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Spatio-temporal Variation of Landscape Heterogeneity under Influence of Human Activities in Xiamen City of China in Recent Decade

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Abstract: Xiamen is an economically competitive and highly urbanized city along the coastal area of Fujian Province, China. The research on spatio-temporal variation of landscape heterogeneity under the influence of human activities is of great importance to the further study on the relationship of landscape pattern and ecological process. It is also crucial to the discovery of spatial variation and intensity distribution of human activities. The research analyzed the intensity of human impacts and the spatial variation features and dynamics of landscape patterns by introducing statistical theories and approaches. We analyzed spatio-temporal variation of landscape heterogeneity using the geostatistical techniques, such as semivariogram and Kriging interpolation. Results show that there is a higher correlation between landscape heterogeneity indexes and human impact index. Both the indexes show a moderate spatial autocorrelation as well as an obvious characteristic of anisotropy. From 1998 to 2008, the spatial differentiation of the changes in the intensity of human activities and the changes in landscape heterogeneity shows that the landscape patterns in Xiamen are closely related with the urban land utilization methods, the condition of traffic and geographical location and the physical geographical condition such as the terrain and the ecological environment. The process of urbanization has a significant impact on the urban landscape pattern.
Keywords: landscape heterogeneity; human impact index; human activities; Xiamen City

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1 Introduction

Landscape heterogeneity refers to the degree of variation of the landscape or the system (Hao, 2009). It is the basic structural characteristic of landscape and one of the principal attributes of the ecosystem (Pickett and Cadenasso, 1995; Turner, 2005). The relationship between disturbance and heterogeneity is one of the hottest topic in the research of landscape ecology (Forman and Godorn, 1986; Wu, 2000; Turner, 2005). In different scales, disturbance could not only respond to the spatial heterogeneity, but also generate new spatial heterogeneity (Turner *et al*., 2006). The study on disturbance could enhance the understanding of the interaction between ecological process and the landscape patterns (Gao *et al*., 2010). This research will contribute to the study on the relationship of landscape pattern and ecological process (Chen *et al*., 2001), as well as the rules of spatial variation and intensity distribution of human activities (Hao *et al*., 2009).

Xiamen is an economically competitive and highly urbanized city along the coastal area of Fujian Province,

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China, as well as an eco-sensitive zone between the land and the ocean, so it has the ecological features of the island and the bay. The relationship between man and nature is very serious in the region. Since the 1990s, the city has witnessed a rapid process of urbanization and experienced fundamental land use changes. It has become the most vigorous and promising economic center in Fujian Province. Meanwhile, a lot of problems have also arisen. For example, the population, the building density and Floor Area Ratio (FAR) increased dramatically. The rapid industrialization and urbanization has caused the increasing demands of lands. The transportation and construction expanded rapidly. Landscape transformation led by urbanization and intensive human economic activities has brought a number of ecological and environmental issues and challenged the sustainability of the city.

Some researchers have studied the carbon and oxygen balance model based on ecological service of urban vegetation (Yin *et al.*, 2010), the ecological service value (Wang *et al.*, 2010), the pre-warning of ecological safety (Li *et al.*, 2010) and the construction of urban ecological networks in Xiamen (Zhang and Wang, 2006; Guo *et al.*, 2010). However, researches on spatio-temporal variation of landscape heterogeneity under the influence of human activities are rare.

The research first discusses landscape heterogeneity by adopting non-linear regression analysis combined with GIS technology and seeks to establish a connection between human activities and landscape heterogeneity patterns. Then it analyses the intensity of human impacts and the spatial variation features and dynamics of landscape patterns by introducing statistical theories and approaches. This helps to understand the spatial distribution, the change of gradient and directional characteristics of landscapes under the influence of human activities. Finally, it attempts to visually and quantitatively show the condition of human impacts and spatial differentiation of landscape heterogeneity patterns in the study area through the spatial interpolation approaches. The purpose of this research is to provide theoretical evidence for the reasonable utilization of lands and ecological safety in the process of urban construction in Xiamen.

