Spatio-temporal Change Detection of Forest Patches Due to the Recent Land Development in North Korea

Kim, Sang-Wook · Park, Chong-Hwa

Graduate School of Environmental Studies, Seoul National University

북한 도시지역의 산림파편화 변화조사

김상욱 · 박종화

서울대학교 환경대학원

요 약

본 연구는 지리정보시스템 및 원격탐사기법을 응용하여 북한의 자연환경을 조사하기 위한 기초연구로서 수행되었으며, 과거 약 20년 동안의 평양 및 남포지역의 산림면적의 변화 및 경관구조 변화측면에서의 산림 파편화 양상을 조사하였다. 조사자료로는 Landsat MSS 및 TM 영상의 NDVI값을 이용하였으며, 보다 정확한 피복분류를 위하여 변형된 Cluster-Busting 알고리즘을 활용하여 산림과 비산림지역으로 단순화시켜 분석하였다. 경관구조의 변화를 살피기 위해서 조각밀도, 형태 및 핵심내부지역의 면적 등의 경관지수(Landscape Indices)를 활용하였다.

분석과정을 거쳐서 도출된 결론은 다음과 같다. 첫째, Cluster-busting 방법을 활용한 토지피복 분류결과 87.3%의 총 분류 정확도를 얻었으며, Binary Map을 이용한 변화감지(Change Detection)기법 또한 그 결과가 정확한 것으로 판단되었다. 둘째, '79년에서 '98년에 이르는 기간 동안, 평양의 경우 '79년 산림면적의 15%, 그리고 남포지역의 경우 14%가 감소하였다. 셋째, 경관지수를 이용하여 북한 산림의 파편화 변화를 조사한 결과 산림조각의 개수는 늘어나고 조각의 평균면적 및 핵심내부면적은 감소하였으며 조각크기의 다양성 또한 낮아졌다. 산림조각 형태지수 또한 매우 증가하였는데 이러한 결과들은 평양 및 남포지역의 산림조각이 파편화되고 그 형태 또한 불규칙적이며 복잡하게 변화하였음을 보여주고 있다.

주요어: 변화감지, 산림파편화, 토지피복분류, 경관지수, 원격탐사, 지리정보체계

I. INTRODUCTION

For two decades, planning and implementation of the nation-wide land development have resulted in severe land transformation in North Korea. Clear-cutting for the firewood production and the reclamation for the expansion of croplands on steep hills by rural households have devastated hills and mountains adjacent to urban areas in the Pyongyang metropolitan area. The forest denudation and forest fragmentation have certainly reduced the buffering capacity to the natural hazards such as intensive rainfall and drought, and have accelerated the vicious cycle of flooding, soil erosion, and landslide of Pyongyang and Nampo regions. Consequently, the food production capability of the country has been deteriorated significantly.

Recent reports on the widespread starvation in the North Korea and the open request for the massive amount of food assistance to the outside world have also triggered research activities by outside experts on the management of the agricultural lands and forest of the country. But data collection by outsiders in the country is still strongly restricted by various red tapes of the country. Even decision makers responsible for the management of the natural resources and food production seem to have very limited knowledge on the status of their forests in terms of the trend of forest destruction and fragmentation.

Remote sensing techniques could be applied for the land cover classification and change detection of the North Korea in order to provide essential but unreliable or unavailable data for the decision making by the North Korean officials and outside experts. But few researches in this field have investigated the landscape structure of North Korea which can offer an important clue toward the environmentally sound and sustainable development(ESSD) of Korean peninsula in the near future.

To investigate forest conditions, various vegetation biophysical variables have been modeled using remotely sensed data. Vegetation indices are one of them and there are more than 20 vegetation indices in use, and especially Normalized Difference Vegetation Index(NDVI) derived from Landsat MSS and TM has been used as an indicator of relative abundance and activity of green vegetation in South and North Korea(Park et al., 1995; Kim and Joung, 1998; Seo and Jeon, 1998; Jeon et al., 1999; Lee and Yoon, 1999) and especially Jeon et al.,(1999) and Lee and Yoon(1999) corrected the radiometric distortion due to the terrain effects in mountainous area using Digital Elevation Model(DEM) data.

