농촌계획
Vol. 16, No. 1, 2010 (63-71)

Analysis on characteristics of shape indices through the comparison of regional woodland patches

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지역별 산림패치 비교를 통한 형태지수의 특성분석

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ABSTRACT : 지난 수십 년 동안 형태지수는 패치의 복잡성을 정량화하여 생물종 다양성 보존과 같은 경관생태계획에 활용되어 왔다. 지역계획 연구자들이나 정책결정자들에게 경관구조와 패턴을 정량화하는 경관생태지수는 대상지역을 모니터링 할 수 있는 하나의 수단으로 활용되어 왔다. 그러나 경관생태지수관련 연구를 살펴보면 연구 목적 및 범위에 따라 활용하는 경관생태지수의 종류가 매우 다양하고 복잡한 것을 알 수 있다. 또한 연구목적에 적합한 경관생태지수를 선정하는 것은 복잡한 수학분석과 함께 많은 주의가 필요한 것을 알 수 있다. 따라서 본 연구에서는 형태지수들을 도시지역, 도시외곽지역, 농촌지역 그리고 산림지역 등 4군데 사례지역에 적용하여 그 결과를 통해 형태지수들의 특성을 살펴보았다. 그 결과, 평균형태지수값(MSI)에서는 도시외곽지역이 가장 높게 나타났고, 평균프랙텔차원지수(MPFD)에서는 농촌지역이 높게 나타났다. 넓은 면적을 가진 패치에 가중점을 고려한 평균형태지수값(AWMSI)과 평균프랙텔차원지수값(AWMPFD)에서는 산림지역이 가장 높게 나타났다. 사용한 네 가지 형태지수값의 순위가 4군데 사례지역에서 다르게 나타났다. 특히 둘레와 면적의 로그전환을 이용하고 있는 프랙텔차원지수들의 경우, 도시와 도시외곽지역의 MPFD값은 같고, 도시외곽지역, 농촌지역과 산림지역의 AWMPFD값 차이는 적어 순위 분별력이 떨어졌다. 따라서 넓은 면적을 가진 패치에 가중점을 고려한 평균형태지수(AWMSI)가 지역별 산림패치의 복잡성을 잘 정량화할 수 있음을 본 연구결과에서 보여주고 있다.

Key words : Landscape ecology, Landscape ecology metrics, Patch shape index.

I. INTRODUCTION

Landscape ecology principles and methods have been applied at different scales, to different landscape types and to address a variety of issues: rural agricultural; natural resource areas for forestry, wildlife, and biodiversity; and corridors and green ways and land-use planning (Dramstad et al., 1996; Forman and Godron, 1986). The three fundamental dimensions of landscape ecological studies are landscape structure, function and change. Landscape structure has been defined as the spatial relationships among the distinctive ecosystems or elements of a landscape. Landscape functions are the interactions amongst the spatial elements of a landscape such as the flow of energy, water and nutrients. Landscape change is the alteration in the structure and function of the ecological mosaic over time (Forman and Godron, 1986). All the ecological processes occur in a certain period and are modified over time. It is important to note that landscape structure influences ecological functions and changes (Forman, 1995). In other words, landscape structure can have important effects on a wide variety of ecological processes.

A wide range of landscape ecology metrics quantifying landscape structure and pattern have been introduced to provide information of landscape ecology to assist policy makers in meeting wider biodiversity conservation

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objectives in the last two decades (Cook, 2002; Leitão and Ahern, 2002; McGarigal, 2002; Wiens, 2002; Antrop and Eetvelde, 2000; Gustafson and Parker, 1992). However, many of these metrics are complex and have unclear ecological meanings (Li and Wu, 2004).

Patch shape is important because it can influence a number of ecological processes such as small mammal migration (Buechner, 1989), woody plant colonization (Hardt and Forman, 1989) and animal foraging strategies (Dramstad et al., 1996; Forman and Godron, 1986) in a landscape.

