한국지리정보학회지 8권 2호 : 81~93(2005)

Spatio-temporal Change Detection of Forest Landscape in the Geumho River Watershed using Landscape Metrics

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경관메트릭스를 이용한 금호강 유역 산림경관의 시·공간적 변화탐지

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요 약

본 연구의 목적은 각종 환경적 교란이 야기되고 있는 금호강 유역의 경관구조를 정량화, 모니터링하기 위한 경관메트릭스의 적용가능성을 평가하는데 있다. 경관메트릭스는 토지피복지도(1985년, 1999년)의 산림패취만을 대상으로 계산하였다. 최초 사용된 12개 메트릭스는 인자분석을 통해서 전체 변량의 91% 이상 설명하는 3개의 공통인자로 축소되었다. 또한, 다중회귀분석을 사용하여 토지개발이 산림경관구조의 변화에 미치는 영향을 규명하였다. 산림패치에서 도시지역과 농경지로의 전환은 파편화의 증가를 초래한 것으로 나타났다. 특히, 도시지역으로의 전환은 패치면적과 패치크기를 감소시키고, 패치밀도는 증가시켰다(R^2=0.696, p<0.01). 패치크기의 이질성과 패치모양의 복잡성은 농경지로의 전환에 의해서 감소하였다 (R^2=0.405, p<0.01). 핵심구역과 가장자리의 밀도는 증가하는 경향을 보였으나, 산림의 도시지역과 농경지로의 전환과는 뚜렷한 상호관계를 가지지 않았다. 향후에는 경관구조와 특정한 환경적, 사회경제적 경관기능 사이의 상호관계성을 분석하는 연구가 필요할 것이다.

주요어: 산림경관, 경관메트릭스, 경관생태학, 유역관리, 토지피복

ABSTRACT

The purpose of this study is to test the applicability of landscape metrics for quantifying and monitoring the landscape structure in the Geumho River watershed, which has undergone heavy environmental disturbances. Landscape metrics were computed from land cover maps(1985, 1999) for the forest patches. The number of variables were reduced from 12 metrics to 3 factors through factor

2005년 4월 18일 접수 Recieved on April 18, 2005 / 2005년 5월 26일 심사완료 Accepted on May 26, 2005

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analysis. These factors accounted for above 91% of the variation in the original metrics. We also determined the relative effects of land development on the changes of forest landscape structure using multiple linear regression analysis. At the forest patches, the conversion of forest to urban areas and agriculture resulted in increased fragmentation. Patch area and patch size decreased, and patch density increased as a result of the conversion of forest to agriculture($R2=0.696$, $p<0.01$). The heterogeneity of patch size and complexity of patch shape mainly decreased as a result of the conversion of forest to urban areas($R2=0.405$, $p<0.01$). The density of core area and edge showed the tendency increase, but there was no relationship with the conversion of forest to urban area and agriculture The future research will be needed to analyze correlations between landscape structures and specific environmental and socioeconomic landscape functions.

KEYWORDS: Forest Landscape, Landscape Metrics, Landscape Ecology, Watershed Management, Land Cover

INTRODUCTION

Scientists and environmental managers alike are concerned about broad-scale changes in landscape structures and their cumulative impacts on hydrological and ecological processes associated aquatic resources, including streams and estuaries(Hunsaker and Levine, 1995; O'Neill et al., 1997; Jones et al., 2001). In recent decades, a number of studies have focused on the quantification and modeling of the relationships between landscape structure and function at the watershed scales(Montgomery et al., 1995; He et al., 2000). Landscape structure includes composition and configuration of landscape elements. The former refers to features related to the presence and amount of landscape elements types, whereas the latter to the spatial distribution of landscape elements within the landscape. In a natural ecosystem, changes in the landscape structure are in state of balance and evolve slowly, excepting conditions of natural disasters, but in a human-modified ecosystem, that changes are artificially accelerated and the habitats are often destroyed(Turner, 1989; Naiman et al., 1995; He et al., 2000). Accordingly, the ability to quantify landscape structure and change induced from human activities is prerequisite for successful ecosystem management(McGarigal and Marks, 1995; Griffith et al., 2000).

For this reason, a variety of landscape metrics have been developed so far to quantify landscape structure(Forman and Gordron, 1986; Turner and Gardner, 1991; Gustafson and Parker, 1992; Li and Reynolds, 1993; McGarigal and Marks, 1995). However, their developments and widespread applications became possible with the advent of spatial tools such as geographic information systems(GIS) and remote sensing. Moreover, several spatial pattern analysis programs(e.g. FRAGSTATS, Patch Analysis) that can compute landscape metrics automatically are now available.