Objectives of this study are (1) to quantify the rates of forest change during recent large scale land development in Pyongyang and Nampo area, (2) to analyze forest fragmentation pattern in spatio-temporal aspect, (3) to assess the effectiveness of the adopted classification algorithm and land-cover inference logic for the land-cover classification of North Korea where ancillary and ground truth data is scarce.

II. METHODS

Landsat Multispectral Scanner(MSS) (Aug. 30, 1979) and Thematic Mapper(TM) (June 10, 1998) imageries of Pyongyang and Nampo areas were used in this study. The selection of the acquisition dates for the remotely sensed data used for this research was mainly affected by the phasing of the planning and implementation of the successive development plans, significantly affected the forest of the North Korea.

Digital topographical maps(1: 50,000) of North Korea produced in 1975 by the Agency for Defense Development(ADD) were used as ground truth data and the IRS-1C panchromatic image (Jan. 10, 1996) as ancillary data. Most of the digital map layers like roads, rails, reservoirs and so on, used for this research, were lastly updated in the mid 1990s, and the TM image of 1998 was used as the base and geocoded image for the image to image rectification of the MSS image of 1979. But forest boundary polygons which were the militarily less important layer have not been updated since the mid 1970s. Therefore, the MSS image of 1979 was used as the base image for the forest-cover classification and the inference of 1998 forest-cover map.

In this study, NDVI which is less sensitive to water than Green Vegetation Index(GVI), Infrared Index(II), Perpendicular Vegetation Index(PVI) and so on, was used to classify the forest-cover in the metropolitan area of North Korea. But in this study, topographic normalization was not considered due to the lack of topographic data like DEM and digital topographical maps with elevation values of the regions.

The ADD digital topographical maps were originally registered to Universal Transverse Mercator(UTM) Zone52 projection and WGS84 datum. With the map to image geocoding algorithm, the TM image was warped by the linear polynomial transformation and resampled to 80m x 80m resolution with the nearest neighborhood interpolation method for the data ratioing, pixel by pixel, between two time series data. 15 Ground control points(GCPs) were selected inside and outside of the study area occurring in the TM image and Root Mean Square(RMS) error was maintained by 0.33 pixel. ER-mapper 5.5 for image processing and ArcView v3.0 for GIS overlay were used in this study.

Cluster-busting algorithm(Jensen, 1996), a kind of unsupervised classification algorithm, was

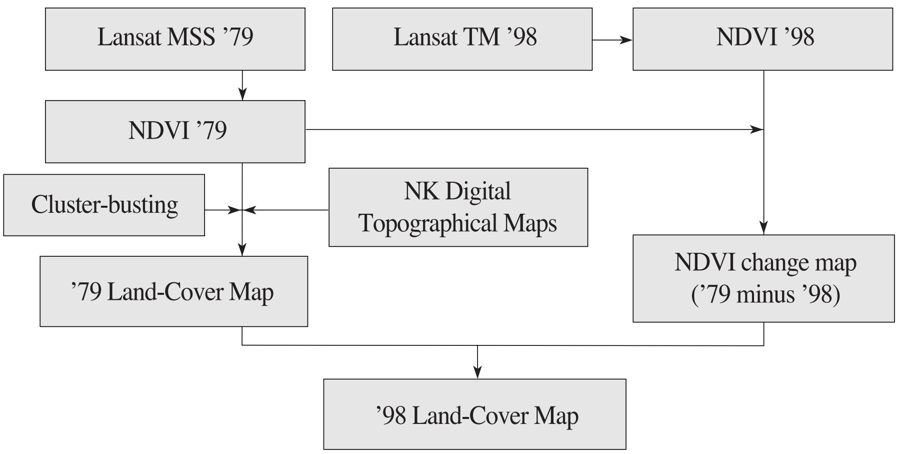

Figure 1. Flow diagram for the inference of the land cover maps of 1979 and 1998

adopted to improve the classification accuracy in the study site to overcome the inaccessibility problem for the ground truth data collection. In order to achieve higher forest classification accuracy of the site, outcome clusters were grouped into only two layers: forest and non-forest. The forest layer consists of deciduous, conifers and mixed forests, and the non-forest layer consist of urban and built-up land, agricultural land and barren land.

Methodologically, this study is composed of two major stages.