The patch shape index which is one of landscape ecology metrics have been widely used or proposed to analyze landscape processes and species richness for biodiversity conservation planning (McGarigal, 2002; Moser et al., 2002; Forman and Godron, 1986). The most previous studies of patch shape indices suggest that the patch shape complexity in a landscape in particular decreases with increasing human land use activities, accompanied by a decrease of habitat heterogeneity and species richness (Moser et al., 2002; Kammerbauer and Ardon, 1999; Mander et al., 1999). The patch shape index has been also used for landscape ecological analysis of urban parks and changes in pattern of forest patches (Lee, 1998; Kim and Ahn, 1996).

Although recent researches have reviewed behaviors, limitations and problems of using landscape ecological metrics, limitations and problems of patch shape indices have not been sufficiently examined (Lee and Yoon, 2008; Corry and Nassauer, 2004; Lee, 2004; Li and Wu, 2004). Using inappropriate shape indices may provide misleading or undesired results for various landscape conservation planning purposes. The choice of shape indices can significantly influence the assessment of ecological values for landscape ecology planning. Thus, this research aims:

to test common patch shape indices in the different landscape types,
to discuss their limitation and problems,
to select a suitable one to assess shape complexity.

II. METHODS

1. The study area

The Gwangju city is located in South-western area of South Korea. The local authority covers 501 square kilometres and has a population of 1.4 million. In previous research (Kim, 2005), 46 landscape character units were distinguished and grouped into 12 landscape types based on a methodology of landscape character assessment that

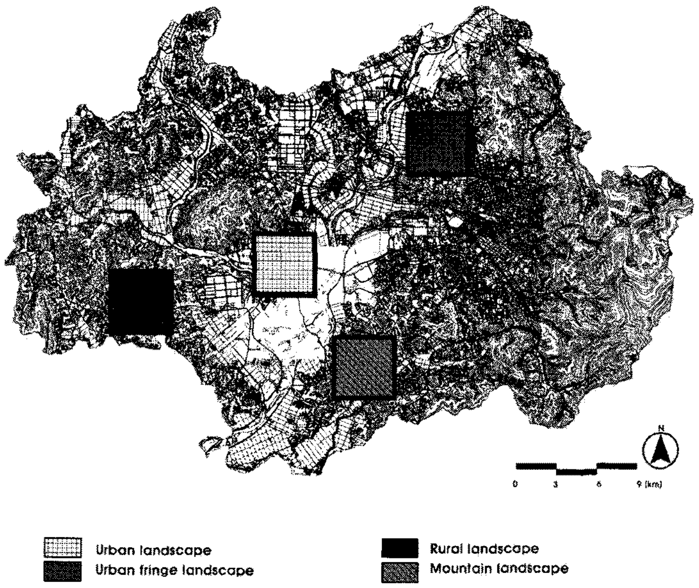


Figure 1 The four selected landscapes in Gwangju.

was adopted from the Countryside Agency and Scottish Natural Heritage(2002). The landscape character units and types are distinguished by their unique combination of bio-physical factors and land cover. To test woodland patch shape indices, four landscape character types which represent the urban landscape, the urban fringe landscape, rural landscape and mountain landscape, respectively, were chosen for this research (Figure 1). The different four landscape types were used as the base units for data collection and analysis of spatial information to compute the patch shape indices. Each landscape type had a size of 900 ha. The urban landscape was located in the centre of Gwangju. The urban fringe landscape was situated in the northern part of Gwangju. The rural landscape was located in the west part of the study area. The wooded mountain landscape was situated in the southern part of the study area.

