

SPATIAL ANALYSIS OF VEGETATION DISTRIBUTIONS IN URBANIZED AREAS ON A REGIONAL SCALE

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ABSTRACT:

Vegetation plays a key role in not only improving urban environments, but also conserving ecosystems. The spatial distribution of vegetation can be expected to make green corridors for landscape management, wind paths against heat island phenomena, etc. It is required to investigate the spatial distribution of vegetation on a regional scale because there should be green corridors and wind paths in the areas between urban areas and suburbs. We have developed a spatial analysis method of vegetation distributions using remotely sensed data on a regional scale. The method consists of a spatial autocorrelation analysis, an overlay analysis, and a hydrological analysis with the NDVI adopted as the potential of the vegetation abundance. Application of the method leads to the extraction of the lines between the core areas and sparse areas of vegetation. The purpose of this study was to analyze the vegetation distributions in urbanized areas. We applied our method to the urbanization areas and analyzed the features of vegetation distributions regarding spatial continuity through the verification of its applicability. We used a vegetation map digitized from aerial photographs as the reference. The map contained three vegetation types of land cover: grasslands, agricultural fields, and tree-covered areas.

1. INTRODUCTION

Vegetation plays a key role in not only improving urban environments, but also conserving ecosystems. The spatial distribution of vegetation can be expected to make green corridors for landscape management, wind paths against heat island phenomena, etc. It is required to investigate the spatial distribution of vegetation on a regional scale because there should be green corridors and wind paths in the areas between urban areas and suburbs. Remotely sensed data have traditionally been applied to the regional analysis of vegetation. Wu and Murray (2003) estimated the distribution of impervious surface, vegetation cover, and soil cover through a fully constrained linear spectral mixture model using Landsat ETM+ data for monitoring urban areas and understanding human activities. The Normalized Difference Vegetation Index (NDVI) calculated from the remotely sensed data has been conservatively applied to the remote sensing of urban heat islands, the estimation of vegetation cover ratio, the mapping of the urban forest carbon storage, etc (Wilson, et al. (2003), Myeong, et al. (2006)). However, there have been few methods used for extracting the area of high spatial continuity of vegetation distributions that can be expected to make green corridors and wind paths, etc. We have developed a spatial analysis method of vegetation distributions using remotely sensed data on a regional scale (Kumagai, 2006). The method consists of a spatial autocorrelation analysis, an overlay analysis, and a hydrological analysis with the NDVI adopted as the potential of the vegetation abundance. Application of the method leads to the extraction of the lines between the core areas and sparse areas of vegetation. The purpose of this study was to analyze the vegetation distributions in urbanized areas. In general, the spatial distributions of vegetation in urbanized areas tend to be scattered and sparse. Nevertheless, it is required to conserve these rare vegetation distributions because of their roles in improving urban environment, conserving landscape, and ecosystems. In this study, we applied our method to the

urbanization areas and analyzed the features of vegetation distributions regarding spatial continuity through the verification of its applicability. We used a vegetation map digitized from aerial photographs as the reference. The map contained three vegetation types of land cover: grasslands, agricultural fields, and tree-covered areas. We applied four kinds of remotely sensed data, acquired in August 2000, December 2000, April 2001, and October 2001 as regional-scale data, including the information on the seasonal fluctuation of the vegetation.

2. LITERATURE REVIEW

The concept of spatial continuity has been discussed in the field of landscape and urban planning. Within the framework of nature conservation, the notion of an ecological networks and greenways has become increasingly important (Jongmann, et al. 2004). The analysis of forest fragmentation is one of the specific approaches concerned with the spatial continuity. Monitoring with remotely sensed data was performed against the fragmentation of forest that may be occurring as a result of timber harvesting, wildfires, and so on (Brown, et al. (2000), Hansen et al. (2001), Batistella et al. (2003)). In the field of landscape, Townsend, et al. (2009) examined sensor type, resolution, extent, and the metrics used to quantify ecologically significant change for landscape monitoring applications in national parks. Using a graph theoretic approach and common landscape metrics, they analyzed potential connections among the parks derived from land classification results and compared patterns of forest habitat between 4 kinds of satellite image. Goetz, et al. (2009) also applied graph theory to extract the connectivity for the analysis on landscape context using satellite imagery. They provided maps showing the relative importance of core habitat areas for potentially connecting existing protected areas, and also provided an example of the vulnerability of connectivity to projected future residential development around one park ecosystem. On the other hand,