The first one is to classify forest-covers from satellite imageries. The process is as follows:

a. to produce NDVI map of '79 and '98

b. to classify land-cover (forest vs. non-forest) map of '79 using the cluster-busting method

c. to calculate differences between NDVI of '79 and '98, and generate the NDVI change map

d. to infer land-cover (forest vs. non-forest) map of '98 using the NDVI change map and land-cover Map of '79.

This process is shown in the figure 1.

1) Classification of land-cover map of 1979 by using cluster-busting algorithm

Cluster-busting is a technique to iteratively bust up spectrally mixed classes. It separates forest vs. mixed classified pixels into a binary mask to mask out the forest image and extract the mixed image data. It re-runs the unsupervised process and re-evaluate clusters, keep forest and toss out mixed or confused clusters again and again. Finally, it creates a final cluster map using a GIS

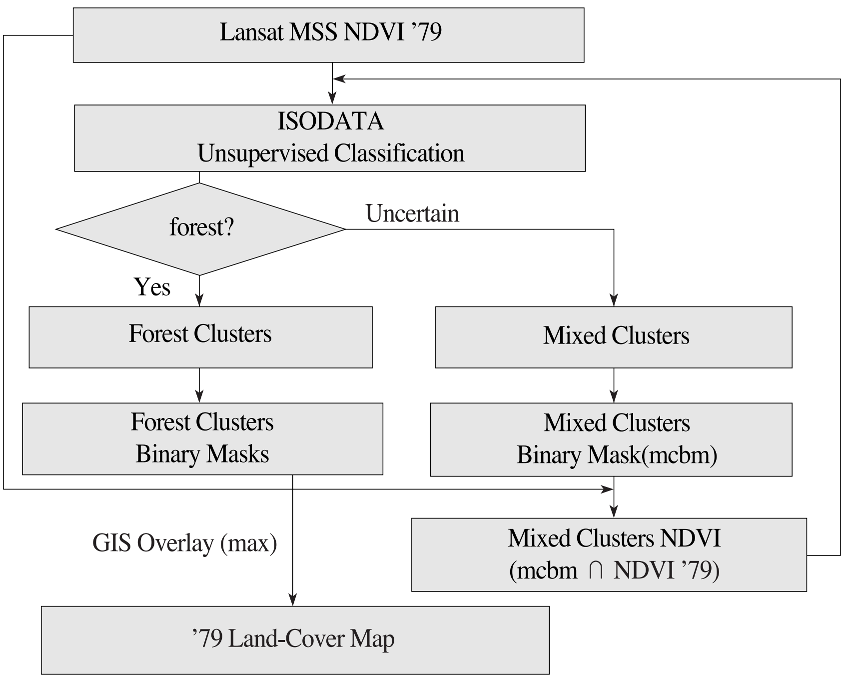

Figure 2. Flow diagram for the classification of the land cover map of 1979 by using cluster-busting algorithm

overlay of exact forest clusters with a maximum dominant function as shown in the figure 2.

2) Generation of NDVI change map (1979~1998)

Digital numbers(DNs) of NDVI difference map between two time period (NDVI '79 minus NDVI '98) can be grouped into three categories: 1) negative DN values for the regeneration, 2) values near 0 for unchanged pixels, 3) positive DN values for the forest denudation. Thresholds to segment these three categories were selected through iterative and empirical handling of standard deviation value width using mean and standard deviation of DN value statistics of the difference map (Table 1).

3) Inference of the land-cover map(forest vs. non-forest map) of 1998

As shown in the Table 2, the land-cover map of 1979 was divided into two binary layers, and NDVI change map with three different layers combined each by each to infer forest vs. non-forest map of 1998. For example, non-forest layer of 1979 and regeneration layer of NDVI change map could infer a forest layer of 1998. These combinations generate three forest layers that were overlaid with maximum values and drew the land-cover map of 1998.

Table 1. Threshold values for the NDVI change map

(X: DN)

regeneration layer	unchanged layer	denudation layer
$x<\mu-1.5\sigma$	$\mu-1.5\sigma \leqq x \geqq \mu+1.5\sigma$	$x>\mu+1.5\sigma$

The second major part of this study is to quantify the landscape pattern changes of the site. For landscape pattern analysis, landscape indices obtained with Patch Analyst v2.0, which is an extension to ArcView v3.x, and developed to facilitate the analysis of the patch numbers, size, shape and core areas, were used. This program includes capabilities to characterize patch pattern and the ability to assign patch values based on combinations of patch attributes (Elkie et al., 1999). Patch Analyst suggests six categories to group 52 landscape indices to reduce redundancy. Among 52 landscape indices, the following eight indices were used in this study.