As the number of available metrics is potentially so large, many are correlated, therefore one focus of research has been finding a subset of landscape metrics comprising a minimum set of them to adequately quantify and describe the landscape structure(EPA, 1994). Consequently, many studies in the field of landscape ecology have focused on the data reduction analyses of landscape metrics through factor analysis or principle components analysis(PCA). For example, Riitters et al.(1995) performed a factor analysis of 55 landscape metrics calculated from 85 USGS Land Use Data quadrangles. Griffith et al.(2000) performed PCA on 27 landscape metrics derived from a Kansas land cover database at three spatial resolutions, which identified the principle landscape pattern measures for characterizing the agricultural landscape of Kansas. O'Neill et al.(1997) have pointed out that the investigation of regions increases the sensitivity and interpretability of landscape metrics.

In South Korea, the urbanization and agricultural intensification within landscape have resulted in forest fragmentation reducing the area of mature forest cover, increasing edge density, and isolating remaining mature forest stands. With the increasing needs of research related to environmental impacts due to increased fragmentation, recently, Lee(1998), Sim et al.(1999), Park and Jang(1999), and Kim and Park(2001) performed case studies to quantify the change patterns of forest landscape structure using satellite imagery and landscape metrics. However, most studies of forest landscape structure only utilized the administrative boundaries as fundamental units and were in needs of determining the effects of human activities on the forest fragmentation. The specific objectives of this research are: (1) to test the applicability of landscape metrics for quantifying the landscape structure and change of forest cover (2) to analyze the relative effects of land cover conversion on the forest fragmentation (3) to outline how the landscape metrics can be used in support of integrated watershed management.

MATERIALS AND METHODS

1. Study area

The Geumho River watershed(128°28′~129°23′E, 35°42′~36°17′N) is located in the middle reaches of the Nakdong River, which includes the Daegu and three local cities of Gyeongsan and Yeongcheon(FIGURE 1). The watershed is approximately 2,200 square kilometers in size with land cover being dominated by forest(over 60 %), non-woody vegetated lands such as agriculture, grassland, barren, and urban make up approximately 30 % of the study area. Since early times, the Geumho River played an important role as fishery resources, and recreation for locals, but in the last few decades rapid urbanization and industrialization in the watershed levels have posed significant risk to the aquatic ecosystem health specially, in the Daegu and adjacent cities located in the lower reaches of the Geumho River, which have resulted in a variety of environmental problems such as forest fragmentation, water pollution and so on(Daegu Regional Environmental Office, 2000). Besides this, in recent years the approach of integrated watershed management to sustain natural ecosystems health and diversity has been a booming issue in Korea(Kim, 1999).

