城市景观格局的空间尺度分析

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【摘要】 景观生态学研究的核心内容是景观格局与生态过程。因为景观格局与生态过程中都存在的尺度多样性问题，导致尺度成为理解景观格局和生态过程相互作用的关键，但是由于理论和方法的限制，目前对景观生态学的尺度研究还不够深入，特别是景观格局对尺度变化的响应特征。目前 GIS 与 RS 技术的发展为不同尺度下的空间格局特征和空间异质性研究提供了有效的工具。论文以上海市为背景，用景观生态学方法研究了不同粒度下景观格局特征，同时用半变异函数分析了不同幅度下景观多样性的格局特征。结果显示：(1) 不同的指数对粒度的响应不同；(2) 空间多样性在小幅度内变化较复杂；(3) 不论粒度还是幅度都揭示出景观格局具有尺度依赖性规律。

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Spatial analysis of the urban landscape pattern

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Abstract Because of the multiplicity in spatial pattern and ecological processes, scale plays an important role to understanding the pattern-process interactions and, indeed, becomes one of the corner-stone in landscape ecology. Based on the research of Shanghai city, this paper studies the pattern characteritics at different grains by using the methods of landscape ecology; and the semi-variogram is used to analyze the pattern characters at different extents. The results of analysis indicate: (1)Ddifferent landscape indices responds dissimilarly to the changes of grains. (2) Spatial variation of landscape diversity shows the most complexity at the smallest extent. (3) The response of landscape indices and SHDI semi-variance to scale is respective. So landscape spatial pattern has scale dependency.

Key words: Landscape pattern; Grain; Extent; Shanghai city

1 Introduction

Landscape pattern is one of the most important contents of landscape ecology. Landscape indices are used to quantify the characters of landscape pattern [1]. Scale is a basic concept in both physical and social science [2]. As a result, multi-scale is always the essential problem in landscape ecology. Pattern and process are the important paradigm in ecology. Pattern and process highly depend on scales, i.e. scaling, is essential to comprehend the relationship between pattern and process. Yue (2003) figured out that multi-scale problem is the vital theory in eco-geography modeling [3]. Wu (2003) considered that in landscape ecology, scale refers to grain and extent in spatial and temporal dimension. Spatial grain is the finest level of spatial resolution possible for a given data set, e.g. pixel size for raster data. Extent is the size of the study area or the duration of time under consideration [2]. Since the spatial pattern of landscape is the function of scale, so are the indices of landscape pattern. Therefore, we consider it significant to disclose the change of landscape pattern and the coupling of the function and process in landscape system comparing and analyzing the characters of landscape indices and their spatial heterogeneity at different scales [4].

2 Research data and methods

2.1 Urban Landscape Classifying

Urban landscape, usually regarded as an artificial landscape, is distinctly different from other landscapes [5]. According to the characteristics of urban landscape, combined with the economic, cultural and ecological function of landscapes, the paper divided urban landscapes in Shanghai city into the types as follows: residential landscape; industrial and warehouse landscape; road landscape; construction landscape; green space landscape; urban agriculture landscape; river and water landscape and commercial landscape.

2.2 Landscape Indices

Landscape indices can condense the landscape pattern information and reflect the characteristics of its structural components and spatial configuration. In accordance with the characteristics of the research area, Landscape Shape Index (LSI), Shannon's Diversity Index (SHDI), Shannon's Evenness Index (SHEI), Contagion Index

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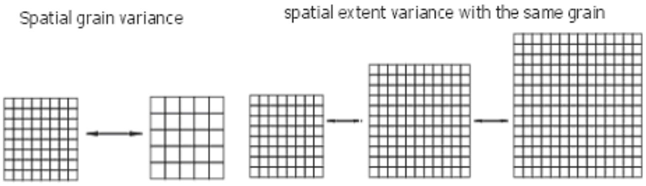

Fig.1 The sketch map of grain and extent variance

(CONTAG), Perimeter-area Fractal Dimension Index (PAFRAC) are selected to describe the landscape pattern at the level of landscape mosaic. The indices above are calculated with the software "*Fragstats*".

2.3 Spatial Heterogeneity of Landscape Indices: Semi-variance

It is generally admitted that spatial heterogeneity gives main cause for forming the spatial landscape pattern [6]. Turner (1991) considered the coupling of spatial heterogeneity and ecology-related model as a challenge to theoretic ecology. Relying on its own attribute, semi-variance can well disclose the spatial heterogeneity at a certain scale. By analyzing the spatial heterogeneity of landscape indices, we can effectively explain the influence on the ecological processes with some certain change of landscape pattern [7]. Therefore, the semi-variance becomes the major method in quantitative analysis of landscape spatial heterogeneity. Meanwhile, spatial heterogeneity is the function of scale. Levin (1992) pointed out that since ecological system and its pattern exist at multi-scale, we must take scales into account when analyzing spatial heterogeneity [4].