Wickham, et al. (2010) introduced morphological spatial pattern analysis (MSPA) as a complementary way to map green infrastructure. MSPA applied series of image processing routines to a raster land-cover map to identify hubs, links, and related structural classes of land cover. They used NLCD land-cover change data derived from Landsat TM using classification and ancillary data sources. Lechner, et al. (2009) indicated the importance of the accurate mapping of small, fragmented and linear vegetation patches for natural resource management because of their ecological significance. They investigated classification accuracy and extraction probability resulting from differences in the geometric properties of the raster grid and the features alone through the simulation of the effect of grid position, detectability, feature size, and shape on classification.

There have been a lot of researches concerned with the spatial continuity of vegetation distribution. However, there have been few methods for the extraction of the vegetation distributions between the urbanized areas and suburbs. In addition, the classification results derived from remotely sensed data tended to be applied to the analysis, even though seasonal fluctuation of the vegetation occurred generally.

3. MATERIALS AND METHODS

3.1 Study Area

In this study, the whole area of the Osaka prefecture was adopted as the area of interest. This area is located in the Kansai district in the western part of Japan. It covers about 1,900 km² and contains 33 cities, 9 towns, and 1 village. The Osaka prefecture has master plans for parks and open spaces.

3.2 Remotely Sensed Data

Landsat ETM+ data, observed on August 2000, December 2000, April 2001, and October 2001 were adopted as the basic data. We applied atmospheric corrections based on the MODTRAN and geometric correction to the data. We defined the NDVI calculated from the Landsat ETM+ data as the potential of the vegetation abundance.

3.3 Methods

3.3.1 Spatial Analysis of the Vegetation Distribution: The spatial analysis method of vegetation distribution we have developed consists of a spatial autocorrelation analysis, an overlay analysis, and a hydrological analysis with the NDVI. The spatial autocorrelation method is described in Equation (1) as

$$G_i(d) = \frac{\sum_{j=1}^n w_{ij}(d)x_j}{\sum_{j=1}^n x_j} \quad (1)$$

where G is G statistics, w_{ij} is a symmetric one/zero spatial weight matrix with ones for all links defined as being within distance d of a given i ; all other links are zero including the link of point i to itself (Getis, et al. 1992). We assigned the NDVI to a variable x . If the null hypothesis is that the set of x values

(NDVI) within d of location i is a random sample, we derive the Z value described in Equation (2). Positive or negative spatial autocorrelation is obtained depending on whether the Z value is positively or negatively greater than the specific level of significance. As a result of the statistical tests, the area of interest was divided into the three kinds of results of a statistical test with a significance level of 10%: a positive spatial autocorrelation, no spatial autocorrelation, and a negative spatial autocorrelation.

$$Z_i(d) = \frac{G_i(d) - E[G_i(d)]}{\sqrt{VarG_i(d)}} \quad (2)$$

We examined the fluctuation of the ratio in correlation areas to no-correlation areas with an increasing distance of d . The convergence of the differences of the correlation and no-correlation areas between adjacent distances appeared when d was more than 1050 m. We researched the fluctuations and convergences for four kinds of NDVI and got the range of distances of d , respectively (see Table 1).

Table 1. Ranges of distance d derived from the research of the difference fluctuation.

| NDVI | Range of d (m) |
|---------------|------------------|
| April 2001 | 90 - 1100 |
| August 2000 | 90 - 1050 |
| October 2001 | 90 - 870 |
| December 2000 | 90 - 870 |

We have developed a potential map that describes the spatial continuity of vegetation (Kumagai, 2006). The map consists of positive/negative spatial correlation areas. They are overlaid on the map depending on d , from a wide range to a narrow range, under a "no-overhang rule." This map, which we have called the Spatial Scale of Clumping of vegetated areas (SSC), presents contour lines based on fluctuations in the number of layers of the positive/negative spatial autocorrelation areas. The main concept of SSC is shown in Figure 1. As an instance of application of negative spatial correlation areas, the area "A" in Figure 1 denotes that a dense distribution area of low vegetation abundance exists from the narrowest range to the widest range. Therefore, the area might mean a low-potential area in spatial continuity of vegetation. On the other hand, the area "D" also means that the dense distribution area of low vegetation exists within only the widest range, even though there is no/positive spatial autocorrelation in the area. The four negative SSCs were produced by the application of the four seasonal NDVI, respectively.

