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Quantification of spatial structures in two landscape regions

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Abstract—Landscape process and pattern are closely related, hence recognition of landscape pattern is very important to recognize landscape process, and vice versa. Two new methods have been introduced: variable clumping method (VCM) and variable core area method (VCAM) which may be used to analyze spatial structure of landscape. VCM is used to quantify patch distribution while VCAM is for quantifying patch shape. To evaluate these methods, two different landscapes in southwestern Japan were applied. Saijo is selected as agricultural landscape and Hiwa is selected for region of mountainous rural landscape. By applying the two methods, several landscape elements showed that spatial structures depend on spatial scales. It can be concluded that the two tested methods are effective in understanding the characteristics of landscape structure which are difficult to detect by traditional analytic methods.
Keywords: heterogeneity, patch distribution, qualification, variable clumping method.

1 Introduction

Landscape ecology focuses on structure, function, and changes in landscape (Forman, 1986). Heterogeneity in landscapes is shaped as a result of complex interactions between climate, terrain, soil, water availability, biota (Whittaker, 1975) and various human work (McDonell, 1993). Landscape pattern comes from characteristics and alternations of these factors, and landscape pattern also changes temporally. To predict or manage landscape changes, recognizing qualitative and/or quantitative landscape patterns and functions are needed. Therefore, various studies had been done on qualification of landscape pattern as well as landscape functions and changes (O'Neill, 1988).

Fractal dimension is one of the most commonly used as qualification method for landscape pattern (Turner, 1988). This method is an application of fractal geometry to study landscapes, and has been used to characterize shape and size of patches. It is a based on an idea that complexity of patches, either belong to each specific landscape element types or one landscapes, is unchanging or gradually changing along any spatial scales. Therefore it is difficult to detect changing of spatial structures that depend on spatial scales.

In this paper, we applied two methods which are variable clumping and variable core area methods. Both methods are the extension of traditional methods, which qualify structures at the specific scales. The traditional methods have been applied on one scale, and we extended these methods to be used with gradual scales, for continuously recognition of changes of the structures depending on scales. From these methods, we try to draw outlines of spatial structures of two different landscape systems, and test the possibility of these methods.

2 Methods

2.1 Buffering and core area

"Buffering" is one of the most major and basic spatial analytic methods using geographic information system (GIS) applications. It is an operation that draw lines from determined distance away from specific objects. This determined distance is called a "buffer radius" or a "buffer distance". If specific object is only one point, a drawn line with buffering becomes a circle, which have radius equal to buffer radius and have a center at the same point as specific object. The inner area of the circle is called "buffer zone" (Fig. 1) in GIS operation. Similarly, buffer zones can be drawn around lines or polygons. "Buffer zone" means approximately the zone receiving the same influence from any object, and is commonly used in term of zonal belt including core.

When buffer zones are created based on some objects, there are some possibilities that buffer zones will overlap with each other, and make one clump. If a distance between two objects is farther than twice of buffer radius, two buffer zones are isolated from each other. But in case that a distance is closer than twice of buffer radius, those buffer zones create one clump. Therefore, number of clumps of some buffers can be determined by definition of length of buffer radius and arrangement of based objects.

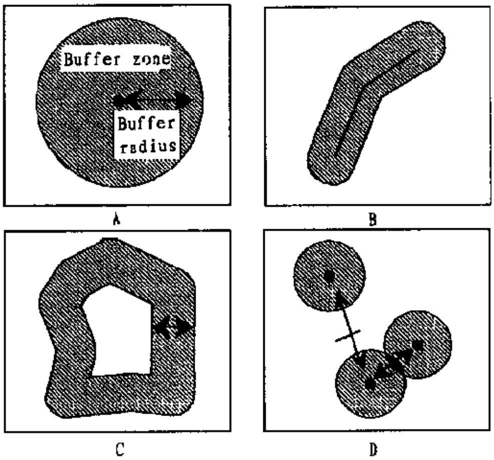

Fig. 1 Buffer zones based on a (A) point, (B) line, and (C) polygons. (D) shows that buffer zones based on some objects shapes "clump" when objects are closer than twice of buffer radius

It is possible to operated interior buffering, not exterior buffering. These areas at the inner side of interior buffer zone are called "core area" in GIS operation, and buffer radius used for this operation is called "core area radius" (Fig.2). The size of core area can be determined by shape and size of based object. If the based area is large and round patch, created core area is also large. On the contrary, if the based area is long and narrow such as a corridor, the core area is also small in size.

