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A Study on the Evaluation Method of Urban Open Spaces of Seoul with Remote Sensing: Detection of the Ecotone of the Mt. Pukhansan National Park[1)]

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위성영상자료를 이용한 서울시 도시녹지의 평가기법 연구: 북한산 국립공원 주연부 탐지

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Abstract

The purposes of this research were to find ways to detect ecotone between the Mt. Pukhansan National Park and adjacent urban residential areas, to measure the width and size of ecotone around the park, and to investigate temporal change of ecotone around the park. Normalized Difference Vegetation Index(NDVI) derived from TM data (May of 1985, 1987, and 1993) and the analytical capabilities of GIS were used to investigate the impacts of human activities inside of and outside of the bounadry of the park.

Major findings of the study can be summarized as follows: First, ecotone around the boundary of the national park could be identified from NDVI-distance curves derived by a series of buffering operations with a GIS. Second, average width of ecotone around the park was nearly doubled during 1985-1993 period. Third, NDVI values of the park were about 14 percent higher than those of surrounding areas. Finally, it seems that the expansion of the ecotone of the park is related to heavy trampling of visitors and various types of environmental pollution of the adjacent urban areas.

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요 약

본 연구의 목적은 북한산 국립공원 경계선 일대의 추이대를 탐지하는 기법을 개발하여 추이대의 폭을 조사하고, 시간경과에 따른 추이대의 폭의 변화여부를 조사하여 과도한 이용자의 집중과 주변부의 환경오염에 의한 추이대 식생의 피해 여부를 규명하는 것이다. 이를 위해서 1985, 1987, 1993년 5월 중순에 수신된 TM영상을 이용하여 계산한 정규식생지수(NDVI)를 도출하고, 버퍼링작업에 의하여 경계선으로 부터의 거리별 NDVI를 산출하여 추이대를 조사하는 방법을 제시하였다. 연구 결과 본 연구대상지의 추이대의 식생은 생물계절(phenology), 인접지역의 토지이용의 영향을 받는 것이 확인되었으며, 1993년에는 1985년에 비해서 추이대의 폭이 약 2배로 증대되어 탐방객의 과도한 이용 등으로 인하여 공원경계부 인접한 식생 피해지역의 범위가 확대되고 있는 것으로 판명되었다.

INTRODUCTION

Major topics of landscape ecology are the mosaic structure of landscapes and the influence of spatial heterogeneity in ecosystems. Fundamental concepts of landscape ecology are those of the landscape 'patch', 'edge' and 'corridor', and the dynamic nature of ecological patterns (Haines-Young, 1993). Previous ecological researches were usually focused on processes within relatively homogeneous landscape units or the collective characteristics of a composite landscape. Nowadays, however, there is an appreciation that abiotic and biotic components move across heterogeneous landscape patches or corridors, and that, therefore, boundaries between units take on important control functions in such a dynamic spatial system. Because landscape boundaries have such intensive biotic-abiotic interactions, they may be particularly sensitive indicators of change in adjacent ecosystems (Forman, 1986).

The zone where two or more different plant communities meet and integrate is an ecotone or edge. This zone of integration may be narrow or wide, regional or local (Smith, 1980). The highly variable nature of the edge results from certain attributes that influence the amount of edge and its richness. The value of ecotones or buffer zones between conflicting land use types is very important to those concerned with environmental conservation (Leopold, 1949). The width, length, and configuration of edge are often influenced by adjoining land use practices. For example, urban development of any type in an area adjacent to a protected ecosystem usually removes vegetation covers, which diminishes protective functions of the ecotones.

Traditional method of field survey has been very successful to identify edge species, gradual change of composition of plant and wildlife species (Clements, 1905). But many questions related to shapes, width, and spatial configuration of edge are left unanswered (Smith, 1980). Edge detection based on filtering techniques of remote sensing data is frequently employed to enhance images for the identification and analysis of geological lineaments (Lillesand, 1994; Mather, 1987). The only information conveyed by an ecotone drawn as a line on a map is its location, and new techniques are needed to characterize ecotones as entities in themselves (Johnston and Bonde, 1989).