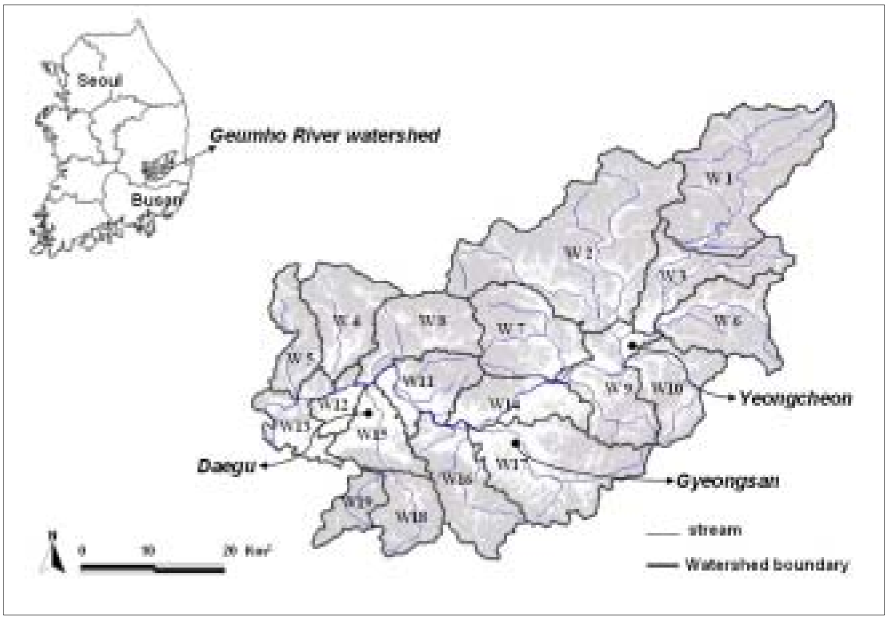

FIGURE 1. Location of the Geumho River watershed

2. Land cover classification

Land cover maps from Landsat TM images(25 October 1985 and 7 May 1999) were used to detect the spatial distributions and change patterns of each land cover type, and to quantify landscape structure of forested cover in the Geumho River watershed(path:114/raw:35). As the preprocessing, geometric correction was performed by polynomial warping functions of ERDAS IMAGINE 8.4 (ERDAS Inc., 1999). A set of geo-referenced ground-control points(GCP's; n = 33) were collected from the features which can be identified in topographical maps(scale 1:25,000) and Landsat TM data, such as road intersections and bridges. Nextly, the transformation was applied to warp the image based on Traverse Mercator coordinate system, and then the warped image was resampled into 30m grid cells using a nearest neighbor algorithm. The geometric correction of Landsat TM in 1985 was performed using image-to-image method using the geometrical corrected Landsat TM from 1999. The rectified images dataset maintained less than one-half pixel(15m) root mean square error. Land cover classification process was conducted in two stages. First, unsupervised classification by ISODATA(Itera tive Self-Organizing Data Analysis Technique) algorithm was performed to categorized into 255 unique clusters according to similarity of spectral characteristics. Next, in order to assign the each of 255 clusters of pixels to 5 distinct classes, supervised classification technique was performed using RGB composite images, which was produced for each of the image data and aerial photos(1:20,000gray scale). For comparison with the change pattern of land cover from 1985 to 1999, also the land cover change detection matrix was used(FIGURE 2).

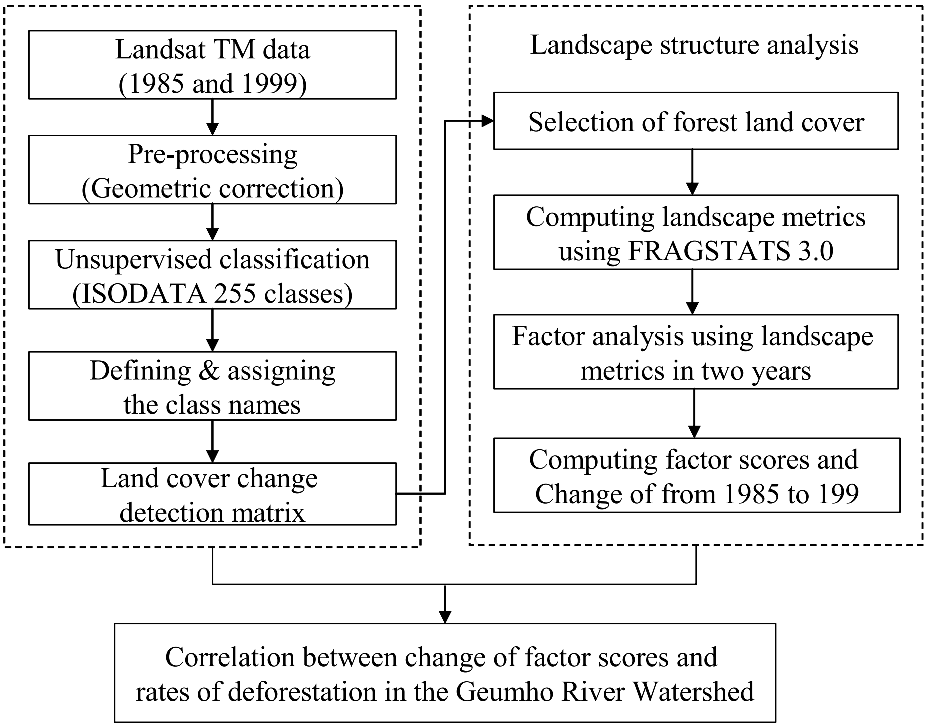

FIGURE 2. The analysis processes for land cover classification and forest class-level metrics

3. Landscape metrics and factor analysis

The spatial pattern analysis program FRAGSTATS 3.0 was used to calculate landscape metrics for quantifying landscape structure. Land cover categories not relevant to the forest were coded as background cover(value = zero), so that they were not treated as patches themselves, but formed distinct edges with forest cover. Procedures for determining a subset of metrics from FRAGSTATS 3.0 are as follows; when pairs of metrics led to an absolute Spearman's correlation coefficient of 0.9 or more, only one of the two metrics was retained(Griffith et al., 2000; Herzog et al., 2001), and eliminated some metrics that were not standardized per unit area such as total edge length(TE). Metrics with questionable meaning or reliability, such as double log fractal dimension(DLFD), were also excluded from the analysis. List and brief description of the metrics used in this study is described in TABLE 3. We computed core area metrics using a 100m edge effect distance. Core area means the area remaining after removing the edges, defined by buffering the patch with the specified edge effect distance inward from the patch boundary. This edge depth was determined considering the spatial resolution of Landsat TM data, and past references like Chen et al.(1996) who reported in their site studies that the edge effects

