Ph.D. Dissertation of Engineering
(Landscape Architecture)

Impacts of Landscape Pattern Change on Ecosystem Services in a Highly Urbanized Area

- Spatiotemporal Perspective -

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IMPACTS OF LANDSCAPE PATTERN CHANGE ON ECOSYSTEM SERVICES IN A HIGHLY URBANIZED AREA - SPATIOTEMPORAL PERSPECTIVE -

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ABSTRACT

Massive and rapid urbanization causes considerable land use transformation that can lead to the degeneration of Ecosystem Services (ESs) and a loss of biodiversity. The quality of ESs that a habitat provides can be significantly affected by landscape patterns. However, quantitative knowledge of historical changes in both landscape patterns and ESs at various urban scales is limited. This thesis sought to map and quantify changes in landscape patterns and ESs and their relationships through three case studies in a human-dominated, modernized landscape in Seoul, Republic of Korea. To achieve these goals, a time-series dataset of land use and land cover (LULC) maps from 1950 to 2015 was created using ArcGIS software. Changes in landscape patterns were quantified using FRAGSTATS software (ver. 4.2.1). A specific subset of landscape metrics was used for each study. Each ES indicator was mapped and quantified using an Integrated Valuation of Ecosystem Services and Tradeoffs model (InVEST).

The Chapter one proposes to identify ESs, especially those generated by urban green space, and quantify their spatiotemporal variations at the regional scale in the southern part of Seoul City. The study first detected changes in landscape patterns, and then chose one ES indicator—carbon sequestration (CS)—as a test case, and explored its spatial pattern using InVEST model. Total potential CS decreased by 41.2% from 1975 to 2015, with loss and fragmentation of landscapes occurring and patches becoming smaller and simpler in shape in the urban area, as indicated by landscape metrics. Moreover, strong decreases in urban forest and agricultural areas were the primary causes of loss of CS. On the other hand, a 120% increase in the grassland area somewhat offset these two factors.

Chapter two aims to changes in the extent of forest ecosystems and the role played by historical forest remnants (HFRs) in generating ESs in the human-dominated modernized landscape of Seoul, Republic of Korea, using the spatial configuration of habitats to measure an index of biodiversity as an ES. Land-cover maps from two periods were used to identify and sample 37 isolated patches within current parks with HFRs. Then landscape patterns and modeled habitat quality and habitat units (HUs) were quantified as proxies for biodiversity using the InVEST model. Subsequently, Pearson correlation coefficients and forward stepwise multiple regression were used to examine the landscape metrics combined with HUs to explore key indicators that affect the biodiversity of HFRs. A 35.31% decline in total HUs was observed due to a significant decline in total forest area; however, the HUs of the HFRs increased by 0.5%. The shapes of current forests may positively affect the biodiversity of HFRs, whereas the area of newly formed habitats may negatively affect biodiversity. Thus, the careful design of newly formed habitats during city planning should include the preservation of historical remnants.

In Chapter three, based on the landscape pattern theory, a specific landscape types at a local scale is explored to improve the current understanding of informal settlements and their formation in a landscape of the metropolitan fringe, using a case study of Guryong Area (GA) in our study region. The study measured LULC changes in the entire GA from 1950 to 2015, and then analyzed the changes in one specific land-use type defined as "spontaneous settlements", then combined these changes with ecological data (landform, slope) in 600-m-wide bands along the gradient of urbanization. The results showed spontaneous settlements distributed in small clusters in 1975, and the growth of this distribution into larger, more condensed clusters beginning in 1985. Between 1950 and 2015, the total area of spontaneous settlements decreased, while the settlement locations shifted from the urban

core to the marginal area of the GA. Meanwhile, the locations selected for spontaneous settlements moved from plain areas with slopes of 2%-7%, to more steeply sloped, remote areas such as the mountain foothills with slopes of 15–30%. These results suggest that the spatial characteristics of informal settlements are shown in the degree of aggregation and marginalized trend indicated from the analysis of spontaneous settlements.

Keyword: Habitat fragmentation, habitat quality, carbon sequestration, urban fringe, InVEST model, informal settlements, Seoul.

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PUBLICATIONS

Please note that chapter 1-3 of this dissertation proposal were written as stand-alone papers (see below). Chapter 1 and 3 were published in 2017 and 2018, and chapter 2 will be submitted to the international peer-reviewed journal soon.

CHAPTER 1

Yiwen Han, Wanmo Kang, Youngkeun Song*,(2018). Mapping and Quantifying Variations in Ecosystem Services of Urban Green Spaces: a Test Case of Carbon Storage at a District Scale in Seoul (1975-2015); *International Review for Spatial Planning and Sustainable Development,* 6(3), 110-120.

CHAPTER 2

Yiwen Han, Wanmo Kang, James Throne, Youngkeun Song*; Effects of Landscape Patterns of Current Forests on the Habitat Quality of Historical Remnants in a Highly Urbanized Area: Seoul (1972–2015). (Submitted)

CHAPTER 3

Yinwen Han, Younkeun Song*, Lindsay Burnette and David Lammers, (2017). Spatiotemporal Analysis of the Formation of Informal Settlements in a Metropolitan Fringe: Seoul (1950-2015). *Sustainability,* 9(7), 1190

CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Extensive and rapid urbanization causes considerable land-use transformation, which can lead to the degeneration of ecosystem services (ESs) and a huge loss of biodiversity (Martínez-Harms & Balvanera, 2012). Thus, instead of merely managing urban landscapes, the concepts of ecosystem functions, sustainability, and resilience must be translated and integrated into policymaking by urban planners and policymakers.

ESs refer to how ecosystems benefit humans (Bodin, Tengo, Norman, Lundberg, & Elmqvist, 2006; Costanza et al., 1997). The concept of ESs has developed rapidly in the last two decades. Hundreds of projects and groups are currently working toward a better understanding of ESs and their modeling, evaluation, management, and natural capital (Costanza et al., 2014). Since Costanza et al. (1997) evaluated ESs at a global scale in a paper published in *Nature* (Costanza et al., 1997; De Groot, Wilson, & Boumans, 2002), the term ESs has gained wide attention. From 2001 to 2005, the United Nations conducted its Millennium Ecosystem Assessment (MEA), a 4-year, study for policymakers performed by 1,300 scientists (Costanza et al., 2014). The MEA defined four ES functions: provisioning, regulating, cultural, and supporting. These were broadly accepted and applied by both the public and professionals. Between 2007 and 2010, the United Nations Environment Program undertook a program called The Economics of Ecosystems and Biodiversity (TEEB), which brought ESs to the attention of a wider audience through the mass media (Costanza et al., 2014). Subsequently, the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) was created in 2012 and further enhanced the ability to evaluate, manage, apply policy, and cooperate internationally regarding ESs.

Urban ESs are defined as those services that are directly produced by ecological structures within urban areas or peri-urban regions (Luederitz et al., 2015). Urban green space (UGS) can be viewed as a central component of "green structure "or "green infrastructure" and has a major role in urban ecosystems (James et al., 2009; Tratalos, Fuller, Warren, Davies, & Gaston, 2007), providing critical urban ESs (Wolch, Byrne, & Newell, 2014), ranging from high-maintenance urban parks to natural areas and buffer space between noisy infrastructure and other land uses (Panduro & Veie, 2013). As a focal point for the delivery of social and environmental goods (Young, 2010), these diverse types of ESs confer great benefits to urban environments.

In this study, landscape patterns were defined according to the number, frequency, size, and juxtaposition of landscape elements that are important for the determination or interpretation of ecological processes[①]. Increasing numbers of studies have shown that landscape patterns, i.e., the arrangement, size, and shape of habitat fragments, have important effects on ES provision (Bodin et al 2006, Kremen et al 2007, Syrbe and Walz 2012). The size and shape of habitats are the most important predictors of species richness and diversity (Carpintero & Reyes-Lopez, 2014; Ramalho, Laliberte, Poot, & Hobbs, 2014). For example, the richness of woody species is higher in large habitats compared to small ones (Ramalho et al., 2014). Another factor to consider is the age of fragmented habitats. There are time-lag and feedback mechanisms in play within socio-ecological systems when the land use types change. Many long-lived plants, and those with certain life-history traits, are able to persist for long periods after conditions become unfavorable (Eriksson, 1996).

However, quantitative knowledge of historical changes in both landscape patterns and ESs at various urban scales is limited (Derkzen, Teeffelen, &

[①] U.S Forest Service: https://www.fs.fed.us/

Verburg, 2015; Gómez-Baggethun & Barton, 2013; Haase, 2013). Most publications have sought to quantify ESs at regional or national scales, with a focus on natural and rural landscapes (Byrd et al., 2015). For example, Martínez Harms et al. (2012) concluded that of 70 Web of Science[2] publications between 1995 and 2011 that mapped ESs, 57% of mapping was at a regional scale, followed by 15% at a national scale; far fewer studies have been conducted at patch, local, or global scales (Martínez-Harms & Balvanera, 2012).

This thesis comprises three case studies on the human-dominated modernized landscape of Seoul, the Republic of Korea, during a period of rapid urbanization. ESs are still prone to frequent rapid degradation and depletion by multiple natural and anthropogenic disturbances (Fraterrigo & Rusak, 2008; Sharp et al., 2014). Land cover and land use (LULC) changes have been characterized as the most important anthropogenic disturbances to the environment at the local level, and can greatly alter the provision of ESs (Lawler et al., 2014). Thus, a comprehensive spatiotemporal analysis of LULC is useful for understanding changes in both landscape patterns and ESs. Chapter 1 proposes an indicator of ESs, carbon sequestration, based on UGS in seven districts of Seoul, and a method to quantify the spatiotemporal variation therein from 1975 to 2015. Chapter 2 addresses changes in the extent of forest ecosystems and the role of historical forest remnants (HFRs) in generating ESs, in a case study based on biodiversity. In our study area, the urban forest was fragmented into hundreds of patches during urbanization, constituting islands in a sea of buildings and infrastructure. Based on landscape pattern theory (S. K. Hong, I. J. Song, H. O. Kim, & E. K. Lee, 2003). Chapter 3 explores specific landscape types at the local scale to improve the current understanding of informal settlements and their formation in the metropolitan fringe, through a

[2] http://apps.webofknowledge.com

comprehensive spatiotemporal analysis of the Guryong area (GA). The major research questions for the three chapters comprising this study are:

✧ **What has been the response of ESs to changing landscape patterns in UGS?** (Chapter 1)

1) How did the historical landscape change from 1975 to 2015?

2) What were the characteristics of these landscape changes?

3) What was the response of carbon sequestration to historical landscape changes?

✧ **How do the landscape patterns of current forests affect the habitat quality of HFRs?** (Chapter 2)

(1) How did landscape pattern and habitat quality of forest habitats change during the urbanization process at 7 districts in the Seoul city between 1972 and 2015?

(2) What is its role of HFRs played in supporting urban biodiversity?

(3) What are the dominated landscape metrics of modern forests habitats in affecting the biodiversity of HFRs?

✧ **What does landscape pattern analysis show regarding the formation of informal settlements in the metropolitan fringe?** (Chapter 3)

1) What was the historical development of LULC from 1950 to 2015?

2) What characteristics of informal settlement formation were revealed by the changes in LULC?

3) How is the formation of informal settlements related to the topographical characteristics of the marginal area?

4) What are the potential future implications of the historical and ecological research for urban planning and informal settlement redevelopments?

CHAPTER 1

Mapping and Quantifying Variations in Ecosystem Services of Urban Green Spaces: A Test Case of Carbon Sequestration at the District Scale for Seoul, Korea (1975-2015)

1.1 Introduction

The concept of ecosystem services (ESs) has developed rapidly over the past two decades. Hundreds of projects and groups are currently working toward better understanding, modeling, valuation, and management of ESs (Costanza et al., 2014). However, previous studies have generally focused on quantifying the ESs of natural and rural landscapes at regional or national scales (Byrd et al., 2015; Martínez-Harms & Balvanera, 2012), while less than 10% of all ES publications deal with urban ESs (Derkzen et al., 2015; Gómez-Baggethun & Barton, 2013; Haase, 2013). Urban ESs can moderate many common environmental issues in cities, such as air pollution, biodiversity loss, and heat stress, as caused by the land-use transformation that occurs during urbanization (Larondelle & Haase, 2013; Y. Li, Kang, Han, & Song, 2018).

As a central component of cities' "green infrastructure" (James et al., 2009; Tratalos et al., 2007), urban green space (UGS) provides critical urban ESs for local residents (Wolch et al., 2014). UGS includes many types of space, ranging from high-maintenance urban parks to natural areas and buffer spaces between noisy infrastructure and other land-use types (Panduro & Veie, 2013). These diverse types of UGS are important for the delivery of social and environmental goods (Ricard & Bloniarz, 2006; Young, 2010), providing a great benefit to the urban environment; thus, more attention should be paid to UGS.

Previous studies have evaluated the benefits derived from UGS in cities. These studies often estimated the economic value of UGS (J. K. Abbott & Klaiber, 2010; Morancho, 2003), as well as the aesthetic (Southon, Jorgensen, Dunnett, Hoyle, & Evans, 2017), environmental (Sandström, Angelstam, & Mikusiński, 2006; Yang, Sun, Ge, & Li, 2017), and social value (Barbosa et al., 2007; Chan, 2017; Dennis & James, 2017). Several studies have also investigated UGS directly based on ES theory. For example, Derkzen et al. (2015) quantified the ES of UGS in Amsterdam and Niemela et al. (2010) addressed the most important ES in functional urban regions in Finland through measurement of UGS. However, studies investigating ESs at various urban scales are still limited.

Comprehensive spatiotemporal analyses of the landscape can offer a powerful tool for uncovering historical relationships between human activities and the environment (Fuchs et al., 2015; Grecchi, Gwyn, Benie, Formaggio, & Fahl, 2014; Han, Song, Burnette, & Lammers, 2017; S. Li, Wang, & Zhang, 2017; Shahraki et al., 2011), and also provide evidence for urban ecosystem conservation and restoration through analysis of urban ESs from a historical perspective.

In this study, we propose to identify an indicator of ESs at the regional scale in the metropolitan area of Seoul, the Republic of Korea, and to quantify spatiotemporal variations therein from 1975 to 2015. The potential for urban habitats to capture and store atmospheric carbon is increasingly important amid growing concerns over the role played by anthropogenic CO_2 in global climate change (Grafius et al., 2016; G. G. Lee, Lee, & Lee, 2015). Thus, we chose carbon sequestration (CS) as a test case, and explored the response of CS to landscape changes. We aimed to answer three questions: 1) how did the historical landscape change from 1975 to 2015? 2) what were the characteristics of these landscape changes? and 3) what was the response of CS to historical landscape changes?

1.2 Methods

1.2.1 Research site

This study investigated historical changes in a region that has been expanding and developing since the 1960s in southern Seoul City. Land use in this urban region showed significant changes from the 1960s to 2000s, largely

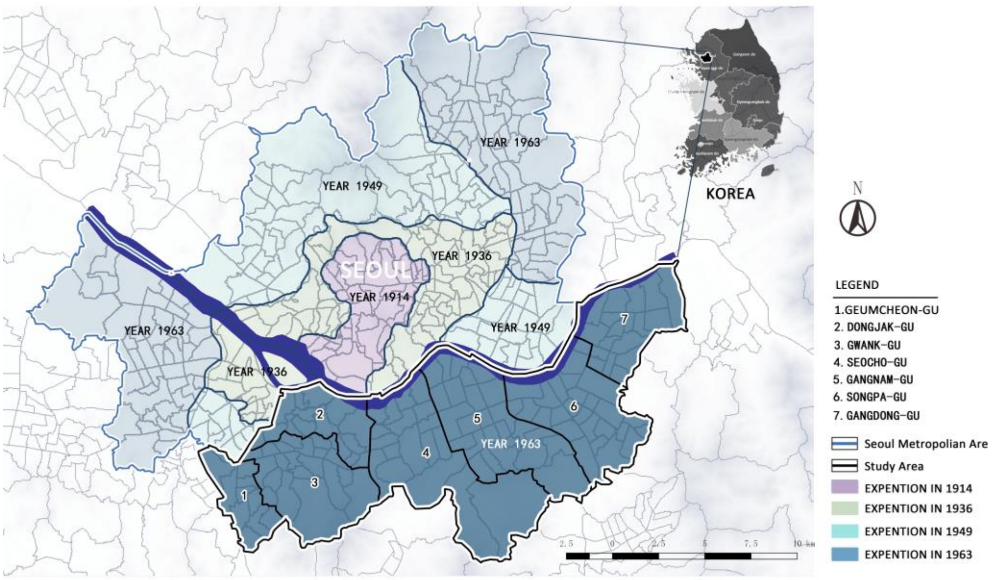

Figure 1-1. Research site

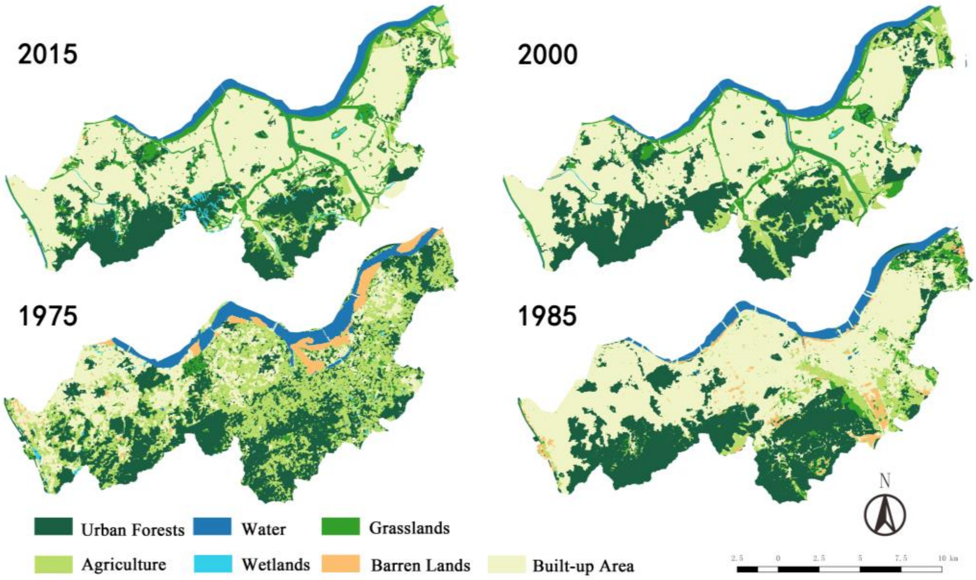

Figure 1-2. Landscape maps from 1975 to 2015

due to the urbanization of peri-urban areas. The study region is approximately 20,430 km^2 in area, including Gangdong-gu District, Songpa-gu District, Gangnam-gu District, Seocho-gu District, Gwanak-gu District, Geumcheon-gu District, and Dongjak-gu District (Figure 1-1).

