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Forest Cover Changes in North Korea Since the 1980s

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Abstract

North Korea used to have abundant forest stocks but underwent substantial deforestation and degradation of forest in recent decades. This study examined morphological changes of forest cover in North Korea between the 1980s and 2000s. Land cover data based on Landsat TM imagery were obtained as images from the Republic of Korea's Ministry of Environment. The images were processed and used for the Morphological Spatial Pattern Analysis and network analysis. MSPA classified the forest cover into morphological classes such as core, islet, bridge, perforation, edge, loop, and branch. The network analysis identified individual networks of forest, each of which represents a patch of connected forest. The results are summarized as follows: (1) Forest cover sharply decreased between the 1990s and 2000s, particularly in western provinces; (2) Morphological classes indicating forest fragmentation such as islet, branch and edge consistently increased in their fraction to the total area between the 1980s and 2000s; (3) Islet, branch and edge also increased in number during the same period; (4) Forest networks shrank in size and increased in number. Overall, the results demonstrate that deforestation and fragmentation of forest occurred simultaneously in North Korea during the time.

Keywords: Morphological Spatial Pattern Analysis; network analysis; deforestation; fragmentation; green infrastructure; North Korea

Introduction

North Korea (Democratic People's Republic of Korea) has very rugged terrain in most of the country, particularly in the north and the east. Many streams originate from the mountains and flow west- or eastward, producing some flat lands suitable for farming (Korea Institute for National Unification 2009). In 1945, it was estimated that the area under forest was about 9.7 million hectares out of the land area of 12.3 million hectares (ca. 79%), but it reduced to 8.2 million hectares in 1997 (Piddington 2003). A range of socio-economic factors explains the decline in forest cover in North Korea, particularly during the 1980s and the 1990s when the decline was sharp (Lee et al. 1999).

One of the most important factors is thought to be conversion of forest to farmland. Food shortage was already a problem in North Korea in the 1980s, largely due to declining agricultural productivity (Kim 2005) and stagnating economy (Park et al. 2009). One of the measures to alleviate food shortage was to expand farmland, particularly in hilly areas as terraced fields. This type of farmland is called a *darakbat* in Korean. Even though *darakbat*s were built as part of a government program to expand productive farmlands, many of them were poorly built and managed, and resulted in land degradation and low productivity (Lee et al. 2005). Logging can be pointed out as another major contributor to deforestation. Energy was already in short supply in the 1980s, too (Kim 2005). Lack of energy supply reduced agricultural productivity and deepened economic hardship. People adapted to energy shortage by logging in the absence of government monitoring (Park et al. 2009).

Deforestation not only reduces biomass stock and ecological integrity, but also exacerbates flood damage (Bradshaw et al. 2007). Big floods are not uncommon in North Korea, but those in 1995 and 1996 were particularly devastating (Kim and Ryu 2009). The floods in July and August of 1995 resulted in displacement of 5.4 million people, destruction of 330,000 hectares of agricultural land, and loss of 1.9 million tons of grains (Noland et al. 2001). The 1996 floods were less severe but occurred well before recovery from the previous year's floods. Such floods were caused by downpours with decades-long cycles but the damage was exacerbated due to environmental degradation (Kim 1999).

In general, not a lot of studies are found regarding deforestation in North Korea. Some studies examined deforestation in North Korea in terms of overall statistics (Lee et al. 1999) or for a limited area (Tang et al. 2010). However, morphological studies on land cover change are hard to find. A noticeable example of morphological studies was conducted by Zheng et al. (1997). They examined forest changes in the Changbai (*Baekdu* in Korean) Mountain Reserve located on the China-North Korea border between 1972 and 1988 to find that forest became more fragmented and smaller in size. Not only reduction but also fragmentation of forest cover can be a threat to ecological integrity and sustainability. The forest ecosystem in North Korea is inhabited by various animals, plants (mostly trees) and microorganisms (Piddington 2003), and it has been well documented that the forest ecosystem continues to decrease in size. However, it is rarely documented how the forest is changing in shape. Negative effects of habitat fragmentation have been widely studied (Fahrig 2003), and we certainly think that it is happening in North Korea's forest. The definition of habitat fragmentation is diverse, but the diverse definitions imply four main effects on habitat pattern (Fahrig 2003 p. 491): (1) reduction in habitat size, (2) increase in number of habitat patches, (3) decrease in sizes of habitat patches, (4) increase in isolated patches. These four elements form a guideline on how to examine morphological changes in forest in North Korea.

