*Journal of Environmental Sciences* Vol. 11, No. 2, pp. 195—199, 1999 ISSN 1001—0742

# Fractal properties of patch perimeters in a disturbed montane landscape, Beijing, China*

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**Abstract**—The forest landscape has been highly fragmented in Donglingshan montane region, Beijing, China, where the folding degree of patch perimeters considerately influenced the spatial distribution of biological diversity, therefore the quantitative description to it is very helpful to conservation biology studies. The fractal dimensions of landscape patch perimeters of this region were estimated and compared. The results showed that fractal dimensions of all the landscape types were between 1.00 and 1.58. The fractal dimensions of natural vegetation types were higher than that of artificial vegetation type. Where forests (1.21) and shrubs (1.24) are near to farmland (1.12), so they were both highly disturbed by human activities regarding the smallest mean patch areas. But the grassland (1.58) had the largest mean patch area, its disturbance intensity was the lowest in this region. The fractal dimension of the overall landscape was 1.24, which was near to those of forests and shrubs, and obviously different from those of farmland and grassland. The fractal dimension of the overall landscape was 1.13 in small scales, and that was 1.65 in large scales. Which means that a large number of small area patches had regular perimeters, their fragment degrees were higher; whereas the large area patches had folding perimeters, their fragment degrees were lower, they had smaller patch numbers, however occupied most of the landscape area. Large areas and highly folded perimeters were the main property of the landscape patch in Donglingshan montane region.

**Keywords**: Beijing Dongling montane region, landscape fragmentation, patch perimeter, fractal dimension.

## 1 Introduction

Landscape fragmentation and its impacts on biological diversity have been the highly concerned topics in the recent years' biological conservation studies (Harris, 1984; Hudson, 1991). Landscape fragmentation mainly exhibits as the increased patch numbers and decreased areas, the shrinking interior patch habitat, the broken corridors, the isolated patches, and the irregular patch shapes (Li, 1992). Landscape fragmentation would thus lead to a series of impacts on the species inhabitant inside. For example, it would influence population size and extinction rate, immigrants, heredity and variations and so on (Han, 1994). It would change a series of important relationships of ecosystems, the predator-prey, parasite-host, plant-animal, and symbiosis (Harris, 1984).

As an important aspect of landscape fragmentation, the folding degrees of patch perimeters will be different because of their origins, environmental conditions, patch areas, numbers and neighboring landscape types. And on the contrary, the folding degree of patch perimeter will lead to the differences of related ecological processes. For example, it will influence the distribution of edge species, and material and energy exchanges via patch perimeter. Hence it will determine the structure, function and dynamics of interior patch habitat (Turner, 1989; Milne, 1991). The quantitative description to patch perimeter is thus ecological meaningful in landscape ecology.

As an ideal parameter for describing the folding degree of landscape patch perimeter, fractal dimension has been widely applied in landscape pattern analysis till now (Krummel, 1987; Turner, 1989; Milne, 1991; Ma, 1996; Liu, 1997). Fractal dimensions not only could describe the folding degree of patch perimeter, but also be useful to disclose the scaling regularities of a group of patches with different areas. If a landscape pattern has different fractal dimensions in different scale ranges, the fractal dimensions implied the differences in related ecological processes (Turner, 1989).

* Supported by the National Natural Science Foundation of China(No.39570148 & 39770150)

The fractal dimensions of the patch perimeters of landscape types, the forests, shrubs, grassland, and farming ecosystem, as well as the overall landscape were analyzed and compared in order to show their different functions in landscape fragmentation.

# 2 Methodology

## 2.1 Study area

Beijing Donglingshan Mountain belongs to Taihangshan Mountains, is 100 km northwest from Beijing City, China. The study area, the Beijing Forest Ecosystem Research Station, the Chinese Academy of Sciences, located in 40°00′—40°03′N and 115°26′—115°30′E. Total area is 63.436 $km^2$. The altitudes of most mountains are more than 1000 meters, the highest peak being as 2303m. Landforms are mainly of mountain erosion structure, mountains are steep, streams down cut deeply. Soil type is fertilized brown soil. The climate is typical warm temperate zone continental monsoon climate. The vegetation, the warm temperate zone broad leaf forest, has been seriously destroyed, and the main vegetation types are secondary and artificial forests at present.