1.2.2 Data

A time series of land cover and land use maps was derived from historical aerial photographs taken in 1975, 1985, 2000, and 2015 containing land cover information. The maps for 1975 and 1985 had resolutions of 60m and 30m, respectively, and were created by the Water Management Information System③. The maps for 2000 and 2015 were provided by the Seoul Metropolitan

③ WAMIS, www.wamis.go.kr

Government[④], with 5m resolution. All maps were converted to 5m resolution using ArcGIS 10.2.2 software. We then standardized the significant landscape types represented in the maps according to a common classification scheme. The seven re-classified landscape types were: urban forests, agriculture, water, wetlands, grasslands, barren lands, and built-up area (Figure 1-2). Of these newly classified landscape types, three included areas of UGS: urban forests, agriculture, and grasslands.

1.2.3 Data analysis

Table 1-1. Re-classified landscape types classification.

NO.	Landscape class	Class description
01	Urban forests*	Forests or parks with clustering trees in urban areas; orchards.
02	Agriculture*	Cultivated fields, open agricultural lands.
03	Water	Broad-scale river and stream.
04	Wetlands	Wetlands, lake, pool, or irrigation.
05	Grasslands*	Tombs, creamery park, golf playgrounds, children's park, or grasslands of waterfront areas, parks, and communities.
06	Barren lands	Barren lands, heath, or undeveloped area without vegetation.
07	Built-up area	Urban residential, commercial, industrial areas, transportation, or mixed-use areas.

*Urban green space (UGS) includes landscape types of urban forests, agriculture, and grasslands by reference to the official land use classification in Seoul.

④ SMG, www.gis.seoul.go.kr/SeoulGis/

1.2.3.1 Landscape patterns analysis

To study how landscape changes affect urban ESs, landscape pattern analysis was applied. Landscape metrics have been used previously to analyze spatial characteristics at both the landscape level (i.e., of an entire region) and

Table 1-2. Landscape metrics of landscape types

Acronym	Landscape Metric	Class Level (UGS)	Landscape Level	Description
TLA	Total Landscape area	√		The area of each landscape type
NumP	Number of patch	√	√	Degree of spatial fragmentation of landscape type; complexity
MPS	Mean Patch Size	√	√	Average patch size for or a landscape/ a class
MSI	Mean Shape Index		√	Spatial complexity of a patch's size; artificial (geometric forms) versus irregular natural forms
AWMSI	Area-Weighted mean shape index	√	√	An average shape index of patches, weighted by patch area so that large patches are weighted higher than smaller ones
SDI	Shannon's diversity index		√	SHDI increases as the number of different patch types increases and/or the proportional distribution of area among patch types becomes more equitable.

the class level (of individual UGS) using FRAGSTATS, which is a comprehensive software package for analysis at the patch, class, and landscape levels (McGarigal, Cushman, Neel, & Ene, 2002). FRAGSTATS includes a large number of spatial metrics, classified as area and edge metrics, shape metrics, and aggregation metrics. A specific subset of these three categories was selected for this study (Deng, Wang, Hong, & Qi, 2009). Several landscape metrics, including number of patches (NumP), mean patch size (MPS), mean shape index (MSI), area-weighted mean shape index (AWMSI) and Shannon's diversity index (SDI) were applied herein to clarify changes in overall landscape loss and fragmentation trends at the landscape level. At the class level, landscape metrics were useful and directly relevant to correlated changes in UGS. The landscape metrics were calculated for each year examined, as shown in Table 1-2.

1.2.3.2 Calculating carbon sequestration using the InVEST model

We assessed the amount of CS during four historical periods in the study area using the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) model. InVEST was developed as part of the Natural Capital Project by Stanford University[⑤], the University of Minnesota, The Nature Conservancy, and the World Wildlife Fund. InVEST uses maps of landscape types, which also detail the amount of carbon stored in carbon pools, to estimate the net amount of carbon stored in a given parcel of land (see InVEST user's guide for further details on this method) (Sharp et al., 2014).

The CS module requires an estimate of the amount of carbon in at least one of the four fundamental carbon pools: above-ground biomass, below-

⑤ InVEST: www.naturalcapitalproject.org

Table 1-3. Indexes used for carbon model in InVEST software.

NO.	Landscape type	C_ABOVE	C_BELOW	C_SOIL	C_DEAD	Total
1	Urban forest	53.59	17.36	47.22	11.79	129.96
2	Agriculture	0	0	66.05	0	66.05
3	Water	0	0	0	0	0
4	Wetland	0	0	88.00	11.00	99
5	Grasslands	0.33	0.89	88.20	0.20	89.62
6	Barren lands	0	0.33	0.33	0	0.66
7	Built-up area	0	0	0	0	0

ground biomass, soil organic matter, and dead organic matter. Aboveground biomass comprises all above-soil living plant material; belowground biomass encompasses the living root systems attached to the aboveground biomass; soil organic matter, the largest terrestrial carbon pool, is the organic component of soil; dead organic matter includes litter, as well as lying and standing dead wood (Sharp et al., 2014). All four fundamental pools were examined in our study. The CS index was derived from previous studies (Chung, Kang, & Choi, 2015; KEI, 2016; NIFoS, 2015; Tomasso & Leighton, 2014)(Table 1-3); Based on the input parameters, we quantified the total CS for each period examined.

1.3 Results and discussion

1.3.1 Detection of historical changes in the urban landscape

Seoul experienced rapid urbanization between the 1960s and the 1990s, with landscape changes occurring in relation to numerous projects, and with

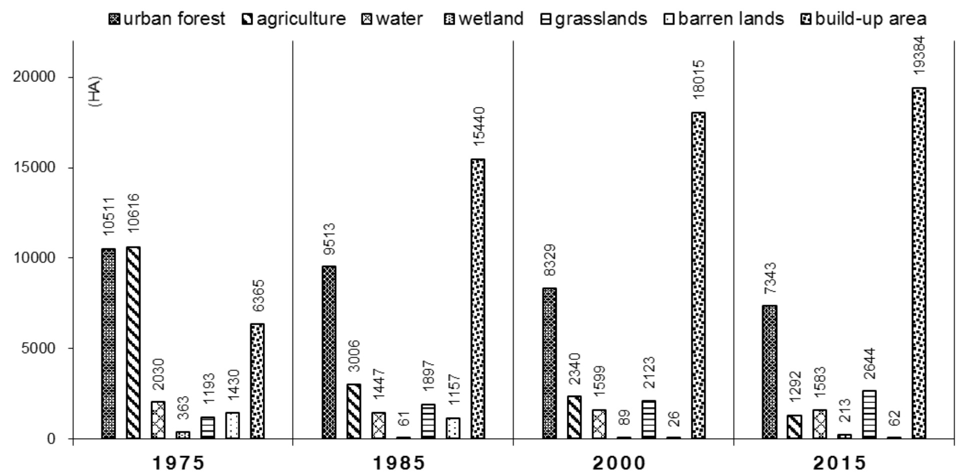

Figure 1-3. The total landscape area of each landscape type from 1975 to 2015

little consideration for the natural environment (S. K. Hong et al., 2003). Data on the areas covered by each landscape type in the four years examined in this study are presented in Figure 1-3. The most significant change was in the large areas of natural landscape that were lost with the dramatic increase in construction area (Han et al., 2017). Built-up area covered approximately 19,384 ha in 2015, compared with 6,365 ha in 1975 (Figure 1-3). The second most significant change occurred in the agricultural landscape: the proportion of agricultural land decreased by 90% over the 40-year period and, by 2015 (Figure 1-3), only a small amount of agricultural land remained on the outskirts of the district (Figure 1-2).

Significant changes in landscape type occurred during the period 1975–1985. The agricultural landscape declined in extent by approximately 72%, while the amount of built-up area increased significantly (Figure 1-3). Most of the rural landscape was urbanized during this period. In addition, after the 1990s, although the process of urban transformation slowed, forest area still decreased between the years of 2000 and 2015, while the built-up area increased steadily.

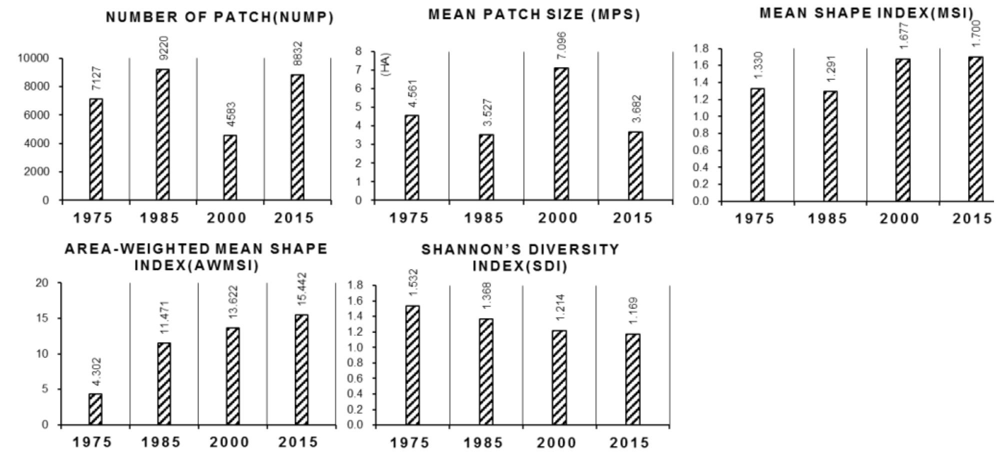

Figure 1-4. The results of examined landscape metrics at the landscape level from 1975 to 2015

UGS in the study area changed significantly, as indicated by the proportions of the urban forest, agriculture, and grassland landscape types. The area covered by urban forests decreased by about 30%, while that covered by grasslands increased by 120%, approximately; most of the grasslands had previously been forest and agricultural lands. This shift could be attributable to the “Parks Act”, enacted in the 1980s, which had the goal of enhancing urban greenness via park-related laws, and which transformed cultural and historical sites into neighbourhood parks.

In addition, a trend toward urban landscape fragmentation was indicated by the NumP and MPS values. At the landscape level, the overall NumP increased from 7,127 in 1975 to 8,832 in 2015. MPS showed its highest value (7.096) in 2000, but this decreased by approximately 50% (3.682) by 2015 (Figure 1-4). The fragmentation trend can also be explained by reference to the spatial metrics of UGS at the class level. Urban forests were present in only 2,188 patches in 1975, versus 4,844 patches in 2015 (Figure 1-5). Meanwhile, the NumP of agriculture decreased steadily, from 2,037 patches in 1975 to 744

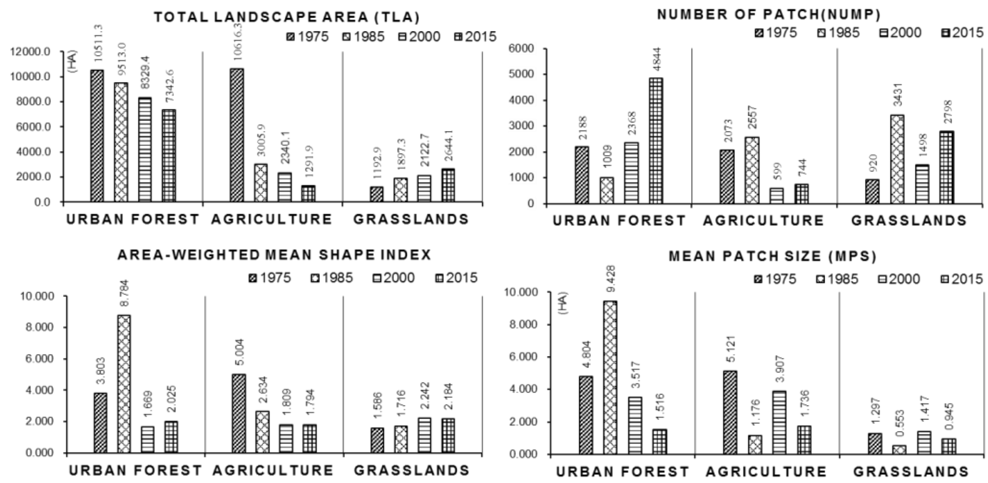

Figure 1-5. The results of examined landscape metrics of UGS at the class level from 1975 to 2015.

patches in 2015, except in 1985 (2,557), when it increased slightly. Meanwhile, the NumP of grasslands increased from 920 in 1975 to 3,431 in 1985, but then decreased to 1,498 in 2000, before finally increasing again to 2,798 in 2015 (Figure 1-5).

Moreover, the diversity of patch types decreased, while the shapes of patches became simpler, and the patch size smaller. At the landscape level, AWMSI increased from 4.302 in 1975 to 15.442 in 2015, and SDI decreased from 1.532 in 1975 to 1.169 in 2015 (Figure 1-4). However, UGS at the class level shows different results, both in terms of landscape types and year of study. For example, a previous study reported that forest patches decreased during the period 1988–1999 and patch shapes became smaller and simpler (S. K. Hong et al., 2003), as indicated in our study by the sharp declines in MPS and AWMSI from 1985 to 2000; however, AWMSI showed a contrary trend for the period 2000–2015, with a slight increase from 1.669 to 2.025 (Figure 1-5).

1.3.2 Historical changes of carbon sequestration (CS)

Land use transformation affects the CS capability of urban areas. The total potential CS in our study area decreased by 41.2% from 1975 to 2015 (Table 1-4). UGS provides important ecosystem-related goods and services at the city level, and plays a particularly critical role in CS. Thus, in this study, the decline in the area of UGS was the main cause for the loss of CS. The proportion of UGS relative to the total study area decreased from 95.5% in 1975 to 81.6 % in 2015 (Table 1-4). Urban forests decreased by 30%, which was the main reason for the decrease in CS, as urban forests and urban soils can significantly increase CO_2 sequestration and storage (Pulighe, Fava, & Lupia, 2016). Urban agriculture contributed to storage of CO_2 in gardens, and could decrease greenhouse gas production in relation to the distance over which food is transported to reach consumers. Our results show that the agricultural landscape in the study area decreased by 90% from 1975 to 2015. Lee et al. (2015) explored the area available for urban farming in the metropolitan area of Seoul, and concluded that urban agriculture in a 51.15 km^2 area within Seoul city could reduce CO_2 emissions by 11.67 million kg annually. The 120% increase in the area of grasslands, which somewhat offset the decreases in agriculture and urban forests, was mainly in the form of urban green infrastructures, such as parks and community gardens.

Table 1-4. The historical changes in carbon sequestration (CS)

Year	1975	1985	2000	2015
Total CS (ton)	1387427.88	1012851.47	902769.47	815535.81
CS of UGS	1317770.62	904879.89	782688.05	665533.74
Proportion	95.5%	89.3%	86.7%	81.6%

1.3.3 The role and applications of UGS in ESs

For certain ESs, the spatial arrangement of UGS is a key determinant of whether a service is actually supplied (Andersson et al., 2015). The type, size, and location of UGS affect ESs supply in different ways. For example, whether a city has a few large or many small habitat areas does not matter in terms of CS, although long and continuous vegetation strips are optimal for noise reduction (McGarigal et al., 2002).

Through mapping the landscape patterns in the research area, the fragmentation of natural habitats was shown to be due mainly to the process of urbanization. CS in our study area decreased by 41.2% from 1975 to 2015. Natural habitat was found to be the UGS type playing the most crucial role in CS. Thus, consideration of the potential for UGS to capture and store atmospheric carbon in urban areas is essential (Darren, Petruccelli, Patton, Winemaker, & de Beer, 2016).

It is also important to differentiate among UGS types when quantifying ESs in an urban area (Pulighe et al., 2016). Although urban forests play an active role in most ecosystem functions, artificial green spaces, such as parks and community gardens, could support several ESs when the forested area shows a sharp decrease. Thus, the importance of careful UGS design during city planning initiatives for the provision of ESs should be highlighted. Moreover, further consideration should be given to enhancing the CS capability of UGS during urban planning and policy making. We hope that our study will contribute to a greater understanding of the potential of historical processes to inform future policy decisions related to green infrastructure and land-use planning.

CHAPTER 2

Effects of Landscape Patterns of Current Forests on the Habitat Quality of Historical Remnants in a Highly Urbanized Area: Seoul (1972–2015)

2.1 Introduction

Extensive and rapid urbanization causes considerable land-use transformation, which can lead to the degeneration of ecosystem services (ESs) and a huge loss of biodiversity (Chiang et al., 2014; Martínez-Harms & Balvanera, 2012; Terrado et al., 2016). Thus, instead of merely managing urban landscapes, the concepts of ecosystem functions, sustainability, and resilience must be translated and integrated into policymaking by urban planners and policymakers (Pulighe et al., 2016).

The increased fragmentation of natural habitats caused by anthropogenic land use in cities has resulted in the creation of small and isolated remnants. These remnant habitats, often being a part of urban green spaces, support a number of valuable direct and indirect ESs such as air purification (Derkzen et al., 2015), carbon storage (Jo, 2002), run-off retention(Young, 2010), and biodiversity (Strohbach, Lerman, & Warren, 2013). In particular, older remnant habitats are better able to support biodiversity (e.g., species richness and evenness) and have fewer invasive species relative to newly developed habitats (Mitchell, Bennett, & Gonzalez, 2015). In addition, after conditions become unfavorable, many long-lived plants or those with certain life history traits are unable to change, even over long periods (Eriksson, 1996).

Previous studies have determined that the amount and quality of ESs provided by a habitat can be drastically altered by the spatial patterns of the landscape (Dallimer et al., 2015; Dearing et al., 2012; T. H. Li, Li, & Qian, 2010). Ecological changes may be driven primarily by changes in spatial configuration (Didham, Kapos, & Ewers, 2012). Several studies have implied that the size and shape of habitats are the most important predictors of biodiversity (Carpintero & Reyes-Lopez, 2014; Ramalho et al., 2014). For example, succession of woody vegetation proceeds more slowly within small fragments (Cook, Yao, Foster, Holt, & Patrick, 2005). Moreover, the spatial configuration of the landscape appears to be crucial for indirect or interactive effects among habitats (Bodin et al., 2006; Kremen et al., 2007; Syrbe & Walz, 2012), and in some cases, it actively affects the provisioning of ESs (Ewers & Didham, 2006; Haddad et al., 2015). For example, the pollination of agricultural fields can potentially be increased when the interspersion of natural habitats increases (Brosi et al., 2008). Much of the research on the effects of landscape patterns during urbanization has focused on densely forested regions in cities (Fahey & Casali, 2017; Ripple, Bradshaw, & Spies, 1991). However, our understanding of the effects of urban landscape patterns on the provisioning of ESs remains limited in urban areas (Dallimer et al., 2015). Few studies have distinguished historical forest remnants (HFRs) from recently established habitats (Fahey & Casali, 2017), and we do not currently understand how ESs are provided by HFRs based on the spatial configuration of current habitats. However, HFRs have been examined in some urban environments. For example, Ramalho et al. (2014) reported that the abundance and richness of woody species were higher in large HFRs in the rapidly expanding city of Perth, Australia. Fahey et al. (2017) demonstrated that a higher canopy cover, basal area, and dominance by natives occurred in HFRs of the metropolitan region of Chicago, United States.

