Review of Issues and Problems in Using Landscape Ecology Indices

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경관생태지수 사용에 대한 고려사항과 문제점에 관한 고찰

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초 록

경관생태지수는 녹지의 이질성(Heterogeneity)을 계량화하기 위하여 제안되고 발전되어 왔다. 지난 수십년간 많은 연구에서 경관생태지수가 광범위하게 사용되어 그 효용성이 인정되었지만, 경관생태지수의 사용에 따른 많은 문제점들이 제기되고 있다. 본 연구의 목적은 경관생태지수 사용에 따른 고려사항과 문제점들을 기존 연구들을 통해 고찰하고, 이를 기초로 적절한 응용방법을 제안하고자 하는 것으로, 지수의 문제점을 내재적인 문제들과 응용상의 문제들로 구분하여 논의하였다. 지수자체의 내재적인 문제로는 녹지구조와 기능과의 관계, 녹지구조의 측정 및 대표, 그리고 지수들의 불안정성 등을 들 수 있으며, 응용상의 문제점들로는 지수 선택, 스케일 변화와 피복 분류과정에 개입된 문제, 해석상의 오류 등을 들 수 있다. 이러한 문제들을 최소화하는 방안으로는 첫째, 가설에 입각한 연구가 필요하며, 둘째, 측정하고자 하는 녹지의 공간적 특성을 명확히 규정하여야 하고, 셋째, 변위가 예측 가능한 지수를 사용해야 하고, 넷째, GIS나 인공위성 자료의 축척을 변화시키지 말아야 하며, 마지막으로 다섯째, 피복분류 알고리즘을 사용하여 분류상 오류를 최소화해야 한다는 점이다.

주요어: 경관생태지수, 경관생태학, 경관 이질성

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I. Introduction

1. Background and Study Purpose

Recent studies in landscape ecology have emphasized the relationship between landscape pattern and process in understanding ecology phenomena (Risser et al., 1984; Turner and Gardner, 1990). In relating pattern and process of landscapes, quantifying landscape pattern has theoretical benefits such as predicting ecological outcomes, comparing alternatives, surrogating ecological functions and measuring ecological impacts of landscape changes (Li and Reynolds, 1994; Turner and Gardner, 1990). These theoretical benefits of quantifying landscape pattern have led scientists to develop landscape metrics. Many landscape metrics have been proposed to quantify various aspects of spatial heterogeneity of landscapes in the last two decades (Gustafson, 1998; McGarigal and Marks, 1995). In spite of theoretical benefits and increasing uses of landscape metrics, quantifying spatial heterogeneity still remains problematic for various reasons (Gustafson, 1998).

Despite the internal and external problems, quantification of landscape patterns is still promising in several ways for landscape planners. Without sound quantification method, it is hard to anticipate the magnitude of ecological consequences of planning activities, to make objective decision among alternatives, to share the common ground with neighboring disciplines such as urban planning, ecology, biology and environmental planning. Planners, as practitioners of ecological findings, often do not have enough knowledge to make valid projection of responses of ecosystems to the new pattern that will be changed by planning activities (Gustafson, 1998). To avoid creating adverse environments for both, human and eco-systems, planners need to be able to make appropriate decisions by sharing the objectively measured information with other experts in planning processes.

It is, thus, necessary to understand behaviors, limitations and problems of using landscape metrics in predicting the influence of planning activities on ecosystems. Previous reviews on these problems have focused on limited aspects, such as conceptual and theoretical aspects (e.g., Kolasa and Rollo, 1991; Li and Reynolds, 1994) or implicational issues (e.g., Li and Wu, 2004; Kepner et al., 1995). Yet there have not been enough comprehensive reviews on using landscape metrics across a wide range of aspects such as backgrounds, conceptual limitations, estimating problems, and their implantations. In particular, it is meaningful to review these limitations and problems for future studies in Korean landscapes ecology that is about to incorporate landscape metrics.