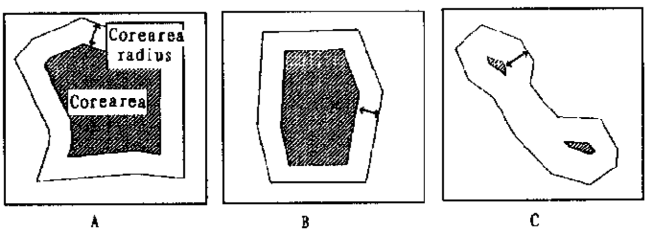

Fig.2 Core area based on (A) specific patches, (B) simple and (C) narrow shape patch

Creation of buffer zone and core area needs to decide specific length of buffer/core area radius. It is, however, difficult to decide such radius in suitable length.

2.2 Variable clumping method

There is a method applying buffering by decided only one radius, and qualifying distribution of objects by measuring the number of clumps and objects. This method is called "clumping method", and is used in mainly urban technology for measuring locations of shops and so on (Asami, 1984). This method includes arbitrariness when determining buffer radius, and has problems that it cannot recognize spatial scale but determined one.

Thus, clumping method is extended in order to decide on various radius, and to plot buffer radius and number of clumps in this buffer radius, this method is called "variable clumping method" (VCM; Funamoto, 1995). The VCM is developed in urban technology, however its current usage has limitation on based objects to only point object, and never based on polygon. In this study, we extended VCM to be able to apply spatial distribution of polygons, and use it to measure the connectivity and concentration of the areas.

Number of clumps depends on buffer radius and the isolation of each object. Assuming that,

X-axis is the buffer radius, and Y-axis is the number of clumps, then a curved line depend on the disturbance of objects may be plotted. When the objects are close to each other, this curve close to the left side of the scale, while when the objects are dispersed, it will be close to the right side. The slop of this curve becomes steeper when each object has arranged with comparatively regular intervals.

This method has a characteristic that it can detect changes of the spatial distribution of the objects that are scale depended. For example, the areas have some objects which concentrate and dispersed at the same time, this curve has steep place in the intervals of the concentrate area and flat place in the intervals of the void area (Fig.3).

2.3 Variable core area method

Similarly, it is able to create core area with gradual buffer radius. Number of core area is not a very suitable way for detecting characteristics of spatial structures. Because number of core areas can have same value in different pattern, especially in this method that has variable core area radius, it is difficult to make sense out of structure. So we used total size of core areas instead of the number of core areas. We call this method "variable core area method" (VCAM). In VCAM, X-axis is the core area radius; Y-axis is the total size of core area.

Size of core area depends on core area radius and shape and/or size of the objects. Thus, the curve line plotted with VCAM indicates the configuration of objects. If two objects have the same shape, larger object has larger core area, and if two objects have the same sizes, the object, which is narrower or more complex shape, has smaller core area than simple objects. The curve, therefore, become steep when broad area in objects width about twice core areas radius. This means that many objects include corridor-like shapes also have twice radius. If the curve is gentle, broad central area of in objects has few irregularities in that twice of core area radius (Fig.4).

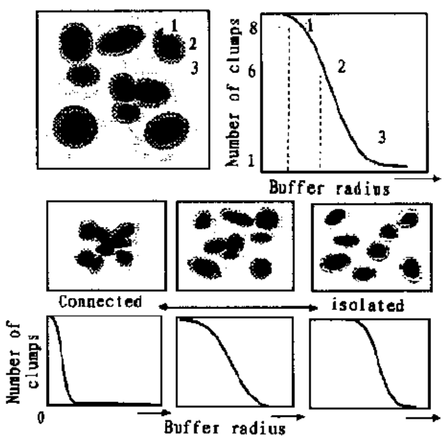

Fig.3 Variable clumping method

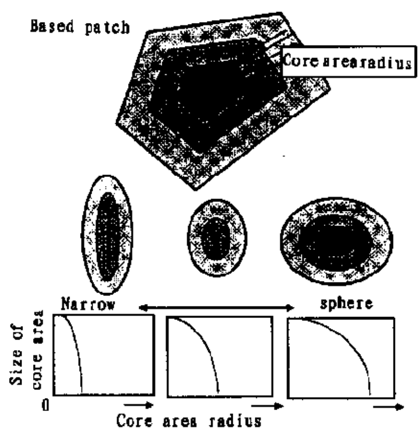

Fig.4 Variable core area method

2.4 Fractal dimension

Fractal dimension is one of the most common methods to qualify spatial pattern of landscapes. This method frequently uses to estimate patch shape (Mandelbrot, 1983). Fractal dimension is described by:

$$S = kP \wedge d/2,$$

where S equal to the area of object, P is the perimeter, k is a constant, and d is the fractal dimension. This value is ranging from 2.0 to 1.0; the value 2.0 shows the most complex while

1.0 shows the simplest shaped-circle or square.

In this paper, this fractal dimension is simply used for qualifying the shapes of objects.

2.5 Investigation areas

To evaluate these methods, we applied them on two different landscapes; an agricultural region and a mountainous rural region in southwestern Japan. Japan is not a very large country, but it have diverse landscapes reflected various climate types include that of the subtropics to the sub-arctic zones. We selected two types of the representative landscapes. Saijo area, locates about the center of Hiroshima Prefecture, is set up as a target region for agricultural landscape. This region has been used for agricultural land for a long time. Another area, Hiwa-cho also locates in Hiroshima Prefecture, has about 1000m high mountains. Hiwa is selected as sample region of mountainous rural landscape (Fig.5). Both landscapes have long history of human impacts. In these regions, detailed actual vegetation maps of 1: 25000 scale were published in 1980s (Nakagoshi, 1989; 1991).

In this study, we reconstructed these maps in database using ARC/INFO one of GIS. Because the classification of legends in these original maps is too fine, there is a risk to compare legends themselves and difficulty in discussion. So we re-classify legends of maps based on characteristics of functions and structure to nine vegetation or landuse types, primary forest, secondary forest, afforested area, bamboo grove, riparian vegetation, grassland, cultivated land, residence, and others.

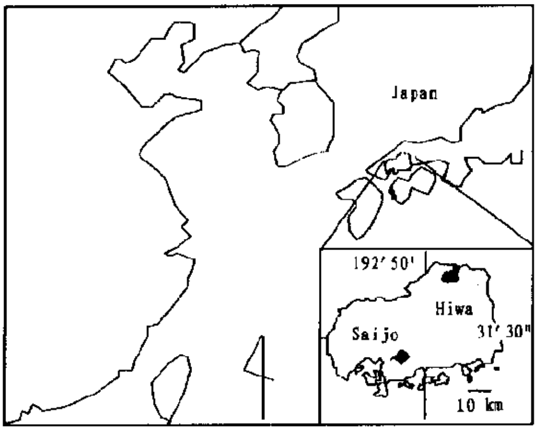

Fig.5 Map showing the study regions

Number and a size of each land-cover type shown in Table 1. Both of the landscape have been receiving strong human impact, agriculture, plantation, coppice and so forth, for hundreds years. In southwestern Japan, primary broad-leaved forests are in retrogressive succession by human impacts, the secondary forests dominated by *Pinus densiflora*, *Quercus serrata*, *Q. mongolica* var. *grosserrata* etc. (Numata, 1974). These two landscapes have compositions that reflect human impacts. The primary forest exists scarcely or none in these areas (0.3% in Hiwa and 0% in Saijo) and the secondary vegetation occupies about half of landscapes (49% in Hiwa and 54% in Saijo). Saijo, which is located in a basin, includes extensive flat area, and its landuse types tend to be plains extend ones (27% cultivated land and 9% residence). In the contrary, Hiwa, which is mountainous site, cultivated area spread in narrow valley is comparatively small (8%) and afforested area that is planted in lower place of mountains is comparatively large (33%).

3 Results

3.1 Fractal dimension

The result from the calculation of fractal dimensionis shown in Table 2. The cultivated land in Hiwa and the riparian vegetation in Saijo show the highest value. The secondary forest in both landscapes and the cultivated land and the residence in Saijo follow these landscape element types. This means that these landscape element types have complex shapes. It cannot recognize "how" complex they are. The primary forest, the plantation, the bamboo grove and grassland show comparatively low value, so these landscape elements can be recognized as simple shapes.