In this study, we addressed variation in the extent of urban forests in a rapidly urbanized region and quantified the role of HFRs in generating ESs within a human-dominated modernized landscape, using biodiversity as a representative ES. Our study area was located in the southern part of Seoul, the Republic of Korea. During urbanization, the original forest was severely fragmented into hundreds of patches, which now constitute islands in a sea of constructed land-use types (S.-K. Hong, I.-J. Song, H.-O. Kim, & E.-K. Lee, 2003). A time-series of images was useful for determining whether an urban tree canopy cover was associated with remnants or planted forests (Fahey & Casali, 2017). We used two periods to identify HFRs and then selected fragmented samples using historical land-cover maps from 1972 to 2015. Then we quantified the landscape patterns and modeled habitat quality (HQ) and habitat units (HUs) as a proxy for biodiversity using InVEST model. The specific objectives of this study were to process joint analyses of landscape metrics and HQ of forest habitats during the urbanization process in Seoul between 1972 and 2015, to identify HFRs and their role in supporting urban biodiversity, to explore the role of the landscape metrics of current habitats in affecting the biodiversity of HFRs, and to discuss implications for planning and design strategy in urban forest conservation.

2.2 Methods

2.2.1 Study Area

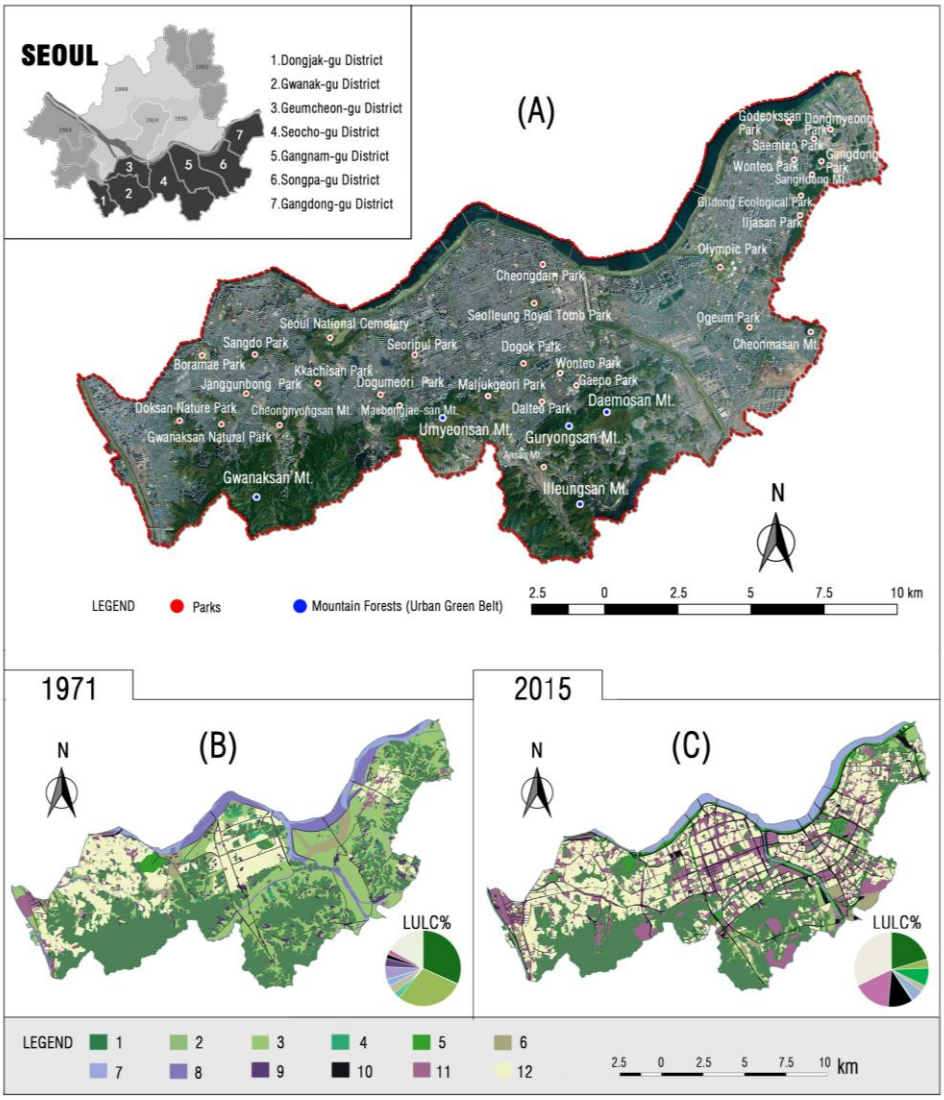

Figure 2-1. (A) Study area; (B) and (C) shows the reclassified land use and land cover (LULC) maps in 1972 and 2015; Legend: 01. Urban Forests; 02. Pasture; 03.Agricultural Areas; 04.Orchards; 05. Designed Green Spaces; 06. Vacant Lands; 07. River; 08. Wetlands; 09. Rural Settlements; 10.Transportation; 11. Service Business and Infrastructure; 12. Urban Residential Area.

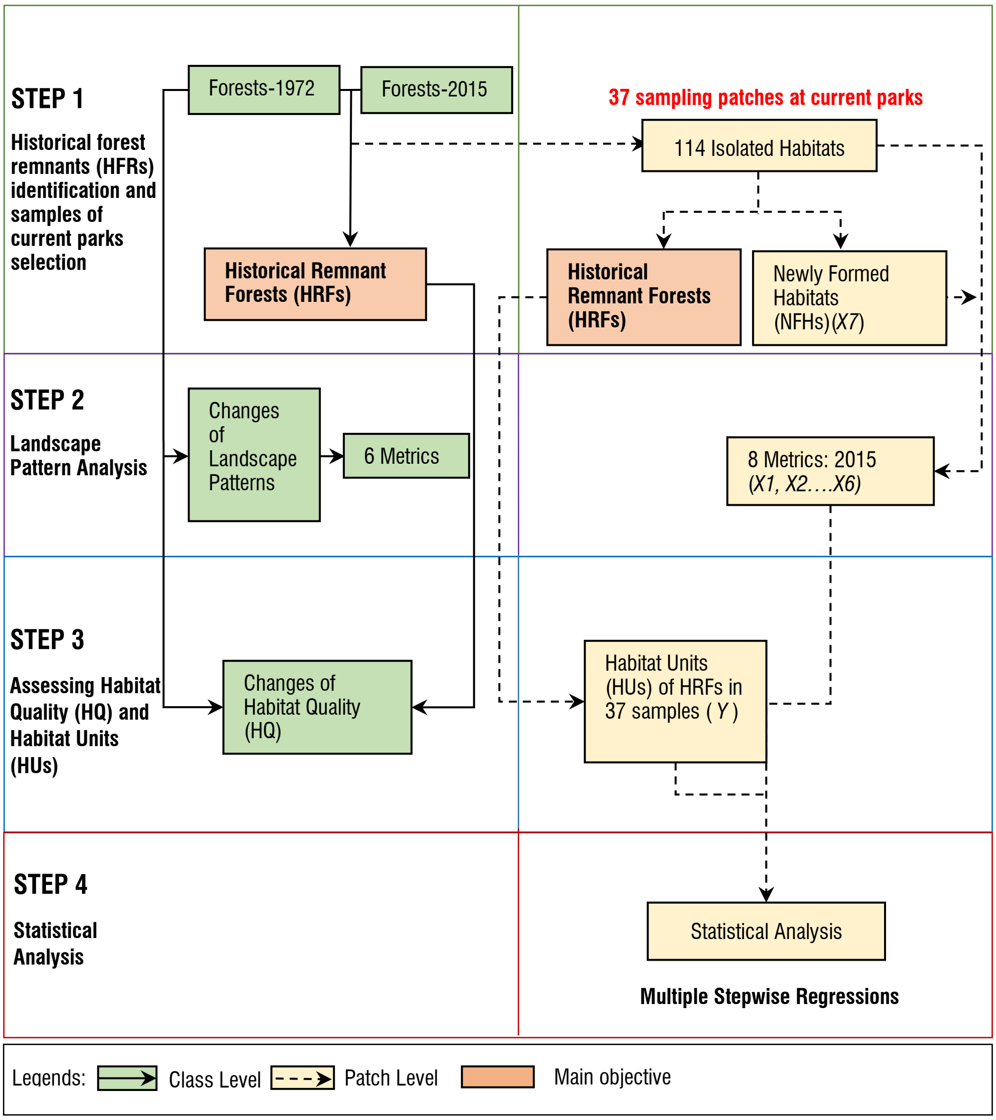

Figure 2-2. The overall modeling process

Table 2-1. Reclassification of LULC used in the analysis.

NO	Land cover class	Class description
01	Urban Forests	Remnant nature forests (deciduous forests, conierous forests) and planted woodlands.
02	Pasture*	Nature grasslands
03	Agricultural area	Cultivated field, open agricultural land, crops or paddy fields.
04	Orchards*	Fruit trees
05	Designed Green Spaces**	Designed grasslands, open fields withour trees or with sparsly distributed trees, such as parks and recreation centers, golf course and cemeteries.
06	Vacant Lands	Newly developed residential area, commercial area or roads that, at the time of constrution, were cleared, containing no tree canopy cover.
07	River	River, stream, pool, and canal.
08	Wetlands	Riparian plantated areas, pools or lakes in urban parks
09	Rural Settlements	Historic villages hamlets, urban villages with informal characteritics
10	Transportation	Roads, large scale/public parking lots.
11	Service Business and Infrastructure	Commercial and industrial areas, or public facilities.
12	Urban Residential Area	Housing sites, settlements and urban sprawl.

*The land use type only shows in 1972; **The land use type only shows in 2015.

The city of Seoul was originally famous for its forested and mountainous landscape, but rapid urban growth since the 1960s has significantly degraded the natural landscape (Oh, 1998). The metropolitan area and surrounding districts of Seoul are still encompassed by forested mountain landscapes (Han et al., 2017), and a number of fragmented forest remnants are scattered throughout the city. These remnants are in need of direct connections outlying forested mountain areas.

This study investigated an urban area developed from the 1970s to the 1990s in the southern part of Seoul. The region covers about 204.36 km^2, including seven districts (Figure 2-1A). The research area borders numerous still-forested mountain areas to the south, and is bounded on the north by the Han River. Aside from the forested mountains, remnant patches of forest found within the urban boundary are generally fragmented and separated.

2.2.2. Base Data

We used land cover and land use (LULC) datasets from 1972 to 2015, which were generated from historical aerial photos with 5 m resolution. We digitized a 1972 map from a paper version (National Construction Research Institute, 1972), and the 2015 map was provided by the Seoul Metropolitan Government (Government, 2015); then we standardized and transformed the most important types of LULC on the different maps into a common classification using ArcGIS software. Finally, 12 re-classified LULC types were created (Figure 2-1B & 2-1C) (Table 2-1). Forest covers from 1972 and 2015 in combination with historical forest data from 1985, 1995, 2000, and 2010 (also provided by Seoul Metropolitan Government) were used to manually identify the HFRs.

2.2.3. Data Analyses

Once the HFRs were identified, we selected the city parks containing them for our analyses. Then we quantified the landscape patterns (metrics) of these areas and also modeled the Habitat Quality (HQ) and Habitat Units (HUs) as a proxy for biodiversity. Lastly, the defined landscape metrics combined with HUs were analyzed using Pearson correlation coefficient and forward stepwise multiple regression to explore the key landscape metrics of current forests that affect the HQ of the HFRs (Figure 2-2).

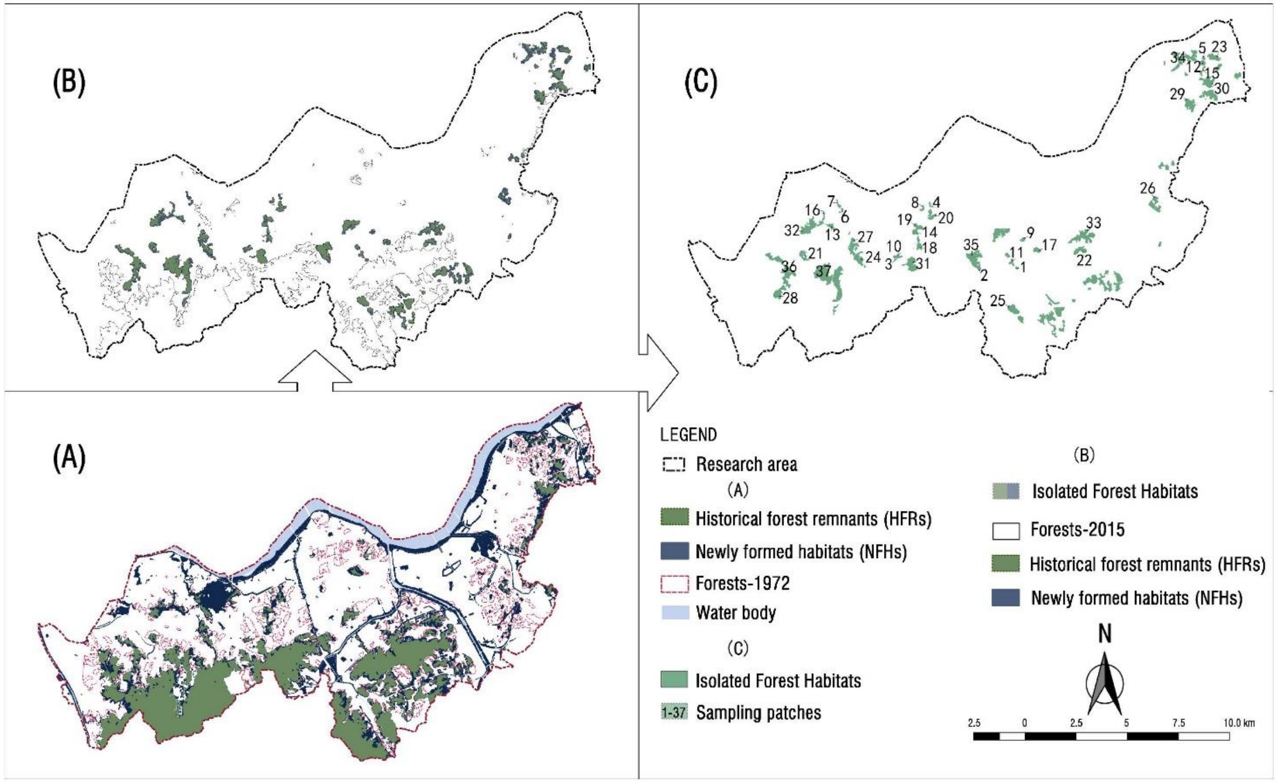

Figure 2-3. (A) Habitat classification including 581 historical forest remnants (HFRs) ;(B) 114 isolated patches in Forest 2015; (C) Selected 37 sampling patches of 114 isolated patches at current parks.

Table 2-2. Definitions of terms using in this study.

Defined term	References	Descriptions
Forests-1972	1972	The forest habitats in 1972; most of forests area were not fragmented by urban built-up area.
Historical Remnant Forests (HFRs)	1972,1985, 2000,2015	The forest area which has existed in 1972 and is still present in 2000 and 2015.
Newly Formed Habitats (NFHs)	2015	The green spaces which designed, planned or constructed by artificial way.
Forests-2015	2015	The forest habitats in 2015, including HFRs and NFHs. A Part of HFRs is built as current parks.

Table 2-3. Selected 37 sampling HFRs of isolated forest habitats at current parks in 2015.

No.	Name	No.	Name	No.	Name	No	Name
25	Ansan Mt.	34	Godeokssan Mt.	21	Janggunbong Park	5,12, 15	Saemteo Park
37	Cheongnyongsan Mt.	28,36	Gwanaksan Natural Park	24,27	Kkachisan Park	6,7	Seodalsan arboretum
1,11	Dalteo Park	29	Gildong Ecological Park	31	Maebongjae-san Mt.	4,8, 14,18, 19,20	Seoripul Park
3,10	Dogumeori Park	17	Gaepo Park	2,35	Maljukgeori Park	9	Wonteo Park
22	Daemosan Nature Park	33	Gwangsusan Mt.	26	Ogeum Park		
23	Dongmyeong Park	30	Gangdong Park	13, 16,32	Sangdo Park		

2.2.3.1. Step 1: HFRs identification and samples of current park selection

The classes of forests-1972 and forests-2015 that are composed of HFRs and newly formed habitats (NFHs) were defined after examination of the spatial characteristics of the historical process (Figure 2-3A, Table 2-2). Forest-1972 comprises the original forest landscape in 1972 before urbanization, whereas forest-2015 is the forest landscape in 2015 after rapid urbanization. HFRs were determined by comparing the two maps, resulting in 581 remnant patches. The HFRs in 114 isolated patches were identified in forest-2015. Then we removed patches that crossed the administrative border of our research area (Figure 2-3B), resulting in 37 samples of 114 isolated patches within current parks that had an area of more than 1 ha (Figure 2-3C). Finally, we classified these patches into three classes: <5 ha, 5–20 ha, and >20 ha (Table 2-2).

2.2.3.2. Step 2: landscape pattern analyses

Landscape patterns can be quantified using statistical methods in terms of the landscape unit itself, as well as the spatial relationship of the patches and matrix comprising the landscape. Therefore, a selection of these measures can describe several aspects of fragmentation that have occurred as a result of human disturbance (Ripple et al., 1991). The spatial metrics of forest habitats at the class level and patch level were chosen for the description of landscape structure and patterns in 1972 and 2015 using FRAGSTATS version 4.2.1. (McGarigal et al., 2002). FRAGSTATS provides a large number of spatial metrics classified into area and edge metrics, shape metrics, and aggregation metrics; a subset of these three categories was selected for this study (Table 2-4) (Deng et al., 2009). At the class level, we chose total area (TA), total edge (TE), number

Table 2-4. The examined landscape metrics at (A) class level and (B) patch level.