Suppose regionalized variable $Z(x)$ meets the second order stationary and intrinsic hypothesis, the semi-variance $\gamma\ (h)$ is defined as follows [8]:

$$\gamma(h)=\frac{1}{2N(h)}\sum_{i=1}^{N(h)}[Z(x_i)-Z(x_i+h)]^2 \qquad (1)$$

h is lag distance between two samples, $Z(x_i)$ and $Z(x_i+h)$ is the value of $Z(x)$ at the location of x_i and x_i+h ($i=1,2,\cdots\cdots,N(h)$), $N(h)$ is the number of pairwise comparisons at lag h. Therefore, semi-variance is a synthetical index to show the spatial dependency and heterogeneity. Semi-variance has four important parameters: nugget, sill, range and fractal dimension. When distance $h=0$, $\gamma(h)=C_0$, which is called nugget. When h extends to A_0, $\gamma(h)$ grows to a relatively stable constant from nonzero, which is sill C_0+C. A_0 is range parameter and fractal dimension (*D*) shows the curvature of semi-variance。

2.4 Methods and Approach

In this paper grain is equal to the size of ARCINFO grid. We can obtain all kinds of landscape patterns of different grains through converting the vector landscape data into different sizes of grid data. For the extent counterchanging, we overlay the vector landscape data with nets of different size. Then at the same grains we calculate the SHDI at different extents. The processes of grain and extent counterchange are illustrated as fig.1.

SPOT satellite image is used as data source in this paper. We analyze the spatial scale effect of urban landscape through the variance of grain and extent. The approach is listed in figure 2.

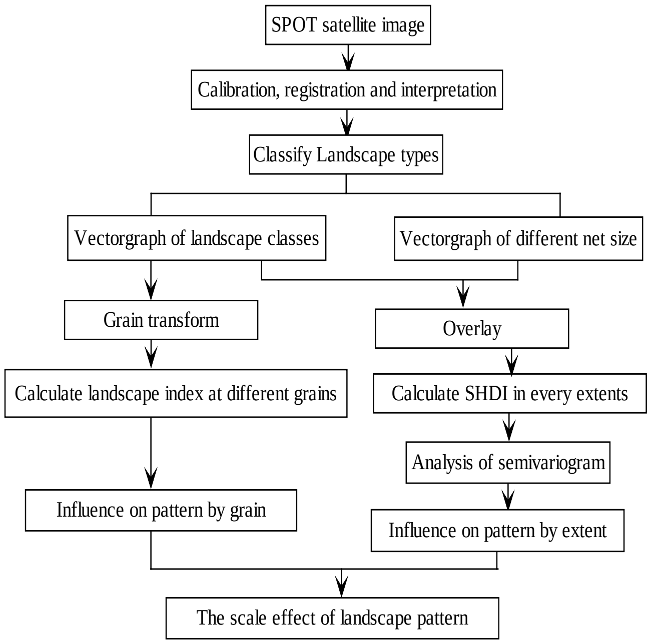

Fig.2 Research methods and technology

3 Results

3.1 The Change of Landscape Indices under Different Grains

Landscape indices have close relationship and show differently under different scales. We calculate six different grains as 20m, 30m, 50m, 80m, 100m and 120m to illustrate the sensitivity of landscape indices to the change of grains. In essential, the increase of grain is the aggregation of the adjacent grid cells [9]. Patches are the minimum parts to form landscape and their areas are directly affected by the increase of grain. The smaller the patches are, the more they change. With the increase of grain, bigger ones adjacent will swallow up tiny patches scattered in landscape, which may cause the change of bigger patches' area. In the process of grains changing, the number and shape of patches altered. As a result, all the landscape indices relative to patch area, shape and quantity may alter [10].

It can be drawn from the figure3~5 that the results may differ a lot with the changing grains. As the grains vary from 20 m to 120 m, LSI declines in exponential form. Comparatively the changing trend slows down as grain increases. Contagion declines as the grain increases

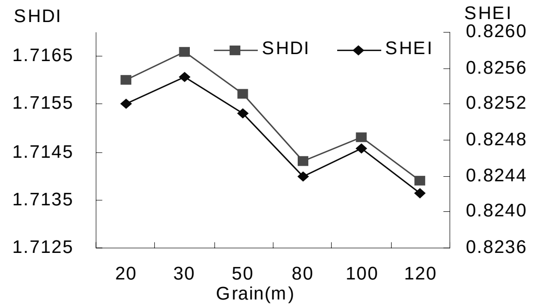

Fig. 3 The curves of SHDI and SHEI at different grains.