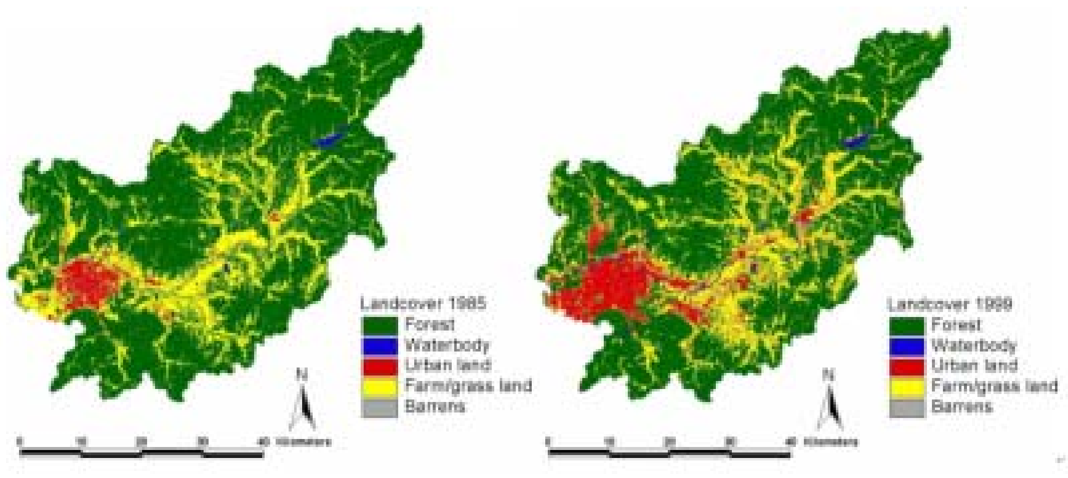

FIGURE 3. Spatial distribution of land cover in the Geumho River Watershed

were evident approximately 50m or 100m into the surrounding forest, and Park(1995) who determined that edge depth of transient zone was observed up to 112m in Sorak-san National Park of Korea. Because landscape metrics from FRAGSTATS were correlated, we performed factor analysis using SPSS for windows release 10.0(SPSS Inc., 1999) to group metrics into uncorrelated factors that explained most of the variation in the original metrics. Factor scores for each watershed in two years were used to analyze the structural changes of forest landscape over space and time. we also performed correlation and stepwise multiple regression analysis to determine the effects of the conversion of forest to urban and agriculture on forest fragmentation. In linear regression analysis, we used changes in scores for factor Ⅰ, Ⅱ, and Ⅲ of landscape metrics as dependent variables and percentage of each watershed for the conversion of forests to urban and agriculture as independent variables.

RESULTS

1. Land cover changes: 1985-1999

FIGURE 3 shows land cover maps of 1985 and 1999 using Landsat TM data. The land cover change matrix of these two maps

TABLE 1. Land cover change detection matrix between 1985 and 1999 unit: ㎢

Category		Land cover in 1999					
		Forest	Agriculture	Urban	Barrens	Water	Total
Land cover in 1985	Forest	1,359.5	210.4	24.6	3.2	7.1	1,604.8
	Agriculture	0.0	301.5	99.2	18.7	12.0	431.4
	Urban	0.0	3.3	56.6	2.5	1.4	63.8
	Barrens	0.0	2.5	11.4	0.6	2.5	17.0
	Water	0.0	2.0	1.7	0.5	16.5	20.7
	Total	1,359.5	519.7	193.5	25.5	39.5	2,137.7

efficiently provides the change patterns of land cover types(TABLE 1).

TABLE 2 describes the change patterns of forest cover such as CFA(conversion of forest to agriculture) and CFU(conversion of forest to urban) in each of the 19 watersheds. In 1999, these two cover types particularly comprised more than 90% of the entire study area; forest cover accounts for over 63% and agriculture approximately 25% of the total area. Indeed, most of the 19 watersheds were comprised of forest cover more than 50% of the total area, moreover some watersheds were comprised of complete forest cover.