2 Study Area

Xiamen City (24°25′–24°55′N, 117°53′–118°27′E) is located in the Jiulongjiang River estuary in Fujian Province of the southeastern China. This city is close to Zhangzhou Plain and Quanzhou Plain as well as the Taiwan Strait. It is also confronted with the Jinmen Islands, Taiwan Island and the Penghu Islands. Xiamen is comprised of Xiamen Island, Gulang Island and the inland areas including the coastal area of Jiulongjiang north shore and Tong'an district. The total land area is 1569.3 km^2 and the sea area is 390 km^2.

The land resources in Xiamen are various and the main land use types are cultivated lands, orchards, forest lands, grasslands, beaches, shallow sea, *etc*. The coastline along the coastal areas of Xiamen is winding and there are numerous bays, harbours and reef islands. The major coastal types are silt coast, river estuary, mangrove coast, sandy coast, bedrock coast and artificial coast. The coastal accumulative landforms and erosion landforms are developed and the main types are marine-built terrace, mudflat, sea-cut cliffs, sea caves, *etc*.

Xiamen has a sub-tropical marine monsoon climate. The climate is mild, with plentiful sunlight, heat resources and precipitation. The annual average temperature is about 21℃ and the annual and daily range of temperature is small. The annual sunshine duration is more than 2200 hours. Frost-free period is over 360 days. The annual average precipitation is approximately 1200 mm, which mainly occurs from May to October. The annual average relative humidity is about 78%. The wind along the coast is generally 3 to 4 levels and northeast winds are the prevailing. Because of the air temperature difference from the Pacific Ocean, Xiamen is often affected by typhoon (about 4–5 times per year), which happens from July to September.

3 Methods

3.1 Selection and construction of quantitative indexes

3.1.1 Selection of landscape heterogeneity indexes

As spatial heterogeneity exists in various scales of landscape, it is necessary to quantify spatial heterogeneity when establishing relations between structures and process of landscape (Garrigues *et al.*, 2008). The paper adopts landscape diversity index and fragmentation index to reflect variability and complexity of landscape components and spatial structure on landscape scales (Ou *et al*., 2004).

(1) Landscape diversity index

Landscape diversity refers to richness and complexity of patch types in landscapes and reflects the heterogeneity of landscape areas. The higher diversity index (H) means the higher landscape heterogeneity and the more stable landscape. The computational formula is as follows:

$$H = -\sum_{i=1}^{m}\left[P_i \ln(P_i)\right] \quad (1)$$

where P_i is the proportion of the area of landscape type i in total landscape area; and m is the total number of landscape types.

(2) Landscape fragmentation index

Landscape fragmentation refers to the divided degree of landscape, reflecting the interference degree of landscape influenced by human activities. Landscape fragmentation index (F) is positively related to the number of patches and negatively related to the average patch area. The index is calculated by the following formula:

$$F = (N - 1) / A \quad (2)$$

where N is the total number of patches; and A is the total area of landscapes.

3.1.2 Human impact index

Human activities tend to result in the continuous decrease in original and natural characteristics of landscape components (Yoshiko and Dieter, 1995). Different types of landscape components represent different human activities or development intensity. As a spatial variable, human impact index is established based on the corresponding relationship between human activities and landscape components as well as the area proportion of different landscape components. It is used to describe the influence of human activities on landscape and the artificial modification intensity of landscape. The formula is as follows:

$$D = \sum_{i=1}^{m} A_i E_i \Big/ A \quad (3)$$

where D is human impact index; m is the number of landscape component types; A_i is the area of landscape component type i; E_i is the parameter of human impact intensity reflected by landscape type i; A is the total area of landscapes. The parameter of human impact intensity reflects the intensity and attributes of human participation, management and transformation of different components. Chen *et al*. (2001) calculated it through the Leopold matrix method and Delphi scoring method and this paper uses the average of the two methods to determine the parameter (Table 1). The value of D ranges between 0 and 1. The maximum of D in one area demonstrates larger proportion of landscape components that human activities are dominant, thus the intensity of human impact is larger.

3.2 Basic data sources

The research used two land use maps in the year of 1998 and 2008 of Xiamen as the basic data sources and the data were saved in the format of Shapefile. The land use maps were collected from LandSat ETM remote sensing images (spatial resolution is 15 m).