The purpose of the study was to quantitatively analyze morphological changes in forest cover in North Korea between the 1980s and 2000s. The novelty of the study is that this is the first attempt, to the best of our knowledge, to analyze morphological changes in forest for the entire North Korea. During the time, North Korea had the first ever leadership change (or hereditary succession) and underwent socio-economic changes. The results from the study are expected to provide a basis for scientific research on social and ecological effects of forest fragmentation. The Materials and Methods section introduces data used and our analysis methods, Morphological Spatial Pattern Analysis (MSPA) and network analysis. Following the guideline suggested by Fahrig (2003), our analysis focused on the size, frequency, and connectivity of forest patches. We hypothesized that during the time period in North Korea forest patches generally decreased in size, increased in frequency, and isolated patches or strips of forest increased in frequency. The Results and Discussion section presents statistics and maps from the analyses, and is followed by conclusion and recommendations.

Materials and Methods

Land cover data

Land cover data as images were obtained for the years 1980, 1990, and 2000 from the Web site of the Republic of Korea's (South Korea) Ministry of Environment (http://egis.me.go.kr/bc/largeGrdCover_2000.do). Each data set was produced from the Landsat TM imagery taken for three years for the entire Korean Peninsula. The spatial resolution of the Landsat imagery is 30 m, but the land cover data maps were available at a 100-m spatial resolution. They had more than 70% accuracy for classification in the North Korean region. It should be noted that ground truthing is virtually impossible in North Korea due to political reasons. Land cover types had already been classified into urban, agricultural, grassland, forest, wetland, barren, and open water using the unsupervised classification method.

First, the portion of North Korea was clipped out from the original data sets for the three years. The land cover maps were then pre-processed to produce the binary foreground and background image files, where foreground is the land cover of interest and background is the rest. Here forest pixels constitute foreground (2 bytes) and non-forest ones background (1 byte) in the terminology of MSPA used in the study. Next, the pre-processed image files were converted to 8-bit TIFF files without compression in a geographic information system (GIS) environment. After the series of processes, the image files for the years 1980, 1990, and 2000 were made ready for the morphological analysis.

Fig. 1 shows the land cover in North Korea for 2000. The land cover is overlaid by provincial boundaries. Generally the eastern half of the country is heavily forested and the western half is more dominated by agricultural land. Pyongyang is the largest metropolitan area and is a special administrative district as the capital of the country.

Morphological Spatial Pattern Analysis

Morphological changes of forest cover were analyzed using the Morphological Spatial Pattern Analysis (MSPA) (Soille and Vogt 2009). MSPA is based on concepts from mathematical morphology (Soille 2003), and segments arbitrary binary patterns into a series of categories or classes representing different size, shape, and connectivity (Soille and Vogt 2009). In other words, when there is a binary raster data set (forest or foreground = 1, non-forest or background = 0), MSPA analyzes the patterns of forest (foreground) cells and categorize based on the size, shape, and connectivity of the cells. This is a useful alternative to overlaying multiple thematic layers in a GIS environment for mapping green infrastructure such as forest, because it only requires a single, binary layer (Wickham et al. 2010).

A size-parameter, *s*, is used as a threshold to determine the categories, and defined as $\sqrt{a^2 + b^2}$ where *a* and *b* are the distance along the horizontal and vertical axes, respectively, between any two pixels (Soille and Vogt 2009). Connectivity between pixels is defined based on one of two rules, eight-neighbors and four-neighbors. If $s = 1$, $a = 0$ and $b = 1$ (or vice versa), it corresponds to the width of one pixel. If an eight-neighbor rule is chosen for foreground, a four-neighbor rule is applied for background, or vice versa.