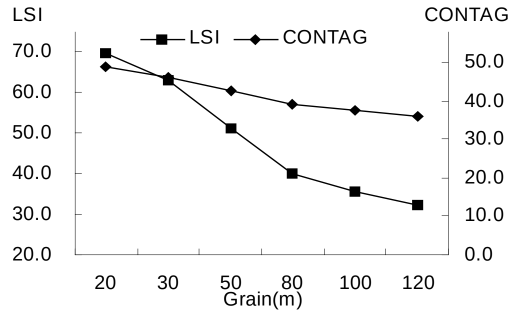

Fig. 4 The curves of LSI and CONTAG at different grains.

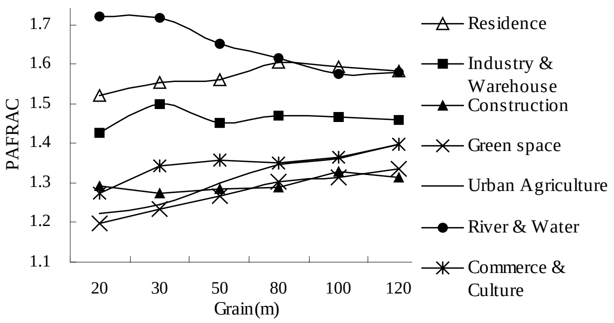

Fig. 5 The curves of PAFAC of landscape types at different grains

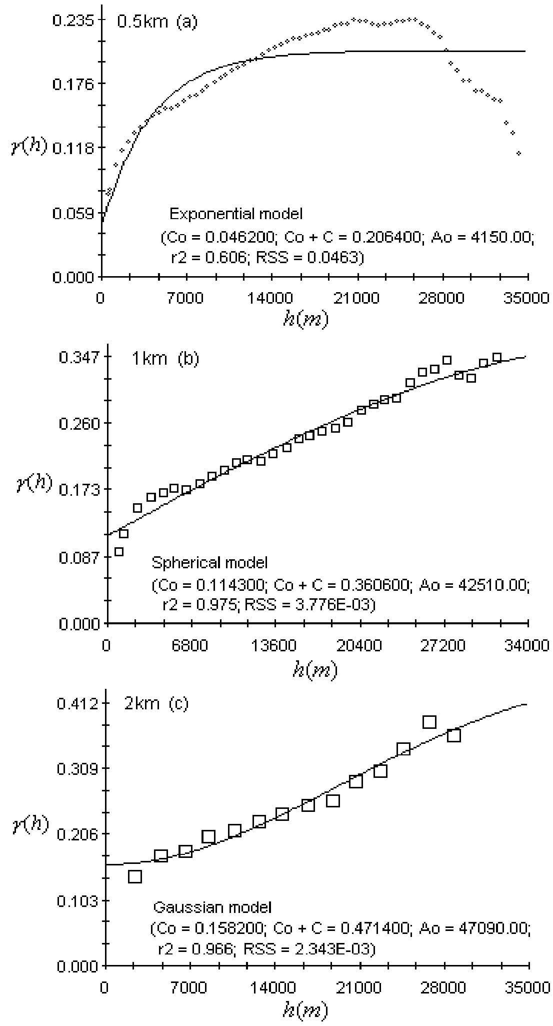

Fig. 6 Semivariogram and its theoretical model of SHDI at different extents

but the trend is smoother. PAFRAC changes little as the grain increases. As is shown in the figure, PAFRAC of residential area almost remains the same and that of river and water decreases a little. Besides, others go up slowly as the grain increases. In a word, the difference between landscape patterns with different land use becomes Inconspicuous. SHDI, as well as SHEI, declines slowly while the grain is relative fine (20m~50m); but declines sharply when the grain becomes moderate (50m~80m), it declines sharply again as the grain grows (>80m), the index increases and especially when grain exceeds 100m.

3.2 Spatial Dependence and Heterogeneity of SHDI

According to the spatial distribution of Landscape Diversity, semi-variance is used to quantify the spatial heterogeneity of Landscape Diversity in urban landscape. The spatial distribution of SHDI basically satisfies the intrinsic assumption and the second order stationarity assumption. Suppose the variation of SHDI below is isotropic, and then the semi-variance function of SHDI and its theoretical simulation model with parameters in multi-extent can be obtained (Fig. 6).