In this light, this study aims 1) to review the inherent issues and limitations in application and 2) to suggest some fundamental guidelines for quantitative analysis of landscape pattern in order to avoid the misuse of landscape metrics. This study pays close attention to the theory and backgrounds, mathematic equations, analysis and applications in landscape planning for reviews. Some of the target journals of this review include *Journal of Landscape Ecology, Journal of Ecology, International Journal of Landscape and Urban Planning,* and *Journal of Photogrammetric Engineering and Remote Sensing.* In recent years, a few Korean articles have demonstrated the possibilities of using landscape metrics in analyzing Korean landscape pattern. However, this study does not intensively review Korean articles.

2. Definitions of Key Term and Approach

It is necessary to define terms for discussion in this paper. As Gustafson (1998) argues, there has been considerable inconsistency of terminology in the literature. Particularly, this chapter tries to clarify concepts of metrics, index (indices) heterogeneity, scale (grain and extent), pattern (structure) and process (function) and threshold. These concepts are not self-standing concepts, but are concepts dependent on each other.

Indices are the quantitative measures of particular aspects of spatial heterogeneity of landscapes, and the subset of landscape metrics. Usually, the term landscape metrics is used on a broad level (e.g., patch metrics, edge metrics and edge metrics) while indices are used to describe particular spatial attributes (e.g., fragmentation index and connectivity index, see McGarigal and Marks, 1995) of landscapes. The concept of heterogeneity is defined as the complexity and the variability of landscapes over space and time (Li and Reynolds, 1995, see next chapter for more details of landscape heterogeneity). Spatial and temporal heterogeneity measured by landscape metrics depend on the scale of measure. It is well known that grain size and extent of scaling affects the measure of landscape heterogeneity (Gustafson, 1998). Grain size is the resolution of the data (e.g., cell size, mapping unit and time interval) and extent refers to the size of the study or period of time (Turner et al., 2001). Understanding and specifying these two concepts in using landscape metrics is critical because different grain and extent can provide different value for some landscape metrics even with the same landscape pattern (Li and Wu, 2004). Landscape pattern referring specifically, the distribution of energy, materials, and species in relation to the sizes, shapes, numbers, kinds, and configurations of the ecosystems (McGarigal and Marks, 1995), is the subset of spatial heterogeneity of landscapes (Li and Reynolds, 1994), and this term is often synonymously used with spatial heterogeneity and landscape structure. Landscape process refers to the interactions among the spatial elements, that is, the flow of energy, materials, and species among the component ecosystems (McGarigal and Marks, 1995; Turner et al., 2001), and very often used synonymously with the term 'function' in literature. Threshold refers to the point at which there is an abrupt change in quality, property, or phenomena (Turner et al., 2001). Researchers found that the relationship between landscape pattern and process may be nonlinear (Wiens et al., 1997) and there is a critical threshold. The importance of this concept in using landscape metrics is that variance in landscape metrics does not always represent functional changes

II. Landscape Metrics

1. Landscape Heterogeneity

Using landscape metrics should be based on sound understanding of heterogeneity to avoid misuse of metrics because landscape metrics measure the spatial and temporal heterogeneity of landscapes. In general, heterogeneity of landscapes can be defined as the complexity and variability of a system property (e.g., patch, biomass) in space and time (Kolasa and Rollo, 1991). Landscape metrics measures landscape spatial pattern that is the major subset of the concept of spatial heterogeneity (Gustafson, 1998). As the major subset of heterogeneity, landscape pattern has two attributes: configuration (i.e., spatial) and composition (i.e., non-spatial, McGarigal and Marks, 1995; Turner et al., 2001).