## 2.2 Fractal dimension calculation

The area and perimeter of each patch of the study area was calculated in GIS based on vegetation map. The fractal dimension of patch perimeters was estimated through linearly regress a series of patch areas and perimeters in log-log coordination (Turner, 1989; Milne, 1991). Because the following relationship existed among patch areas and perimeters (Mandelbrot, 1982; Lovejoy, 1983),

$$P^{1/D} \propto A^{1/2}, \tag{1}$$

then

$$\ln P \propto \frac{D}{2} \ln A. \tag{2}$$

So the 2 times of the regressed slope is the estimation of fractal dimension for a group of landscape patch perimeters.

The fractal dimension should fall into 1 and 2. A 1 fractal dimension means the patch perimeters is straight or regular, and a 2 fractal dimension means it has a more folding degree. The larger the fractal dimensions, the more folding degree are the patch perimeters.

# 3 Results and discussions

## 3.1 Comparisons of fractal dimensions among landscape types

The fractal dimensions of patch perimeters in Donglingshan montane region are shown in Table 1. Where 4 types were without fractal dimensions, i. e., *Caragana jubata* shrub and orchard because they had only 2 patches, *Larix principis-rupprechtii* and *Populus davidiana* forests because the regressions were not remarkably significant.

All of the other fractal dimensions were within 1.00 and 1.58. They can be divided into several grades: (1) four types, *Pinus tabulaeformis* (1.00), *Betula dahurica* (1.02), Mixed shrubs (1.08) and *Betula costata* (1.09) were within 1.00—1.09; (2) three types, farmland (1.12), *Platycladus orientalis* (1.14) and *Betula platyphylla* (1.16) were within 1.10—1.19; (3) five types, residential (1.20), *Spiraea* spp. shrubs (1.21), *Vitex negundo* var. *heterophylla* shrub (1.22), *Prunus* spp. shrubs (1.22) and *Quercus liaotungensis* (1.26) were within 1.20 and 1.29; and (4) two types, Broad leaf mixture (1.36) and subalpine meadow (1.58) were larger than 1.30. The differences of fractal dimensions among landscape types were remarkable, the greatest difference was occurred between *Pinus tabulaeformis* and subalpine meadow, which reached 0.58. Because the *Pinus tabulaeformis* forest was a plantation, its fractal dimension was nearly 1, it had a regular patch perimeter. Subalpine meadow had finger shape breaks, its fractal dimension was high.

**Table 1 Fractal dimensions of the landscape patches of Donglingshan montane region, Beijing, China**

| Landscape type | Fractal dimension | Standard error | Significance | Area, $km^2$ | Patch numbers | Mean patch area, $km^2$ |
|---|---|---|---|---|---|---|
| Overall landscape | 1.24 | 0.02 | <0.01 | 63.436 | 299 | 0.212 |
| Separate regression (1) | 1.13 | 0.02 | <0.01 | 11.251 | 239 | 0.047 |
| Separate regression (2) | 1.65 | 0.10 | <0.01 | 52.185 | 60 | 0.870 |
| Forests (9 types) | 1.21 | 0.02 | <0.01 | 30.376 | 170 | 0.179 |
| Shrubs (6 types) | 1.24 | 0.03 | <0.01 | 19.900 | 85 | 0.234 |
| Grassland (1 type) | 1.58 | 0.08 | <0.01 | 5.635 | 8 | 0.704 |
| Farmland (1 type) | 1.12 | 0.06 | <0.01 | 7.259 | 24 | 0.302 |
| Residential | 1.20 | 0.16 | <0.01 | 0.185 | 10 | 0.019 |
| *Larix principis-rupprechtii* * | 1.28 | 0.22 | >0.05 | 0.668 | 3 | 0.223 |
| *Pinus tabulaeformis* | 1.00 | 0.04 | <0.01 | 0.393 | 16 | 0.025 |
| *Platycladus orientalis* | 1.14 | 0.13 | <0.01 | 0.259 | 7 | 0.037 |
| *Betula costata* | 1.09 | 0.04 | <0.01 | 0.540 | 12 | 0.045 |
| *Betula platyphlla* | 1.16 | 0.04 | <0.01 | 7.298 | 42 | 0.174 |
| *Betula dahurica* | 1.02 | 0.06 | <0.01 | 1.475 | 15 | 0.098 |
| *Pupulus davidiana* * | 0.93 | 0.69 | >0.05 | 0.310 | 7 | 0.044 |
| *Quercus liaotungensis* | 1.26 | 0.03 | <0.01 | 16.35 | 47 | 0.348 |
| Broad leaf mixture | 1.36 | 0.06 | <0.01 | 3.082 | 21 | 0.147 |
| *Caragana jubata* shrub* | – | – | – | 0.423 | 2 | 0.212 |
| *Lespedeza biocolor* shrub | 1.32 | 0.12 | <0.01 | 2.815 | 11 | 0.256 |
| *Prunus* spp. shrubs | 1.22 | 0.05 | <0.01 | 7.964 | 24 | 0.332 |
| *Vitex negundo* var. *heterophylla* shrub | 1.22 | 0.05 | <0.01 | 7.511 | 24 | 0.313 |
| *Spiraea* spp. shrubs | 1.21 | 0.13 | <0.01 | 0.736 | 12 | 0.061 |
| Mixed shrubs | 1.08 | 0.08 | <0.01 | 0.451 | 12 | 0.038 |
| Subalpine meadow | 1.58 | 0.08 | <0.01 | 5.635 | 8 | 0.704 |
| Farmland | 1.12 | 0.06 | <0.01 | 7.259 | 24 | 0.302 |
| Orchard* | – | – | – | 0.083 | 2 | 0.042 |