From Fig 6 we note that semi-variance curves at different extents differ a lot. The finer the extent is, the larger the number of samples is. The theoretical simulation models at different extents vary greatly. When the extent moves from 0.5 km, 1km to 2 km, accordingly the model alters from Exponential model, Spherical model to Gaussian model. Generally, when *h* exceeds semi-diameter of the research area, spatial auto-correlation disappears. Yet at the extent of 0.5 km, $\gamma(h)$ shows an inverse-U trend along with the growing *h*. Spatial Heterogeneity of SHDI, instead of increasing, decreases when *h* exceeds a certain value.

4 Discussions

4.1 Analysis of Landscape Indices at Different Grains

Landscape indices show difference at different scales and we should consider the influence of scales when analyzing the whole region. With the calculation of 5 landscape indices above at the grains from 20m to 120m, we can find the laws as follows.

(1) LSI related with the perimeters of patches closely. LSI increases without limit as landscape shape becomes more irregular or as the length of edge within the landscape increases. With the increasing grain, the tiny patches are swallowed by the bigger ones, which cause the perimeters of patches to change and results in the perimeters of landscape patches shortening and the more regular patch shape. LSI continuously decreases as the grain increases. (2) The change of CONTAG is comparatively stable. CONTAG affects both the richness of landscape components and the relationship among different patch types. In addition, it is noted that CONTAG is affected by both the dispersion and interspersion of patch types. The low levels of dispersion and interspersion results in high contagion, and vice versa. The richness of patch reduces as the grain shrinks, which has more influence than the adjacency increasing and as a result, CONTAG decreases. (3) SHDI and SHEI are influenced by both the quantities of patch type and the percentage of each one in the region. As the grains increases, cells continuously aggregate and SHDI and SHEI decrease. In this research, we notice that when the grain grows to 80m, SHDI and SHEI begin to increase. It is because with the increasing of grain, new spatial structure of landscape is formed by the aggregation of cells, which results in the increasing of SHDI and SHEI. But if the grain continues to increase and exceeds a certain degree, the two indices will inevitably decrease. Since the SHDI and SHEI have strong relationship with each other, in this research the two indices varies the same [11]. (4) PAFRAC of different patch types differs a little as the grain increases. It is because with the increasing grain, patches begin to swallow which results in the more regular patch shape and the reduce of stability. The figure illustrates that PAFRAC of river and water declines obviously. The complexity of river and water is higher and the increasing of grain may simplify the shape of it, so the PAFRAC decreases. PAFRAC of residential, industrial and warehouse area almost remain the same. It is basically due to the fact that the two landscape types belong to the manmade landscape and the shape of patches is rather regular. Besides, in the green space, the bigger ones as the grain increases swallow the tiny patches, as a result, new landscape structure is formed and the PAFRAC of urban green space increases.

If fractal dimension of an ecological process remains the same at different scale, i.e. self-similarity, then we can choose the most appropriate scale to study the process and induce the rules of this process at other scales [10]. In the paper, the grain cannot exceed 80m. The difference among landscapes becomes vague as the grain exceeds 80m and the results are not identical to the reality. From the range 20m to 80m, the smaller the grain is, the more obvious the difference among landscape types is.

4.2 Spatial Heterogeneity of Landscape Diversity at different extents

It is generally accepted that the spatial heterogeneity of regionalized variable Z ($SH(z)$) is composed of two parts. One is brought on by random error (SH_R)which is induced by scale and measuring; the other is by spatial autocorrelation(SH_A). Thus, it can be expressed as follows:

$$SH(z) = SH_R(random\ error) + SH_A(spatial\ autocorrelation) \quad (2)$$

Nugget C_0 stands for the spatial heterogeneity because of random error. It shows that some processes at finer scale cannot be ignored if the value of C_0 is relatively bigger. C is the spatial heterogeneity caused by autocorrelation. Thereby, sill $C_0 + C$ is the most variation of system attribute or regionalized variable. The more the sill is, the higher degree the total spatial heterogeneity is. The ratio of nugget to sill $C_0 / C_0 + C$ reflects the proportion of spatial heterogeneity by random to the total spatial heterogeneity [6].

Compared with semi-variances of Landscape Diversity at different extents, the variation of spatial heterogeneity of SHDI at increasing extents has some similarity at a certain extent. Tab1 lists SHDI’s theoretical models and parameters of semi-variance at different extents.