Table 1 Number and size of each land use type in Saijo and Hiwa

	Hiwa			Saijo		
	Total area, hm^2	%	Number of patches	Total area, hm^2	%	Number of patches
Primary forest						
Fagus crenata forest	37.3	0.3	6	–		–
Secondary vegetation						
Quercus mongolica var. *grosserrata* forest	2336.1	17.8	152	–		–
Quercus serrata-Q. variabilis forest	4086.2	31.1	387	180.2	1.9	6.9
Pinus densiflora forest	186.2	1.4	144	4797.6	50.9	470
Others	1047.0	8.0	260	107.6	1.1	6.3
Subtotal	7655.5	58.3	943	5085.4	54.0	602
Afforested area						
Chamaecyparis obtusa and *Cryptomeria japonica* plantation	4231.3	32.2	722	179.0	1.9	38
Orchard (*Vitis vinifera*/*Castanea crenata* etc.)	4.3	0.0	11	8.3	0.1	9
Subtotal	4235.6	32.2	733	187.4	2.0	47
Bamboo grove						
Phyllostachys sp.	22.9	0.2	107	55.9	0.6	116
Riparian vegetation						
Pterocarya rhoifolia forest	1.2	0.0	3			
Miscanthetum sinensis				68.8	0.7	22
Subtotal	1.2	0.0	3		0.0	
Grassland						
Miscanthetum sinesis	64.9	0.5	21	130.5	1.4	137
Erigeron sumatrensis		0.0		52.2	0.6	62
Phragmites communis		0.0		1.5	0.0	5
Moliniopsis japonica		0.0		4.5	0.0	3
Artifivial lawn and meadow		0.0		67.4	0.7	32
Subtotal	64.9	0.5	21	256.1	2.7	239
Cultivated land						
Upland field (*Chenopodietea*)	34.1	0.3	49	171.4	1.8	148
Paddy field (*Oryzea sativae*)	1044.6	7.9	4.0	2365.8	25.1	210
Subtotal	1078.7	8.2	89	2537.2	26.9	358
Residence						
Inhabitated area	30.8	0.2	33	745.2	7.9	291
Industrial area		0.0		75.9	0.8	28
Subtotal	30.8	0.2	33	821.1	8.7	319
Others						
Open water	3.3	0.0	2	185.2	2.0	329
Park and athletic filed	3.8	0.0	1	41.3	0.4	19
Constructed and denuded land	5.8	0.0	5	187.6	2.0	133
Subtotal	12.9	0.1	8	414.1	4.4	481
Total	13139.8	100.0	1943	9425.9	100.0	2184

3.2 Variable core area method

The result of calculated VCAM is shown in Fig. 6. In Hiwa, riparian vegetation and bamboo grove have very small and/or narrow shape, thus their core area vanish in a distance of core area radius 50m or less. This means that almost all of these land use types are included in edge of patch, and received strong "edge effects". Grassland and residence are follows them. Primary forest, secondary vegetation, and afforested area have very simple shape together. Afforested area is more complex shape than secondary vegetation in small scale, though it is simpler shape than in large scale. Cultivated land in Hiwa consists all valleys which width 200m to 300m and small basins with 400m long.

In Saijo, cultivated land occupies almost the whole area of the basin, and because it involves many small patches, it has very long perimeters, and thus it shows high fractal dimension. Cultivated land in Saijo does not have corridor-like characteristics and almost all cultivated land extends in flat plain. Cultivated land does not extend boundlessly, but always contain different types of patches. So it is rare that full-cultivated land is more than 700m in width. Secondary forest in Saijo has high fractal dimension, but it has extensive core area which receiving less influence from other patches.