Date	Acronym	Landscape Metric	Unit	Description
(A) 1971 2015	CA	Total Area	Hectare	The area of forest landscape;
	NumP	Number of Patches	None	Degree of spatial fragmentation of landscape type; complexity
	TE	Total Edge	Meter	The sum of the lengths (m) of all edge segments involving the corresponding patch type
	MEAN	Mean Patch Size	Square meter	Average patch size for or a forest
	PD	Patch Density	Number of per 100ha	The number of patches of the corresponding patch type divided by total landscape area (m^2), multiplied by 10,000 and 100 (to convert to 100 hectares).
	LPI	Largest Patch Index	Percent	The percentage of total landscape area comprised by the largest patch. As such, it is a simple measure of dominance
(B) 2015	AREA	Total Area	Hectare	The area of each patch
	PERIM	Perimeter	Meter	The perimeter (m) of the patch, including any internal holes in the patch, regardless of whether the perimeter represents 'true' edge or not.
	GYRATE	Radius of Gyration	Meter	The mean distance (m) between each cell in the patch and the patch centroid（meters）; Radius of gyration is a measure of patch extent (i.e., how far-reaching it is); thus, it is effected by both patch size and patch compaction.
	SHAPE	Shape Index	None	The simplest and perhaps most straightforward measure of shape complexity.
	PARA	Perimeter-area Ratio	Percent	A simple measure of shape complexity, but without standardization to a simple Euclidean shape
	CONTIG	Contiguity Index	Percent	The spatial connectedness, or contiguity.
	FRAC	Fractal Dimension Index	None	The shape complexity across a range of spatial scales (patch sizes). Thus, like the *Shape index* (SHAPE), it overcomes one of the major limitations of the straight perimeter-area ratio as a measure of shape complexity.
	ENN	Euclidean Nearest-neighbor Distance	Meter	The simplest measure of patch isolation.

of patches (NP), large patch index (LPI), patch density (PD) and mean patch size (MEAN) for the forest-1972 and forest-2015 datasets to measure patterns of fragmentation. At the patch level for forest-2015, the metrics of total area (AREA), perimeter (PERIM), radius of gyration (GYRATE), shape index (SHAPE), perimeter-area ratio (PARA), contiguity index (CONTIG), fractal dimension index (FRAC), and Euclidean nearest-neighbor distance (ENN) were measured. Subsequently, the results for the 37 sampling patches were selected for further statistical analyses.

2.2.3.3. Step 3: assessing HQ and HUs

We applied the InVEST model produced by Clark Labs to evaluate HQ as a proxy for biodiversity (Kareiva, 2011). The modeling process of the HQ module was based on the hypothesis that areas with higher HQ support higher native species richness, and that a decrease in HQ leads to a decline in species persistence (Sharp et al., 2014). We assumed that changes in ESs are mainly caused by changes in land use (Polasky, Nelson, Pennington, & Johnson, 2011). Thus, habitat suitability across land-use types was defined for general biodiversity, considering the sources of degradation to be human-modified land-use types (e.g., urban, agriculture, and roads) that cause edge effects (McKinney, 2002), which refer to changes in the biological and physical conditions that occur at a patch boundary and within adjacent patches (Polasky et al., 2011).

Three factors were considered in the HQ model: the suitability of land-use types for providing habitat for biodiversity, the different anthropogenic threats that likely impair habitat quality, and the sensitivity of each land-use type to each threat. Firstly, a relative habitat suitability score (H_j), determined from a literature review, was assigned to each habitat type (j) (Table 5). Only forest area was

Table 2-5. Parameters used for simulation of habitat quality of forest cover in the InVEST model. Agricultural area (AA); Vacant Lands (VL); Rural Settlements (RS); Transportation (TR); Service Business and Infrastructure (SBI); Urban Residential Area (URA)

	Parameter type	AA	URA	SBI	VL	RS	TR
01	Sensitivity of Habitat to threats	1 [c]	0.7 [a c]	0.80 [c]	0.72 [a]	0.78	0.6 [c]
02	Max. distance of impact to habitats	4 [ab]	5 [c]	5.6 [a]	4	4	2.0 [c]
03	Relative impact to threats	0.8 [b]	1 [c]	0.8 [a]	0.7 [b]	0.68 [a]	0.7 [c]

[a.] Terrado, M., Sabater, S., Chaplin-Kramer, B., Mandle, L., Ziv, G., & Acuna, V. (2016). Model development for the assessment of terrestrial and aquatic habitat quality in conservation planning. Science of the Total Environment, 540, 63-70.

[b.] Chiang, L. C., Lin, Y. P., Huang, T., Schmeller, D. S., Verburg, P. H., Liu, Y. L., & Ding, T. S. (2014). Simulation of ecosystem service responses to multiple disturbances from an earthquake and several typhoons. Landscape and urban planning, 122, 41-55.

[c.] Polasky, S., Nelson, E., Pennington, D., & Johnson, K. A. (2011). The Impact of Land-Use Change on Ecosystem Services, Biodiversity and Returns to Landowners: A Case Study in the State of Minnesota. Environmental & Resource Economics, 48(2), 219-242.

measured, and forests that scored at least 0.93 were considered habitats (Terrado et al., 2016). Subsequently, agriculture, residential land, industrial land, vacant land, rural settlements, and transportation were ranked as threats (r). The examined habitats were not affected by all threats in the same way, and the model recognized this variability. Generally, the impact of a threat on habitat decreased with increasing distance (D_{xy}: Eq. 2) from the degradation source, such that cells closer to threats experienced higher impacts than those further away *(Max. D*) (Terrado et al., 2016). The weight of a degradation source (w_r) could have any value from 0 to 1, indicating the relative effect of a degradation source on all habitats. Lastly, sensitivity scores (S_{jr}) were determined from the literature (see InVEST Users' Guide for further details on this method) (Sharp et al., 2014). The values obtained for HQ after applying the model ranged from 0 to 1 (Q_{xj}: Eq.3), with 1 indicating the highest suitability for species. The impact of threat *r* that originates in grid cell *y*, r_y, on the habitat in grid cell *x* is given by i_{rxy}:

$$i_{rxy} = 1 - \left(\frac{d_{xy}}{d_{r\,max}}\right) \quad (1)$$

The total threat level in grid cell *x* with land use type or habitat type *j* is given by D_{xj} :

$$D_{xj} = \sum_{r=1}^{R} \sum_{y=1}^{Yr} \left(\frac{w_r}{\sum_{r=1}^{R} w_r}\right) r_y \, i_{rxy} \, \beta_x S_{jr} \qquad (2)$$

The quality of habitat in parcel *x* that is in land use type *j* be given by Q_{xj}:

$$Q_{xj} = H_j \left(1 - \left(\frac{D_{xj}}{D_{xj} + k^2}\right)\right) \qquad (3)$$

where *y* indicates all grid cells on *r*'s raster map, and y_r indicates the set of grid cells on *r*'s raster map; In Eq.(1), i_{rxy} is the linear distance between grid cells *x* and *y,* and is the maximum effective distance of threat *r*'s reach across space. W_r is the weight of the degradation source. Sensitivity scores ($S_{jr} \in [0,1]$) indicate the sensitivity of habitat type *j* to threat *r*, where values closer to 1 indicate greater sensitivity. In Eq.(3), *k* is a scaling parameter. The HQ values are multiplied by the area of available habitat to obtain HUs for individual species or habitat types. The number of HUs at one time is defined as the product of the pixel-scale HQ and the total area of available habitat (Eq.4). The total number of HUs in a habitat type is given by:

$$\text{Habitat Units} = \sum_{k=0}^{n} (\text{HQ}_k(\text{A}_k) \qquad (4)$$

Where HQ_k is HQ with value *k* (0~0.93)*;* A_k is area of habitat type*,* and *n* is the number of HQ-value in a patch. Changes in HUs represent potential impacts of proposed actions. HUs are usually individual patches (Blazquez-Cabrera, Bodin, & Saura, 2014). For the purposes of this study, the total HUs for forest habitats (1972 and 2015) at the class level and the HUs of HFRs in the 37 sampling patches at the patch level were quantified using ArcGIS software

2.2.3.4 Step 4: Statistical Analyses

At the class level, we first detected changes in the biodiversity of forest habitats from 1972 to 2015 by comparing the HQ and HUs between forest-1972 and forest-2015. Then we quantified the changes in HUs within the HFRs during the historical period, as well as the proportion of HUs in HFRs of the total HUs of forest cover.

Using sample patches as a case study, the HUs of HFRs were analyzed using Pearson correlation coefficient, and each variable (landscape metric) at the patch level was verified using prior predictions. Moreover, only the variables that yielded significant results in the correlation analyses were used as independent variables for subsequent multiple regression analyses ($p < 0.005$). Subsequently, the HUs of HFRs were analyzed using multiple stepwise regression to select significant landscape metrics (*X*) of the sampling patches (forward method, F to enter = 4.00, F to remove = 3.99) (Virgos, 2001). HUs (*Y*) were examined for normal distribution, and all data were $\log_{10}$ transformed (Zar, 1984). Prior to the covariance analyses, we verified that the condition of parallelism between covariates and factors was met (Neter, Johnson, & Leitch, 1985). Moreover, to explore the role of newly shaped information in the historical aspect, the metric AREA of NFH was used as an independent variable instead of the metric of the total area of each patch. All statistical analyses were performed using SPSS statistics software for Windows.

2.3 Results

2.3.1 Landscape fragmentation of forest habitats at class level

Extensive urbanization in the southern part of Seoul has resulted in a profound change in landscape patterns, with high fragmentation of natural habitats. The natural forest-dominated landscape has mostly been converted into urbanized land-use types. Overall, the CA and MEAN decreased by 35.31% (6481.6–4203.13 ha) and 49.64% (26.24–13.22 ha), respectively. The LPI slightly decreased from 11.26 to 10.55. By contrast, the PD increased from 1.2089 to 1.5569, while NumP dramatically increased by about 28.74% from 247 to 318 (Figure 2-4).

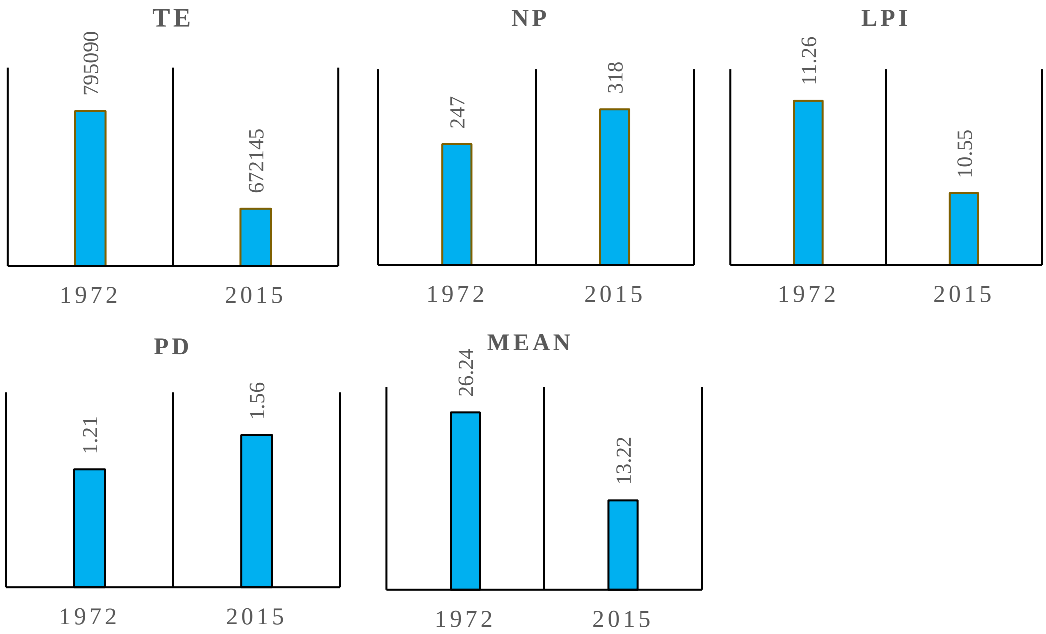

Figure 2-4. Landscape patterns of forest habitats to indicate fragmentation from 1972 to 2015.TE: Total Edge(meter); NP: Number of Patch; LPI : Large Patch Index; PD: Patch Density; MEAN: Mean Patch Size (ha).

2.3.2 *Estimating and characterizing the HQ and HUs*

The 35.31% decline in total HUs was driven by the significant decline in total forest area from 1972 to 2015 (Table 2-6). Moreover, the average HUs per hectare decreased from 370.6 to 369.6, while the mean HQ value decreased from 0.9265 to 0.9241 during the study period.

We found 3655.83 ha HFRs, found in 581 remnant patches. HUs of HFRs, which occupied 56% in forests-1972 and 87% in forests-2015 respectively, increased 0.5% (6387) till 2015 (Table 2-6). The average HUs per hectare in the HFRs correspondingly increased from 366.2 in 1972 to 368.0 in 2015.

Table 2-6. HQ and HUs statistics in forest ecosystem

Date	Term	Area(ha)	Mean HQ	Total HUs	Average HUs/ha
1972	PFH	6095.20	0.9265	2258840	370.6
	HRF	3655.83	0.9275	1338800	366.2
2015	CFH	4203.13	0.9241	1553583	369.6
	HRF	3655.83	0.9245	1345187	368.0

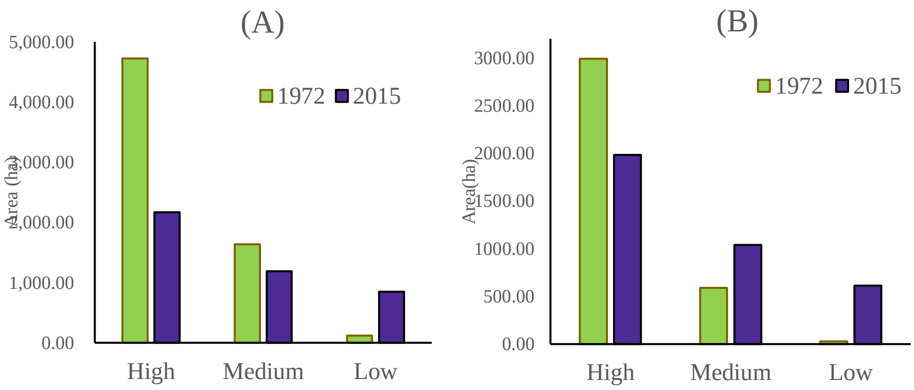

Figure 2-5. HQ of the forest habitat (A) and HFRs (B); High (0.925-0.93), Medium (0.920--0.9249), Low (0.90-0.9199)

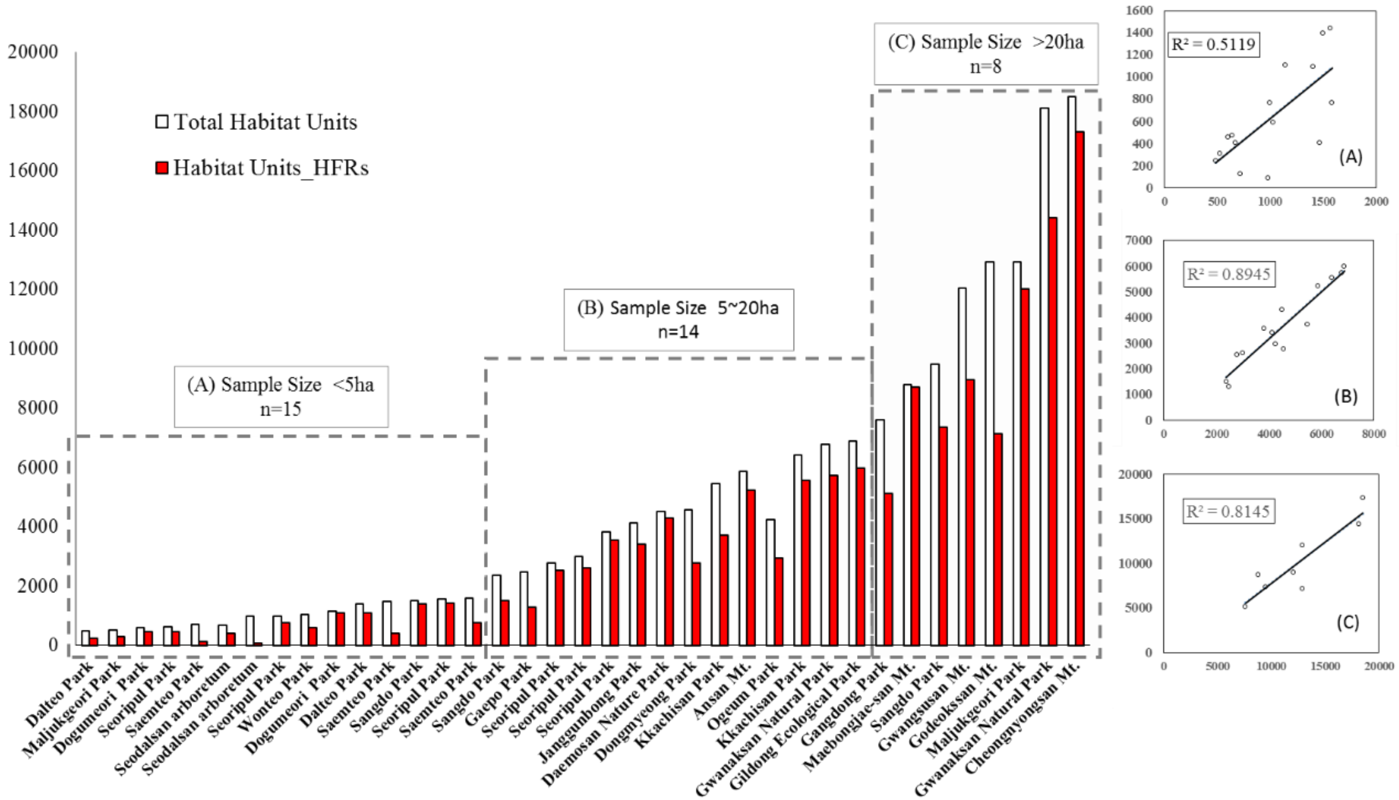

Figure 2-6. Total HUs of 37 sampling patches at current parks and their HUs of HFRs within parks. Correlation between total HUs of sampling patches and HUs of their HFRs grouped into size of (A) smaller than 5 ha, (B) 5ha~20ha, and bigger than 20ha.

However, mean HQ-value in HFRs declined from 0.9275 in 1972 to 0.9245 in 1972. However, the mean HQ value in the HFRs declined from 0.9275 in 1972 to 0.9245 in 2015. We classified the HQ value into three groups: high (0.9250–0.9300), medium (0.9200--0.9249), and low (0.9000–0.9199). The area of forest habitats with high and medium HQ values decreased by 54.13% and 27.30%, respectively, during the rapid urbanization period (Figure 2-5A). The area of habitats with high HQ values of HFRs also declined by 33.72%, but areas with medium HQ values increased by 76.55%. In addition, areas with low HQ values significantly increased in both total forest habitats and HFRs from 1972 to 2015 (Figure 2-5).