Due to close proximity to Seoul Metropolitan Area, the Mt. Pukhansan National Park ($78.45km^2$) is one of the most heavily visited national park in Korea. More than three million visitors pass through 31 ticketing booths of the park every year, and the well developed network of trails are crowded with hikers and rock climbers every weekend. Since the impacts of heavy trampling by visitors can nowadays be observed on many parts of the trails, it is certain that the number of visitors of the park undoubtedly exceeds carrying capacity of the park.

Natural vegetation on extensive areas adjacent to southern and eastern boundary of the park has been removed to develop residential areas since 1970s. It is also strongly suspected that high concentration of air pollution causes severe damage to the natural vegetation of the park. Thus it is expected that a distinctive ecotone, which might also be called as a buffer zone or an impact zone, is being developed between the urban residential area and the national park.

The purposes of this research were to find ways to detect ecotone between the Mt. Pukhansan National Park and adjacent urban areas, to measure the width and size of ecotone around the park, and to investigate temporal change of ecotone around the park so as to find any symptoms of degradation of the plant communities of the park due to various human activities near the boundary of the park. The analytical capabilities of GIS were used to measure the relationship between the distance from the boundary of the park and the gradual changes of Normalized Defference Vegetation Index (NDVI) derived from Landsat-5 Thematic Mapper data

METHODS

Study Area

The study area covers the Mt. Pukhansan National Park and its vicinity. As can be seen from the DEM (Fig. 1), two major peaks, Mt. Pukhansan (837m) and Mt. Tobongsan (740m) are located in the park. The ridge connecting two peaks constitutes northwestern boundary of Seoul, and western and northern slopes of the park belong to suburban cities of Uijeongbu and Koyang. Eastern and southern parts of the park are adjacent to the heavily developed urban residential areas of Seoul, and the rest of the park is adjacent to agricultural fields or forests. Most part of the outside of Seoul city limit was designated as green belt in early 1970s, and development activities in and around of several rural or suburban settlements located along the road passing northwestern part of the park have been strictly regulated ever since.

Elevation of the park can be expressed by following equation, which was obtained by fitting

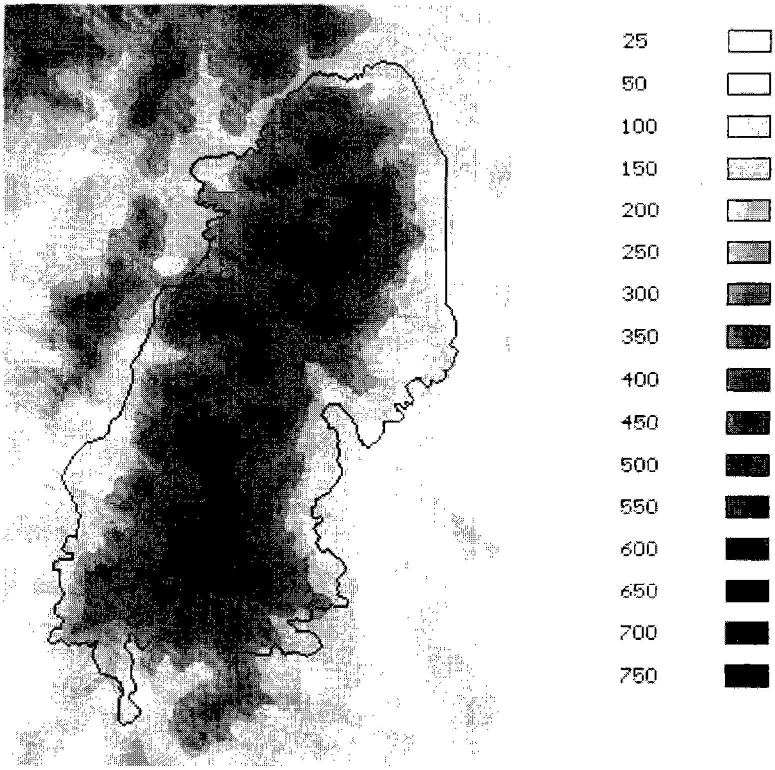

Figure 1. DEM of the Mt. Pukhansan National Park.

a scattergram produced by plotting average elevation, in meters, of each 50m-width buffering zone from the boundary of the park, ranging from 275m outside of the park to the 575m inside of the park.