2. Data collection and analysis

1: 5,000 topographic digital maps (2004) and black and white aerial photographs (2002) with 50cm resolution at the scale of 1:20,000 were used to map the land cover for the four case study areas. Land cover types were derived from the digital maps that contained symbols current land-use types. Twelve land cover types were distinguished and then digitized as polygons in Auto CAD. The land cover types were finally aggregated into three general land cover types for further analysis (Table 1). Urban land was largely artificial and controlled by human activities. Urban land cover types determined for the study area were apartment blocks, commercial areas, industry, modern settlements, traditional settlements, as well as managed and unmanaged open spaces. Agricultural land was mostly controlled by human activities for intensive agricultural productions. Agricultural land categories were defined as comprises arable land and rice fields. The third group was semi-natural areas, which were little influenced by human activities. These areas were reservoirs, rivers and woodlands. These data were then imported into Geographical Information System software ArcView 3.2 to analyze and display the results. Patch Analyst 2.2 was used to measure patch shape indices.

3. Formulas of the patch shape indices used in the analysis

For measuring woodland patch shape, this research used four patch shape indices.

Firstly, mean shape index(MSI) is given by the sum of the patch perimeter divided by the square root of patch area for each patch in the landscape, adjusted by a constant for a square standard, divided by the number of patches. In other words, MSI equals the average shape index of patches in the landscape. The formula used was:

$$MSI = \frac{\sum_{i=1}^{m}\sum_{j=1}^{n}\left(\frac{0.25P_{ij}}{\sqrt{a_{ij}}}\right)}{N}$$

where P_{ij} is the perimeter of the patchij, a_{ij} is the area of the patch ij, $i = 1,.....m$ is the number of patch types, $j = 1,.....n$ is the number of patches and N is the total number of patches in the landscape. MSI has values greater or equal to 1; it is 1 when all patches in the landscape are square. MSI increases without limit as the patch shapes become more irregular.

Table 1 Land cover classification from interpretation of black and white aerial photographs and 1: 5,000 digital maps (Source: National Geographic Information Institute)

Land cover categories: Urban land	Agricultural land	Semi-natural land
Apartment Commercial land Industrial land Modern settlement Managed open space Unmanaged open space Traditional settlement	Arable land Rice field	Reservoir River Woodland

Secondly, the area weighted mean shape index(AWMSI) was also calculated for the four study areas. AWMSI equals the sum, across all patches, of each patch perimeter divided by the square root of patch area, adjusted by a constant to adjust for a square standard, multiplied by the patch area and divided by the total area. In other words, AWMSI equals the average shape index of patches, weighted by patch area so that larger patches weight more than smaller ones. The formula used was:

$$AWMSI=\sum_{i=1}^{m}\sum_{j=1}^{n}\left[\left(\frac{0.25P_{ij}}{\sqrt{a_{ij}}}\right)\left(\frac{a_{ij}}{A}\right)\right]$$

where Pij is the perimeter of the patchij, aij is the area of the patch ij, $i = 1,.....m$ is the number of patch types, $j = 1,.....n$ is the number of patches and A is the total area of the landscape. AWMSI =1 when all patches in the landscape are square. it increase without limit as the patch shapes become more irregular.

Thirdly, mean fractal dimension index(MFDI) equals the sum of two times the logarithm of patch perimeter, divided by the logarithm of patch area for each patch in the landscape, divided by the number of patches. MFDI is given by the equation

$$MPFD=\frac{\sum_{i=1}^{m}\sum_{j=1}^{n}\left(\frac{2\ln(0.25P_{ij})}{\ln a_{ij}}\right)}{N}$$

where Pij is the perimeter of the patchij i, j, and N have their usual meanings. A fractal dimension greater than 1 for a 2 dimensional landscape mosaic indicates a departure from a Euclidean geometry. It assumes that MPFD is 1 for shapes with very simple perimeters such as circles or squares, and approaches 2 when shapes are more complex.

Fourthly, area weighted mean fractal dimension (AWMPFD) was also calculated for the four case study areas. AWMPFD equals the average patch fractal dimension of patches in the landscape, weighted by patch area. The formula used was:

$$AWMPFD=\sum_{i=1}^{m}\sum_{j=1}^{n}\left[\left(\frac{2\ln(0.25P_{ij})}{\ln a_{ij}}\right)\right]\left(\frac{a_{ij}}{A}\right)$$

where Pij is the perimeter of the patchij i, j, and N have their usual meanings. A is the total area of the landscape.