Under the support of remote sensing (RS) and geographic information system (GIS) software, the images were firstly preprocessed through projection and registration. Image fusion was conducted on the bands of 5, 4, 3 and 8 in order to make sure the images are close to true color and are easy to be understood and distinguished. Then related data were collected to know the ecological environment and characteristics of each element in the study area. On the basis of indoor analysis and field investigation, the images were processed by visual interpretation combined with the background data including topographic map, geomorphologic map, pedological map, vegetation map and land use map. Furthermore, they were digitalized in support of GIS software.

In the process of digitalization, the minimum patch unit is approximately 0.01 km^2 (100 m × 100 m). For example on a map at 1∶25000 scale, only the patches whose area is more than 4 mm × 4 mm are drawn and those small patches are merged according to the principle of map generalization.

3.3 Spatial sampling method

Reasonable spatial sampling method is applicable to database management and operation through GIS tech-

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Table 1 Parameter of human impact intensity of each landscape type

Cultivated landscape	Orchard landscape	Forest landscape	Built-up area landscape	Wetland landscape	Low coverage landscape
0.55	0.435	0.10	0.815	0.14	0.075

niques and is also suitable for landscape pattern analysis. In order to ensure that the human impact index and landscape pattern index of each point in geostatistical analysis could stand for the comprehensive condition of human exploration and utilization in certain area, the paper conducted sampling on landscape layers of two periods in 1998 and 2008 using grids covering all the study area. In the research on landscape pattern index, O'Neill *et al.* argued that only when the area of landscape sample plot is 2 to 5 times bigger than the average area of patches, the plot could reflect the landscape patterns around the sampling sites (O'Neill *et al.*, 1996; Steven, 2010). According to the area of landscape patches in the study area (the average area of patches in two periods is between 1.2 km^2 and 1.4 km^2), the research adopts the 2.5 km × 2.5 km grids for sampling.

Supported by the ARC/INFO software, gridding layers were established to cover study area, and then added with landscape layers of different years to get the complex layers of sampling. As for the incomplete quadrats that the edges are cut, those are deleted if the area is less than 3.125 km^2 (1/2 of the quadrat area) and are remained if more than 3.125 km^2. However, when calculating the quadrats, it is necessary to change their area accordingly, rather than using the united one. The next step was to figure out the human impact index, diversity index and fragmentation index of each grid quadrat. Finally, the results were endowed with the central point of the grids that they lie and the sample data outputted are considered as point map layers.

In order to obtain the spatio-temporal difference of human impact intensity and landscape pattern changes, the difference of human impact index, diversity index and fragmentation index between two periods (the value of 2008 minus the value of 1998) was worked out and then outputted as point map layers with attribute values of various index changes.

3.4 Nonlinear regression model

Because of different intensity and ways of human disturbance, the influence of human activities on landscape patterns varied greatly. As a result, there exist many forms of relations between different indexes that reflect regional landscape patterns and between landscape pattern index and human impact index. Generally, it appears to be a complex nonlinear relationship. According to theories of ecology and landscape ecology, this paper intends to explore the potential rules of landscape patterns under the influence of human activities by establishing the empirical models that will help study the landscape ecology and regional landscape pattern development.

The research took Data Processing System (DPS) as the operation platform to establish the nonlinear regression model. It also used Marquardt method (the non-linear least squares method) to do iterative computation and then chose the best-fit regression curve according to determination coefficient (R^2). And finally significant tests were done for each regression formula through F test.

3.5 Geostatistics analysis

Geostatistics is based on the theory of regionalized variable and variogram and it is a science studying natural phenomena that are random and structural in spatial distribution (Matsushita *et al.*, 2006), or are relevant and dependent in space. The human impact index and landscape pattern index are a kind of spatial variable and they can be used to conduct spatial analysis making use of geostatistical methods.

A variable can be called regionalized variable if it is spatially distributed. A regionalized variable is used to describe the regionalized phenomena. The variogram of the regionalized variable $Z(x)$ in the x axis is defined as the variance of the difference between the value of $Z(x)$

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at point of x and the value of $Z(x+h)$ at the point of $x+h$, labeled as $2\gamma(x,h)$. Under the second-order hypothesis, there is:

$$2\gamma(x,h) = Var\,[Z(x) - Z(x+h)] = E[Z(x) - Z(x+h)]^2 \quad (4)$$

From the above formula, the variogram depends on two variables x and h. When the variogram $2\gamma(x,h)$ only relies on distance h and has no relationship with the position x, $\gamma(x,h)$ can be changed into $\gamma(h)$ and $\gamma(h)$ is called semi-variogram.