- NumP(#) : Number of Patches
- MPS(ha) : Mean Patch Size
- PSSD(ha) : Patch Size Standard Deviation
- TE(m) : Total Edge
- AWMSI(MSI≧1, 1=circle or rectangle) : Area Weighted Mean Shape Index
- MNN(m) : Mean Nearest Neighbor

Table 2. The inference of the land-cover map (forest vs. non-forest map) of 1998 (Zheng, 1997)

Land-cover map of 1979 (forest vs. non-forest map)	NDVI change map (NDVI '79 - NDVI '98)	Land-cover map of 1998 (forest vs non-forest map)
Non forest layer	denudation layer	non-forest
	unchanged layer	non-forest
	regeneration layer	forest
Forest layer	denudation layer	non-forest
	unchanged layer	forest
	regeneration layer	forest

- MCA(ha) : Total Core Area
- CASD(ha) : Core Area Standard Deviation

III. RESULTS AND DISCUSSION

1. Assessment of the Classification Accuracy

To evaluate the classification accuracy of land-cover map of 1979(figure 3), overall accuracy from the error matrix and KHAT(k) was measured with overlaying the forest boundary vector layer from the ADD digital maps to the land-cover map of 1979. By analyzing the 1,890 sampled pixels, producer's and user's accuracy were calculated, and results of the error matrix were shown in the Table 3. In this table, the overall accuracy of the classification was 87.3%, and computed KHAT value was 0.72, which might note quite good classification accuracy using the cluster-busting algorithm.

2. Rates and Patterns of Forest Cover Changes

Areas covered with forest in the study site were reduced significantly during the 19-year period (Table 4). Average forest-cover reduced by 14%, and 15% for Pyongyang and 12% for Nampo, respectively. Major causes of the reduction and fragmentation of forest would be the reclamation of lower parts of hills to the dry fields and orchards, construction of roads, railroads and floodgates, and urbanization during this period. Especially, the construction of the Sohae Floodgate Complex near Nampo city have greatly increased the volume of irrigation capacity, which accelerated the process of the reclamation on previously dry fields and even steep, marginal hill sides. Such expansion was later proved to be very vulnerable to flooding and land slides. Temporal and spatial changes were presented in Figure 3 and 4 in the southern part of Pyongyang. In the mountainous region(figure 3), non-forest area were concentrated narrowly through the valley, but in 1998 from the lower elevation area, forest-cover has been denudated widely and large forest patches have been fragmented into small patches(figure 4).

Landscape pattern based on forest patches also changed significantly as shown in the Table 5. The size of forest patches became smaller, but the complexity and irregularity of forest patches

Table 3. Error matrix for classification accuracy of the land-cover map of 1979

Classification Data	Training Set Data (ADD Vector data)		
	Forest	Non-forest	Row Total
Forest	543	109	652
Non-forest	131	1,107	1,238
Column Total	674	1,216	1,890
Producer's Accuracy		User's Accuracy	
Forest	543/674=81.0%	Forest	543/652=83.2%
Overall Accuracy = (543+1107) / 1890 = 87.3%			

Table 4. Forest-cover changes of Pyongyang and Nampo area ('79-'98)

(Unit: ha)

	Total Area		Pyongyang		Nampo	
	non-forest	forest	non-forest	forest	non-forest	forest
'79	193,371.52	142,509.44	136,480.64	125,752.32	56,890.88	16,757.12
'98	213,096.96	122,784.00	154,222.72	108,010.24	58,874.24	14,773.76