* Landscape types without fractal dimensions

The average fractal dimension of forest types was 1.15, with a high variation. The fractal dimension of *Pinus tabulaeformis* was 1.00, whereas broad leaf mixture was 1.36, which difference was 0.36. The fractal dimensions of shrub types were more than 1.21 except the mixed shrubs (1.08), mean value was at 1.18, greatest variation was 0.14 occurred between mixed shrubs and *Prunus* spp. and *Vitex negundo* var. *heterophlla* shrubs. However subalpine meadow was as high as 1.58. This is an interesting result because the fractal dimensions of the landscape types under severe human disturbances were not the lowest ones compared with others. Farmland was 1.12 and residential was 1.20, both near to those of forests and shrubs. Which means having the lowest mean patch areas (Table 1), the forests and shrubs had been seriously disturbed by human activities. Meanwhile the fractal dimension of subalpine meadow was higher than that of farmland and residential, and had the largest mean patch area (Table 1), it had been weakly disturbed.

The Donglingshan montane landscape was fragmented in two ways: (1) patches isolated with small areas and regular perimeters, had nearly 1 fractal dimensions (Table 1), the dispersal fragmentation. And (2) a patch was not broken into several small area patches and remained as a large one (Table 1), but had disturbed zigzag perimeter and nearly 2 fractal dimension, the finger shape fragmentation. The disturbance degree of the former was higher than that of the later.

### 3.2 Comparisons of fractal dimensions among natural and artificial patches

The fractal dimensions of patch perimeters were remarkably different in the landscape types in Donglingshan montane region, and correspondent to different properties of human disturbances.

However some of them have not been compared because of some reasons, say *Caragana jubata* shrub had only 2 patches, which leads to the conclusion above is not very clear. At follows, the landscape types were joined together in order to make comparisons among natural and artificial at a larger scale, to get a clearer result.

The 19 landscape types were joined separately into 3 natural vegetation types, the forests, shrubs and grassland, and 1 artificial vegetation type, the farmland. The forests included 9 types, i.e., *Larix principis-rupprechtii*, *Pinus tabulaeformis*, *Platycladus orientalis*, *Betula costata*, *Betula platyphylla*, *Betula dahurica*, *Populus davidiana*, *Quercus liaotungensis* and Broad leaf mixture. The shrubs included 6 types, i.e., *Caragana jubata*, *Lespedeza biocolor*, *Prunus* spp., *Vitex negundo* var. *Heterophylla*, *Spiraea* spp. and mixed shrubs. The grassland still contained only 1 type and so to the farmland.

The farmland had the lowest fractal dimension 1.12, then the forests 1.21 and the shrubs 1.24, and the grassland had the highest fractal dimension 1.58 (Table 1). The fractal dimensions of the natural types were higher than that of the artificial vegetation in overall, however the differences were not remarkable among forests and shrubs and farmland. Which means again, by combining with the average patch areas (Table 1), these two types had been strongly disturbed by human activities.