$$\gamma(h) = \frac{1}{2}E[Z(x) - Z(x+h)]^2 \quad (5)$$

The above definition is the theoretical semi-variogram, but in practice, the quantity of samples is limited and the data are discrete. The semi-variogram established on the basis of test samples is defined as empirical semi-variogram and is labeled as $\gamma^*(h)$:

$$\gamma^*(h) = \frac{1}{2N(h)}\sum_{i=1}^{N(h)}[Z(x_i) - Z(x_i+h)]^2 \quad (6)$$

where h is the spatial separation distance or distance lag between two sample points; $N(h)$ is the total number of sample points when the separation distance is h; $Z(x_i)$ and $Z(x_i+h)$ are the measured value of the regionalized variable $Z(x)$ at the spatial position x_i and x_i+h respectively.

For different separation distances h, the corresponding values of $\gamma^*(h)$ can be figured out according to semi-variogram formula and the results are used to draw the semi-variogram curve. Then parameters of variogram can be obtained, including the nugget C_0, partial sill C, sill $C + C_0$ and range a. These parameters determine the shape and the structure of variograms and are able to quantitatively describe the spatial variation features of regionalized variables. Figure 1 is a type of idealized semi-variogram curve.

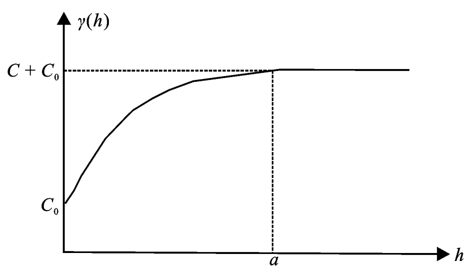

Fig. 1 Diagram of semi-variable function′s structure

3.6 Spatial interpolation method

Spatial interpolation method is also called Kriging method or spatial local estimation. It is established on the variogram theory as well as structural analysis and is one of the major methods in geostatistics. Kriging method is valid under the following condition. If results between variogram and correlation analysis indicate that regionalized variables have spatial correlation, Kriging method can be used to estimate the points or areas of the space that are not surveyed.

Spatial interpolation is indispensable to the research on landscape heterogeneity. The spatial heterogeneity of landscape patterns leads to the change of landscape ecological effects corresponding to the pattern, which is the result of ecological processes that are dominant in the ecosystem (O'Neill *et al*., 1996). Kriging method is a collective term for several spatial interpolation models and is a kind of method to do unbiased optimal estimation for the regionalized variables in limited areas. According to the information of spatial autocorrelation provided by variogram analysis, the research adopted ordinary Kriging method, using spherical model as the fitted model for semi-variogram and the human impact index and landscape pattern index were spatially interpolated. Supported by the Spatial Analyst module of ARC/INFO software, the point map layers acquired from the spatial sampling were interpolated. And then the spatial distribution maps of human impact index, landscape diversity index and fragmentation index of the study area in 2008 were drawn, as well as the distribution map of index changes from 1998 to 2008. The results were output in the grid map of 200 m × 200 m resolution.

4 Results and Discussion

4.1 Correlation between human impact index and landscape heterogeneity indexes

By means of professional judgment and curve fitting of spatial sampling data in the study area, the research established the relationship between landscape heterogeneity (H) and landscape fragmentation index (F) as well as their relationship with human impact index (D). And then it would receive the nonlinear regression formulas and relevant parameters of several types of relationships in 1998 and 2008. Finally the significance tests indicated that their confidence levels were all below 0.01, which proved that the effects of regression were significant.

Table 2 shows that the optimum regression curves of landscape heterogeneity indexes and human impact index of the two periods are both quadratic curves, reflecting that the two types of relations are similar. The regression effects can be reflected through the value of determination coefficient R^2. The determination coefficient of *H-D* formula in 1998 was as high as 0.701, demonstrating that human impact index had a significant influence on landscape heterogeneity index. This was also proved by the correlation coefficient *R* of *H-D* formula (0.837). The determination coefficients of *F-D* in the two periods were both lower than 0.50 and the effect of fitting was worse. However, the correlation coefficient *R* of *F-D* formula was still higher than 0.65, indicating that the influence of human activities on landscape fragmentation was quite obvious. From 1998 to 2008, both the correlation coefficient and the determination coefficient of the two types of formulas have fallen. It shows that with the increase of human management and development intensity (the total human impact index in the study area increased from 0.357 in 1998 to 0.361 in 2008), the landscape heterogeneity patterns tend to be complicated. Therefore, the influence of human activities tends to be diverse.