Heterogeneity may have great effects on functions and processes of ecological systems, and changes in spatial heterogeneity may reflect changes in functions and processes (Forman and Godron, 1986; Kolasa and Rollo, 1991; Risser et al., 1984; Turner and Gardner, 1990; Turner et al., 2001; Turner et al., 1990). Studies validate the importance of heterogeneity in the functioning of landscape in the ecosystem. For instance, many studies indicated that spatial and temporal heterogeneity is important to the flow of species, energy, and materials across landscape (Forman and Godron, 1986; Gustafson, 1998; Risser et al., 1984; Turner, 1989). Heterogeneity also affects habitat and dispersal (Fahrig and Merriam, 1985, 1994; Hanski, 1998; Opdam, 1991), sediment and nutrient flow (Huggins et al., 2001), and disturbance (Franklin and Forman, 1987). There has been a general acceptance among ecologists that more heterogeneous landscapes provide better habitat than homogeneous landscapes (e.g., Colunga-Garcia et al., 1997; Landis and Haas, 1992; Landis et al., 2000; Marino and Landis, 1996; Menalled et al., 1999). Measurement of landscape heterogeneity should be performed based on solid understanding of these concepts. It is noteworthy that landscape heterogeneity, like other phenomena of nature, can be measured as a function of the two fundamental factors of scaling: resolution (e.g., grain size) and extent (Corry, 2002; Li and Reynolds, 1995).

Table 1 summarizes the concept of heterogeneity, major attributes and elements, and provides some examples of conceptual measures. Table 1 states that landscape metrics were developed to measure the complexity and the variability of the spatial landscape

Table 1. Spatial and temporal concepts of landscape heterogeneity and some examples of measures.

			Examples of conceptual construct	Examples of measure
Spatial heterogeneity	Complexity	Composition	· number of categories (species) · proportions · domains in size · diversity	- the number of patch types - the proportion of each patch type - richness - evenness
		Configuration	· spatial arrangement · contrast	- shape and edge complexity - patch density - connectivity - fractal dimension - contagion - lacunarity - isolation - correlogram and (semi)variogram
	Variability	Composition	· variance in number of categories, proportions, domains and diversity	- range and standard deviation in number, proportion and size over space
		Configuration	· variance in arrangement and contrast	- range and standard deviation in size, distance, density, and dimension
Temporal heterogeneity	Temporal complexity	Temporal composition	· number of category over time · proportions over time · temporal domains · temporal diversity	- the number of patch types - the temporal proportion of each patch type - temporal richness - temporal evenness
		Temporal configuration	· temporal arrangement	- sequence (frequency, duration) - correlogram, (semi)variogram
	Temporal variability	Temporal composition	· variance in number, proportions, domains and diversity in time	- range and standard deviation in frequency, number, duration in time
		Temporal configuration	· variance in temporal arrangement	- range and standard deviation in number and duration in time

From Li and Reynolds, 1994, 1995; Gustafson, 1998.

heterogeneity. As Turner (1989) states, landscape ecology focuses on the relationship between spatial pattern and process of landscape, rather than the relationship between temporal pattern and process. Very few heterogeneity indices measure temporal variation. According to Gustafson (1998), this is a serious deficiency because it encourages a static view of nature and unrealistic concepts of change in the natural system. Most studies in measuring temporal heterogeneity detect the changes in spatial heterogeneity of landscapes and relate them with functional changes (e.g., colonization, species extinction, gene flow, accumulation of energy and materials) for a relatively short period of time.

2. Critical Issues and Known Problems

As seen from recent debates about the aggregation index, contagion and fractal among researchers (Bogaert et al., 2002; Frohn, 1998; He et al., 2000; Wu et al., 2002), landscape metrics are still in pilot phase. Issues and problems in using landscape metrics can be classified into two categories: inherent problem and application problem.

1) Inherent Issues of Landscape Metrics

Since all ecological processes occur in a spatial context, researchers believe that landscape pattern has impacts on landscape process and changes in landscape pattern reflect the functional changes of landscapes (Forman, 1995; Turner and Gardner, 1990). Ideally each landscape index represents particular characteristics of landscape pattern which are meaningful for an ecological process. However, literatures show that this is not always true. Based upon experiments, simulations, and tests, with neutral or actual landscapes, numerous studies call cautions of researchers in using landscape metrics for several reasons. Inherent issues, problems and limitations of landscape metrics found from literatures were classified into three categories: (1) issues in relating pattern with process, (2) issues in representation, and (3) issues of behavioral uncertainty of metrics.