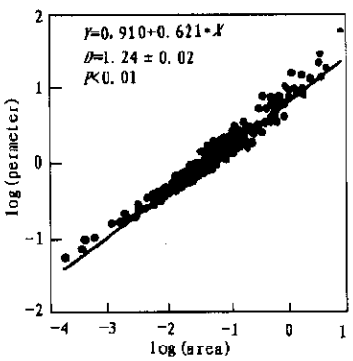


Fig. 1 Fractal dimension of patch areas and perimeters of the overall landscape of Donglingshan montane region, Beijing, China

### 3.3 Fractal property of patch perimeters of the overall landscape

The fractal dimension of patch perimeters of the overall landscape in Donglingshan montane region was 1.24 (Fig.1), which was near to that of forests and shrubs, and remarkably different from farmland and grassland. It was because forests and shrubs not only occupied most of the landscape area (79.253%), but also represented the properties of patch perimeters of the landscape (78.323%) in the region (Table 1).

The linear regression was then made separately, since the distribution trend of the points was different in small and large scales (Fig.1). The two fractal dimensions were remarkably different in two scale ranges (Fig.2). It was 1.13 in the small scale range, and 1.65 in the large scale range, which disclosed the obvious changes of folding degrees in different scales. The area was 0.230 $km^2$ and perimeter was 0.056 km at the inflection point. The patches regressed were 239 in the small scales, and that was 60 in the large scales. The total area regressed in small scales was 11.251 $km^2$, whereas it was 52.185 $km^2$ in the large scales (Table 1), which were different as high as 40.934 $km^2$. Therefore the patches with 1.65 fractal dimension played an important role in the overall landscape, the patch fragmentation was mainly of large area and finger shape in Donglingshan montane landscape.

The different fractal dimensions in the two different scale ranges reflected that the landscape's responds to human disturbance were different with scales. The fractal dimension in the small scales was 1.13, which showed that patch areas were small ($<0.230$ $km^2$), perimeters were regular, the patches were isolated in the landscape. Whereas the fractal dimension was 1.65 in the large scales, which exhibited that the disturbance effect was weak, the patches were integrated, the landscape fragmentation was of finger shape.

In summary, the above results disclosed two kinds of disturbance degree of human activities in the study area: (1) serious local disturbance, which generated small scale regular patches,

decreased the landscape heterogeneity, for example, forest clear cut and small area farming exploitation. And (2) regional disturbance effects occurred in large scales, which led to finger shape perimeters of large patches, increased the landscape heterogeneity. Generally speaking, small scale patches can be quickly restored through serious damages, say small area forest cut can be quickly restored into secondary forests or plantations, but the restoration of an overall disturbed landscape will be much more difficult and slower.

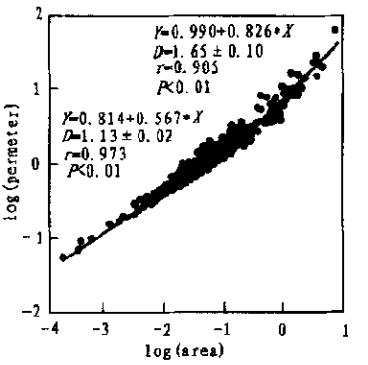


Fig.2 Fractal dimensions of patch areas and perimeters of the overall landscape of Donglingshan montane region Beijing, China through separate linearly regressions

## 4 Conclusions

The fractal dimension of all the landscape types were within 1.00 and 1.58. The lowest type was *Pinus tabulaeformis* 1.00, and that of subalpine meadow was as high as 1.58, which showed the greatest difference of fractal dimension (0.58) among the landscape types. The fractal dimensions of the human controlled types were not the lowest, where farmland was 1.12, and residential was 1.20.

After type joining, the farmland had the lowest fractal dimension 1.12, and then orderly were forests 1.21, shrubs 1.24, and the highest subalpine meadow 1.58. The fractal dimensions of patch perimeters of the natural landscapes were higher in overall than that of artificial type. However it was not remarkably different among forests and shrubs with farmland, the two types had been seriously disturbed by human activities. The disturbance degree on grassland was lower.

The overall fractal dimension was 1.24 in the landscape of Donglingshan montane region, which was near to those of forests and shrubs, but remarkably different from farmland and grassland. So the shape of patch perimeters were similar to those of forests and shrubs in overall.

The fractal dimension of the small scale range was 1.13 in the landscape, and that of the large scale range was 1.65. Which means that the small area patches had regular perimeters, and with a large number (239), but the total area was not large, fragmentation degree was high. However the perimeters of the large area patches were folded, though only a small number (60), but occupied most of the landscape, their fragmentation degree was low, represented the main properties of the montane landscape.

**Acknowledgements**——The authors thank to Beijing Forest Ecosystem Research Station, the CAS for supplying the vegetation map of Donglingshan montane region, and Mr. Zhou Huafeng for helps in data processing.

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