In addition, this spatial analysis of the vegetation distribution has the function of extracting the lines connected between the core areas and sparse areas of urbanization, such as the areas "A" and "D" in Figure 1. Interpreting the map as a topographic map, the valley lines that can be expected to contain spatial continuity of the vegetated area were extracted by hydrological analysis. The image of the valley lines is represented by an arrow in Figure 1.

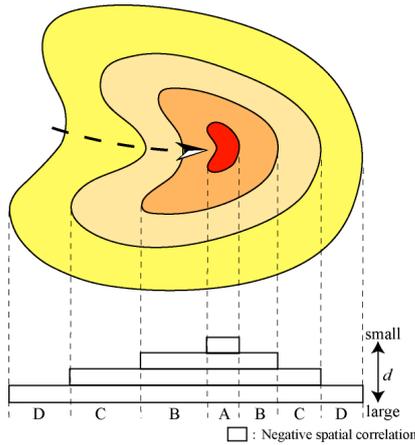


Figure 1. Concept of Spatial Scale of Clumping (SSC).

While we extracted the valley lines from the four SSCs, we discussed the method of retrieving definitive valley lines throughout all SSCs (Kumagai, 2008). The definitive valley lines can be expected to lead to the extraction of steady areas unaffected by the seasonal fluctuation of the vegetation. We compared the layers of the four SSCs and obtained an integrated result through selecting the highest layer. Figure 2 shows the concept of the integration. We call the result the ISSCs (Integration of seasonal SSCs).

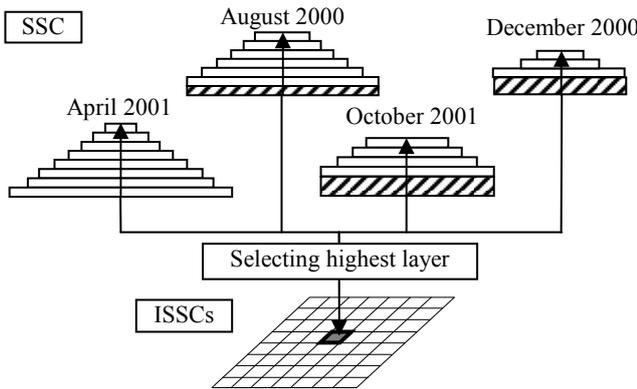


Figure 2. Concept of the Integration of Seasonal SSCs (ISSCs).

4. RESULTS AND DISCUSSION

4.1 Concept of Verification

For reviewing the appropriateness of extracting the valley lines, investigation of the statistics of the land-cover ratio of vegetation types along the valley lines in detail was carried out. In this study, we adopted a vegetation map digitized from aerial photographs as vegetation type data. The map, generated by the Division of Environment, Agriculture, Forestry and Fisheries, Osaka prefecture, contained three vegetation types of land cover: grass lands, agricultural fields, and tree-covered areas. Figure 3 shows the concept of the local calculation of the statistics along the valley lines. In the investigation, the calculation of the statistics was carried out whenever the range of a local area varied from the widest d to the narrowest d . We

got the highest values of the land-cover ratios of vegetation types for each local area and compared the average of these values between the valley lines and the green corridors on the master plans for parks and open spaces. A statistical test of the difference in the averages of the statistics of land-cover ratios between the valley lines and the green corridors was carried out.

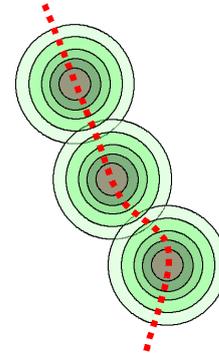


Figure 3 Concept of the calculation of local statistics along the valley line.