The issues in relating pattern with process have to deal with threshold concept and nonlinear relationship between pattern and process. Because of this nonlinearity of the relationship, variance in landscape metrics may not be meaningful for ecological process (Tischendorf, 2001; Turner et al., 2001). Considering that variance in landscape pattern may be most ecologically significant at thresholds(Gustafson, 1998; Tischendorf, 2001), only a certain range of variance of landscape pattern represented by metrics may be ecologically significant. Furthermore, most thresholds are not known (Harrison and Bruna, 1999; Turner et al., 1989). Thus it is recommendable to look at simple XY-plot before any further statistical analysis.

Issues in representation are associated with ambiguity and complexity of ecological concepts, definitions and phenomena. For instance, the term (bio) diversity means different things for different people such as list of species, heterozygosity and variety of species and vegetation. For ecologists and planners, diversity means the relative frequency or abundance of each species or other entity (Noss, 1983; Parresol, 1998) and use, in general, diversity index, richness or evenness index to measure diversity of landscapes (Nagendra, 2002). Pielou (1975) noted that "diversity index is merely a single descriptive statistic, only one of the many needed to summarize its characteristics, and by itself, not very informative". Despite of warning, these indices, unfortunately, have been extensively used in misleading ways in some ecological studies (Noss and Harris, 1986). Ambiguity and complexity of ecological concepts regarding representation of landscape pattern by metrics also can be found in fragmentation concept and its representations (i.e., metrics). Landscape fragmentation, breaking of a whole into small pieces, has been shown to be important to ecosystems and its ecological consequences, such as loss of species, increased soil erosion, invasion of exotic species, and decreased water quality, are well documented(e.g., Collinge, 1996; Forman, 1995). Typically, fragmentation process involves various structural changes of landscapes. By breaking into small pieces, fragmented landscapes can be characterized by high edge density, isolated, less core areas, small patch size, highly contagion and high patch density (Hargis et al., 1999). To represent these complex ecological concepts by metrics, one should understand various aspects of ecological phenomena in selecting metrics and measuring. There is no one-to-one relationship in the relations between pattern, process and metrics. Turner et al.(2001) succinctly states that there is no one metric characterizing a landscape and there is no standard recipe for determining how many and which one should be used.

Although landscape metrics have been extensively used in ecological studies, the behaviors of most landscape metrics are not fully tested in terms of sensitivity to variances and consistency over scales (e.g., Gustafson, 1998). For instance, most common diversity indices are Shannon's diversity index(i.e., richness, Shannon and Weaver, 1949) and Simpson's diversity index(i.e., evenness, Simpson, 1949). Theoretically, these two indices are supposed to show similar pattern for representing landscape diversity. However, Nagendra (2002) demonstrated that there is a possibility of opposite responses of these two indices to the same landscapes. Similarly, Wu et al.(2002) extensively tested the consistency of landscape metrics with scaling factors(i.e., grain size and extent). They found that changing grain size or extent of measurement for the same landscapes have great impacts on the value of landscape metrics. Furthermore, the magnitude and pattern of these responses vary among metrics and across landscapes. Frohn (1998) also demonstrated that even direction of image can change the values of landscape metrics although the pattern of landscapes is the same.

2) Issues in Application

It is clear that there is no geographical consideration in developing landscape metrics, since landscape metrics are purely based upon the experiments, mathematical equations, and theories. Although most landscape metrics have been developed in US, landscape metrics are not specialized for American landscapes. This is an important statement because there is a misconception regarding the applicability of landscape metrics due to geographical location (e.g., Hulshoff, 1995). Literally hundreds of landscape metrics have been developed in the last few decades. However, most of them are redundant to each other. Popular landscape metrics do not mean generality for everywhere nor feasibility for all circumstances. It is valuable to test less popular landscape metrics for different environments. Specifically, lacunarity index calculated by "moving (gliding) window" seems to reveal interesting aspects of landscapes, such as dominant scale of landscapes, segregation, and gaps (Plotnick et al., 1993, 1996).