MSPA has seven mutually exclusive morphological categories: core, islet, loop, bridge, perforation, edge, and branch (Soille and Vogt 2009). The definition of the categories is given in Table 1 according to Soille and Vogt (2009) and illustrated in Fig. 2. Core and islet pixels can be viewed as patches of foreground pixels, while islet pixels are not connected to any other category. Branch pixels extend out from an area of core but do not connect to another area of core. Core can be viewed as hub, and bridge is equivalent to corridor or link in the literature of ecological networks (Wickham et al. 2010). The selection of the size-parameter *s* affects the minimum size of core and the number of core pixels, and the relationship is non-linear (Wickham et al. 2010).

Table 1 Definition of morphological categories.

Type	Category	Definition
Patch	Core	Foreground pixels whose distance to the background is

		greater than *s*
	Islet	Patch of foreground pixels that do not contain any core pixel
Connector	Bridge	Pixels emanating from two or more core connected components
	Loop	Pixels emanating from the same core connected component
Boundary	Perforation	Pixels whose distance to the core pixels is lower than or equal to *s* and located within a core → inner boundary
	Edge	Pixels whose distance to the core pixels is lower than or equal to *s* and facing background on other sides → outer boundary
	Branch	Pixels that do not belong to any of the previously defined categories

To perform MSPA, we used the GUIDOS (Graphical User Interface for the Description of image Objects and their Shapes) program available online for free from European Commission Joint Research Centre (http://forest.jrc.ec.europa.eu/download/soft-ware/guidos). We used eight-neighbor connectivity for foreground and the size-parameter value of one. Since the spatial resolution of the data used here is 100 m, we set the edge width at 100 m.

Network analysis

A network analysis was conducted on the MSPA results by employing GUIDOS. The analysis is based on the graph-theory application (Saura and Torne 2009). A graph in the analysis is a collection of vertices or nodes and edges or links that connect nodes. In the terminology of GUIDOS's network analysis, nodes are cores and links are bridges, and the remaining MSPA classes including islet, loop, perforation, edge, and branch, are neglected (Vogt 2010). Bridges are connectors between different cores. A connected set of nodes and links is called a component — as an interchangeable term of the graph — in GUIDOS. Thus, a set of cores without any links (i.e. nodes only) will not be considered as a component in this study.

Results and Discussion

We present the results in the following subsections: land cover change, forest cover change, morphological changes of forest, and forest network change. The land cover change subsection presents overall statistics of all land cover types during the three decades. The forest cover change subsection presents detailed information regarding the amount of forest cover. The morphological changes of forest subsection presents the results from the MSPA, and the forest network change subsection presents those from the network analysis.

Land cover change

Table 2 shows the fraction of each land cover type for the years 1980-2000 to the entire area of North Korea. Between 1980 and 1990, forest decreased by 4 percentage points whereas agricultural fields increased by 2 percentage points. Between 1990 and 2000, forest decreased by 13 percentage points whereas grassland increased by 7 percentage points and agricultural fields by 4 percentage points. Urban lands increased by up to 1 percentage point for each decade. It seems forest was replaced largely with agricultural and grassland. Grassland increased a lot between 1990 and 2000, and is generally located between agriculture and forest (see Fig. 1). We speculate that it indicates degradation of forest cover. Urban lands increased about 50% each decade, but are still quite small in size.

Table 2 Fraction of land cover types to the entire land area of North Korea

Year Land cover type	1980	1990	2000
Open water	2.0%	2.1%	1.4%
Urban	1.1%	1.6%	2.6%
Barren land	0.8%	1.4%	0.4%
Wetland	0.4%	0.4%	3.0%
Grassland	4.0%	4.8%	11.6%
Forest	74.6%	70.5%	57.7%
Agricultural	16.9%	19.0%	23.2%
TOTAL	100%	100%	100%

Forest cover change

Table 3 portrays overall changes in forest in North Korea between 1980 and 2000, and suggests that deforestation accelerated during the 1990s. From 1980 to 1990 it decreased by 5% and from 1990 and 2000 it decreased by 18%. It is generally known that the sharp deforestation in the 1990s is related to severe famine that led to the so-called 'Arduous March' (http://tinyurl.com/2e7eefu). During the same time, both urban and agricultural lands increased (see Table 2).