2.3.3 Correlation analysis and regression model for sampling patches at current parks

The HUs of sampling patches and HUs of their HFRs at the patch level are shown in Figure 2-6. The HFRs played an essential role in the biodiversity of current parks, but HFRs correlations with biodiversity varied with remnant size (Figure 2-6). Areas smaller than 5 ha exhibited the weakest correlation (n = 15, R^2 = 0.5119) between HUs of sampling patches and HUs of their HFRs, whereas areas larger than 20 ha exhibited a higher correlation (n = 8, R^2 = 0.8145). Patch sizes of 5–20 ha exhibited the highest correlation (n = 14, R^2 = 0.8945). Pearson correlations between the HUs of HFRs and different variables grouped by categories of landscape metrics in the 37 sample patches are detailed in Table 2-7. The HUs of each sample patch exhibited a positive correlation with most of the landscape-pattern variables that were considered to be part of the AREA of NFHs (with the exception of ENN). PARA was the only variable to exhibit a negative correlation with the HUs of the HFRs. Table 2-8 presents the final models resulting from multiple stepwise regression analyses between HUs and the significant variables in the Pearson correlation analyses. The key indicators affecting HUs of HFRs (Y) include CONTIG (X_4, positive), GYRATE (X_6, positive), FRAC (X_5, positive), and AREA of NFHs (X_7, negative).

Table 2-7. Pearson correlation between HUs and landscape metrics of sampling patches at current parks measured in this study.

2015 Habitat Units (HUs)	Landscape metrics							
	PERIM (X_1)	SHAPE (X_2)	PARA (X_3)	CONTIG (X_4)	FRAC (X_5)	ENN -	GYRATE (X_6)	AREA(NFH) (X_7)
Historical Forest Remnants (HFRs)	0.847**	0.549**	-0.620**	0.621**	0.349*	-0.171 (n.s.)	0.849**	0.455**

*$P < 0.05$; **$P < 0.01$; n.s., not significant,
X: independent variable will be used for subsequent multiple regression analyses.

Table 2-8. Final models resulting from the multiple stepwise regression analyses (forward) between HUs of HFRs and the significant variables in landscape metrics in the previous Pearson correlation analysis.

Habitat Units (HUs)	Adjusted R^2	Selected variable(s)	B	*T*-value	*P*-value
Historical Forest Remnants (HFR) (Y)	0.864	Regression constant	-21.915	-5.611	<0.001
		GYRATE(X_6)	.002	2.224	<0.033
		CONTIG(X_4)	19.129	6.804	<0.001
		FRAC(X_5)	5.950	4.215	<0.001
		Area (DGS) (X_7)	-.047	-3.064	0.004

Note: Durbin-Watson=2.104

2.4. Discussion

The landscape pattern analyses and habitat quality models were designed to quantify the role of HFRs in supporting urban biodiversity (Figure 2-2), and to explore the influence of landscape metrics of extant parks containing these remnants on the biodiversity value of remnants (Table 2-7 & 2-8). We considered the spatiotemporal aspects of forest landscape changes (Figure 2-4) to be essential for identifying the HFRs (Figure 2-3) and for quantifying and characterizing the changes in HQ and HUs (Figure 2-5 & Table 2-6). Our results can be used to inform urban biodiversity conservation efforts within a forest landscape, particularly by allowing planners and designers to understand how patch configuration and spatial arrangement can potentially be applied to improve urban biodiversity preservation. Below, we connect biodiversity responses to urban forest conservation by addressing our four original objectives.

(Objectives 1) Changes in landscape patterns and HQ in forest habitats

Landscape changes in the urban area of Seoul are strongly related to landscape fragmentation and habitat isolation (Song & Kim, 2016). Habitat fragmentation commonly leads to a decrease in patch size and a relative increase in the edge to interior ratio and the distance between patches (Hansson, Fahrig, & Merriam, 2012; Reed, JohnsonBarnard, & Baker, 1996). During the period of 1972–2015, we found high levels of fragmentation in modern forest ecosystems, including a 35.31% decrease (1892 ha) in total area and a decrease in mean forest patch size (MEAN) and the size of the largest patches in the total landscape (LPI) (Figure 2-3). The model results also indicated an 11.69% (92,945 m) decrease in total edges as well as the predicted increase in the edge to interior ratio within the area of remnant forest in the LULC maps (Figure 2-2). The primary reason for the observed loss of habitats was the extensive historical development with little consideration for the natural landscape (S.-K. Hong et al., 2003).

The biodiversity loss and ecosystem degradation were primarily caused by the loss and fragmentation of natural habitats (Wu, 2013). The modeled high HQ value dramatically decreased over the study period (Figure 2-5A). In addition, the proportional decline in total HUs was the same as the proportional decline in total area of forest habitats, followed by a decline in the average HUs per hectare and the mean HQ value (Table 2-6). Forest landscapes around the metropolitan area of Seoul have become increasingly fragmented since the 1980s, when the extensive land development plan began (S.-K. Hong et al., 2003). By 2015, 114 isolated patches remained, including the 37 sampling patches within the parks analyzed in this study. These patches are fragmented by roads, residential areas, and other anthropological land uses, and all comprise differently sized urban vegetation polygons. Most of these fragmented remnants were re-shaped after isolation from the main part of the mountain forests (Samseong-san Mt., Gwanak-san Mt., Umyeon-san Mt., Guryong-san Mt., Daemo-san Mt., and Geumamsan Mt.), and their total area has drastically declined, particularly in locations such as Janggunbong Park, Seoripul Park, and Dogumeori Park (Figure 2-6).

(Objectives 2) Identification of HFRs and their role in supporting urban biodiversity

The 3655.83 ha of HFRs identified in 2015 occupy nearly the same proportion of total forest area and total HUs (87%) as in 1972 (Table 2-6). Some sample patches were larger in 2015, but exhibited lower HUs. We found that the

ESs provided by the fragments of natural habitats to their neighboring areas may follow a distance-dependent pattern; that is, the proximity to fragments may strongly affect the flow of ESs (Mitchell et al., 2015). For example, Ogeum Park is nearly the same size as Kkachisan Park, but the former has lower HUs (Figure 2-6), as it is located in a highly dense residential area in the Songpa-gu District (Figure 2-1); Several other sample patches with high proportions of HFRs exhibit higher HU values compared to some of the larger remnants (e.g., Ansan Mt. Park) (Figure 2-1 & 2-6), because these patches are located closer to the continuous outer forest perimeter of Gwanak-san Mt.

Despite the forest landscape fragmentation elucidated by the landscape metrics from 1972 to 2015, the total HUs of HFRs increased by a surprising amount (0.5%). This trend was also illustrated by the value of HUs per hectare and the high value of the mean HQ value in the HFRs, which increased from 366.2 to 368.0 (HUs) and 76.55% (HQ). In some cases, the spatial configuration and the network of remaining small forest patches may be more crucial than their size (Andren, 1994; Bodin et al., 2006; Didham et al., 2012). These authors also suggested that when fragmentation causes less than 30% of a specific habitat type to remain in a landscape, the spatial arrangement of the patches may play a more important role in species survival than does the habitat size (Andren, 1994; Bodin et al., 2006).

(Objectives 3) The effects of dominant landscape metrics of current forest habitats on the HQ of HFRs

The shape of habitat fragments significantly affects biodiversity (Bodin et al., 2006; Kremen et al., 2007; Syrbe & Walz, 2012). The stepwise multiple regression indicated that the HUs of the HFRs in the sample patches were mainly positively affected by the landscape metrics of GYRATE, FRAC, and CONTIG of forest-2015 (Table 8). FRAC and CONTIG are both considered shape metrics. Our results are consistent with the landscape theory that the shape of the perimeter may play an ecological role in population distribution and migration routes by species in and out of patches (Forman, 1995). In some cases, the shape of patches appears to be irrelevant for animal diversity but is an effective criterion of plant species richness (Gimona, Messager, & Occhi, 2009). We suspect that the latter was the case in this study, which suggests that plant species composition and abundance inventories in the HFRs could help to confirm the results of the HQ model.

The AREA of NFHs may play a negative role in maintaining and protecting the biodiversity of HFRs, as indicated by the regression model (Table 8). Some remnant forest habitats exist within larger matrices of urban green spaces but have been separated by non-native vegetation, such as landscape plantations. Thus, the proportion of non-native to native-dominated vegetation in these locations would pose a potential threat to HFRs.

(Objectives 4) Implications for planning and design strategy in urban forest conservation

According to Forman (1995), the major human-influenced change to a landscape is the progressive division of large, homogeneous tracts of forest into a heterogeneous mixture of much smaller patches, which is what has occurred in Seoul (S.-K. Hong et al., 2003). In our research area, half of the isolated forest habitats identified in 2015 are smaller than 5 ha. Of the sampling patches, the total HUs was only moderately correlated with the HUs of HFRs (n = 15, R^2 = 0.5119) (Figure 2-6). This result suggests that HFRs conservation has been less successful in small remnants than in larger ones. Sitzia *et al.* (2016) highlighted that minor forest fragments can maintain diverse urban green infrastructures that may supply a series of ESs (Sitzia, Campagnaro, & Weir, 2016). In Seoul, although most of the forest patches along the urban fringe are protected as part of a greenbelt, the smaller patches receive low to no protection. Yet, the role of small habitat patches has been emphasized as complementary to larger reserves (Fischer & Lindenmayer, 2002; Gotmark & Thorell, 2003; Schwartz, 1999; Shafer, 1995; I. M. Turner & Corlett, 1996). When well-distributed over the landscape, networks of small remnants can contain many types of species that may contribute to the maintenance of regional biodiversity (Pither & Kellman, 2002), for example, by providing stepping stones and resting places for migratory and seed-dispersing animals (Shafer, 1995; I. M. Turner & Corlett, 1996), nesting habitats for pollinator abundance and diversity (Banaszak, 1996; Cane, 2001; Donaldson, Nanni, Zachariades, Kemper, & Thompson, 2002), and serving as propagule sources to allow forests to expand (Chazdon, 2003; Janzen, 1988; I. M. Turner & Corlett, 1996). However, in our model, the benefits of small patches need to be quantified (Fischer & Lindenmayer, 2002; Strohbach et al., 2013). We suggest conducting observations of birds and native annual plants over time in a series of larger and smaller patches to discern the overall value of small patches to the urban forest network of Seoul.

Although urban forests play a direct role in most ecosystem functions, intentionally planted habitats can also support several ESs when the area of forest remnants sharply decline. To create an ecological network that can adequately represent the biotic interactions of an ecosystem, intentionally planted forest habitats may permit an ecological linkage among historical and protected habitat patches (Gao et al., 2017). However, our model results indicate that the patch shape of current forests around historical forest patches may actively affect their biodiversity, while the area of NFHs may negatively affect biodiversity. This study will contribute to a greater understanding of the potential of HFRs to inform conservation planning of urban forests. Ideally, our model results will be used to strengthen the protected area network at the urban level and to develop ecosystem services-based management and policy.

Although our model was only applied to the seven districts of Seoul, it can be adapted for use in other areas with similar ecological problems at different scales.

CHAPTER 3

SPATIOTEMPORAL ANALYSIS OF THE FORMATION OF INFORMAL SETTLEMENTS IN A METROPOLITAN FRINGE: SEOUL (1950-2015)

3.1 Introduction

3.1.1 Informal settlements in the urban fringes

Urban fringes are seen as unique land-use areas because of their geographic location, soil type, and topography (Firey, 1946). In these areas, the complex mosaic of land use and land cover (LULC) produces sprawling settlements characterized by low-density residential areas, neighbored with agricultural plots and farmlands. These areas are often defined by highly sensitive habitats such as forests, wetlands, and rivers (López, Bocco, Mendoza, & Duhau, 2001; La Rosa, Barbarossa, Privitera, & Martinico, 2014). These existing natural habitats are worth being conserved because they can generate diverse ecosystem functions for cities, such as crop production, biodiversity, and carbon storage. However, the explosive growth of Asian mega-cities in the post-war decades has created a chaotic mixture of urban and rural land use in metropolitan fringes. It has provoked the formation of several informal settlements in such areas, which has resulted in heightened social and environmental problems (Ooi & Phua, 2007; Yokohari, Takeuchi, Watanabe, & Yokota, 2000).

Informal settlements - which are variously referred to as autonomous urban settlements, slums, barrios, bidonvilles, shantytowns, squatter settlements or favelas - have generally sprung up without, or in defiance of, government approval (Drakakis-Smith, 2012; Gilbert & Gugler, 1992; S.-K. Ha, 2004; S. K. Ha, 2001; Leeds, 1971; J. F. Turner, 1977; Zeilhofer & Topanotti, 2008). These settlements tend to share some common features globally (Patino & Duque, 2013), such as limited economic activities, difficult living conditions, lack of adequate housing, and residential infrastructure that tends to be unsafe and unhygienic. This living environment not only causes a social divide whereby settlement dwellers easily become impoverished and face social exclusion, but it also impacts the natural environment in often harsh and irreversible ways.

3.1.2. Spatial analysis for informal settlements

To identify potential strategies and plans for future management of informal settlements in the urban fringe, the process of spatial transformation must first be elucidated. Comprehensive spatiotemporal analyses of LULC offer a powerful tool for uncovering historical relationships between human activities and the environment (Fuchs et al., 2015; Grecchi et al., 2014; S. Li et al., 2017; Shahraki et al., 2011). This is useful for improving our understanding of informal settlement development in Asian cities. There have been many studies on informal settlements, which have used LULC change detection as a decision-making tool for urban planners and policy makers. The previous studies primarily concentrated on: 1) the impact of scale on land-cover fractions in informal settlements (Stoler et al., 2012), 2) the advantages of using high-resolution satellite images to identify informal settlements (Jain, 2007; Kohli, Sliuzas, & Stein, 2016), and 3) the detection of spatial and temporal patterns of informal settlement growth to inform future planning (Dubovyk, Sliuzas, & Flacke, 2011; H. Liu, Huang, Wen, & Li, 2017; Y.-h. LIU, CHEN, LIN, & WU, 2015). However, few studies have analyzed informal settlement formation through the LULC shifts for a specific urban region along the gradient of urbanization, for example, the urban fringe. In this study, examination at the local scale of small urban areas can provide more accurate information on the local characteristics of a specific targeted area (J. Abbott, 2003; Kohli et al., 2016; Stoler et al., 2012; Swanwick & Heritage, 2002; Ward & Peters, 2007).

3.1.3. Informal settlements in Seoul metropolitan fringe

In the late 1960s and 1970s, South Korea experienced immense economic growth, which was accompanied by expansive rural to urban migration across the country. During this time, due to the difficulty in accommodating the massive influx of people to urban areas, an estimated 20-30% of housing developments across South Korea were informal and deficient in adequate space and basic facilities (S.-K. Ha, 2007). In response, the city of Seoul began to focus primarily on controlled urban development (Sehoon Oh, 2009). As part of this planning, slum clearance projects were implemented in the 1970s. However, these projects led to further deterioration of the housing situation – leaving the poor with nowhere to go and forcing informal settlements to develop in the marginal areas of Seoul. In the early 1980s, after the ineffective slum clearance of the 1970s, communities labelled as, “newly built slum settlements,” “vinyl house communities,“ or “hillside informal neighborhoods” began to sprout up in vacant hillsides and public open green spaces. These communities were characterized by poor housing conditions, overcrowding and a lack of land ownership and building permits (S.-K. Ha, 2004). One of the remaining settlements from that period, and the largest until 2015, is now known as the Guryong Slum Village (GSV).

The formation of the GSV resulted from the demolition of informal settlements near the stadiums built for the 1988 Olympic Games in the Gangnam District. To make space for the Olympic venues, the government demolished several illegal settlements near the stadiums. The former residents of these areas were not given alternative living spaces, and subsequently were forced to squat in illegal housing areas on the outskirts of Seoul (S.-K. Ha, 2007). This gave rise to the beginnings of the GSV, which is one of the few remaining informal settlements in the Seoul urban area, and is located on the outskirts of one of its wealthiest districts, Gangnam. In addition to the GSV, several other informal settlements, hosting approximately 2,000 households, continued to exist as the "hillside informal neighborhoods" near the fringe of the Gangnam District until 2011.

Seoul's metropolitan area and its surrounding districts are encompassed by mountains on all sides (Kuitert, 2013). As a result, the urban fringe's informal settlements have impacted, and are impacted by, ecological characteristics of mountains. Previous studies on the "hillside informal neighborhoods" of Seoul have focused primarily on socioeconomic factors, including policy alternatives (S.-K. Ha, 2002), housing regeneration (S. K. Ha, 2001; Sehoon Oh, 2009), living conditions (S.-K. Ha, 2004). However, none of these studies have investigated the spatially explicit characteristics of informal settlements that result from specific site selections and their relationship with the topography, particularly in a marginal urban area.

In this study, we propose to improve understanding of informal settlements' formation at the metropolitan fringe through a comprehensive spatiotemporal analysis that considers the role of topographical characteristics. We have conducted this study using the Guryong Area (GA) in Gangnam District, Seoul, Korea as a case study. Through this study, we wish to answer the following four questions: What was the historical development of LULC from 1950 to 2015? What characteristics of informal settlement formation were revealed by the changes in LULC? How is the formation of informal settlements related to the topographical characteristics of the marginal area? And finally, what are the potential future implications of the historical and ecological research for urban planning and informal settlement redevelopments? We measured the changes in the LULC for a specific land-use type defined as "spontaneous settlements." This allowed us to interpret autonomous features of the targeted areas, considering the formation of informal settlements at two scales: the entire GA, and 600-m-wide bands of the area along the gradient of urbanization. In addition, we identified patches of spontaneous settlement that were gained or lost during

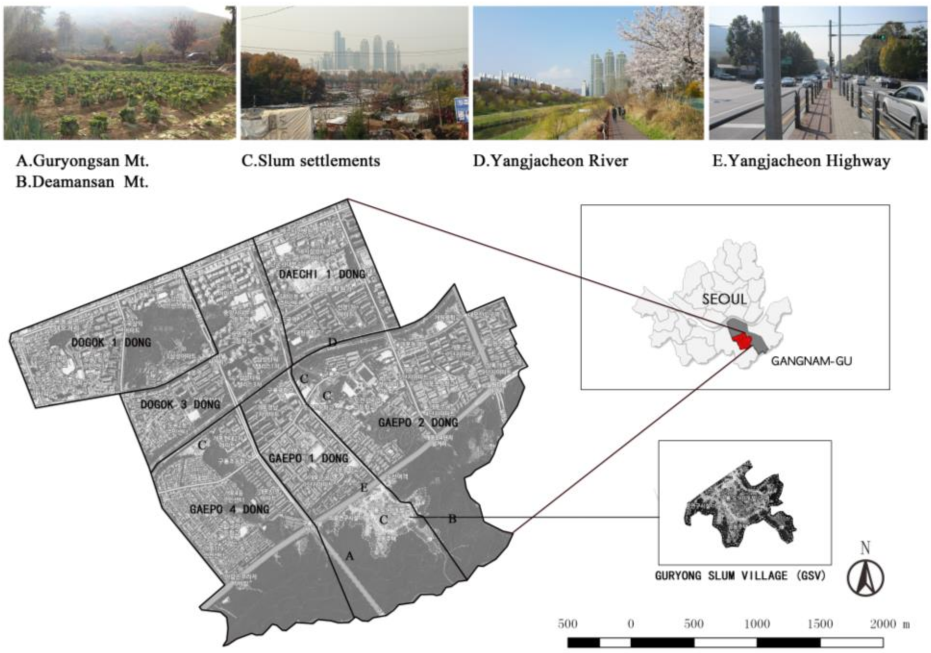

Figure 3-1. Map showing the location of the Guryong Area on the outskirts of Gangnam District. This includes the units: Dogok 1 Dong, Dogok 3 Dong, Daechi 1 Dong, Gaepo 4 Dong, Gaepo 1 Dong, and Gaepo 2 Dong.