On the other hand, few watersheds located in Daegu and neighboring Gyeongsan were only covered by less than one-third forest of total area. Forest cover decreased above 12% of total area from 1985 to 1999, which mainly distributed adjacent to existing forest edges(FIGURE 3). In particular, over 90% of decreased forest area during this period was converted to urban and agriculture cover by residential land development, clear-cutting, and road building. In despite of a decrement in agricultural areas, the total area increased over 4% of the entire watershed. This increasing tendency is the reason that forest was converted to agriculture by 10% of the entire watershed. The area of urban increased from 3% to 9% of total area due to land developments. From the above results, the

TABLE 2. Changes of forest cover in 19 sub-watersheds resulted from deforestation and urbanization within the Geumho River watershed

Watershed No.	Area (km^2)	Forest cover				Deforestation		Urbanization	
		1985		1999					
		Area (km^2)	% of total area	Area (km^2)	% of total area	Area (km^2)	% of total area	Area (km^2)	% of total area
W01	234.3	218.5	93.1	200.5	85.6	16.3	7.0	1.1	0.5
W02	339.4	275.9	81.2	238.8	70.4	33.6	9.9	2.0	0.6
W03	100.8	76.2	75.6	62.6	62.1	11.8	11.7	1.3	1.3
W04	99.6	80.9	81.1	70.6	70.9	7.8	7.8	2.1	2.1
W05	63.7	54.6	85.4	47.9	75.1	6.1	9.6	0.4	0.5
W06	112.3	95.9	85.4	81.7	72.8	12.6	11.3	0.9	0.8
W07	125.5	95.6	76.3	77.1	61.4	16.9	13.5	1.1	0.8
W08	103.6	88.3	85.3	78.0	75.3	9.5	9.2	0.6	0.5
W09	115.5	74.4	64.4	56.5	48.9	16.2	14.0	1.1	1.0
W10	91.5	70.4	77.0	57.4	62.7	11.2	12.2	1.0	1.1
W11	82.5	45.2	54.7	36.4	44.1	7.2	8.7	1.3	1.6
W12	32.6	7.7	23.6	6.0	18.4	1.1	3.4	0.4	1.2
W13	63.6	27.3	43.0	20.8	32.7	3.4	5.3	2.7	4.2
W14	84.7	41.2	48.6	27.4	32.3	10.7	12.6	2.5	2.9
W15	73.4	28.2	38.2	24.2	33.0	2.3	3.2	1.3	1.8
W16	121.2	97.1	80.1	83.5	68.9	10.9	9.0	2.1	1.7
W17	183.9	126.5	68.7	95.3	51.8	27.3	14.8	2.6	1.4
W18	67.9	60.2	88.6	55.6	81.8	4.3	6.4	0.2	0.3
W19	42.1	40.6	96.1	39.2	93.0	1.1	2.7	0.0	0.0

overall change patterns of land cover from 1985 to 1999 showed a conversion of forest to agriculture, and then agriculture to urban due to human activities within the watershed landscape.

2. Descriptive statistics of landscape metrics

The simple summary statistics of landscape metrics for each watershed at the forest cover class-level in 1985 and 1999 is presented in TABLE 3.

Looking at the individual metrics in detail, the percent of patches(%LAND), largest patch index(LPI), core area percentage of landscape(C%LAND), and total core area index(TCAI) relatively showed a tendency of decline compared with the metrics of 1985 in all cases(mean, minimum, and maximum), especially the mean values of %LAND and C%LAND decreased more than 10% between 1985 and 1999. Conversely, edge density(ED), landscape shape index(LSI), and core area density(CAD) increased throughout the period of investigation, even though there were relatively minor changes in the mean values of these metrics. The interspersion and juxtaposition index(IJI) also increased, meaning that the configuration of forest patches within the watershed landscape became more uniform(McGarigal and Marks, 1995). Through the above-mentioned change patterns of landscape metrics from 1985 to 1999, we could recognize forest fragmentation in the Geumho River watershed process, that is, reducing the amount of forest cover, increasing the length of edge, patch area, core area, and patch density.