Table 3 Changes in forest cover in North Korea

Year	Total area (km^2)	Forest area (km^2)	Change from previous data (km^2)	Percent change from previous data
1980	122,762	91,717	N/A	N/A
1990	122,762	86,678	-5,039	-5%
2000	122,762	70,858	-15,820	-18%

Fig. 3 shows fraction of forest cover in each province between 1980 and 2000. Between 1980 and 1990, forest cover fraction decreased particularly in Yanggang-do, Hamgyeongbuk-do, Raseon-si, and Nampo-si. The first three are in the northeast and Nampo-si is on the west coast, close to Pyongyang-si. Tang et al. (2010) report that the forest in the *Baekdu* area, located in Yanggang-do on the border with China, continued to degrade largely due to strip logging by the early 2000s. Between 1990 and 2000, forest cover decreased particularly in Jagang-do, Gaeseong-si, Gangweon-do, Pyeonganbuk-do, Pyeongannam-do, Hwanghaenam-do, Pyongyang-si, and Nampo-si. Except for Gangweon-do, all are located in the western half of the country, which is different from the period 1980-1990. They include three urban provinces

(Gaeseong, Pyongyang and Nampo), and Pyeongannam-do and Hwanghaenam-do border at least two of the urban provinces respectively.

Morphological changes of forest

MSPA categories of forest in North Korea are shown in Fig. 4 for the three different years. What is noticeable between 1980 and 1990 includes a large increase in islet class in south of Pyongyang, clearing of forest in the northwestern corner of the country, and widespread conversion from core to bridge classes in the northeastern 'arm'. Deforestation is obvious, but fragmentation was of problem as much. There is a large harbor city south of Pyongyang, called Nampo, along the long narrow inlet. The northwest corner of the country has been a long-time gateway to China and an industrial center since the early 20th century. At the same time, topography-wise, the western part of North Korea is where most of plains are located, thus a lot of agricultural fields. Considering that urban areas occupy a very small fraction of the land area, conversion to farmland is thought to have had more influence than urban and industrial development. Urban areas increased by less than 2 percentage points during 1980-2000 nationwide, whereas farmland increased by 6 percentage points (Table 2). On the other hand, the northeastern 'arm' has very high (easily exceeding 2000 m above sea level) mountains and plateaus, and is the most remote part of the country. Therefore fragmentation in the area may be due largely to individual and local activities.

Between 1990 and 2000, a large decrease in core, bridge, and islet classes in the southwest is remarkable. Not just core shrank in size but also a lot of bridge and islet disappeared. It coincides with a large increase in agricultural land during the period. The land cover maps showed that agricultural lands substantially increased during the time in the western part of the country. Many of small cores in the southwest are surrounded by agricultural lands.

The upper panel of Fig. 5 portrays the fraction of MSPA classes to the entire country, and the lower panel portrays the changes in the fraction of the MSPA classes out of the entire forest cover. Therefore the upper panel shows absolute changes (smaller fractions meaning smaller in area) whereas the lower panel shows relative changes within forest. In the upper panel core continues to decrease whereas in the lower panel it decreased and increased during the time. Because the graphs show fractional changes, a smaller fraction of core does not necessarily mean fewer cores. The fraction of core to the entire land area decreased along with overall deforestation during the time, but its areal share within forest increased between 1990 and 2000. Both graphs show that bridge increased and then decreased. Because bridges connect cores, if cores become smaller, some core cells convert to bridge cells. The opposite trends between core and bridge in the lower panel can be explained in this way. Both core and bridge decreased absolutely during 1990-2000 (upper panel), but core increased relatively and bridge decreased (lower panel). The relative decline of bridge seems to be related to the increase in branch because bridge becomes branch when the connection to core is broken. Islet and edge continued to increase both absolutely and relatively. Increasing fractions of islet and edge suggest an increasing degree of fragmentation. Islet is unconnected to anything and too small to be core, and edge increases when cores are broken or change shape.