4.2 SSC and ISSCs

Figure 4 shows the results of the spatial analysis. In this paper, we compared the results between the SSC in August 2000 and ISSCs, so that seasonal fluctuation of vegetation in these results could be viewed through the simple comparison. In Figures 4a and 4b, gradations in color from red to yellow denote the top to bottom layers of the SSC and ISSCs, respectively. Green lines represent the valley lines extracted by hydrological analysis. Blue lines represent the green corridors in the master plans for parks and open spaces, as a reference. There were many valley lines in northeastern part of the test site in the SSC and ISSCs. There is a main river, named as Yodo river, with large grass lands on its floodplains and embankments in the northeastern part.

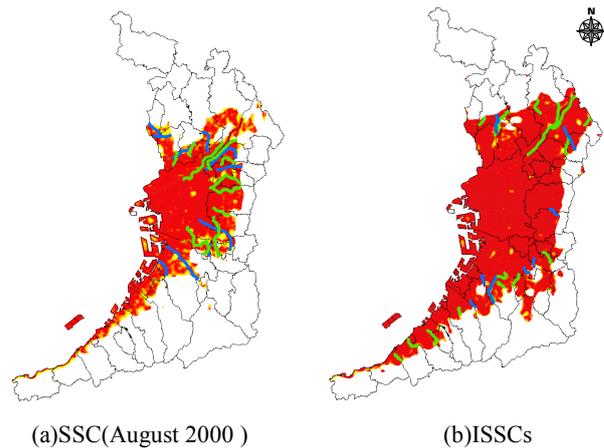


Figure 4 Results of the SSC and ISSCs with the valley lines extracted.

4.3 Discussion

The shapes and lengths of the valley lines were different between the SSC and the ISSCs, as shown in Figure 4. We calculated the local statistics of land-cover ratio along the valley lines and the green corridors planned, as noted before. Figure 5

indicates the statistical test of the differences in the averages of vegetation-cover ratio between the valley lines and the green corridors in the 4 SSCs. In the case where the statistics of the test showed more than 0, the average of the vegetation-cover ratio statistics along the valley lines was greater than the green corridor. It is shown that there is a variety of patterns of the statistics of the test in Figures from 5a to 5d. In case of the agricultural fields, the areas of higher vegetation-cover ratio were extracted along the valley lines than the green corridors in Figures 5b and 5c, even though they indicate negative statistics in Figures 5a and 5d. It seems to be influence of the chances of reaping agricultural fields during four seasons.