Typical procedures of ecological studies dealing with GIS(Geographic Information System), remote sensing data and landscape metrics includes hypothesizing, selecting landscape metrics, classifying land cover, manipulating land cover maps, calculating landscape metrics, interpreting statistics and testing the hypothesis. We summarize the issues in applications of landscape metrics for each procedure from literatures, particularly focusing on 1) selecting, 2) (re)scaling, 3) classifying, and 4) interpreting.

Since there is no standard in selecting landscape metrics (Turner et al. 2001), selecting metrics should solely be based upon the study purposes and hypothesis. One may attempt to use all potential metrics. However, it is well known that many indices are correlated (O'Neill et al., 1988; Ritters et al., 1995), show statistics interactions with each other (Li and Reynolds, 1994), measure multiple components of spatial pattern (Li and Reynolds, 1994; Ritters et al., 1995). Selecting landscape metrics might be easier if we can identify principle components of landscape heterogeneity because landscape metrics ultimately measure landscape heterogeneity. We summarize the 11 principle components of landscape heterogeneity from literatures in Table 2. It includes number of type, proportion of each type, spatial arrangement, image distribution, patch size, patch shape, patch density, patch compactness, contrast with neighboring patch, fractal, and edge contrast(for more details, see Li and Reynolds, 1995, McGarigal and McComb, 1995; Ritters et al., 1995). In general, class level indices show stronger statistical relationship with landscape pattern than landscape level indices (Tischendorf, 2001). Landscape level indices are sensitive to scaling (e.g., re-sampling, aggregation, magnification) as well as landscape pattern per se.

Working with GIS in ecological study often requires scaling process including resampling, magnification and aggregation for various reasons. However, yet it is not fully tested how landscape metrics respond to the changes in scale of landscapes (Wu, 2004). Responses of only few landscape metrics are known and our understanding is still rudimentary (Li and Wu, 2004). Wu et al. (2002) found that changes in grain size and extent have great impact on the value of landscape metrics. In Table 3, they classify landscape metrics into three classes based on the predictability corresponding to changes in grain size: Predictable (Type I), Stair-case (Type II), and Erratic (Type III). However, since total number and height of the steps are not predictable, there is no difference between Type II and Type III in terms of predictability of responses of landscape over scale. Some studies indicate that rescaling process can eliminate small

Table 2. Principle components of landscape heterogeneity in selecting landscape metrics.

Level	Principle Components	Remarks
Landscape	· Number of types · Proportion of each type	· Li and Reynolds (1995) · McGarigal and McComb (1995) · Ritters et al.(1995)
Class	· Spatial arrangement · Image distribution	
Patch	· Patch size · Patch shape · Patch density · Patch compaction · Contrast with neighboring patch · Area-Perimeter scaling (Fractal) · Edge contrast	

Table 3. Examples of behavioral differences among landscape metrics over scales.

Behavioral pattern		Landscape Metrics
Type I	Predictable (12 metrics)	Number of patch (NP) Patch density (PD) Total edge (TE) Edge density (ED) Landscape shape index (LSI) Areas weighted mean shape index (AWMSI) Area weighted mean patch fractal dimension (AWMFD) Patch size coefficient of variation (PSCV) Mean patch size (MPS) Square pixel index (SqP) Patch size standard deviation (PSSD) Largest patch index (LPI)
Type II	Stair-case (3 metrics)	Patch richness (PR) Patch richness density (PRD) Shannon's diversity index (SHDI)
Type III	Erratic (4 metrics)	Contagion (CONT) Landscape fractal dimension (DLFD) Mean patch fractal dimension (MPFD) Mean patch shape index (MSI)

From Wu et al.(2002).

patches from analysis up to 80 percent (e.g., Frohn, 1998; Fauth et al., 2000). O'Neill et al. (1996) recommends to have 2~5 times smaller resolution than the patch or spatial features in interest. Nevertheless, one must be aware of scaling effects on landscape metrics if a study evolves scaling process for some reasons. Particularly, it is problematic to compare landscape metrics of two landscapes with different scales.