III. RESULTS AND DISCUSSION

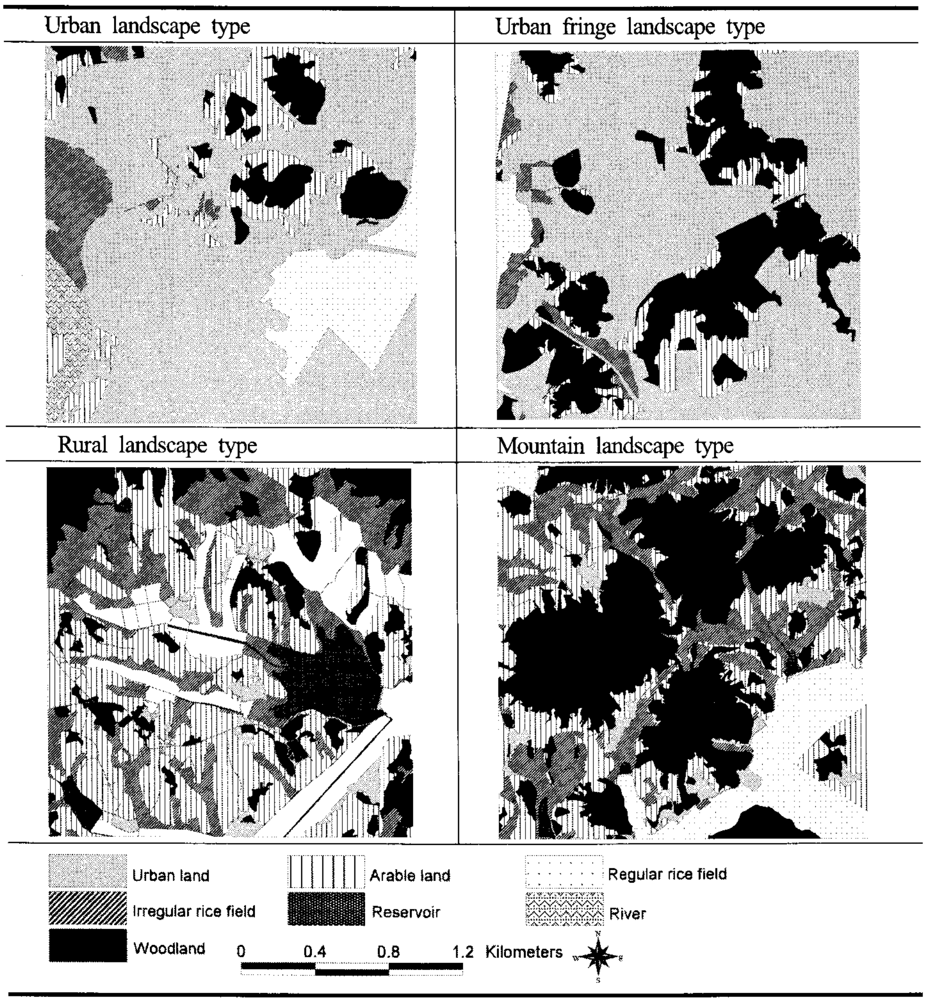
1. Land cover analysis

The four landscape types could be clearly distinguished by their landscape characteristics and the predominating land cover types (Figure 2). Urban land cover strongly dominated the urban landscape where the percentage of woodland cover was just 7.2 % (Table 2). The mean woodland patch size (4.6 ha) and the number of woodland patches (n=14) were the smallest of the four study areas. The urban fringe landscape type was strongly occupied by urban land (60%) and woodland (24.7 %). Although this landscape had a small number of woodland patches (n=17), the mean woodland patch size (13.1 ha) was the largest of the four study areas. The rural landscape was characterized by a high proportion of arable land (35.2%). Woodland patches were scattered within this landscape and covered 2.5% of the land. The number of woodland patches (n=58) was the highest of the study area, but the mean woodland patch size (2.5 ha) was the smallest of the four study areas. Woodland (43.3%) was the predominant land cover type in the mountain landscape type. The mean woodland patch size was 11.8 hectares and the number of woodland patches was 33. This landscape also had the second largest woodland patches.