ELEVATION = 106.73 + 0.1505 * DISTANCE

According to the equation, average elevation along the boundary of the park is 106.73m, and average slope of the buffering zone is 15.05%. Since growing condition on steep slope and higher elevation is usually worse than that of the gentle slope of lower elevation, NDVI values of the area close to the boundary of the park are expected to be much higher than those of the inner part of the park.

But vegetation of a popular park is always subject to various types of stresses resulting from human exploitataion and occupation. Natural vegetation can be deteriorated by heavy trampling along trails, construction of park facilities, and various types of air polutants coming across the boundary of the park. This research was based on an assumption that such harmful stresses on the vegetation of a heavily visited park should be closely related to the distance from the boundary of the park.

The Mt. Pukhansan National Park was established on Apr. 2, 1983, and 11.3 percent and 84.7 percent of the park is zoned for Nature Preservation District and Natural Environment District where exploitation and occupation of resources are severely regulated. Settlement District and Visitor Accommodation District occupy 1.2 percent and 2.8 percent of the park, respectively. Though residential and commercial buildings constructed prior to the establishment of the national park are still existing, new construction activities are strongly regulated by the Nature Park Act.

Three full scenes of Thematic Mapper data, path 116 - row 34, acquired on May 14, 1985, May 20, 1987, and May 20, 1993, were selected for temporal change detection of vegetation of the study area. Latter part of May is the best season for studies related to NDVIs derived from multitemporal TM data because monsoon season starts in June in Korea.

Data Analysis

The image analysis and GIS operations were carried out with IDRISI (Eastman, 1992). As can be seen from the formula, the Normalized Difference Vegetation Index (NDVI) was stretched to eight-bit scale and stored in a byte binary format so as to reduce the amount of memory storage and accelerate processing time.

$$NDVI = 128 \times \left(\frac{(TM4-TM3)}{(TM4+TM3)} + 1 \right)$$

NDVI is widely accepted as an excellent indicator of primary production or vegetative vitality, and it is preferred for vegetation monitoring of wide areas because it helps compensate for changing illumination conditions, surface slope, aspect, and other extraneous factors (Lillesand, 1994). The modified NDVI images were resampled, with bilinear interpolation algorithm, to 25 x 25m resolution, resulting in the image size of 720 scan lines by 480 pixels.

Mean values of NDVI were calculated for each 50m-width buffering zone from the boundary of the national park, ranging from 275m outside of the park to the 575m inside of the park. As can be seen from the Figure 2, the shape of a scattergram produced by plotting mean NDVI of each distance zone is a sigmoid or logistic curve. The NDVI-distance curve approaches a certain maximal level, which resembles carrying capacity (K) of a population growth curve. During the take-off period of a growth curve, the inherent growth rate of a population can hardly be realized because of many types of environmental pressure (Krebs, 1982).

The NDVI value of a distance zone adjacent to the boundary of the park reflects the amount