Table 2 Fitting curve equation between human impact index and landscape heterogeneity indexes

Correlation type	Year	Fitting curve equation	Correlation coefficient (*R*)	Determination coefficient (R^2)
H-D	1998	$H=-8.601D^2+7.386D-0.408$	0.837	0.701
	2008	$H=-8.185D^2+7.099D-0.327$	0.789	0.623
F-D	1998	$F=-11.911D^2+11.000D-0.615$	0.697	0.486
	2008	$F=-11.459D^2+10.636D-0.590$	0.657	0.432

The regressive curves (Figs. 2, 3, 4 and 5) display the influence of human activity intensity on landscape heterogeneity. The curves of their relationship are all parabolic: with the increase of human impact index, landscape heterogeneity index and landscape fragmentation index firstly increases to the maximum and then decreases gradually. The rate of change (slope of the curve) firstly decreases and then increases. Similar results are discovered from the transformation of the regression formulas in the two periods, that is: when landscape heterogeneity index and landscape fragmentation index reach to the maximum, human impact index is 0.43 and 0.46 respectively and the difference between the two periods is less than 0.005. This indicates that the landscape heterogeneity index influenced by moderate-intensity human activities is the highest, and the distribution of natural landscapes and artificial landscapes are interlaced.

From data deviating from regression curves, the deviation level of landscape fragmentation index is much higher than that of landscape heterogeneity index, reflecting that the artificial factors have a greater influence on landscape heterogeneity than landscape fragmentation. The influence of physical environment on landscape fragmentation is relatively larger. Respective comparisons of *H-D* and *F-D* regressive curves in the two periods show that the deviation degree increases and the fitting effect decreases. On one hand, the reason is that factors affecting landscape heterogeneity changes are more than human activities; on the other hand, it is because the human impact index established could not completely represent the influence of human activities on landscape.

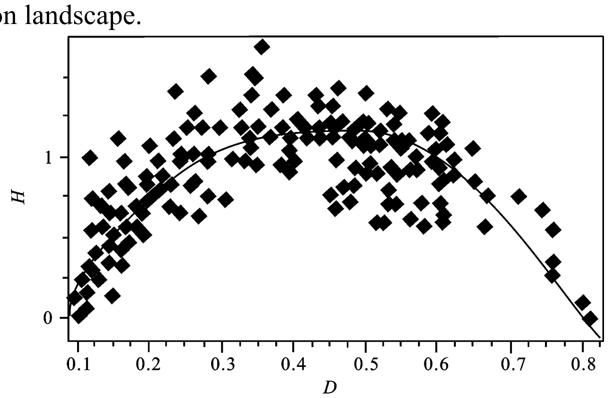

Fig. 2 Regressive curve of landscape heterogeneity index (*H*) and human impact index (*D*) in 1998

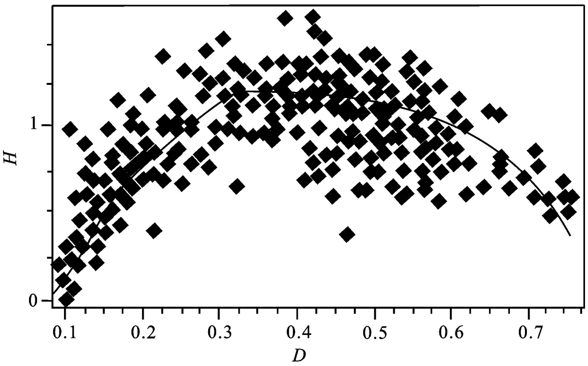

Fig. 3 Regressive curve of landscape heterogeneity index (*H*) and human impact index (*D*) in 2008