Table 3-1. Maps used for LULC reclassification

Year	Scale	Description
1950	1:50,000	Topographic map of Doonjeon; National Geographic Information Institute of the Republic of Korea
1975	1:25,000	Topographic map of Doonjeon; based on aerial photos with 10m&5m resolution and field survey; National Geographic Information Institute of the Republic of Korea.
1975	1:25,000	Land cover map of Doonjeon; based on topographic map of Doonjeon in 1975, National Construction Research Institute Ministry of Construction
1985	1:25,000	Topographic map of Doonjeon，based on aerial photos with 10m&5m resolution and field survey; National Geographic Information Institute of the Republic of Korea
1994	1:5,0000	Topographic map of Suwon，based on aerial photos with 10m&20m resolution and field survey; National Geographic Information Institute of the Republic of Korea
2015	1：1000	Vector data of land use, Seoul Metropolitan Government

four successive periods. We then examined the relationship between informal settlement formation and topographical characteristics.

3.2. Materials and Methods

3.2.1. Study area

The study area, the GA, extends from Guryongsan Mountain (Figure 3-1A) and Deamansan Mountain (Figure 3-1B) to the Yangjacheon River (Figure 3-1D). The area is approximately 825 ha. The GSV is located in a valley at the base of Guryongsan Mountain and Deamansan Mountain, facing the Yeongycheon stream.

3.2.2. Date collecting

A series of LULC maps were assembled using five historical maps with land-cover information from 1950 to 1994, and a contemporary digitized land-use map from 2015 (Government, 2015; Institute, 1974, 1988, 1994) (Table 3-1). The topographical characteristics (landforms, slopes, and soil characteristics), were obtained using soil data from the Korean Rural Development Administration (RDA, 2010) (Department, 2010)

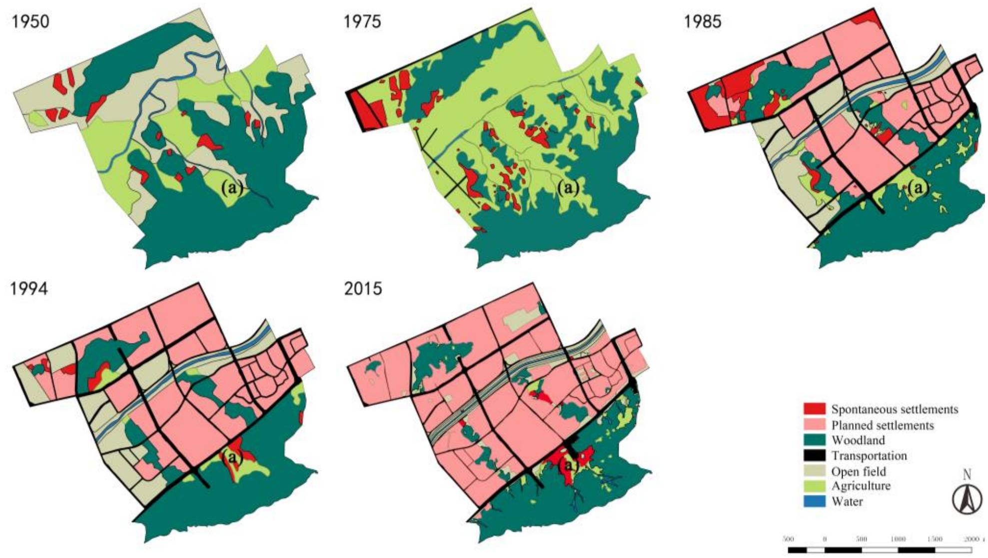

Figure 3-2. Reclassified maps of LULC in 1950, 1975, 1985, 1994, and 2015. (a) is location of GSV.

Table 3-2. Reclassification of LULC types used in the analysis

NO.	Land cover class	Class description
01	Spontaneous settlements	Autonomous urban settlements, informal settlements including slums or squatter settlements and unplanned; other unidentifiable settlements with spontaneously formed characteristics
02	Planned settlements	Urban residential, commercial or industrial areas according to official urban planning.
03	Transportation	Roads, large scale/public parking lots.
04	Agriculture	Cultivated field, open agricultural land.
05	Woodlands	Forest or parks with clustering trees.
06	Water	River, stream, pool, canal.
07	Open field	Planned or designed green spaces; Un-development or unused lands, heath.

3.2.3. Date processing

3.2.3.1. Mapping and re-classifying the LULC

The first step in data processing involved standardizing and transforming the significant LULC types in each map into a common LULC classification with a unified legend covering the study periods (Figure 3-2). The LULC classifications were based on significant information interpreted from the historical maps (Van Eetvelde & Antrop, 2009). They were then mapped as polygons in a vector-based geographical information system (GIS) using ArcGIS 10.2.2. Each LULC type was quantified to identify the nature of land cover and its transitions. Because historical maps differ in details, survey techniques, accuracy, and map content, there are some shortcomings of these maps. However, the transformation of specific map categories into a generic

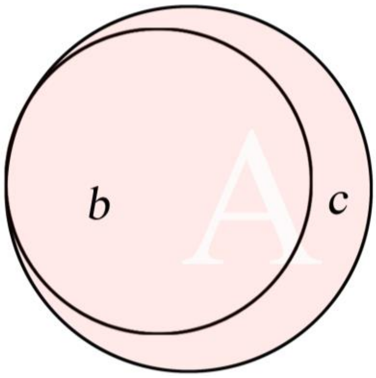

Figure 3-3. The conceptual figure of relationship between "spontaneous settlements" and "slum settlements". (A) Spontaneous settlements are not *(b)* informal settlements, because of *(c)* other unidentifiable spontaneous settlements.

type is a common technique used in historical landscape analysis to make comparisons between time periods (Rippon, 2004; Van Eetvelde & Antrop, 2009)

The study periods were selected to represent key periods in South Korea's history. Given the available historical data, five different years have been used to analyze the changes in the LULC: 1950, 1975, 1985, 1994, and 2015. Until the late 19th century, the original network of Seoul's primary streets remained unchanged (Sehoon Oh, 2009). The Korean War, a major historic turning point for the Korean Peninsula, lasted from 1950 to 1953, during which many natural habitats were destroyed. Following the war, the concentration of South Korea's population in Seoul accelerated the development of roads and residential land due to rapid industrialization. The Gangnam District developed rapidly during this time, as can be seen from the 1975 map (Institute, 1974). The maps from 1985 and 1994 represent the periods before and after the Olympic Games, respectively (Institute, 1988, 1994). Finally, the map from 2015 was chosen to represent the current status of the area.

A spatial-temporal database including the five time periods of 1950, 1975, 1985, 1994, and 2015 was created using the historical topographic maps and historical land use maps for the Gangnam districts. LULC patches in 1950 were digitized from a georegistered digital map scanned from a hard copy of the 1950 topographic map of the Doonjeon area (Gangnam district's old name). The 1975 (Doonjeon area), 1985 (Doonjeon area) and 1994 (Suwon area) maps were paper works created from aerial photos with a spatial resolution of 5m by the National Geographic Information Institute of the Republic of Korea. LULC patches in 2015 were digitized from aerial photos by the Seoul Metropolitan Government, with a spatial resolution of 5m. Each map from 1950 to 1994 was digitized using image-to-image georeferencing methods in order to match the scales at a 5 m spatial resolution.

The new LULC classification patches were interpreted and digitized based on a series of criteria that were defined for land cover delineation (Table 3-2). These were identified as the following LULC categories: agriculture, woodland, transportation, open field, planned settlements, water, and spontaneous settlements. The most significant LULC type for this study was the category "spontaneous settlements" (Table 3-1) (Figure 3-3A). This LULC type is useful for examining changes in settlements that form spontaneously during urbanization. As mentioned in the introduction, "autonomous urban settlements" were generally occupied through the match the scales at a 5m spatial resolution.

The new LULC classification patches were interpreted and digitized based on a series of criteria that were defined for land cover delineation (Table 3-2). These were identified as the following LULC categories: agriculture, woodland, transportation, open field, planned settlements, water, and spontaneous settlements. The most significant LULC type for processes of informal occupation rather than through formal planning or construction (Zeilhofer &

Topanotti, 2008). This in turn manifested into spontaneous spatial patterns. However, due to the limited accuracy of historical data, some of unidentifiable autonomously formed settlements were included (Figure 3-3c). Therefore, we use the term "spontaneous settlements" to denote the characteristics of informal settlements (Figure 3-3b).

3.2.3.2. Mapping the topographical characteristics

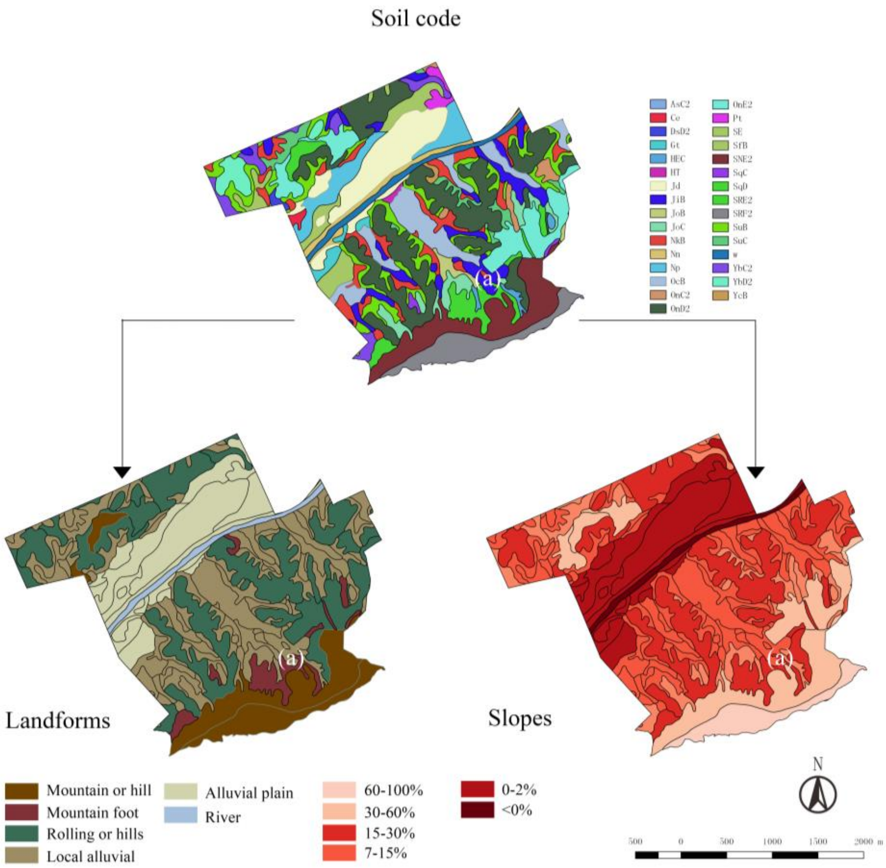

Figure 3-4. Maps of landforms and slopes based on soil data downloaded from the database of Agricultural and Soil Information of South Korea; (a) shows the location of GSV.

In the second step of data processing, the topographical characteristics were assessed. The topographical characteristics were derived from soil codes from the Korean soil information system[⑥]. This included the topographical landscape types, slopes, and recommended use for each soil code. In 1964, the Korean government launched a National Soil Survey Project, testing and documenting soil types throughout South Korea, and increasing the amount of detail each year. Each soil type is defined by its physical and chemical properties, as well as its landscape parameters (Kuitert, 2013). Although landforms and slopes changed significantly during periods of rapid urbanization, the primary landscapes types determined from the soil characteristics retained their natural status. Thirty-two soil codes were identified in the GA and 10 soil codes were found in GSV (Table 3-3). Using the topography type attached to each of the soil codes as an index, the soil types were grouped into eight topographical types throughout Seoul (Kuitert, 2013). Five of these eight topographical types were found in Gangnam District and in the GA: local alluvial, alluvial plain, mountain foothill, rolling or hill, and mountain or hill. Similarly, six slope classifications were identified: 0–2%, 2–7%, 7–15%, 15–30%, 30–60%, and 60–100% (Figure 3-4)(Department, 2010) . The landforms were closely related to slope type, and some landforms included diverse slopes; for example, the local alluvial included slopes of 2–7% and 7–15%.

3.2.4. Date analysis

3.2.4.1.Determination of changes and transition analysis

⑥ http://soil.rda.go.kr

The spatial pattern development in the GA over time was analyzed at two spatial scales: the entire GA, and bands extending from the core of the GSV to the upper end of the GA. The analysis of the bands demonstrated the variability in the spatial patterns of the LULC (Luck & Wu, 2002; Zhang, Wu, Zhen, & Shu, 2004; Zhou, Huang, Pickett, & Cadenasso, 2011), especially that of spontaneous settlements, along the gradient of urbanization in the Gangnam District (Luck & Wu, 2002). Six 600-m-wide bands at intervals of 3.3 km were defined, beginning at the core of the GSV and extending out towards the urban core of the GA (Figure 3-5). The size of each distance band was defined using the size of GSV and the average width from the core of the GSV to the border of the GA (Zhou et al., 2011).

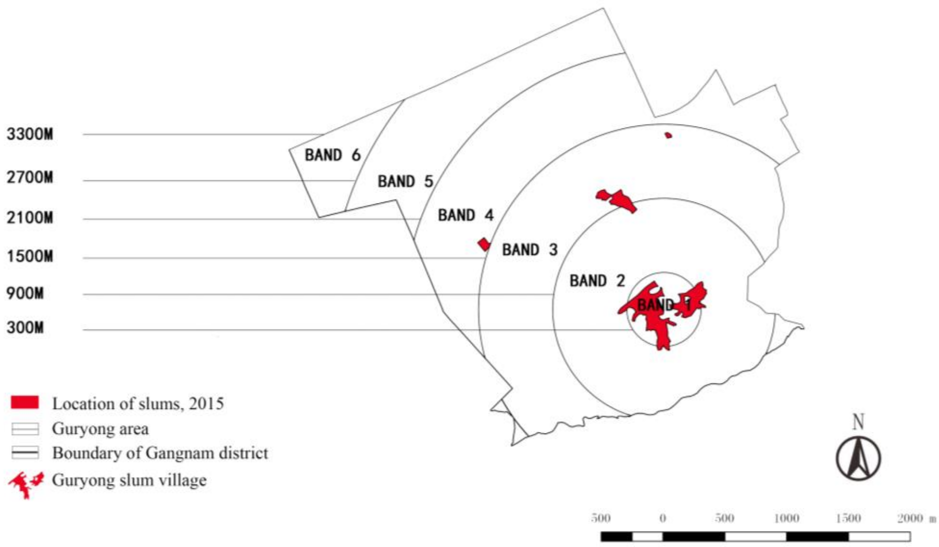

Figure 3-5. Bands separated by 3.3 km starting from the core of GSV, and extending to the upper end of the GA toward the urban core of the Gangnam District. There were six bands in total; each band was 600 m wide.

Table 3-3. Soil types and their description in GA

	Soil-series	Soil order	Landforms	Slope	Recommended use	In GSV
SRF2	Songsan	Inceptisols	Mountain or Hill	60~100	Forest	
OnD2	Osan	Inceptisols	Rolling or Hill	15~30	Orchard and mulberry	△
HEC	Hoegog	Entisols	Local alluvial	7~15	Paddy	△
SqD	Suam	Entisols	Mountain foot	15~30	Native Pasture	△
JoB	Jigog	Inceptisols	Local alluvial	2~7	Cultivated upland	△
JiB	Jisan	Inceptisols	Local alluvial	2~7	Paddy	△
NkB	Noegog	Inceptisols	Local alluvial	2~7	Cultivated upland	
JOC	Jigog	Inceptisols	Local alluvial	7~15	Cultivated upland	△
SuC	Sangju	Inceptisols	Local alluvial	7~15	Cultivated upland	
SuB	Sangju	Inceptisols	Local alluvial	2~7	Cultivated upland	
YbC2	Yesan	Inceptisols	Rolling or Hill	7~15	Cultivated upland	
SqC	Suam	Entisols	Mountain foothill	7~15	Cultivated upland	
SfB	Sachon	Inceptisols	Local alluvial	2~7	Paddy	
SE	Seogcheon	Inceptisols	Alluvial plain	0~2	Paddy	
OnC2	Osan	Inceptisols	Rolling or Hill	7~15	Cultivated upland	
Gt	Gangseo	Inceptisols	Alluvial plain	0~2	Paddy	
Jd	Jungdong	Entisols	Alluvial plain	0~2	Cultivated upland	
OnE2	Osan	Inceptisols	Rolling or Hill	30~60	Native Pasture	△
OcB	Ogcheon	Inceptisols	Local alluvial	2~7	Paddy	△
Np	Nampyeong	Inceptisols	Alluvial plain	0~2	Paddy	
SNE2	Songsan	Inceptisols	Mountain or Hill	30~60	Native Pasture	△
YbC2	Yesan	Inceptisols	Rolling or Hill	7~15	Cultivated upland	
YbD2	Yesan	Inceptisols	Rolling or Hill	15~30	Cultivated upland	
Pt	Pyeongtaeg	Inceptisols	Alluvial plain	0~2	Paddy	
Nn	Nagdong	Entisols	Alluvial plain	0~2	Cultivated upland	
HT	Hwasu	Inceptisols	Alluvial plain	0~2	Paddy	
DsD2	Dosan	Entisols	Mountain or Hill	15~30	Native pasture	
AsC2	Asan	Entisols	Rolling or Hill	7~15	Cultivated upland	
YcB	Yeongog	Inceptisols	Mountain foothill	2~7	Cultivated upland	
SRE2	Songsan	Inceptisols	Mountain or Hill	30~60	Native pasture	
Ce	Cheongweon	Inceptisols	Alluvial plain	0~2	Paddy	△
DsD2	Dosan	Entisols	Mountain or Hill	15~30	Native pasture	

To determine changes in spatial pattern, and to identify the “from–to “nature of the transitions in spontaneous settlement land-cover types, changes in land cover were examined using successive periods: 1950–1975, 1975–1985, 1985–1994, and 1994–2015. By overlaying the spontaneous settlement patch layers from two successive periods, we identified trends in land-cover transitions. For example, an area was defined as “lost” if spontaneous settlement cover occurred in the earlier sample period, but not in the later one.