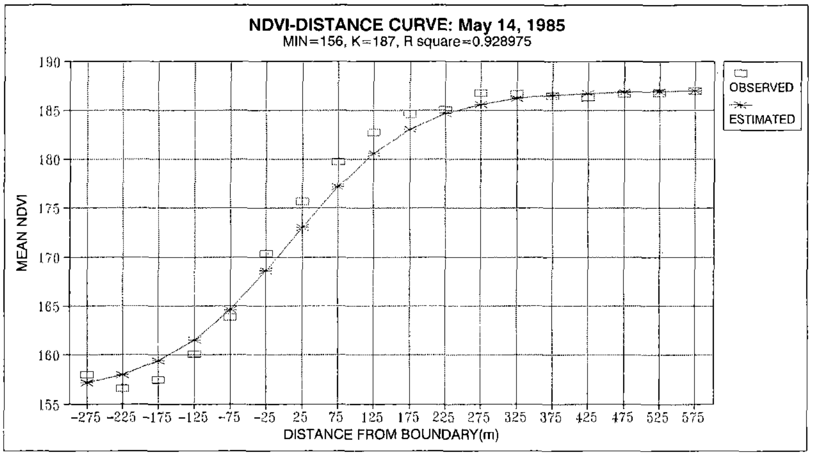

Figure 2. NDVI-Distance Curve of the Mt. Pukhansan National Park Derived from the TM Data Acquired on May 14, 1985.

of human impacts on vegetation. The steep part of a NDVI-distance curve shows that the degree of negative impacts on vegetation is closely related to the distance from the boundary of the park. Therefore, the ecotone between the national park and adjacent urban areas can be defined as the steep part of the NDVI-distance curve. The relationship between human impacts and distance from the boundary of the park can no longer be detected at both ends of the NDVI-distance curve.

The width of an ecotone can be measured by applying one of three operational definitions. First, the most strict definition of an ecotone is the distance from the boundary of the park to the point where the maximum NDVI is reached. Second, the distance from the boundary of the park to the point where statistically meaningful thresholds such as 95% or 99% of the maximum NDVI might also be used as the criterion. Finally, based on the method of determining the size of a minimal sampling area by locating a tangent point between a species-area curve and a line with 5 or 10 percent slope (Mueller-Dombois, 1974), a distance zone confined by two tangent points on the NDVI-distance curve can also be used for the job. An arbitrary slope of 5 or 10 percent or the average slope of a NDVI-distance curve might be used as the criteria (Park et al. 1995). But the last criteria was not used in this study because of its subjectivity.

RESULTS

The result of this research can be summarized as follows: First, as can be seen from the Table 1, vegetation of the park (126,923 cells) is significantly better, in terms of vaitality or

Table 1. Summary Statistics of the NDVI of the Study Area

Year	Total Scene	National Park(A)	Surrounding Area(B)	Ratio(A/B)
1985	173.2769	187.6720	164.9261	1.1379
1987	164.2091	178.5040	155.9051	1.1450
1993	167.8615	183.5722	158.7358	1.1565

primary productivity, than that of the outside of the park (218,677 cells). The mean NDVI values of all three years of the national park are about 14 percent higher than those of surrounding areas.

Second, it can also be concluded that the establishment of the national park is contributing to the conservation of the plant communities of the national park. The ratios of the NDVI of the park(A) over the surrounding areas(B) were around 1.14, and the ratios were increasing from 1.1379 in 1985 to 1.1565 in 1993. The increasing trend of the ratio might also be considered as a sign of fast deterioration of vegetation around the park.

Third, as can be seen from the Figure 3, it can be concluded that plant communities close to heavily developed urban areas were suffering more damage than those located far from the bounadary of the park. NDVI values in southwestern part of the park were lower than those of any other part of the park in 1985 image. It is clear that healthy vegetation in the eastern slope of the park in 1985 image was degraded severely in 1993 image. There has been little change of NDVI values along the western and northern boundarys of the park.

Fourth, by fitting mean NDVI-distance scattergrams of each year with least square method, following three logistic equations were developed:

$$NDVI_{1985} = 156 + 31 / (1 + e^{0.090093 - 0.01152 * DIST}) \quad (R^2 = 0.9290)$$
$$NDVI_{1987} = 150 + 26 / (1 + e^{0.808718 - 0.00969 * DIST}) \quad (R^2 = 0.9613)$$
$$NDVI_{1993} = 151 + 30 / (1 + e^{0.508608 - 0.01007 * DIST}) \quad (R^2 = 0.9662)$$

where

$NDVI_{YEAR}$ = NDVI derived from TM data acquired in May of the year

DIST = distance (m) from the boundary of the park

As can be seen from the equations, the maximum NDVI (K) of each TM data differs from each other and the K value of an equation is divided into two terms. The K value of 1985 can be obtained by summing the constant of 156, which is the minimum value of the logistic curve or the average NDVI of urbanized areas where natural vegetation was completely destroyed, and the numerator of 31, which is the difference of NDVI values between urbanized areas and inside

