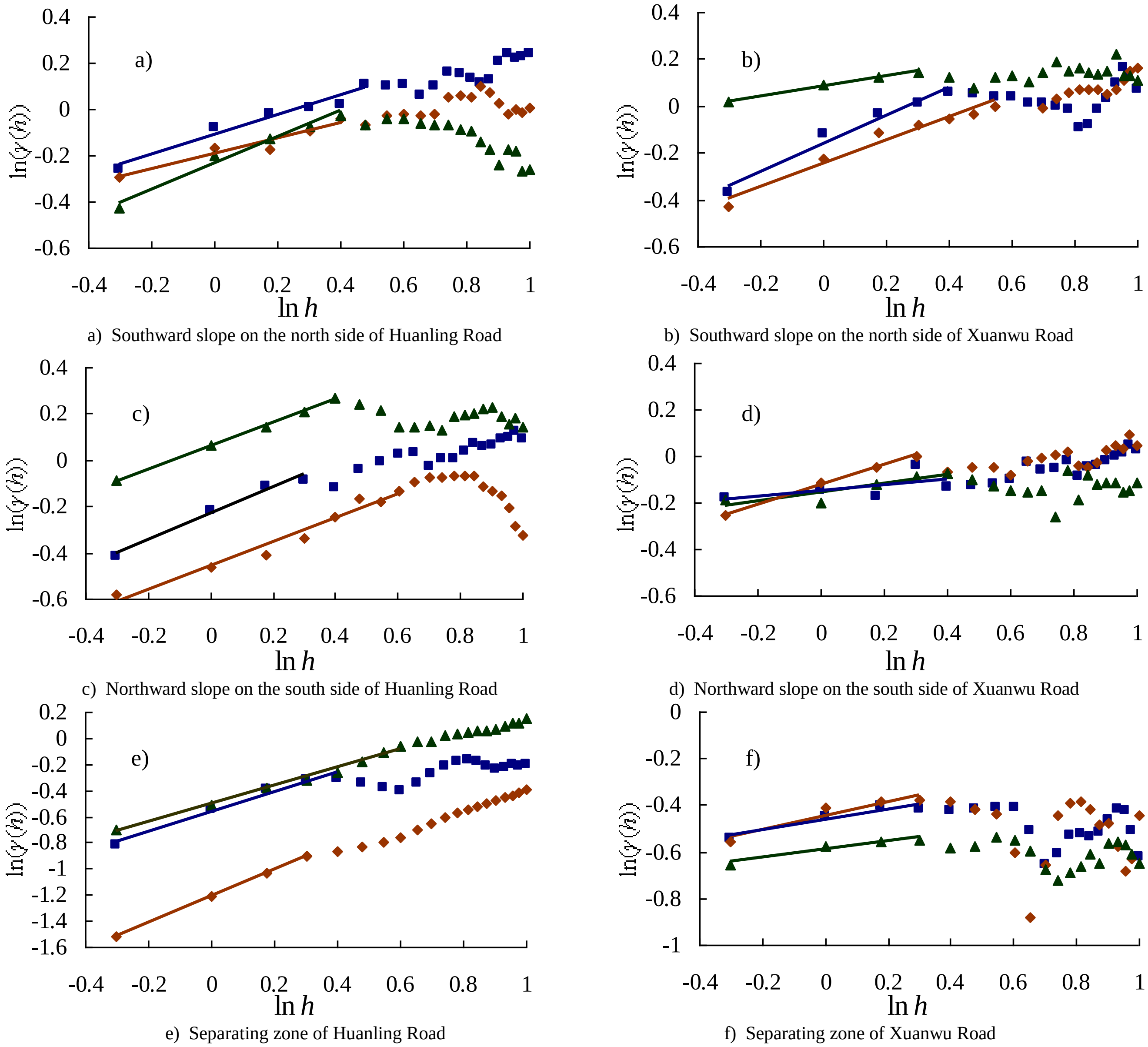

Fig. 3. Comparison of spatial heterogeneity in Huanling Road and Xuanwu Road vegetation ecosystem of different slope directions and separating zones in semi-variogram double logarithmic coordinate graph

The fractal dimensions (D) of different roads, slope directions and road-regions, according to the semi-variogram double logarithmic coordinate graph, were obtained, as shown in Table 1.