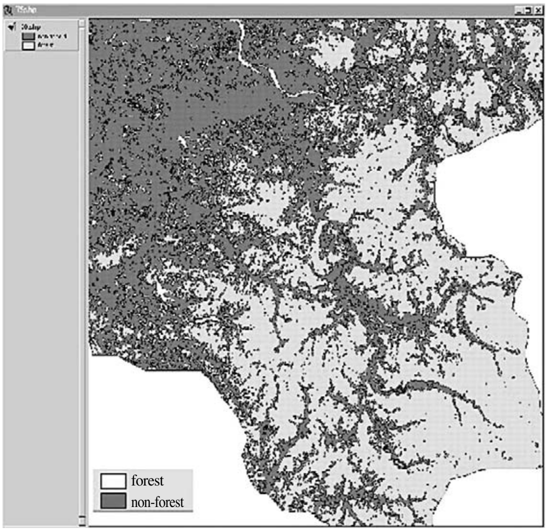

Figure 3. Land-cover map of 1979

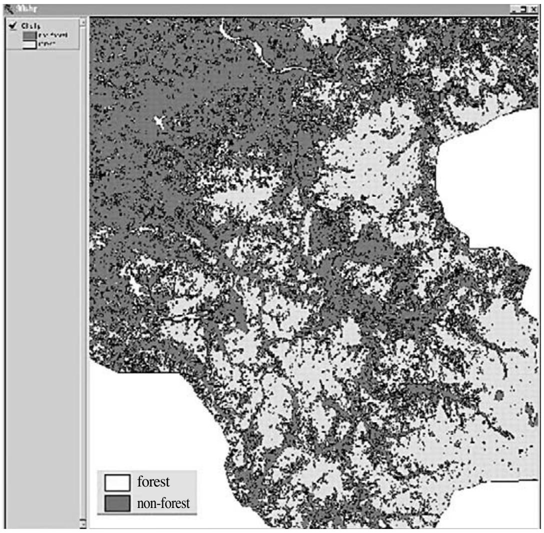

Figure 4. Land-cover map of 1998

increased during this period. NumP have increased enormously from 5064 to 8027 in the whole area. The Increasing trend of forest patches could be caused by two reasons. One would be the forest fragmentation to small patches resulting from the intentional alteration or biotic or abiotic disturbance of forest patches, and the other would be forest regeneration and the intro-

Table 5. Computed landscape indices in the study area

Landscape Indices		Total Area		Pyongyang		Nampo	
		'79	'98	'79	'98	'79	'98
Patch Density	NumP	5064	8027	4079	6282	985	1746
	MPS(ha)	28.14	15.30	30.83	17.19	17.01	8.46
	PSSD(ha)	789.92	535.72	876.17	604.24	111.96	75.84
Edge Metrics	TE(m)	11,677,120	14,602,400	9,719,360	12,180,000	1,957,760	2,422,560
Shape Index	AWMSI	15.36	21.81	16.71	24.04	5.13	5.56
Diversity	MNN(m)	130.65	122.29	122.35	117.76	166.15	139.72
Core Area Metrics	MCA(ha)	46.67	26.17	53.49	28.73	22.82	13.67
	CASD(ha)	969.13	607.74	1075.39	665.81	106.34	85.95

duction of new patches. But the decrease of MPS and PSSD indicates that the major cause of patch increase was the forest fragmentation during the study period. In case of Nampo area, 985 forest patches increased to 1746 and MPS decreased nearly half from 17.01 ha to 8.46 ha which means forest fragmentation of Nampo region have been happened severer than Pyongyang' s. The reduction of PSSD values would show that the mixture of large and small patches which is usually beneficial for the species diversity enhancement, have changed to homogeneous and monotonous small patches. The increase of TE and AWMSI could explain that edges of patches became more curvilinear, irregular and complex. The MNN also gave a proof of patch fragmentation that the fragmented new patches shortened the space among patches. To compute MCA and CASD, the ecotone width were determined to 80m width, which was because these raster data were resampled to spatial resolution of 80m. To analyze optimum ecotone width between fields and forest in North Korea is one of the important part to study hereafter. Totally, MCA was reduced by 56% from 46.67 ha to 26.17 ha. The reduction of MCA and CASD could badly affects to the species richness of the wildlife, especially interior predators.