3. Factor analysis

Factor analysis is a multivariate statistics method designed to reduce a large number of variable to a smaller set of factors that account for most of the variation among the original metrics. To perform this analysis, we

TABLE 3. Description and range of values for landscape metrics used in the analysis

		Minimum		Maximum		Mean	
Index	Description	1985	1999	1985	1999	1985	1999
%LAND	Percentage of landscape	23.5	18.5	96.5	93.2	70.9	60.1
LPI	Largest patch index(%)	14.4	8.4	96.4	93	64.0	46.3
PD	Patch density(number/100ha)	0.5	0.7	8.2	6.7	3.1	3.0
PSCV	Patch size coefficient of variation(%)	423.6	527.8	2709.9	2706.8	1438.9	1325.1
ED	Edge density(m/ha)	14.0	21.7	73.3	69.4	40.9	45.2
LSI	Landscape shape index	4.0	4.9	25.1	28.0	12.5	13.7
C%LAND	Core area percentage of landscape	11.4	6.7	77.9	68.0	45.8	31.6
CAD	Core area density(number/100ha)	0.0	0.1	0.7	0.9	0.3	0.5
CACV1	Patch core area coefficient of variatio (%)	424.3	529.2	2796.2	3017.9	1568.4	1473.7
TCAI	Total core area index(%)	41.0	28.2	82.9	72.9	62.5	49.5
CONTAG	Contagion index(%)	0.8	0.9	1.0	1.0	0.9	0.9
IJI	Interspersion and Juxtaposition index(%)	6.8	14.9	46.4	51.3	19.4	29.5

* Calculation methods and details of metrics can be founded in McGarigal and Marks(1995).

used the computed values of landscape metrics for each watershed as a result of diagnostic tests for the factor analysis, Kaiser-Meyer-Olkin measure of sampling adequacy(equal to 0.692 and so, acceptable), and Bartlett's test of shpercity(sig. = 0.00, so the model is possible) indicated a moderate to good level of appropriateness. The number of factors to use in this analysis should include only factors with eigenvalues greater than 1.0(Norusis, 2000). For forest class-level metrics, factor analysis produced three common factors that accounted for more than 91% of the variation in the original metrics of 1985 and 1999(TABLE 4). First, the first factor explained over 42.5% of the variation in the original forest class-level metrics, and this factor was strongly correlated with seven metrics(%LAND, LPI, C%LAND, CONTAG, IJI, TCAI, and PD) closely connected with patch size and density, core area, and diversity of forest patches. In general, a watershed with a high score on the factor I indicates that the structure of forest landscape was much patch and core area, large patches, low patch density, and low contagion and interspersion based on factor loadings. The second factor explained above 25% of original metrics, and was strongly correlated with three metrics(CACV1, PSCV and LSI), notably representing attributes of the heterogeneity of patch sizes, core areas and patch shapes. A watershed with a high score on factor II is characterized by more heterogeneous patch sizes and more convoluted forest patch edges. Finally, the third factor explained over 23% of original forest class-level metrics, and was strongly correlated with two metrics(CAD and ED). A

TABLE 4. Factor loadings by varimax rotate method

Index	Common factor 1	2	3	Cum.
%LAND	0.983	0.022	-0.097	0.976
LPI	0.939	0.081	-0.276	0.964
C%LAND	0.907	-0.059	-0.395	0.982
CONTAG	-0.867	0.002	-0.273	0.827
IJI	-0.866	-0.291	0.002	0.836
TCAI	0.696	-0.064	-0.667	0.934
PD	-0.605	0.439	0.356	0.686
CACV1	-0.024	0.977	0.180	0.987
PSCV	0.111	0.975	0.085	0.971
LSI	0.123	0.760	0.565	0.912
CAD	-0.222	0.158	0.913	0.908
ED	0.012	0.497	0.842	0.956
Eigenvalue	5.101	3.047	2.791	
Cum.%	42.510	67.903	91.158	

■ core area metrics, ▲ area metrics, ◆ patch density and size metrics, ● contagion and interspersion metrics, ◑ shape metrics, ◈ edge metrics

watershed with high score on factor III represents a forest landscape with high density of core area and edge.

4. Changes of factor scores in each watershed

To detect the spatio-temporal change patterns of forest landscape structure for each watershed in 1985 and 1999, we used the changes on factor scores for factor I and factor II. The change patterns of each factor score was described in FIGURE 4.