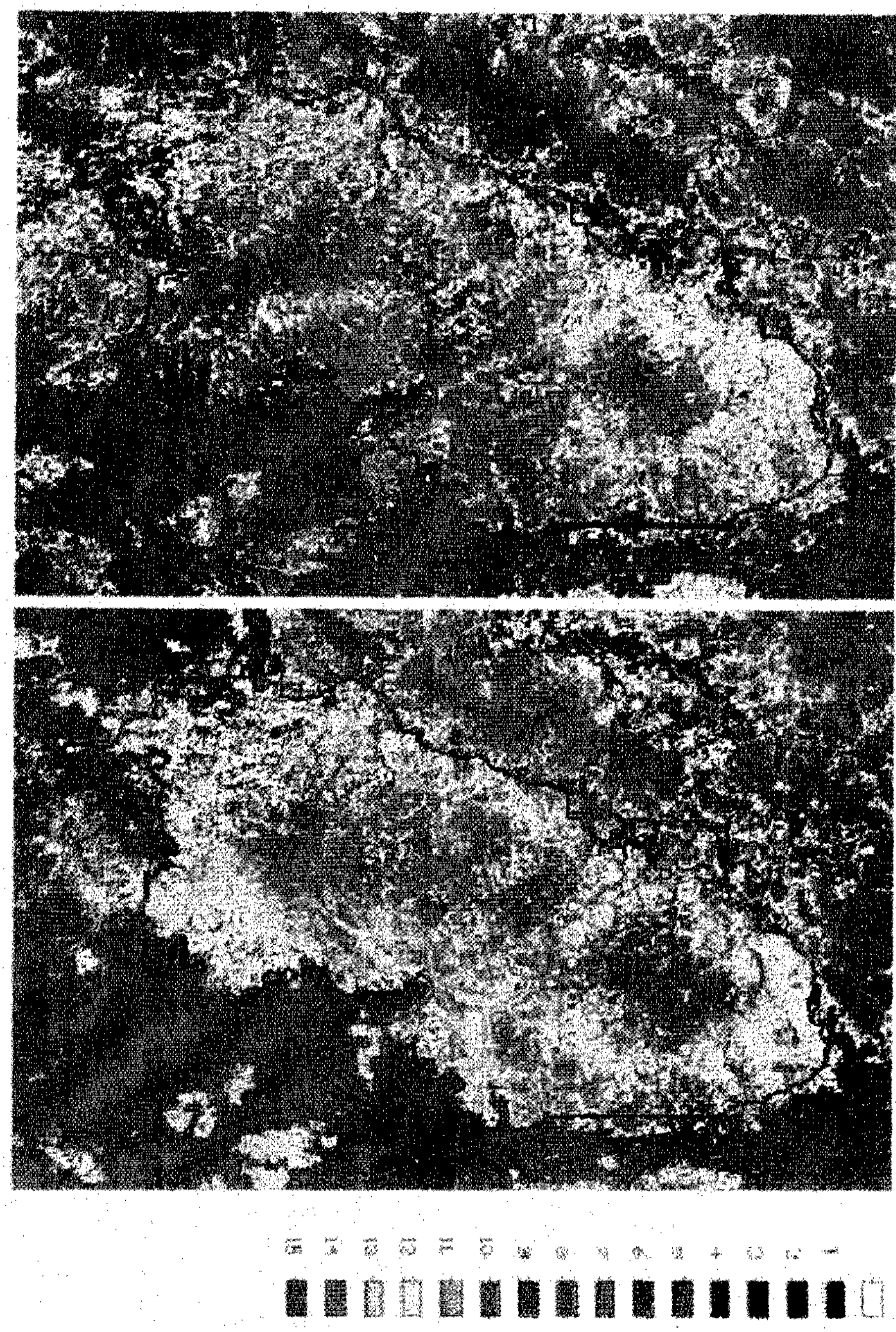

Figure 3. NDVI Maps of the Mt. Pukhansan National Park (Left May 14, 1985; Right May 20, 1993)