3.2.4.2. Analysis of relationships between LULC changes and topographical characteristics

The band analysis also examined the association of topographical characteristics with the location of spontaneous settlements. We overlaid the spontaneous settlement layers with the maps of landforms and slopes to investigate their relationships within the specific bands.

3.3 Results

3.3.1 Changes in land cover types over time

3.3.1.1. Changes in the time series across the entire GA

The changes in LULC for the entire GA are presented in Figure 3-6. The most significant change was the transformation of other land-cover types into planned settlements and transportation. Approximately 405 ha of the GA were planned settlements areas in 2015, compared with 284 ha in 1985. Additionally,

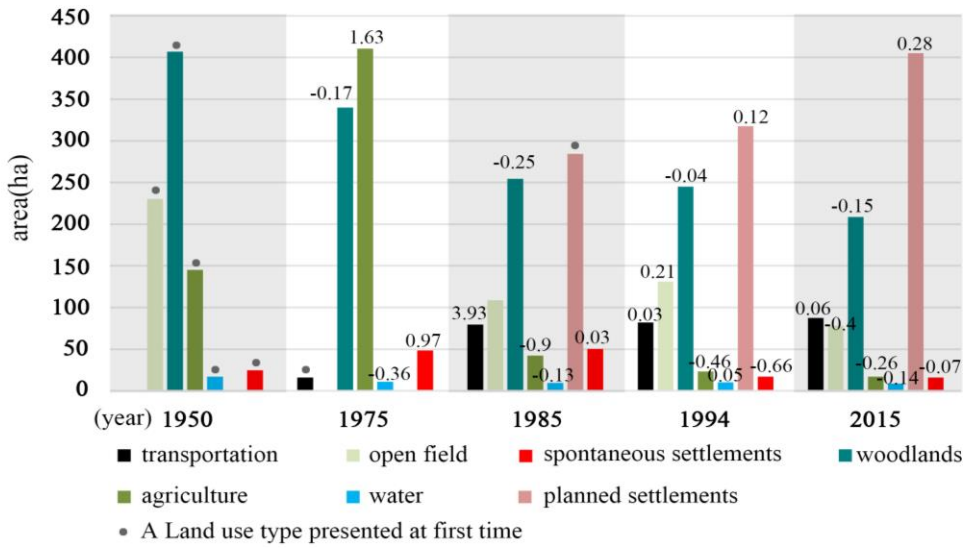

Figure 3-6. Total area of LULC types for five sampling periods. Annual rates of LULC change by class from 1950 to 2015 in percent (decimal fraction).

the area occupied by road construction increased 3.3-fold between 1975 and 2015. The second most significant change occurred in agriculture. The percentage of agricultural land increased 1.63-fold between 1950 and 1975, but decreased by 90% between 1975 and 1985. The area of agricultural land was larger in 1975 than in all other sample periods, occupying almost 50% of the entire GA. However, by 2015, only a small amount of agricultural land remained in the outskirts of the district. The third most significant change occurred in woodland cover, which decreased year by year. Most of the loss occurred in the periods 1950–1975 and 1975–1985, when the percentage of woodland cover decreased by 17% and 25%, respectively, subsequently decreasing by a further 15% between 1994 and 2015 (Figure 3-6).

3.3.1.2. Changes within the bands across the entire GA

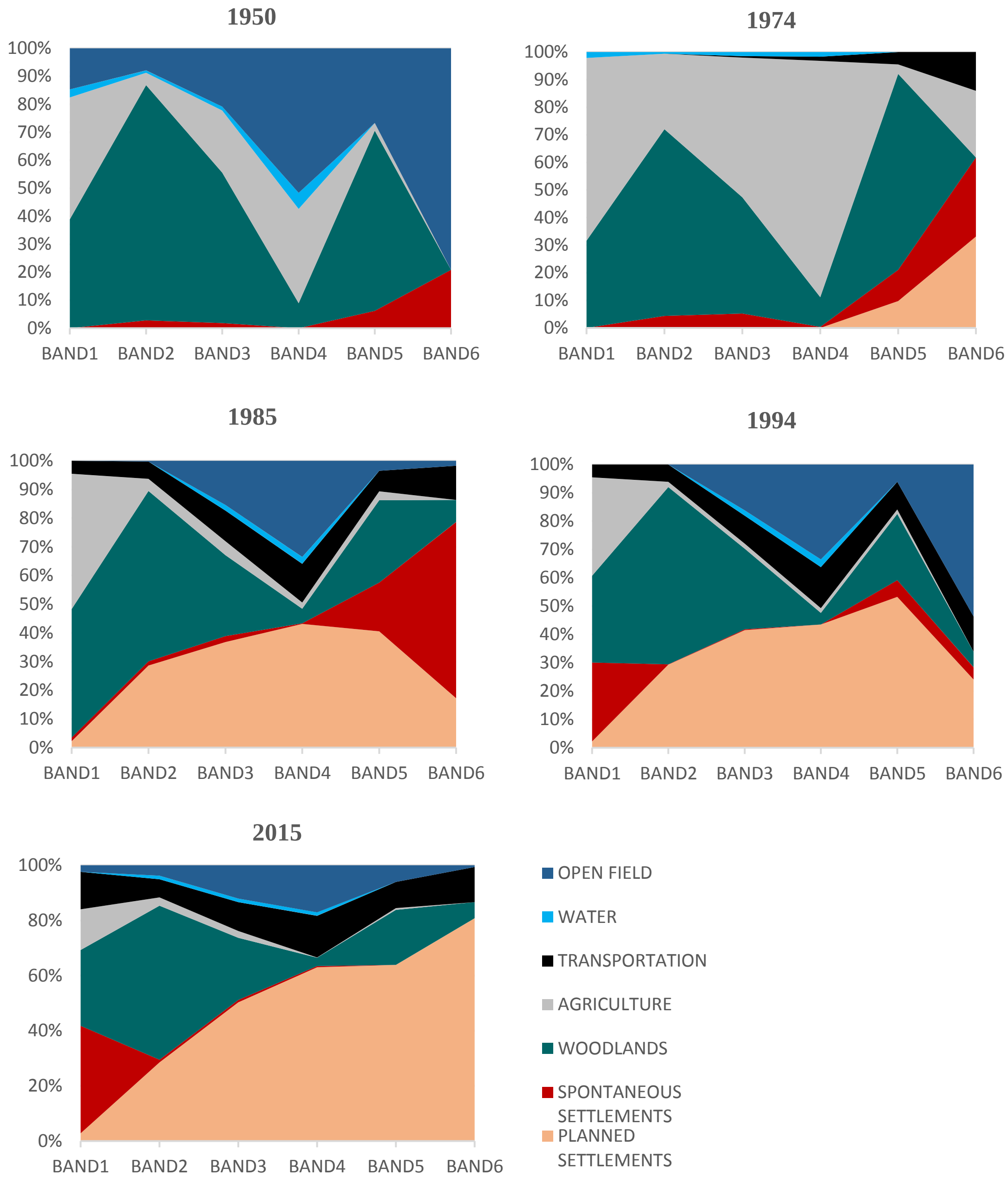

Figure 3-7. The proportion of LULC types within the 6 distance bands

The percentages of various land-cover types within each band changed over time (Figure 3-7). The area of natural landscape cover decreased along the gradient of urbanization over time. This is illustrated by the decrease in the water and woodland land-use types and corresponding increases in the planned settlements area and transportation categories. The water landscape type disappeared in bands 1 and 2 by 1985, but reappeared in band 2 in 2015. This is interpreted in Figure 3-2, where maps from 1950 and 1975 show a tributary stream originating from the Daemosan and Guryongsan Mountains, and flowing through the GSV to the Yangjacheon River. In the 1985 map the tributary is no longer visible. The loss of this tributary is also reflected in the decrease in water area from 17.07 ha in 1950 to 9.55 ha in 1985 (Figure 3-6). Furthermore, the shape of the water corridors was more diverse and natural in 1950 than in 1975 (Figure 3-2). The reappearance of the water landscape type in band 2 in 2015 is due to the Korean government building several canals in the Guyongsan and Deamansan Mountains for hydrological projects.

Most of the woodland area was located in bands 1, 2, 3, and 5. The percentage of woodland cover decreased with increasing distance from the core of the GSV. This was true particularly in bands 4 and 5, in which it decreased from more than 10% (17.30 ha) and 60% (73.02 ha) in 1950 to less than 4% (5.96 ha) and 25% (22.54 ha) in 2015. The area of woodland in bands 1 and 2 decreased from more than 35% (11.04 ha) and 80% (174.17 ha) to less than 30% (7.78 ha) and 55% (115.66 ha), respectively. Between 1985 and 2015, the highest percentage of woodland was maintained in the bands where the GSV is located. While the percentage of woodland decreased, the percentage of transportation and planned settlements areas increased correspondingly. Road construction began near the urban core (band 6) in 1974, then spread to the marginal area (band 2) in 1994, and finally occupied approximately 20% of each band in 2015. The planned settlements area gradually increased correspondingly from bands 6 to 1.

The agricultural area almost completely disappeared with urbanization. It peaked in 1975 from band 1 to band 4. However, during the period of rapid development from 1975 to 1985, large areas of agricultural land were lost in bands 3, 4, and 5. Currently, agricultural activities remain only in bands 1 and 2. Agricultural activities often developed alongside built-up villages. We examine this feature in the following section, where we analyze spontaneous settlements.

3.3.2. Changes in spontaneous settlement cover over time

3.3.2.1. Transition analysis of spontaneous settlements: the entire GA

The changes in spontaneous settlements in the bands between two successive sample periods were mapped to highlight differences. These maps illustrated not only where changes in spontaneous settlement cover occurred but also whether spontaneous settlement cover was lost, which LULC types they were converted to and, if spontaneous settlement cover increased, which LULC types they replaced (Grossinger, Striplen, Askevold, Brewster, & Beller, 2007). Figure 3-8(a) shows that the area of spontaneous settlements increased by about 26 ha between 1950 and 1985. However, it decreased markedly by approximately 33 ha between 1985 and 1994, subsequently decreasing by a lesser amount between 1994 and 2015. Spontaneous settlement land cover developed alongside agricultural activities, yet the area is only shown to

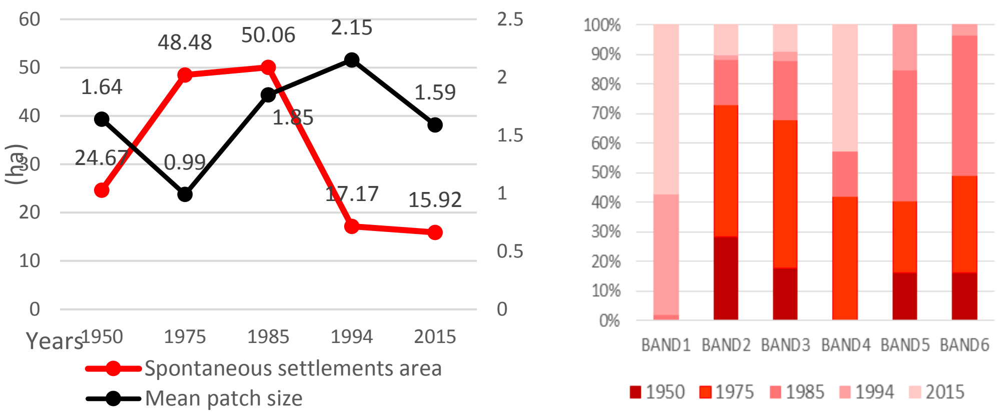

Figure 3-8. (a) Changes in total spontaneous settlement area, and changes in the mean size of spontaneous settlement patches from 1950 to 2015 in the GA; (b) percentages of spontaneous settlement patches in different bands.

increase significantly in the 1975 map (Figure 3-6). In the 1985 map, the area of spontaneous settlements increased by a lesser amount, but the area of agricultural land dramatically decreased at the same time. The size of a mean patch in 1985 was almost double that in 1975, indicating that settlements were more clustered in 1985 than in 1975 (Figure 3-8a). Although the percentage of spontaneous settlements was largest in 1985, that was a transition period before the total urbanization of the GA. The settlements built in the present-day location of the GSV first appeared in 1985(Figure 3-2). In 2015, not only the GSV but also the remaining area of spontaneous settlements were informal settlements.

Transition analysis indicated significant turnover in spontaneous settlement cover. The increase in spontaneous settlement land varied from 21% between 1985 and 1994 to 144% between 1950 and 1975. Whereas the decrease varied from 36% between 1950 and 1975 to 89% between 1985 and 1994 (Table 3-4). The largest decrease (89%) from 1985 to 1994 represented conversion to planned settlements land use (28.2 ha) during the period of rapid urbanization. Subsequently, only 4.26 ha was left unchanged from 1994 to 2015, compared with the 26.01 ha left unchanged from 1975 to 1985 (Table 3-4). The GSV occupied the largest percentage of unchanged land from 1994 to 2015, after being converted from the land-cover types of agriculture and woodland since 1985 (Figure 3-8). The substantial area of spontaneous settlements that replaced woodland was due to rapid urbanization in earlier years. However, this phenomenon continued in the period from 1994 to 2015, indicating that the formation of spontaneous settlements occupying natural land continued after the period of rapid urban development.

3.3.2.2. Changes in patches of spontaneous settlements within bands

The total percentage of spontaneous settlement cover in the different bands showed not only differences in location during different periods but also the marginalization that accompanied the process of urbanization. The annual rate of change in spontaneous settlement cover varied significantly among the bands. When patches began to appear in band 1 in 1985, the percentage of spontaneous settlement cover in the other bands (2–6) decreased gradually with increasing distance from the GSV. In 2015, most spontaneous settlements were in bands 1 and 3 (Figure 3-7, Figure 3-9). The GSV initially consisted of small fragmented areas of inhabited land, which subsequently expanded in size from 1985 to 1994 and finally shaped into one of the biggest urban informal settlement areas between 1994 and 2015. In 2015, the GSV covered the largest percentage of land in band 1, farthest away from the urban core of the GA (band 6) (Figure 3-7).

Table 3-4. Summary of results from the transition analysis of changes in spontaneous settlement areas for four periods.

	1950-1975	1975-1985	1985-1994	1994-2015
Unchanged land cover (ha)	14.35	26.01	4.05	4.26
Loss of spontaneous settlements cover (converted to) (ha)				
Transportation	0.35	3.03	0.31	2.49
Open field	0	2.52	12.58	0.12
Woodland	1.6	2.35	1.87	2.79
Agriculture	6.81	3.21	1.5	0.64
Water	0	0	0	0
Planned settlements	0	11.5	28.2	6.58
Total*	8.76	22.61	44.46	12.62
Percent**	0.36	0.47	0.89	0.74
Gain of spontaneous settlements cover (regenerated from) (ha)				
Transportation	0	0	0	0
Open field	19.87	0	0.15	0.15
Woodland	12.8	6.1	4.69	6.46
Agriculture	2.68	17.93	5.83	5.12
Water	0.35	0	0	0
Planned settlements	0	0	0	0
Total*	35.7	24.03	10.67	11.73
Percent**	1.44	0.5	0.21	0.68

*Total: the total area of spontaneous settlements gained or lost during the period between two successive sampling periods. **Percent: the percentage total area of spontaneous settlements gained or lost compared to the previous sample year.

3.3.3. Relationships between topographical characteristics and spontaneous settlements cover among bands

The locations of spontaneous settlements in Figure 3-10 show a clear pattern, generally occurring in the landforms of rolling or hill, local alluvial, or slopes of 2–7% and 7–15%. Although the area covered by spontaneous settlements in the mountain foothills was insignificant in all the historical sample

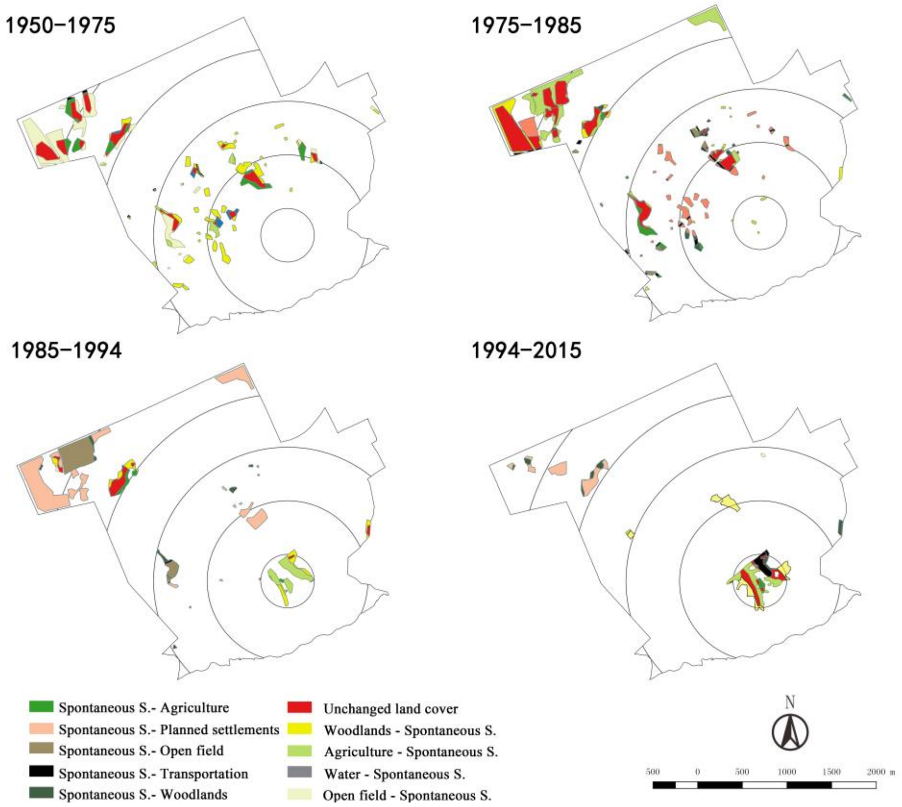

Figure 3-9. Maps of spontaneous settlement cover lost to other land-cover types, and replacing other land-cover types during five successive sampling periods.

periods, it did increase approximately fourfold (2.71 ha) by 2015 compared with that in 1975 (0.7 ha). Rolling hill soils occur along the ridgelines of both mountains, spreading north, in linear patterns towards the Yangjaecheon River (Figure 3-2). Local alluvial soil fills the valleys between these mountain ridges. Mountain foothills soil occur along the ridges of the Guryongsan and Daemosan Mountains.