Table 2 Fractal dimension of each land use type in Saijo and Hiwa

	Hiwa	Saijo
Primary forest	1.09	–
Secondary vegetation	1.39	1.31
Afforested area	1.30	1.23
Bamboo grove	1.01	1.25
Riparian vegetation		1.49
Grassland	1.25	1.27
Cultivated land	1.51	1.38
Residence	1.24	1.33
Others	1.17	1.03

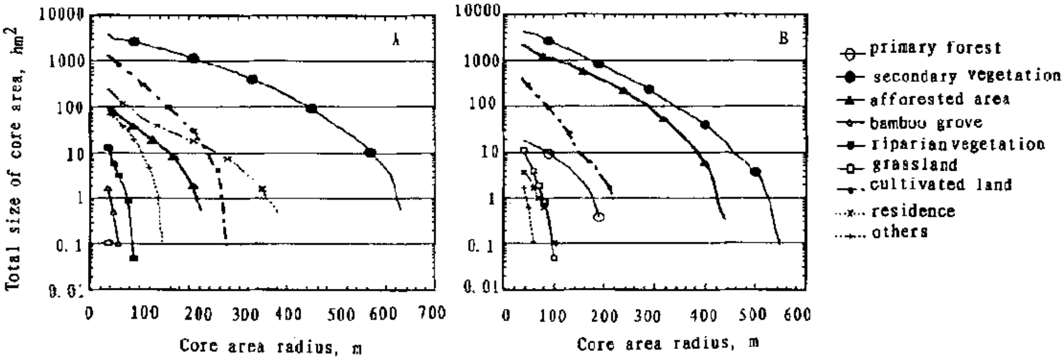

Fig.6 The results of variable core area method in (A) Saijo and (B) Hiwa

3.3 Variable clumping method

In Saijo (Fig.7), the final clumps excluded the afforested areas connect at 2000m or less, so these patches are very crowded. This means that species A, what uses only one landscape element types as a habitat and have migration ability whose maximum is 2000m, can migrate freely among any groups. Especially, the clump of cultivated lands and secondary forests reduce to two clumps only at 400m. Comparably, afforested areas in Saijo have three levels of which intervals are 200m to 300m, 400m to 600m and 1000m to 2000m. Patches like stepping-stones compose the group of 400m to 600m, and if there was no patch composing in this scale, each clump of afforested areas were fragmented, so the migrations between each patch might be very difficult.

In Hiwa, afforested areas, secondary vegetation, and cultivated lands are very close to each other. Especially, secondary vegetation is extremely crowded and even the most isolated patch is only about 250m away from neighboring patch. Afforested areas and secondary vegetation are distributed widely in almost all sections, and then it is quite crowded and continuous distribution. Cultivated lands are not distributed widely in all area, but each patch shape is a continuous shape. Bamboo groves, grasslands and residences show very similar spatial pattern. These are very isolated from each other in small scales under 600m, but almost all patches are distributed regularly about 2000m away from each other. They can be said very regular spatial distribution.

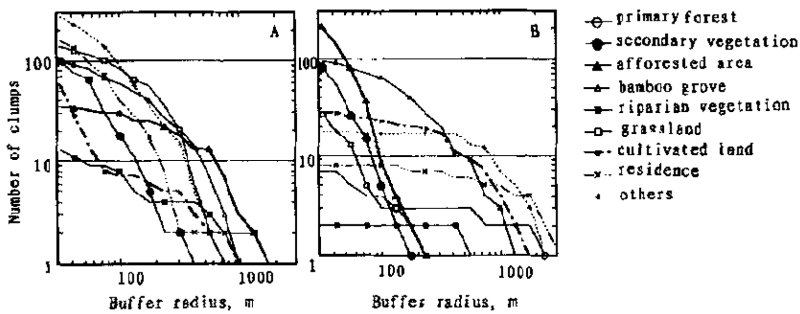

Fig. 7 The results of variable clumping method in (A) Saijo and (B) Hiwa

4 Discussion

Many methods for spatial analysis, which are developed for landscape or any other area of studies (Forman, 1986; O'Neill, 1988) have a tendency to neglect that spatial structure changes depend on spatial scales. Alternation of scale of study area and/or grain size causes transition of spatial structure, and change of result of spatial analysis (Qi, 1996). Some studies, such as *I-σ* Index (Morishta, 1959) pay attention to transition of spatial structure that depend on spatial scale. But using of such methods is decreasing because of difficulty to handle and so on.

In this study, we drew with simple operations that (1) each land use type has different spatial patterns, (2) spatial pattern of landscape changes depends on spatial scale, and (3) change is not always gentle but drastic.

To understand landscape process ranging many spatial scales, it is necessary that spatial pattern recognizes in integrated way among any scales. These two methods can be aimed of recognition. Finally, we could judge that those two methods are useful to apply to landscapes under strong human activities.

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