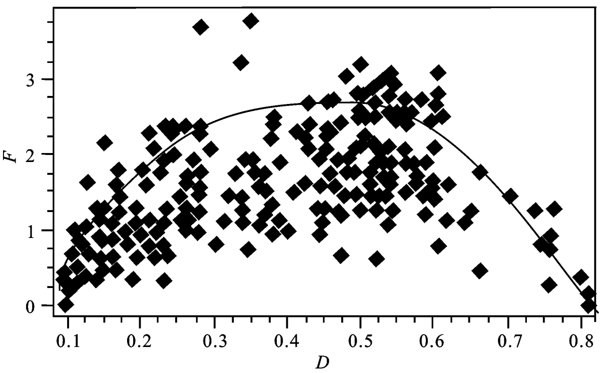

Fig. 4 Regressive curve of landscape fragmentation index (*F*) and human impact index (*D*) in 1998

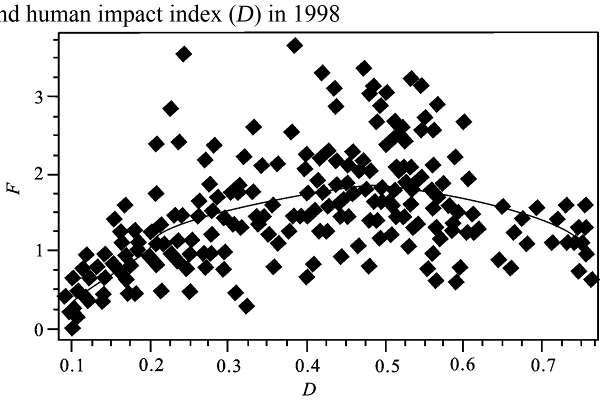

Fig. 5 Regressive curve of landscape fragmentation index (*F*) and human impact index (*D*) in 2008

4.2 Correlation between landscape diversity index and fragmentation index

The regressive relationships between landscape diversity index and fragmentation index in 1998 and 2008 are better fitted by logistic curves and the two determination coefficients R^2 are over 0.60 (Table 3). After calculation, the total diversity in the study area increased from 1.526 to 1.552 and fragmentation decreased from 0.796 to 0.756 from 1998 to 2008. It indicated that human activities had different influences on landscape diversity and fragmentation changes. Therefore, the correlation coefficients of landscape diversity index and fragmentation index decreased to some extent and the determination coefficient of *H*-*F* regressive formula decreased from 0.665 to 0.622. However, the correlation coefficients of the two periods were more than 0.78, indicating that landscape diversity had a significant correlation with landscape fragmentation.

Table 3 Regressive curve equation between landscape diversity index and landscape fragmentation index

Year	Fitting curve equation	Correlation coefficient *R*	Determination coefficient R^2
1998	$H=1.133/(1+e^{2.175-2.972F})$	0.816	0.665
2008	$H=1.261/(1+e^{1.653-2.220F})$	0.789	0.622

The logistic curves indicate that with the increase of landscape fragmentation index, the landscape diversity index firstly increased rapidly (Fig. 6 and Fig. 7). However, when it increased to a certain degree, landscape diversity stopped growing and was close to a fixed value, which was considered as the maximum diversity index. In ecology, the logistic equation is used to study the growth model of population restricted by space and resources, but here the leading factor limiting landscape diversity index is the number of landscape types in the study area.

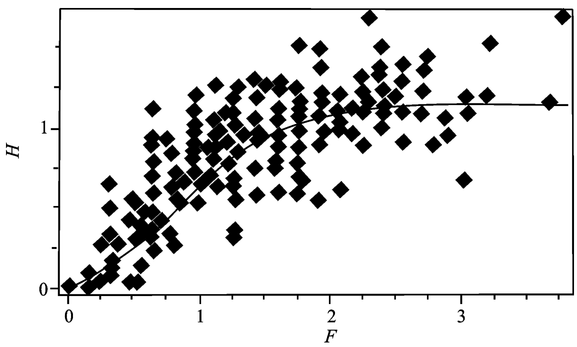

Fig. 6 Regressive curve of landscape heterogeneity index (*H*) and landscape fragmentation index (*F*) in 1998

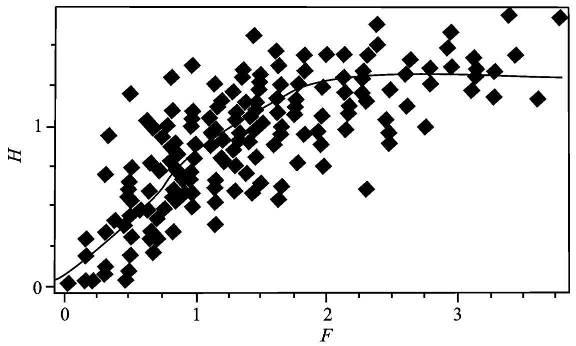

Fig. 7 Regressive curve of landscape heterogeneity index (H) and landscape fragmentation index (F) in 2008