2. Woodland patch shape

Table 3 depicts that woodland patches in the four study areas vary in shape index values. The mean shape index values for all four study areas were greater than 1, indicating that the average patch shape in all four areas was noncircular.

In particular, the mean shape index of urban fringe landscape has more complex shapes than either mountain or rural or urban landscape. The woodland patches in the urban landscape were the least irregular and most fragmented in shape, whereas the patches in the urban fringe and mountain landscape are the most irregular and least fragmented.



Urban landscape type

Urban fringe landscape type

Rural landscape type

Mountain landscape type

Figure 2 Results of land cover analysis in the study area.

Table 2 The proportion of land cover types

Land cover categories		Urban landscape (%)	Urban fringe landscape (%)	Rural landscape (%)	Mountain landscape (%)
Urban	Apartment, commercial, industrial, modern settlement, managed/ unmanaged open space, traditional settlement	65.3	60.0	4.6	3.9
Agricultural	Arable land	9.8	9.1	35.2	22.4
	Rice field	14.4	5.7	37.2	29.6
Semi-natural	Reservoir	0.1	0.5	6.8	0.8
	River	3.2	0.0	0.0	0.0
	Woodland	7.2	24.7	16.2	43.3
Mean woodland patch size(ha)		4.6	13.1	2.5	11.8
Number of woodland patches		14	17	58	33

Table 3 Values of patch shape indices in the four study area

Landscape type	Mean patch shape index (MSI)	Area-weighted mean patch shape index (AWMSI)	Mean patch fractal dimension (MPFD)	Area-weighted mean patch fractal dimension (AWMPFD)
Urban	1.58	1.70	1.35	1.31
Urban fringe	1.83	3.01	1.35	1.36
Rural	1.67	1.95	1.39	1.35
Mountain	1.82	3.87	1.38	1.37

From the results, it suggests that human activities dominated landscapes such as urban landscape and rural landscape made woodland shapes simpler, regular and with straight boundaries. While more natural landscapes such as the urban fringe and mountain landscape had more irregular patch shapes.

The values for MSI and AWMSI did not agree in rank order in the case of the urban fringe landscape (Figure 3). The reason is that it had some large patches, which have a simpler shape than the smaller patches, which is depressing the area-weighted means. The area-weighted values for all four study areas were greater than the unweighted values, indicating that the larger patches in each landscape type were more irregular in shape than the average.

In general, the results indicated that human-induced fragmentation in the urban and rural landscape caused a simplification in patch shapes, when compared to the geometrically complex patch shapes found in the natural, unaltered mountain landscape. Patch shape affects on species movements within patches and influences species richness (Moser et al., 2002; Dramstad et al., 1996). Therefore, it can be assumed that the mountain landscape has much more species richness than other study areas.

Mean patch fractal dimension values did not agree in rank order with mean shape index values (Figure 3). In most cases the shape and fractal indices agree in rank order, but it is not surprising that they differ in subtle ways as the fractal index involves a log transformation of perimeter and area, while the shape index did not. The greatest limitation of the fractal indices is the difficulty in conceptualising the fractal dimension. Even though the fractal dimension is increasingly being used in landscape