Fig. 6 explains that SHDI of urban landscape mosaic pattern has obviously spatial auto-correlation: spatial heterogeneity becomes smaller when the distance diminishes. Within a certain distance, the spatial heterogeneity of SHDI is positively correlative with the distance. The spatial similarity lessens and the spatial variation of SHDI and semi-variance enlarges as the distance grows. In practice, if one region has higher landscape diversity, its neighborhood probably has higher landscape diversity as well. Fig.6 shows that the extent of 0.5km has the most obvious spatial variation within the range. It is concluded that the results at smaller extent tell more details and semi-variance at smaller extent detects more variation.

Fig. 6 and Tab1 tell that SHDI has obvious scale-dependence and its semi-variances differ a lot among different extents. According to the simulation of semi-variance curves, theoretical models and parameters for different extents are different. At the extent of 0.5km, the theoretical model is Exponential one, according with the variation of SHDI. Its nugget C_0 is 0.0462, sill $C_0 + C$ is 0.206, the ratio of nugget to sill is 0.2238 and the range is 4.15km. r^2 and *RSS* reflect how well it simulated. Nugget in Fig.6 illustrates that though 0.5km is relatively small, spatial heterogeneity of SHDI is still influenced by scale or measure error. Sill reflects the total heterogeneity within the scope of spatial auto-correlation. Except for nugget, the rest spatial

Table 1 semivariogram theoretical model and it's parameters of SHDI at the different extent

Extent	Model	C_0	C_0+C	A_0	$C_0/(C_0+C)$	r^2	RSS
0.5km	Exponential	0.0462	0.2064	4.1500	0.2238	0.6060	0.0463
1km	Spherical	0.1143	0.3606	42.5100	0.3170	0.9750	0.0038
2km	Gaussian	0.1582	0.4714	47.0900	0.3356	0.9660	0.0023

heterogeneity is contributed by spatial auto-relation. The theoretical model of 1km is Spherical model, but the one of 2km is Gaussian model. From Fig6～8 and Tab1, we draw the conclusion that with the increasing extents, the nugget of semi-variance also increases, i.e. Nugget effect increases. It shows that the spatial heterogeneity caused by random increases too. Random factors include Influencece of scale and measure error. Due to the same measure error for all the extents, the finer character of variation is covered up with the increasing extent. The scale error shows out in the form of nugget effect. From the extent of 2km to 0.5km, the ratio of nugget to sill is descending from 0.3356 to 0.2238. This shows that the proportion of random-caused spatial heterogeneity to the total spatial heterogeneity $SH(z)$ is decreasing while the contribution of auto-correlation to the spatial heterogeneity is increasing. Fig6 further reveals that the semi-variance of landscape diversity takes on different sensitivities at different extents. According to different parameters, we find the semi-variance of SHDI model at the extent of 1km simulates best.

Range reveals the spatial distance of SHDI's spatial dependency. At 0.5km extent, spatial auto-correlation of SHDI appears within the local scope and disappears when exceeding 4.15km. When extents increase, ranges increase correspondently. Thus SHDI does have spatial dependency in much larger scope. Within extent of 0.5km, when h reaches 23km, semi-variance of SHDI begins to be on the decline. Since urban landscape pattern is annularly expanding. When the distance extends to the other side of the same circle, the similarity will increase, heterogeneity and semi-variance decrease. That perfectly meets the trend of semi-variance in Fig6. And this trend also indicates that the similarity of landscape pattern within every circle is reasonable from interior to exterior [12].

5 Conclusions

(1) As far as the respective landscape indices are concerned, different indices have different responses to the changing grains. In this paper, LSI continuously decreases as the grain increases, SHDI, SHEI fluctuate with the increasing grains. CONTAG and PAFRAC of different patch types differ a little as the grain enlarges. It is concluded that SHDI and SHEI are more sensitive to the change of grain, yet CONTAG and PAFRAC are less sensitive [13].

(2) Spatial variation of landscape diversity has the most complexity with the smallest extent. Random part (scale and measure error) merely contributed little to the total variation (spatial heterogeneity) while spatial auto-correlation contributed most to it. The finer character of spatial variation is covered up along with the enlarging extent. That results in the increase of nugget effect and the decrease of the spatial auto-correlation-caused variation to the total variation.

(3) Landscape spatial pattern is different when the scale (grain or extent) changes. So we must pay attention to scale problem on the research of landscape ecology, select a perfect scale by analyzing scale effect.

(4) The response of landscape indices and SHDI semi-variance to scale is respective. So landscape spatial pattern is of scale dependency, i.e. landscape diversity is the function of scale. It differs a lot among dissimilar scales. Therefore, scale effects on pattern and process cannot be ignored in landscape ecology research.

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