Factor I scores decreased from 1985 to 1999, remarkably, watersheds 3, 9, 6 and 17 showed a large amount of decreases of factor I score, and to a lesser extent in watersheds

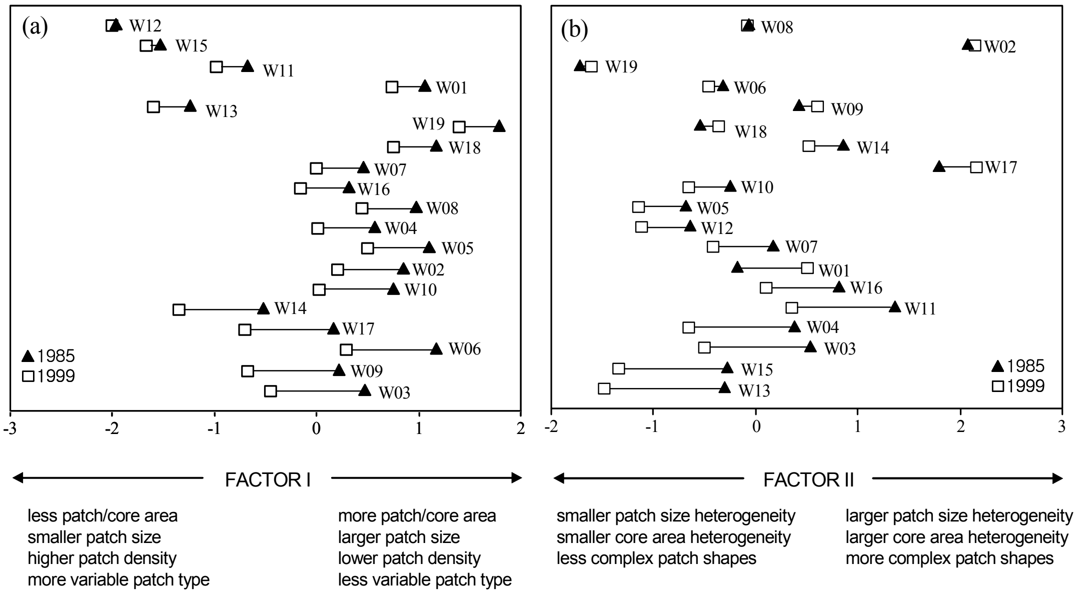

FIGURE 5. Factor scores of forest class-level metrics for each watershed in 1985 and 1999. In each graph, 19 subwatersheds are arranged from bottom to top by the amount of changes in factor scores

14, 10, 2, and 5. In particular, watersheds 9 and 17, which located in the middle reaches of the Geumho River, were the largest amount of conversion of forest to agricultural land cover from 1985 to 1999(TABLE 2). Conversely, watersheds 12 and 15 showed only a relatively small or no change in factor I score, and watershed 12 situated in the center of Daegu showed the least decrease of forest area(FIGURE 4a). The changes of factor II score related to the heterogeneity of forest patch size and the complexity of forest landscape shape for each of the watersheds were the largest amounts in watersheds 13 and 15. These watersheds spatially were located in the upper and middle reaches of the Geumho River, in particular watershed 13 where immediately makes a junction with the Nakdong River has played an important role in the ecological and hydrological aspects, but undergone comparable urbanization due to the housing and industrial complexes developments. On the other hand, watersheds 8, 2, and 19 showed small changes in factor II score. Especially, watershed 19 with Gachang dam, which has been designated as the protection area to provide drinking water for the people in Daegu region, the land cover change by human activities(e.g. clear-cutting and its associated road building) was smaller than in other watersheds, and most of the forest distributed in watershed 8 has been designated as Natural Park(Mt. Palgong), similarly showed the smallest change of all watersheds(FIGURE 4b).

5. Effects of land cover change on forest fragmentation

TABLE 5. The results of correlation analysis

	Factor Ⅰ	Factor Ⅱ	Factor Ⅲ	CFC	CFU
Factor Ⅰ	1.000				
Factor Ⅱ	-0.233	1.000			
Factor Ⅲ	-0.053	-0.312	1.000		
CFC	**-0.812****	0.242	0.023	1.000	
CFU	-0.035	**-0.667***	-0.146	0.095	1.000

*CFC means the conversion of forest to agriculture

*CFU means the conversion of forest to urban

The increasing human influence such as urbanization and deforestation within the watershed landscape results in forest fragmentation(Lund, 1999; Herzog et al., 2001). Also, the amounts of forest boundaries in study area were converted to non-forested cover like urban or agricultural land between 1985 and 1999. We examined the individual relationships between changes of scores in each of the factors(dependent variables) with CFA and CFU(independent variables) using spearman's correlation (TABLE 5), individual scatter plots and stepwise regression analysis (FIGURE 5).