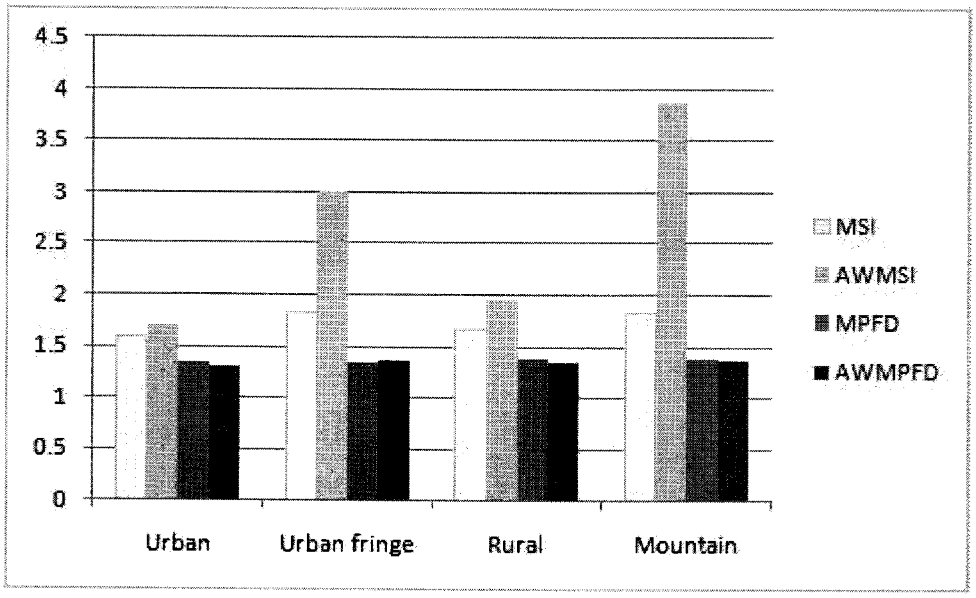


Figure 3 Comparison of woodland patch shape indices for four study areas.

ecological research, it remains an abstract concept to many and it may easily be used inappropriately (McGarigal and Marks, 1995). What is more, one of the main shortcomings of commonly used shape indices is their inability to deal with linear elements and small patches (Moser et al., 2002). AWMSI is more consistent with the results of the other indices and is therefore probably more reliable in this case.

3. Several factors leading to the decrease in the patch shape complexity

There are several driving factors responsible for the decreases in patch complexity associated with increasing human land uses. The majority of landscape elements are designed by man as rectangles with straight and distinct boundaries (Forman, 1995; Turner, 1990; O'Neill et al., 1988). Thus, outside boundaries of semi-natural or natural woodland patches were straightened and simplified by neighbouring cultivated farming areas in rural landscapes in the study area. Figure 4 clearly demonstrates that human activities in the agriculture area created more straight and distinct boundaries in the study area. Circles showed woodlands of straight lines adjacent to agricultural lands and roads.

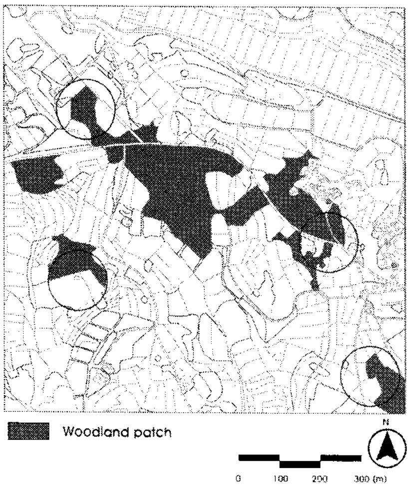


Figure 4 The process of straightened and simplified woodland boundaries in the rural landscape.

Human-based planning overwhelmingly produces straight lines, rectangles, squares, and occasionally circles with radiating lines in urban areas (Forman, 1995). More small, simple and straight woodland patch shapes in the circles were observed due to these symmetrical geometric forms in urban areas (Figure 5). It can be assumed then that woodland patches within urban areas are less stable as they are subject to more frequent and stronger human disturbance-leading to the decrease of species.

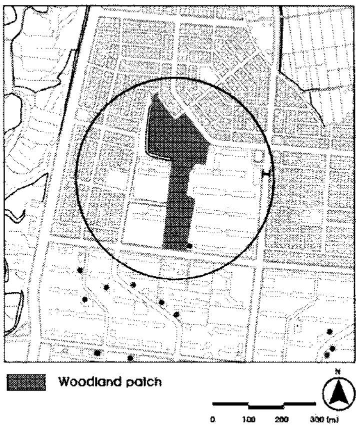


Figure 5 Human based planning produces more regular and straight woodland boundaries in urban areas.