Table 2. Ecotones of the Mt. Pukhansan National Park Identified by NDVI-Distance Curve

Ecotone	95% of Maximum NDVI			99% of Maximum NDVI			100% of Maximum NDVI		
TM IMAGE	Width (m)	Size (cells)	Percent (%)	Width (m)	Size (cells)	Percent (%)	Width (m)	Size (cells)	Percent (%)
05-14-1985	220.72	18,314	14.43	341.49	27,560	21.71	981.16	66,225	52.18
05-20-1987	387.52	27,322	21.53	557.94	41,701	32.86	1,442.44	88,767	69.94
05-20-1993	456.23	35,142	27.69	674.31	48,790	38.44	1,825.09	105,009	82.73

of the park where damage caused by human impacts can no longer be measured by NDVI derived from TM data. Thus the K values of three images are 187, 176, and 181, respectively. Regression coefficients of 0.92 or higher explains that identifying ecotones with NDVI-distance curve is statistically meaningful.

Fourth, it was found that NDVI of 1987 is unsuitable for multitemporal change detection because of phenological difference caused by unusual weather conditions. It was found that values of NDVI at all distance zones of 1987 were lower than those of 1985 and 1993, and it seems that low temperature and less rainfall till May of 1987 are major causes of such anomaly.

Finally, ecotones identified by applying three evalution criteria are shown on the Table 2. The width of ecotones are in the range between 220.72m and 456.23m with the 95% criterion, 341.49m to 674.31m with the 99% criterion, and 981.16m to 1,825.09m with the 100% criterion. The percentage of cells belong to ecotone can be as high as 82.73% of the park with the 100% criterion, which is unrealistically high value. Thus 95% or 99% criterion might be better for such study areas. The fact that the width of ecotones defined by these operational definitions is rapidly expanding reflects that vegetation adjacent to the boundary of the park has been deteriorating since 1980s. It can be concluded that the major causes of the degradation of vagetation along the boundary of the park were heavy trampling and environmental pollution of surrounding urban areas.

CONCLUSION

Ecotone between the Mt. Pukhansan National Park and adjacent urban areas can be regarded as the impact zone where natural ecosystem of the park is being deteriorated by human exploitation and occupation of the park. Residential development along the boundary of the park also reduces the protective functions of vegetation cover of the park. Thus it is very important to monitor the temporal change of ecotone along the boundary of protected ecosystems.

A method to measure the width of an ecotone between two contrasting ecosystems by employing analytical capabilities of GIS and remote sensing was presented in this paper. The method has four steps. First, produce a NDVI map of a study area. Second, calculate mean values of NDVI for each distance zone. Third, make a scattergram by plotting mean NDVI values for each distance zone. Fourth, calculate coefficients of the logistic curve by fitting least square method, and compute the width of the ecotone by identifying steep part of the logistic curve.

The points with 95% and 99% of the maximum NDVI were proposed as the limits of an ecotone. It was found that even TM images acquired on mid May of 1985, 1987, and 1993 resulted in some variation of the width and size of ecotone of the park. Thus the maximum width of ecotone, derived from the TM data acquired on May 20, 1993, of the park is 674.44m from the boundary of the park, and the ecotone occupies about 38.44% of the park.

This approach can also be used to measure the quality of residential areas, or the contribution of urban open spaces for the enhancement of the quality of residential communities. In such a study a wide ecotone can be interpreted as the community has an excellent open space system. This method of identifying ecotone can also be used for game management or for the conservation of edge species in urban or natural ecosystems.

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