The distribution of landforms and slope types overplayed by the spontaneous settlements in the bands reveals that before 1985 most spontaneous settlement areas were located on local alluvial land (2–7% and 7–

15%) in bands 3 and 6. There was subsequent development in a few areas of band 3 that were rolling or hill (15–30%) and in band 1 with diverse landforms of local alluvial, rolling or hill, and mountain foothill (15–30%), followed by other mountain or hill (30–60%) areas by 2015. This indicates that the locations selected for spontaneous settlements moved from plain areas to more steeply sloped and remote areas during the urbanization process.

3.4. Discussion

3.4.1. Historical LULC changes from 1950 to 2015

The mountain-river integrated landscape system was dominant in the GA prior to urbanization. Before 1950, and up until the period when Gangnam rapidly developed in the mid-1970s, the Gangnam District consisted of an integrated landscape system with the Yangjaecheon River and Guryong Mountain. This landscape system was comprised of intact, persistent ecosystems, with scattered areas of agricultural use. Daemosan Mountain and Guryongsan Mountain were completely covered with forests between 1950 and 1975 (Figure 3-2). The historical maps show an undisturbed, continuous area of vegetation up to the boundary of the valley where the present-day GSV is located. However, with rapid urbanization, much of this forested landscape disappeared (Grossinger et al., 2007). Large areas of natural land were lost when constructed areas dramatically increased. For example, between 1975 and 2015, the woodland cover decreased by approximately 39%, while the transportation cover increased by 3.3-fold.

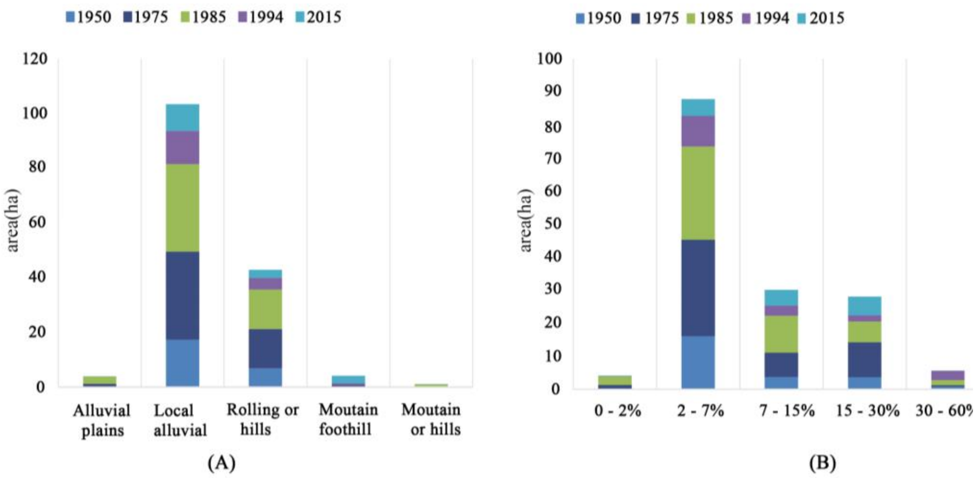

Figure 3-10. Quantification of five landforms (a) and six slope types (b) overlaying with spontaneous settlements for five successive sampling periods.

3.4.2. The spatial characteristics of informal settlement formation in the GA as indicated by topographical characteristics

The spatial characteristics of spontaneous settlements were shown through the degree of aggregation and locational shifts. While the total area occupied by spontaneous settlements in 1975 was almost equivalent to that in 1985, the mean size of the patches were markedly smaller (Figure 3-8a). This indicates that the informal settlements were distributed at a smaller scale with decentralized agricultural activities in 1975, but in 1985, they began to form larger clusters (Figure 3-8a, 3-9). The band analysis indicated that the rates of change in spontaneous settlements varied significantly depending on the distance from the urban core to the GSV. The trend of marginalization was reflected in the increasing spontaneous settlements in bands 1 and 2 since 1985 (Figure 3-8b). When patches began to appear in band 1, the percentage of spontaneous settlements in the other bands (2–6) decreased gradually with increasing distance from the GSV. Since 1994, the location of spontaneous settlements has moved away from most planned urban areas and into natural areas such as the mountains. In addition, the transition analysis revealed a similar trend, which found that most of the new areas of spontaneous settlements in 1994 and 2015 had once been woodland cover in the outskirts of the district (Figure 3-7).

From 1945 to 1961, many refugees from the Second World War and the Korean War settled in the hillside green spaces around Seoul. This was the beginning of the hillside informal neighborhoods that appear in the 1950 map of the GA (Figure 3-2). Han et al. (2004) has concluded that most of the citizens of new informal settlements and squatter settlements in the urban fringe of Seoul in the 1980s came from the 1970's inner-city government's slum clearance projects. This accounts for the trend of marginalization in the GA. In general, city governments have often turned to abolishment as a solution to the informal settlements, subsequently transferring and displacing residents (Kuyucu & Ünsal, 2010). Yet, without a clear understanding of the potential needs of the affected residents, the results have often led to a vicious cycle of forced relocation and informal settlement development (S.-K. Ha, 2004).

Firey (1946) has argued that the isolation from other highly developed areas plays a key role in the process of informal settlement formation. The city of Seoul is spread across an intricate landscape defined by watersheds, mountains, and rivers (Kuitert, 2013), and the topographically isolated areas, particularly the mountains, have often been chosen by low income citizens. Our analysis of the relationships between spontaneous settlements and topographical characteristics showed that the early sites of spontaneous settlements were in flat, plain areas (0–2%, 2-7%). However, as urbanization spread from the north side of the city to the south, informal settlements were established on steeper slopes (15–30%), in areas such as the mountain foothills (Figure 3-10). These areas had little construction and were relatively undeveloped. Therefore they were easily ignored by the government, which motivated informal city inhabitants to choose these sites for their living areas. As an example of this trend, the GSV is surrounded by forest vegetation to the east, west and south. There is only one entrance to the village, which is located at the north end, the side closest to the urban Gangnam District.

3.4.3. Implications for urban planning and the redevelopment of informal settlements

La Rosa et al. (2014) has indicated that urban fringes were comprised of the complex LULC types including some highly sensitive habitats such as forests, wetlands, and rivers. The GA supported a complex pattern of LULC types with different ecological characteristics that were related to persistent features (Grossinger et al., 2007). The transition analysis, as well as the historical preference for settlement construction in mountain areas showed that the spontaneous settlements of the GA took place primarily in the forests and on agricultural lands (Figure 3-9). This trend suggests that advantageous soil fertility was offered by forests, paddies, and croplands. Figure 3-4 shows the natural areas of rolling hill and local alluvial soil extending from the mountain toward the Yeongjaecheon stream. The linear pattern of this soil type represents a continuous vegetation system that extends from the Daemosan and Guryongsan Mountains all the way to the Yeongjaecheon stream, offering a natural landscape corridor (Table 3-3). Furthermore, the southern area of the Yangjaecheon offers an excellent habitat for wild birds since it contains forest linking the Daemosan and Guryongsan Mountains (K.-J. Lee, Han, Hong, & Choi, 2005). This implies that the urban fringe landscape of the GA has retained high biodiversity potential (Kim & Pauleit, 2007). Thus, development planning approaches should be unique to metropolitan fringe areas and should consider the biodiversity of the area (Browder, Bohland, & Scarpaci, 1995), The existence of the natural resources represents an asset to urban fringes, which in turn should be considered in the redevelopment of informal neighborhoods.

Despite this notion, much of Seoul's rapid population growth was accommodated via informal settlements, with little attempt being made to limit the risk of environmental impairments (Dewan & Yamaguchi, 2009). Previous strategies for the preservation or restrained upgrading of informal settlements commonly focused on fluctuating elements of the settlements or communities, such as citizen demands, facilities, and economic development regarding social issues and regional economies (Bhan, 2014; Boussaa, 2014; Cavalheiro & Abiko, 2015; Das, 2015; S. K. Ha, 2001; Ooi & Phua, 2007). These strategies placed little value on the areas' natural and permanent features. The GSV and other remnant informal settlements in the GA have neighbored with persistent forest landscapes for decades. In addition, the soil system directly beneath the GSV is unique in that the rolling hill and local alluvial soil types appear further up the mountains, and the soil types are more diverse in the GSV area than in any other area in the Gangnam District (Table 3-3). This suggests the potential for a wide range of vegetation types to exist within the small area of the GSV. For example, the mountain foothill soil is suitable for sustaining a healthy forest with diverse tree communities including Quercus Acutissima and Betula Schmidtii(K.-J. Lee et al., 2005). Therefore, it is important for future policy-making to consider the ecological potential both in urban fringe developments and in the redevelopment of informal settlements.

CONCLUSION

Based on historical changes in landscape patterns, this thesis has investigated three case studies in Seoul city to map and quantify several indicators of urban ESs.

Study 1 analysed historical changes in ESs at the regional scale from 1975 to 2015. Our results reveal that total potential CS in our study area decreased by 41.2% between 1975 and 2015, with loss and fragmentation of landscapes and smaller and simpler patch shapes appearing in the urban area, as indicated by landscape metrics. UGS played a crucial role in CS at the city level; thus, a sharp decrease in urban forest and agriculture areas was the main cause of CS loss, although a 120% increase in the area of grasslands in part offset these two decrease. The size, shape, and spatial arrangement of UGS, especially in the grassland landscape type, affected ESs in different ways, which should be considered in future policy-making and green infrastructure planning initiatives. These findings contribute to the evidence that historical maps are useful for analysing temporal dynamics and the trajectory of landscape changes, and provide important insights for the conservation of natural habitats in the central urban area of Seoul. However, limitations to the CS model used in our study remain, including an oversimplified carbon cycle, the assumption of linear change in CS over time, and potentially inaccurate discounting rates (Sharp et al., 2014). Further studies should explore the relationship between changes in landscape patterns and multiple ESs.

Study 2 addressed changes in the extent of forest ecosystems, distinguished HFRs from current forest habitats in 2015, and assessed the potential impact of landscape patterns of current forests on the potential for HFRs to provide a biodiversity ES. Our results indicate that HFRs can play significant roles in supporting biodiversity but are affected by the shape metrics of current forests and the current area of NFHs; these findings provide important insight into forest conservation efforts in urban areas. We conclude that the size, shape, and spatial pattern of current forests affect the extent of the biodiversity service provided by HFRs. Limitations of the study included the level of accuracy in the detection of remnants through the use of land-cover maps based on remote-sensing data, the lack of empirical field data available for these sites, and the assumption that threats to the landscape were additive in the habitat quality model. In some cases, the collective impact of multiple threats may be much greater than the sum of each individual threat (Sharp et al., 2014). Understanding the value of ecosystem services provided by forest remnants in large urban areas is a potentially valuable tool for quantifying and assessing functional landscape changes related to urban development (Fahey & Casali, 2017). The challenge remains in developing potential strategies that incorporate the protection of HFRs. Therefore, we emphasize the importance of the careful design of NFHs during urban planning initiatives for conserving historical patches. We contend that in constructing urban green infrastructure, fragmented forest remnants should be increasingly viewed as essential components and historical evidence, and as such, should be integrated into landscape conservation schemes.

Study 3 aims to improve understandings of informal settlement formation in a metropolitan fringe, through a comprehensive spatiotemporal analysis of topographical characteristics, using the case study of the Guryong Area (GA) in the Gangnam District of Seoul, South Korea. The LULC changes indicated that 1) large areas of natural land were lost due to the dramatic increase in constructed areas (Figure 3-6), and 2) spontaneous settlements occupying natural lands continued to emerge after the period of rapid urban development (Table 3-4). The transition analysis showed that while the total area occupied in

1975 by spontaneous settlements was almost equivalent to that in 1985, the mean size of the development patches was markedly smaller (Figure 3-7a). The band analysis indicated that the trend of marginalization was reflected in increasing spontaneous settlements in bands 1 and 2 since 1985 (Figure 3-7), while the percentage of spontaneous settlements in the other bands (2–6) decreased gradually with increasing distance from the GSV (Figure 3-8b, 3-9). The analysis of the relationship between spontaneous settlements and topographical characteristics showed that early spontaneous settlements developed in flat areas, while later settlements were established at the district's border in steeper areas with slopes of 15-30%, such as the mountain foothills (Figure 3-10). These results suggest that the spatial characteristics of informal settlements are shown in the degree of aggregation and marginalized trend indicated from the analysis of spontaneous settlements. The results also support the idea that isolation from other highly developed areas plays a key role in the process of informal settlement formation during the urbanization process. However, the informal settlements at the urban fringe are location-specific, and the urban fringe landscape often retains high ecological potential. For example, the soil system directly beneath the GSV is unique in that the rolling hill and local alluvial soil types are ideal for a wide range of plant communities. Therefore, we suggest that the development of the urban fringe should consider ecological potential as an ecotone bridging the natural and urban systems. This idea can be applied to urban planning and policy-making for informal settlements in the metropolitan fringe. Understanding the strategies of informal settlement redevelopment in rapidly expanding cities requires not only the assessment of the site's current living environments or social structures, but also land-use history and landscape systems. Although the comprehensive spatiotemporal analysis is a useful tool for understanding informal settlement development, there are still limitations to this study. The less accurate nature of historical data required us to use the term "spontaneous settlements" (Figure 3-3A) to research and speculate the characteristics of informal settlements (Figure 3-3b). Also, we chose not to focus on the sociopolitical issues concerning informal settlements in hopes of homing in on specific spatial and ecological factors. However, we believe the political and social implications of informal settlement development are integral to the field and this study should be considered alongside socioeconomic studies of informal settlements. We hope to pave the way for future studies that can elucidate the relationship between informal settlement development and complex social factors. Finally, we hope the spatial analysis can be used as a basis and starting point for the evaluation process of informal settlement redevelopments in other areas of Seoul, as well as in other Asian cities.

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국문초록

경관패턴의 변화가 시가화지역 생태계서비스에 미치는 영향-시공간적 관점에서

대규모의 급격한 도시화는 생태계 서비스의 퇴보와 생물다양성의 손실을 야기할 수 있는 토지 이용의 변화를 일으키는 원인으로 작용한다. 서식지가 제공하는 생태계 서비스의 질은 경관 패턴에 의해 크게 영향을 받을 수 있다. 그러나 다양한 도시 규모의 경관 패턴과 생태계 서비스의 역사적 변화에 대한 양적 지식은 제한적이다. 본 논문에서는 인간이 점유하고 현대화된 한국 서울의 경관에 대한 세가지 사례 연구를 통해 경관 유형과 생태계 서비스의 변화와 관계에 대하여 매핑하고 정량화하고자 하였다. 이러한 목표를 달성하기 위하여 1950년부터 2015년까지의 토지이용/토지 피복에 대한 시계열 자료를 ArcGIS 소프트웨어를 이용하여 만들었다. 경관 패턴의 변화는 FRAGSTATS소프트웨어(ver. 4.2.1)를 이용하여 정량화하였다. 특정 경관 매트릭스의 하위 집합이 각각의 연구에 이용되었다. 생태계 서비스는 생태계 서비스 및 트레이트 오프 통합 가치 모델(InVEST)을 통해 매핑, 정량화하였다.

제 1장에서는 도시 녹지공간에 의해 만들어지는 생태계 서비스에 대하여 식별하고 서울시 남부 지역 규모에서 시계열적 변화를 정량화하였다. 이 연구에서는 먼저 경관의 변화를 탐지하고 생태계 서비스의 지표중 하나인 탄소 격리를 시험 사례로 선정, InVEST모델을 이용하여 공간적 변화를 도출하였다. 총 잠재 탄소 격리는 1975 년부터 2015 년까지 41.2 %

감소하였으며, 경관 메트릭스에서 나타나는 바와 같이 도시 지역에서는 경관의 손실과 단편화가 발생하였고 패치는 단순화되고 축소되었다. 더욱이 도시림과 농업 지역의 큰 감소가 탄소 격리 감소의 주 요인으로 작용하였다. 반면에 초지 면적의 120% 증가는 이러한 두가지 요인을 다소 상쇄하였다.

제 2장에서는 산림 생태계 범위와 인간이 점유하고 현대화된 서울의 경관에서 생태계 서비스를 만들어 내는 HFR 역할의 변화를 생태계 서비스의 지표로서 생물다양성을 서식지 공간 구성을 통하여 측정하였다. 두 기간의 토지피복 지도는 HFR과 현재의 공원 내에서 고립된 37개의 패치들을 식별하고 생플링하는데 이용되었다. 그런 다음, 경관의 패턴과 서식지 질 모델 및 서식지 단위를 InVEST모델을 활용하여 생물다양성의 프록시로서 계량화하였다. 뒤이어, 피어슨 상관 계수와 단계별 다중 회귀 분석을 사용하여 HU와 결합 된 조경 메트릭스를 조사하였으며 이를 통해 HFR의 생물 다양성에 영향을 미치는 핵심 요인을 탐색하였다. 전체 숲 지역의 확연한 감소로 총 HUS의 35.31%감소가 관찰되었다; 그러나 HFR의 HUs는 0.5%증가했다. 현재 숲의 형태는 HFR의 생물 다양성에 긍정적으로 영향을 미치는 반면, 새로 형성된 서식지는 생물 다양성에 부정적인 영향을 미칠 수 있다. 따라서, 도시 계획에서 새로 형성된 서식지의 세심한 설계는 역사적 공간에 대한 보존을 포함해야 한다.

제 3장에서는 경관 패턴 이론에 근거하여, 연구 대상지 내 구룡 지역 사례 연구를 통해 지역 규모의 특정 조경 유형을 조사하여 현재 비공식적 정착지와 대도시 주변 경관 형성에서 그들의 역할에 대한 이해를 증진시키고자 하였다. 이 연구에서는 구룡 지역 전체에 대한 1950년부터 2015년까지의 LULC 변화를 측정한 후 “자발적 정착지”로 정의된 특정 토지 이용 유형의 변화를 분석하였으며, 이러한 변화를 도시화 단계에 따라 600m

넓이의 밴드 생태적 데이터(지형, 경사)와 결합하였다. 도출된 결과는 1975년에 작은 집단에 의한 자발적 정착 분포가 이루어졌으며 1985년부터 이 분포가 더 크고 응축된 집단 분포로 성장하였다는 것을 보이고 있다. 1950년에서 2015년 사이에 자발적 정착지의 총 면적은 감소하였으며 정착지의 위치는 도시 중심부에서 구룡 지역의 가장자리 부분으로 이동하였다. 반면, 자발적 정착지로 선정된 지역은 경사가 2-7%인 평야에서 경사가 15-30%인 산기슭과 같은 가파른 경사가 있는 외딴 지역으로 이동하였다. 이러한 결과는 비공식적 정착지의 공간적 특성이 자발적 정착지의 분석에서 나타난 응집도와 가장자리화 경향으로 나타나고 있음을 시사한다.

Keyword: 서식지 파편화, 서시깃 질, 탄소 격리, 도시 주변, InVEST 모델, 비형식적 정착지, 서울