Fig. 6 portrays the frequency of MSPA classes occurring as individual objects. Core, islet, edge, bridge and branch increased in number between 1980 and 2000. With core area continuing to decrease absolutely, the increasing number of core in the figure suggests smaller cores, a sign of defragmentation. Islet, edge, and branch both increased in size and number, strongly suggesting defragmentation. Bridge is somewhat unique. Its frequency increased along with core. With more and smaller cores, it makes sense that bridge increased in number. However, the total area of bridge decreased both absolutely and relatively between 1990 and 2000 when the frequency increased remarkably. We think this is another sign of fragmentation. With more and smaller cores, bridges increased in number, and at the same time, individual bridges became much shorter, connecting fragmented cores, or were converted to non-forest.

Forest network change

Fig. 7 portrays the changes in forest network between 1980 and 2000. In the figures, each color other than light grey represents a component. In 1980, there was a very large (blue) component covering most of the country, and several small ones mostly in the southwest. In 1990, the large blue component became more porous, revealing more light grey pixels in it, and shrank in overall size. The contraction of the blue component is very startling in 2000. It is most visible in the central and southern parts of the country. At the same time, the North Korean-Chinese border region experienced substantial fragmentation. Unlike in 1980 or 1990, the border is covered with pixels other than blue, meaning small networks separated from the large blue component.

Wickham et al. (2010) said that identifying and mapping of ecological networks are a significant part of green infrastructure research, and focused on forest and wetland for their green infrastructure mapping in the United States. In North Korea, the concept of green infrastructure is premature considering its dire economic and political conditions, but it is not too early to conduct research about its green infrastructure, particularly forest, before it degrades irreparably. North Korea shares borders with South Korea and China, and forest crosses the borders. Human activity degrading forest is constrained by the border, but the negative consequences, such as increased sediment loads in streams or riverine flooding are not. The present study identified degradation of forest cover in North Korea both in terms of quantity and quality, which can be of interest both to environmental managers in South Korea and China.

Conclusion and Recommendations

We examined the changes in forest cover in North Korea between the 1980s and 2000s using the Morphological Spatial Pattern Analysis (MSPA) and network analysis. The findings are summarized as follows: (1) Forest cover sharply decreased between the 1990s and 2000s, particularly in western provinces; (2) Morphological classes indicating fragmentation such as islet, branch and edge consistently increased in their fraction to the total area between the 1980s and 2000s; (3) Islet, branch and edge also increased in frequency during the same period; (4) Forest networks shrank in size and increased in number. Overall, the results demonstrate that deforestation and fragmentation of forest occurred simultaneously in North Korea during the time.

These morphological changes might have been considerably influenced by various land use practices including urbanization, agricultural land expansion, industrial development, or other activities. However, it is difficult not only to pinpoint the main causes of these changes but also to interpret how they interact with each other. Better understanding of cause and consequence relations regarding our findings is deferred to the next step in research.

Our study emphasized the importance of analyzing forest degradation in the form of fragmentation. North Korea's forest stock not only decreased in amount but also degraded resulting in poorer connectivity. Restoring forest in North Korea may require an enormous amount of resources, therefore it is important to set priority. To maximize benefit with limited resources, we think restoration efforts should focus on improving connectivity of forest, which currently receives a lot of attention in ecology and land conservation planning (Saura and Torne 2009). Therefore, it is important to understand the morphological pattern of forest, and it can be done using the approaches of our study. Future studies in this topic need to extend beyond the borders with South Korea and China.

Figure Captions

Fig. 1 Land cover and provincial boundaries of North Korea in year 2000, with the inset map showing neighboring South Korea and China and major cities

Fig. 2 Illustration of morphological categories in MSPA (Image captured from the study results)

Fig. 3 Fraction of forest cover to the entire land area by province, 1980-2000

Fig. 4 Map of MSPA classes for 1980 (a), 1990 (b), and 2000 (c) and their fractions to the entire land area. The fractions may not add up to 100% due to rounding.

Fig. 5 Fraction of MSPA classes to the entire country (upper panel) and to the entire forest (lower panel), 1980-2000. The information in the upper panel also appears in the **Fig. 4** legend.

Fig. 6 Frequency of each MSPA class occurring as individual objects, 1980-2000

Fig. 7 Map of forest network for 1980 (a), 1990 (b), and 2000 (c). Each color other than grey represents a network component.

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