TABLE I. THE SLOPE FITTED AND FRACTAL DIMENSION FROM SEMI-VARIOGRAM DOUBLE LOGARITHMIC COORDINATE GRAPH

Index		**Huanling Road**			**Xuanwu Road**		
Southward slope on north road side	***Correlation coefficient R^2***	***0.9554***	***0.9246***	***0.9627***	***0.9722***	***0.9621***	***0.9920***
	Slope m	***0.4261***	***0.3381***	***0.5661***	***0.6076***	***0.4909***	***0.2125***
	Fractal dimension D	***1.7870***	***1.8310***	***1.7170***	***1.6962***	***1.7546***	***1.8938***
	Average of fractal dimension	***1.7783***			***1.7815***		
Northward slope on south road side	***Correlation coefficient R^2***	***0.9814***	***0.9655***	***0.9974***	~~***0.4974***~~	***0.9976***	***0.8038***
	Slope m	***0.5706***	***0.5163***	***0.5021***	~~***0.1738***~~	***0.4252***	***0.1888***
	Fractal dimension D	***1.7147***	***1.7419***	***1.7490***	~~***1.9131***~~	***1.7874***	***1.9056***
	Average of fractal dimension	***1.7352***			***1.8465***		
Separating zone	***Correlation coefficient R^2***	***0.9755***	***1.0000***	***0.9902***	***0.9148***	~~***0.8928***~~	***0.9279***
	Slope m	***0.7646***	***1.0216***	***0.6918***	***0.2248***	~~***0.2957***~~	***0.1752***
	Fractal dimension D	***1.6177***	***1.4892***	***1.6541***	***1.8876***	~~***1.8522***~~	***1.9124***
	Average of fractal dimension	***1.5870***			***1.9000***		

Among the eighteen sets of data, 16 sets were involved in the result analysis and 2 failed ones were deleted due to correlation coefficient R2 could not meet the requirements.

B. Results and discussion

(1) The fractal dimensions of Huanling Road and Xuanwu Road are both low, which means the two roads are of high vegetation arrangement rationality, spatial heterogeneity and ecosystem stability. This result accords with real situation. Huanling Road is located at Zijin Mountain with natural vegetation, abundant species and reasonable arrangement. Xuanwu Road is a landscape avenue in eastern Nanjing with the scenery of ornamental shrubs and small trees along the road. The fractal dimension can just reflect the situation above.

(2) The average fractal dimension of Huanling Road is lower than that of Xuanwu Road, which means Huanling Road is of higher vegetation arrangement rationality, spatial heterogeneity and ecosystem stability than Xuanwu Road. This result accords with real situation. Huanling Road has not only natural vegetation, abundant species and reasonable arrangement, but also less traffic and artificial disturbance. While Xuanwu Road belongs to arterial roads, which has saplings with immature roots and crown after replanted. There is also heavy traffic and artificial disturbance with campuses, stations and residential areas alongside the road. The factors above lead to different situation in the two road regions, and the fractal dimension can reflect the situation above.

(3) The average fractal dimension in southward slope on the north road side is slightly higher than northward slope on the south road side in Huanling Road, while the average fractal dimension in southward slope on north road side is obviously lower than northward slope on south road side in Xuanwu Road. This situation shows that the spatial heterogeneity and ecosystem stability in the northward slope is higher than those in the southward slope in Huanling Road. While the southward slope is higher than the northward slope in Xuanwu Road. Normally, the situation of southward slope is higher than the northward slope because of the effect of sunshine, which accords with real situation in Xuanwu Road. According to the field survey, the vegetation in the southward slope in Huanling Road is the fence of one golf course and suffers heavy artificial disturbance, while the vegetation in northward slope vegetation is natural and far away from artificial disturbance. All the reasons above lead to the situation that the northward slope is of higher spatial heterogeneity and ecosystem stability than the southward slope in Huanling Road. And in this paper, fractal dimension can reflect the situation.

(4) The average fractal dimension of separating zone in Huanling Road is far lower than Xuanwu Road, which means the separating zone in Huanling Road is of higher vegetation arrangement rationality, spatial heterogeneity and ecosystem stability than that in Xuanwu Road. This result accords with real situation. Huanling Road is constructed with separated subgrade affected by the topography of Zijin Mountain, and has a 6 m wide separating zone. The arrangement is reasonable, the species are abundant and variational with the road and the vegetation is of high spatial heterogeneity and ecosystem stability. While the separating zone of Xuanwu Road has a width of only 1.5 m, which is of less reasonable arrangement, spatial heterogeneity and ecosystem stability. The fractal dimension can reflect the situation as well.

V. CONCLUSIONS AND PROSPECTS

By applying the theory of spatial heterogeneity and fractal, the semi-variogram double logarithmic coordinate graph was established and the fractal dimension of road-region vegetation ecosystem in Huanling Road and Xuanwu Road of Nanjing was obtained. By comparative analysis, the method of quantitatively valuing the spatial heterogeneity and ecosystem stability was obtained in different roads and slope directions with the help of the index of fractal dimension. The result shows that the vegetation in Huanling Road was of higher spatial heterogeneity and ecosystem stability than that in Xuanwu Road. Fractal dimension reveals the regular pattern of vegetation spatial heterogeneity and sampling scales in different scales in a certain range, which is the advantage of fractal theory among pattern analysis.

Although the analysis method of spatial heterogeneity based on fractal dimension is of many advantages, some problems still exist in practical applications. They include the inflection point problem of relationship of variogram and scale in the semi-variogram double logarithmic coordinate graph and the verify problem of heterogeneity analysis of discontinuous transects and quadrats. In addition, if this method combines with RS, GIS and the other technology, the description of real road-region will be achieved in a macro view by a convenient means. This would lead the related research to a wide and deep extensive space and historical period.

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