First, the change in factor I score was highly correlated to the proportion of CFA rather than CFU in each watershed(coefficient = −0.812, $p< 0.01$), and the changes of factor II score was relatively correlated to CFU(coefficient = −0.667, $p<0.05$). However, the change of forest landscape structure based on the factor III score had no correlation to CFA and CFU. In addition, as a result of multiple linear regression by stepwise method, only the proportion of deforestation in each watershed explained about 70% of the amount of change for factor I score(R2 = 0.696, $p<0.01$), therefore, it indicates that deforestation within the watershed had strongly influence on the structural changes of forest landscape; less patch/core area, smaller patch size, higher patch density and more variable patch type(FIGURE 5a).

Second, changes in scores on factor II were significantly correlated to the percentage of urbanization in each watershed, but there were little correlations with changes of scores for other factors. According to the result of multiple linear regression analysis by stepwise method for the percentage of urbanization and deforestation in each watershed and change of factor I score, only the percentage of urbanization explained around 40% of the dependent variable(R2=0.405, $p<0.01$)(FIGURE 5b). Finally, changes of factor III score were no relationships with both the percentage of urbanization and deforestation within 5% significant, therefore the density of core area and edge could not explain by the percentage of conversion of forest to agriculture and urban.

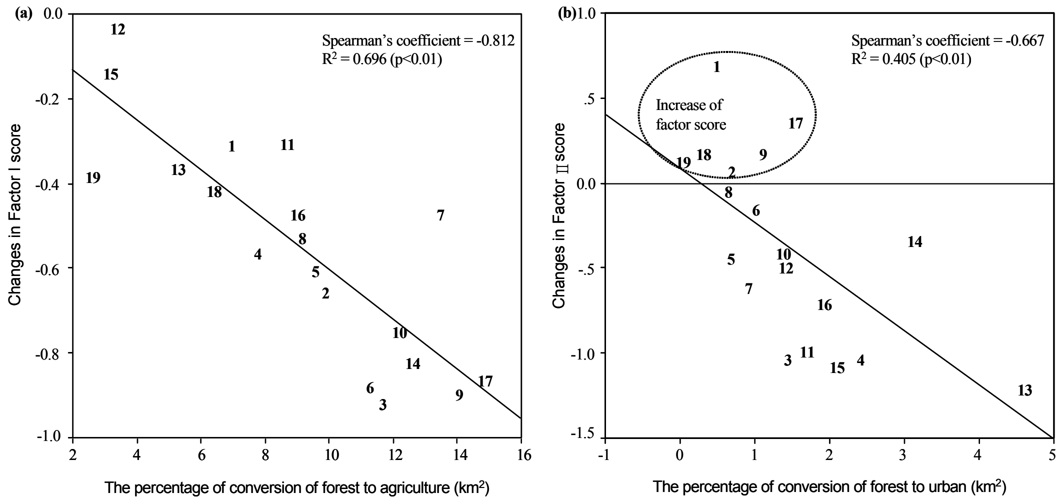

FIGURE 6. The relations of changes in scores of FACTOR I and FACTOR II and the percentage of conversion forest to agriculture(a) and urban(b) of 19 each watershed

CONCLUSION

Most studies related with the spatial change of forest landscape deal with increasing human influence, typically increased forest fragmentation through urbanization and agriculture intensification. Many authors have repeatedly stressed the importance of socioeconomic factors as agents of change in forest landscape structure. This importance was also confirmed in the study area, where the forest landscape has undergone considerable transformation caused by economic need for natural resources such as the residential land development and industrial development.

Forest landscape of the Geumho River watershed has been changed structurally complex, with numerous urban and agriculture in the forest edge during the periods of the study. The important driving force behind landscape change were the clear-cutting near the forest edge for agricultural intensification and urban development. The change patterns of forest landscape and the relative effects of land transformation on the forest fragmentation were explained by the three factors extracted from the 12 original landscape metrics through factor analysis. The results were as follows; (1) decreasing in patch area, patch size and core area(factor I) were mainly affected by the conversion of forest to agricultural land from 1985 to 1999, (2) the heterogeneity of patch size and complexity of patch shape(factor II) generally decreased due to the housing and industrial complexes developments, and (3) the density of core area and edge of forest patch(factor III) increased, however this factor was no relationship with the land transformation in the forest area.

The limitations to this study are that the forest patches from the Landsat TM imagery were not of fine enough spatial resolution to quantify the spatial patterns, therefore it will be necessary to use the higher-resolution satellite imagery. A factor analysis does not identify all of the important dimensions of possible aspects of landscape structures. The reprehensive selection of metrics used in the analysis affects outcome. Nevertheless, this study suggests that a few key metrics could effectively detect the change patterns of landscape structure, but future research will be needed to analyze relationships between landscape structures and specific environmental and socioeconomic.

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