Spatial patterns from unplanned or little-planned human activities, such as farming, new settlements, shopping areas and new infrastructure were founded in urban fringe areas. The final result of the spatial patterns were a mixture of irregular, curvy and geometric forms. Common geometric forms of aggregation and regularity in urban fringe areas caused straight woodland patch shapes (Figure 6).

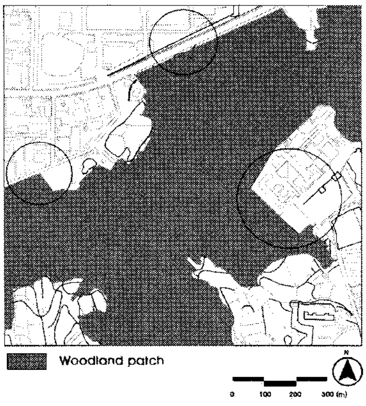


Figure 6 New settlements produce straight woodland shapes in urban fringe areas.

The study shows that human activities in urban, urban fringe and rural areas tend to decrease woodland patch shape complexity. Consequently, it is assumed that the simple and straight woodland shapes induce more losses of species richness.

Several studies demonstrate that human activities, such as land use intensification, cause detrimental effects on biodiversity in rural landscapes (Zechmeister and Moser, 2001; Mander et al., 1999). Therefore, the following assumption can be made: the more complex the woodland shape is, the higher will be species richness. The use of shape complexity indices as indicators for species richness is based on an assumed correlation between geometric landscape complexity and biodiversity (Moser et al., 2002). Apparently, this correlation is not mechanistic, but is supposed to be due to congruent effects of human land uses on landscape shape complexity and species richness.

4. Scale effects on shape indices.

Delineation of patches based on aerial photographs or satellite images or digital maps is always an abstraction or simplification of reality. The scale of the analysis and resolution of the image influence the degree of simplification of real patches (Haines-Young et al., 1993). To measure more accurate patch shapes, high resolution of images is needed at large scales. At small scales, complicated patch shapes can only be detected if they are larger than the image resolution, whereas smaller curves are converted to straight lines. Thus, a study at large scales can reduce the effect of elongated patches on area / perimeter-based patch complexity measures. In the case of the patch index, it is also possible to identify patch shapes, which can be mapped and evaluated at the city-regional level at a scale of 1: 25,000. However, working at the landscape level needs to be complemented with studies at larger scales to measure accurately these patch shapes. When the shape complexity indices are measured at the landscape level, the scale of 1: 5,000 is suitable. If greater detail of each patch shape is required for local or individual projects, work could be carried out at the scale of 1:1,000 or 1: 500. These scales should be used where detailed local information is essential even though working with these scales is time consuming and resource intensive.

IV. CONCLUSION

Patch shape indices are promising tools to measure the biodiversity potential of landscapes and to assess their spatial ecological conditions. This research demonstrated that common shape complexity indices did not work equally well. This study confirms that unweighted MSI and MPFD indicate their limited suitability as biodiversity indicators, because of their inability to deal with elongated and small patches whose frequency inappropriately raises complexity index values. However, as area-weighting eliminates effects of linear and small woodland patches on index calculation, the area-weighted shape complexity index is appropriate to predict the potential degree of biodiversity and species richness in spatial conservation planning. The study is only a first step and test information of sensitivity to elongated and small patches will be required for the suitable patch shape index.

“This research was supported by the Yeungnam University research grants in 2008”

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접 수 일: (2010년 1월 27일)
수 정 일: (1차: 2010년 3월 4일, 2차: 3월 17일
3차: 3월 26일)
게재확정일: (2010년 3월 26일)
▪ 3인 익명 심사필