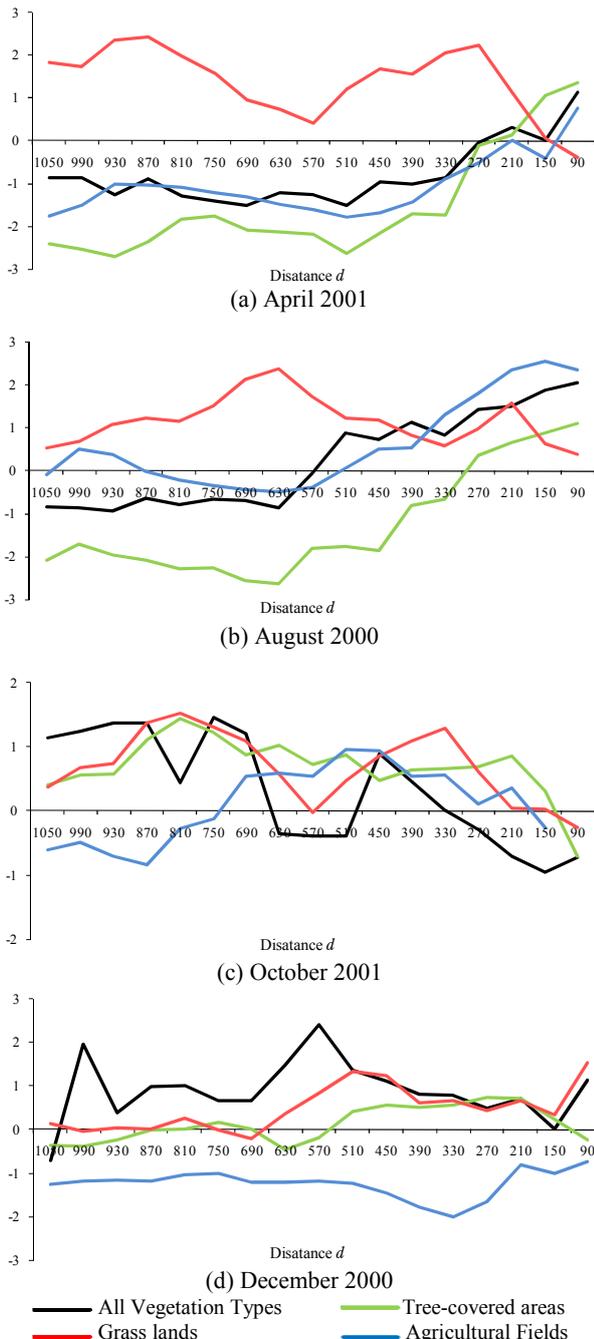


Figure 5 Results of the statistical test for the difference in the averages of the statistics of the vegetation-cover ratio between the valley lines and the green corridor planned, using the SSC calculated from 4 NDVI, respectively.

Figure 6 shows the statistical test of the difference in the averages of vegetation-cover ratio between the valley lines and the green corridors in the ISSCs. It appears that in case of grass lands, the areas of higher vegetation-cover ratio were extracted along the valley lines rather than the green corridors planned in Figure 6. It is suggested that the distributions of grass lands contribute to the structure of spatial continuity of vegetation through 4 seasons in the urbanized areas.

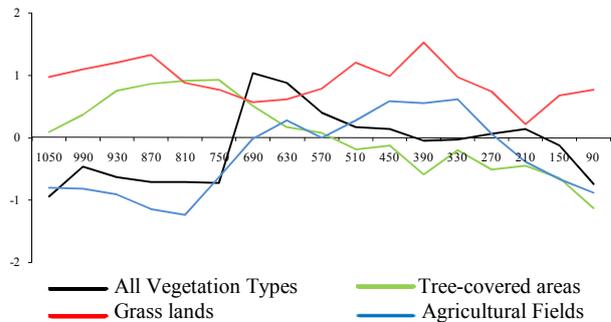


Figure 6 Results of the statistical test for the difference in the averages of the statistics of vegetation-cover ratio between the valley lines and the green corridor planned, using the ISSCs derived from the four kinds of NDVI.

Figure 7 shows examples of the partial images of the Landsat ETM+ data and vegetation-cover ratio. Green lines and green buffers represent the valley lines extracted from ISSCs and the areas of d_{max} radius. In Figure 7, it is shown that there was a dense distribution of the high vegetation-cover ratio of grass lands along the valley lines derived from the ISSCs. Hence, it seems apparent that there are steady areas unaffected by seasonal fluctuation in vegetation were located along the valley lines of the ISSCs in urbanized areas.

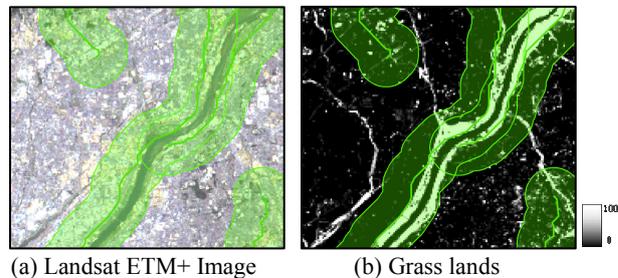


Figure 7 Part of images of the valley lines derived from the ISSCs, overlaid on the satellite images and vegetation-cover ratio. Green buffers represent the areas of d_{max} radius.

5. CONCLUSIONS

We verified the results of the analysis method, which we had developed, for extracting the spatial continuity of the vegetation distributions in urbanized areas on a regional scale. Two cases were adopted for the verification: using the 4 SSCs, and using the ISSCs derived from the 4 seasonal SSCs. Through the comparison of the results using a vegetation map digitized from aerial photographs, it was shown that the valley lines calculated from the SSC were extracted from the dense areas with high vegetation-cover ratios even though dominant vegetation types depended on the season of SSC. On the other hand, dense distributions of the high vegetation-cover ratio of grass lands

seemed to exist around the valley lines in the ISSCs. As a result, it seemed apparent that grass lands play important role in contributing to the structure of spatial continuity of vegetation distributions in urbanized areas.

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