Numerous studies indicate that landscape metrics may be sensitive to the level of details in categorical maps data that is often determined by the criteria used for classification (e.g., Gustafson, 1998; Li and Wu, 2004; Turner et al., 2001; Wickham et al., 1997). However, classifying land cover is somewhat arbitrary. Thus landscape pattern, in part, is determined by this arbitrary decision, rather than ecological property per se (Gustafson, 1998). The underlying assumption of categorical maps is homogeneity within patches. However, patches are never completely homogeneous and there is no clear cut boundary of patches (Fortin, 1994). Furthermore, studies clearly show that the most important source of error is misclassification and error in metrics are not greater than data error itself (Wickham et al., 1997). One way of minimizing misclassification is to use systematic methods including Normalized Difference Vegetation Index (NDVI), Vegetation Index (VI), Leaf Area Index (LAI), Soil-Adjusted Vegetation Index (SAVI), Ratio Vegetation Index (RVI), Global Environment Monitoring Index (GEMI), Perpendicular Vegetation Index (PVI), and Transformed Soil-Adjusted Vegetation Index (TSAVI) (Elvidge and Chen, 1995; Johnston, 2001; Quattrochi and Pelletier, 1990; Turner et al., 2001). Another alternative can be using point instead categorical data (Gustafson, 1998).

As Li and Reynolds (1994) state, it is difficult to interpret landscape metrics. The sources of this difficulty may include all issues discussed earlier. The best way to overcome this difficulty might be going back to basics, understanding concepts of landscape heterogeneity, the relationship between pattern and process, and mathematical relationship of metrics. Similarly, Dale (1999) suggests understanding not only the methods of spatial pattern analysis, but also the concepts on which methods are based.

III. Conclusion

Our review reveals some critical issues in using landscape metrics in ecological studies. Landscape metrics catch the characteristics of landscape heterogeneity (i.e. landscape pattern) that has effects on ecological processes (i.e., ecological functions). To characterize the complexity and the variability of landscapes in the relations between pattern and process, landscape metrics has been widely used across disciplines. Appropriate use of landscape metrics must be based on the sound understanding of the definition of ecological concepts, the ecological relationship between pattern and process and the mathematical definition of metrics. Particularly, considerable thought must be given to issues in application of landscape metrics although issues are tied to each other. We, as landscape planners, are much more interested in ecological consequences of landscape planning activities than in developing landscape metrics itself (e.g., Lee, 2002; Leitão and Ahern, 2002; Palmer, 2004). Furthermore, errors in application processes are more critical to the misled conclusions.

In summary, the review of issues in using landscape metrics leads us to several guidelines for sound analysis. (1) Hypothesize the relationship. Like statistical values, landscape metrics itself does not mean anything. The values of landscape metrics are meaningful only within the hypothesized relationship. (2) Get the definition of pattern clearly and a set of metrics right. As we discussed earlier, there is no one-to-one relationship between landscape pattern, process, and metrics. Definition of a landscape pattern (i.e., fragmentation or connectivity) includes several spatial aspects of landscape pattern, and can not be represented by a single landscape index. (3) Use more consistent metrics. There are some metrics whose behaviors are erratic and unpredictable over scales. In general, class-level metrics are more consistent than landscape level metrics in literatures. If analysis process does not involve the rescaling process, difference, in terms of consistence of behavior, between class level metrics and landscape level metrics should not be minimal. (4) Do not rescale the data, if possible. Many landscape metrics show unpredictable behavior over scales and most landscape metrics are sensitive to scaling. Thus, one must be cautious when scaling data. It is also not recommendable to compare the values of landscape metrics calculated at different scales. In addition, scales must be clearly stated in reports for better credibility of research. (5) Minimize the misclassification. In ecological studies with categorical data, misclassification is one of the most common sources of error. Using systematic algorithm may reduce the misclassification. Since the nature is not thematic but continuous, one might consider using point data instead of categorical data. Whether to use categorical data or point data should be determined by characteristics of pattern and process of interest.

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원 고 접 수 : 2004년 9월 8일
최종수정본 접수 : 2004년 11월 2일
4인익명 심사필