4.3 Human activities impact and landscape heterogeneity space variation

4.3.1 Spatial structure analysis

Table 4 describes the parameters of the academic semi-variable function of each index (D, H and F) in 1998 and 2008, and human impact index changes of the period 1998–2008 (ΔD).

Table 4 indicates that there existed nugget effects for semi-variable functions of the three indexes in 1998 and 2008, which illustrates that the intensity of human activities and the distribution of landscape heterogeneity had fine scale structures and they could not be discovered by the current scale of analysis. The range of index is possible to measure the spatial heterogeneity scale of regionalized variables. From the isotropic perspective, the ranges of each index basically have little difference and they have spatial autocorrelation in the scope of about 50 km. The range is close to the scope of the study area, demonstrating that each index has overall spatial autocorrelation. Reasons for this phenomenon might be the following: the total study area is not large; urbanization of the region is relatively high; and the influence of human activities on landscape is common. The partial sill/sill ratio (C / C + C_0) is less than 0.75 and each index belongs to moderate spatial autocorrelation.

Table 4 Academic semi-variable function of each index

Index	Year	Nugget (C_0)	Structure variance (C)	Sill (C+C_0)	Range (km)	C/(C+C_0)
D	1998	0.014	0.033	0.047	49.4	0.694
	2008	0.015	0.026	0.041	45.3	0.628
H	1998	0.100	0.073	0.173	49.4	0.422
	2008	0.082	0.087	0.169	49.4	0.516
F	1998	0.380	0.305	0.685	49.4	0.446
	2008	0.210	0.543	0.753	49.4	0.722
ΔD	1998–2008	0.003	0.003	0.006	11.1	0.500

The sill of human impact index is lower than 0.05 and the size of sill reflects the change rate of human impact index in the space. This indicates that the human activity intensity does not change very fast in the space. The sill and the range of human impact index in 2008 dropped a little compared with that in 1998. It shows that the overall spread of regional development reduced the spatial difference of human activity intensity. The spatial distribution of human impact intensity tends to be homogenized, but there still exists the accumulative effect (O'Neill *et al.*, 1996). With the process of urbanization, the general level of artificial improvement increases continuously. Hence, the spatial autocorrelation of human impact index has a certain degree of reduction.

From 1998 to 2008, the nugget variance of landscape diversity index and landscape fragmentation index decreased but the structure variance increased, which was particularly notable for landscape fragmentation index. It reveals that the spatial variation caused by random portion declined while caused by spatial autocorrelation increased. As a result, the spatial autocorrelation degree of both landscape diversity index and landscape fragmentation index has risen obviously; especially for landacape fragmentation index, the structure variance/sill ratio increased from 0.446 to 0.722. From the change of sill, the spatial difference of landscape diversity index tends to decrease, showing a similar trend with the human impact index.

On one hand, it is because there is a high correlation between landscape diversity index and human impact index. On the other hand, it is because the landscape diversity index itself is a comparatively stable index and it changes slowly in the space. During the period of research, the sill of landscape fragmentation index had a certain increase. Different with the change of human impact index, the spatial difference of landscape fragmentation index had a clear tendency of increase.

The first reason might be that different natural conditions such as location and terrain coupled with different requirements of social and economic development lead to different ways of artificial transformation and utilization for landscapes in different locations. Thus the tendency of different landscape fragmentation changes is various. Secondly, compared with the rural and the urban landscapes, the mixed landscape is more fragmented. Along with the urbanization process of rural landscape-mixed landscape-urban landscape, there exist both highly fragmented regions as well as low fragmented regions in one area.