IV. CONCLUSIONS

This research was carried out to conduct a basic study to investigate North Korea's natural resources. Landscape changes, especially spatio-temporal variations of forest fragmentation between 1979 and 1998 of Pyongyang and Nampo areas of North Korea were detected using landscape indices obtained from NDVI derived from Landsat MSS and TM imagery. Forest fragmentation of the metropolitan area in North Korea was very severe in the rates and patterns. Average forest-cover was reduced by 14%, and 15% for Pyongyang and 12% for Nampo, respectively. NumP was increased by 58.1% but MPS was decreased by 54.4% during 19 years. The pressing problem of the study site's landscape changes was not only forest shrinkage caused by abiotic disturbance like land transformation from the forest to the paddy or dry fields, but also abandonment of hill slope's fields to fallow fields and finally barren lands that affect catastrophic flooding to the study area. The cluster-busting algorithm which obtained 87.3% overall accuracy of the forest-cover classification, was proper to classify where would be inaccessible to the study site for ground truth data collection.

In this study, the approach to investigate landscape changes leaves some limitations for improvement. Firstly, resolution of the TM image was lowered to 80m×80m pixels for PC-based hardware and software performance enhancement of change detection and landscape indices analysis. But it resulted some disadvantages which distorted original DNs of the TM image and did not reflect patch shape changes precisely. Secondly, it needed more accurate and newly updated data sources. The phenological differences between the early summer TM and the late summer MSS and 4 year time gap between the ADD forest layer and the MSS badly affected forest-cover classification and change detection. Besides, used low resolution imageries have their spatial limitations especially in the hill and mountain region of North Korea to detect landscape structural changes of forest patches. Large-scale digital topographical maps as ground truth data, higher spatial resolution satellite imageries in the same season and ancillary text data from North Korea and around should be recommended to overcome the inaccessibility problem. Thirdly, geometric correction process like a bulk correction to reduce topographical distortion is needed in the forest area using DEM data. Finally, More basic landscape ecological researches to quantify landscape structures which represents Korean landscapes well, should be done to support the theoretical framework of this study.

REFERENCES

1. Forman, R.T.T., M. Godron, 1989, Landscape Ecology, New York, Wiley, 85-120.
2. Forman, R.T.T. 1995. Land Mosaic: The Ecology of Landscape and Regions, Cambridge University, New York, NY, 405-412.
3. Jensen, J. R., 1996, Introductory Digital Image Processing: A Remote Sensing Perspective. 2nd Ed., Saddle River, N. J.: Prentice-Hall, 318.
4. Jeon, S., et al., 1999, The land-cover classification method using satellite imagery, KEI, v-20~25.
5. John G. Lyon, et al., 1998, A Change Detection Experiment Using Vegetation Indices, PE & RS, vol. 64, No.2, 143-150.
6. Kim, C. and Joung, K., 1998, Application of Vegetation Indices for Forest Degradation Using Landsat TM Data, Proceedings of International Symposium on Remote Sensing, EMSEA, 192-197.
7. Lee, K. and Yoon, J. 1999, Development of a Methodology to Estimate the Degree of Green Naturality in Forest Area using Remote Sensor Data, Journal of Environmental Impact Assessment, Vol.8, No.3, 82-83.
8. Michael J. Schuft, et al., 1999, Development of Landscape Metrics for Characterizing Riparian-Stream Networks, PE & RS, vol.65, No.10, 1157-1167.
9. Park, C. et al., 1995, Detection of the ecotone of the Mt. Pukhansan National Park with GIS and remote sensing technologies, Journal of Geographic Information System Association of Korea, Vol. 3, No.2, 91-102.
10. P.C. Elkie, R.S. Rempel, A.P. Carr, 1999, Patch Analyst User's Manual - A Tool for Quantifying Landscape Structure, Ont. Min. Natur. Resour. Northwest Sci. & Technol. Thunder Bay, Ont. TM-002. 13-19. (http://flash.lakeheadu.ca/~rrempel/patch)
11. Robert C. Frohn, 1998, Remote Sensing for Landscape Ecology, Lewis Publishers. 10-18.
12. Rodd D. Macleod and Russell G. Congalton, 1998, A Quantitative comparison of Change-Detection Algorithms for Monitoring Eelgrass from Remotely Sensed Data, PE & RS, Vol.64, No.3, 207-216.
13. Seo, C. and Jeon, S., 1998, Landcover Analysis of DMZ and the Vicinity Using Remote Sensing and GIS Technology, Journal of Environmental Impact Assessment, Vol.6, No.1, 12-19.
14. Zheng, D., D.O. Wallin and Z Hao. 1997, Rates and patterns of landscape change between 1972 and 1988 in the Changbai Mountain area of China and North Korea, Landscape Ecology 12: 241-254.