In order to obtain the spatio-temporal variation characteristics of human impact intensity, the academic semi-variable function fitting was conducted for the change of human impact index (*ΔD*) during 1998 to 2008 in the study area. The sill of the semi-variogram was just 0.006, showing that the intensity of human activities did not change much in the spatial difference. This is largely because the intensity of human activities increased widely in the whole area. The structure variance/sill ratio was 0.500, demonstrating that the spatial variation caused by stochastic factors should not be ignored. The intensity of human impact showed a moderate-degree spatial autocorrelation in the range of just 11.1 km. The reasons are predicted as follows: on the one hand, the process of urbanization in the study area was traditional; on the other hand, the construction lands were scattered around and broke the stable pattern of the landscape transformation intensity.

4.3.2 Anisotropy analysis

As human activities are affected by the terrain, the traffic, administrative boundaries and the distance from the city center, the spatial distribution of human impact index and the landscape heterogeneity indexes shows significant anisotropy following the changes of above conditions.

Table 5 indicates that from 1998 to 2008, the long axis of the three semi-variable functions are all NE-SW or E-W, which is consistent with the directions of highways and coastlines outside the Xiamen Island. It implies the dominant factors that cause changes in the intensity of human impact and landscape heterogeneity patterns.

The anisotropy ratio of human impact index increased from 1.23 in 1998 to 1.37 in 2008, showing that the scale difference of spatial autocorrelation existing in various directions of human impact index is significant. The directional characteristics of artificial activities have an obvious tendency of increase. The anisotropy ratio of landscape diversity index and landscape fragmentation index is small, demonstrating that the spatial variation of landscape heterogeneity has no obvious direction effects and the degree of anisotropy is not big. Only the anisotropy ratio of landscape fragmentation index increases slightly.

Table 5 Directional characteristic of semi-variable function of each index

Index	Year	Long axis	Long axis range (km)	Short axis range (km)	Anisotropy ratio
D	1998	NE-SW	47.5	38.8	1.23
	2008	E-W	47.4	34.7	1.37
H	1998	E-W	47.6	40.9	1.17
	2008	NE-SW	47.7	40.9	1.17
F	1998	NE-SW	47.8	40.7	1.17
	2008	NE-SW	47.5	38.8	1.22
ΔD	1998–2008	NW-SE	37.7	24.2	1.56

Table 5 shows that the semi-variogram direction of human impact index changes (*ΔD*) is quite different from other indexes. The semi-variogram of human impact index reflects the human activity associated with landscape patterns and focuses on the spatial structure. It is the accrued returns of the influence of human activity on landscape and it also incorporates the transformation of natural factors. However, the human impact index change has a different meaning. It reflects the intensity of landscape transformation influenced by human activities and shows the landscape pattern changes (Zhu *et al*., 2001; Yu *et al*., 2010). The semi-variogram of ΔD, especially the directional characteristics, could more directly reveal the driving forces that affect the regional landscape and its pattern changes. The long axis and short axis ranges are shorter than those of other indexes, which indicates that the intensity of human activities has a relatively small-scale spatial autocorrelation and the long axis range could reflect the maximum spatial scale driven by regional urbanization. The anisotropy value of ΔD is as high as 1.56, demonstrating that the value of human impact changes has obvious directional differences. The long axis direction is NW-SE and it is consistent with the principal axis of urbanization promotion and economic development, that is, Xiamen Island expands to Jimei District and Haicang District along the Xiamen Bridge and Haicang Bridge. The change of human activities in the space shows that the development of many non-agricultural lands appears in the Xinglin Bay and the Maluan Bay of Xiamen and urban landscapes grow fast in these areas and will probably continue to exist and be strengthened in the future.

5 Conclusions

The regressive relationship between landscape heterogeneity indexes and human impact index and between landscape diversity index and landscape fragmentation index could be better fitted by the parabolic curve and the logistic curve and the correlation of each index was high. From 1998 to 2008, the spatial autocorrelation of human impact index decreased while landscape heterogeneity indexes increased obviously. The semi-variogram of human impact index changes indicated that the intensity of human activities increased generally in the whole area and showed a moderate-degree spatial autocorrelation. Looking from anisotropy, the long axis of the three semi-variable functions are all NE-SW or E-W, which is consistent with the directions of highways and coastlines outside the Xiamen Island.

There exists clear spatial differentiation of human impact intensity and landscape heterogeneity patterns: regions with high landscape heterogeneity are basically urban-rural integrated areas (desakota) or urban tourism areas with staggered distribution of various landscape types. However, regions with low landscape heterogeneity are usually forest landscape areas or urban area with high construction density.

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