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Greenbelt Systems Play an Important Role in the Prevention of Landscape Degradation Due to Urbanization

Yong-Chan Cho[1,4], Hyun-Je Cho[2] and Chang-Seok Lee[3]*
[1]*Department of Biology, Graduate School of Seoul Women's University, Seoul 139-774, Korea*
[2]*Korea Green Promotion Agency, Daejeon 302-121, Korea*
[3]*Faculty of Environment and Life Sciences, Seoul Women's University, Seoul 139-774, Korea*

ABSTRACT: Greenbelts were designated by the Korean government in 1971 in 14 large cities to prevent uncontrolled urban expansion. Recently, deregulation of the greenbelt system has resulted in further development, but the ecological role of greenbelts has not been fully considered when decisions about urban management are being made. We examined the ecological roles of the greenbelt system in the Seoul metropolitan area and prepared sustainable management and improvement plans based on our analysis of landscape characteristics using satellite images covering a ~30-year period. The loss of forest cover during this period in the greenbelt areas was lower than that in the areas outside and inside of the greenbelt. Fragmentation of forest cover was correlated with the pattern of loss of forest cover. The NDVI of the greenbelt remained steady at 90% of that in outside of the GB for three decades. This suggests that the greenbelt system has performed its primary roles well. However, the remaining green space was not adequate to provide a sink for air pollutants even when the greenbelt area was included. We discuss how the negative effects of urbanization can be reduced through sustainable management and restoration to promote ecological functioning in greenbelts and urban landscapes.

Key words: Fragmentation, Greenbelt, Landscape, NDVI, Pollution, Seoul, Urbanization

INTRODUCTION

The Korean government designated greenbelts (hereafter abbreviated as GB) in 14 large cities in 1971, as strongly restricted development areas to protect green spaces and to prevent uncontrolled urban expansion. The area designated as GB covers 5,397 km^2, which comprises 5.4% of the total land area in South Korea (Lee et al. 2000). The GB surrounding Seoul have been referred to as one of only a few successful landscape management tools in Asian megacities (Yokohari et al. 2000). Similar GB systems have also been created in America, Australia, China, France, German, Great Britain, Japan, New Zealand, Netherlands and several countries in Southeast Asia (Thomas 1970, Schabel 1980, Yokohari et al. 2000).

Humans used traditional living methods and landscape management for thousands of years (Holzner 1983), but have altered the Earth's landscape more in the past 50 years than in any other time in history. Urbanization is occurring worldwide on a massive scale (Alig and Healy 1987, Meyer and Turner 1992), and has brought various alterations to our abiotic and biotic surroundings (Grimm et al. 2008a, Grimm et al. 2008b, Pavao-Zuckerman and Byrne 2009). Changes in land cover due to urbanization and industrialization have resulted in degradation of natural environments via water, soil and air pollution, and by removing the conversion of natural landscapes to other habitat types. The complex and cumulative effects of these changes have resulted in the structural and functional simplification of urban ecosystems, especially vegetation, and those effects are rapidly spreading into suburban and rural areas. Urbanization is also closely associated with climate change (Grimm et al. 2008b).

Korea has pursued rapid industrialization since the 1960s. Seoul, which covers 605 km^2 and is inhabited by >25% of the South Korean population, has been a metropolitan area since the 1970s and is well-known as a representative Asian metropolitan area (Yokohari et al. 2000). Land use in the Seoul metropolitan area has changed as the population has increased and industrialization has led to ongoing conversion of agricultural and forested lands to built-up areas (Lee et al. 2000, Lee et al. 2001, Kim et al. 2003). The GB system has not been immune to these changes. For example, KRIHS (Korea Research Institute for Human Settlements; 1983) reported that natural resources such as forests and valleys near large cities make excellent areas for recreation or sports. However, further development of that land cannot be achieved in Seoul due to the GB policy. The Seoul region experiences greater demand

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* Corresponding author; Phone: +82-2-970-5666, e-mail: leecs@swu.ac.kr

[4] Present address; College of Ecological & Environmental Sciences, Kyungbuk National University, Sangju 742-711, Korea

for residential area and leisure activities than other regions in Korea, and hence more space for construction and recreational parks is urgently needed (KRIHS 1983). Accordingly, the KMC (Korean Ministry of Construction; 1989) prepared guidelines for the utilization of greenbelts for recreational parks and distributed them to local governments. These guidelines, which describe desirable site conditions for different types of recreational parks, stipulates that the sites should be selected after a comprehensive consideration of several factors such as geographical conditions, land tenure, land use and carrying capacity, but consider only human demands and benefits without any consideration of the various ecological functions of the GB, such as air purification, urban heat island mitigation, conservation of biodiversity and natural habitats, etc. Quantifying ecosystem services in a spatially explicit manner can help to make decisions about natural resource use in a more effective, efficient and appropriate manner (Nelson et al. 2009). Recently, deregulation of the greenbelt system has resulted in additional development in GB areas.

To date, no evaluations of the ecological functions of GB or sustainable landscape management plans for GB in urban areas have been prepared. But Park et al. (1996) evaluated the GB in Seoul using remote sensing for 8 of the 25 years of the GB history, a period too short to allow any firm conclusions, and Lee et al. (2001) analyzed landscape patterns, including stand dynamics and the species composition of vegetation, in GB. Kim et al. (1989) also elucidated the relationships among several forest types in GB.

Environmental policies in South Korea require consideration of landscape-level phenomena because those policies are closely associated with human activities and landscape ecology addresses the impacts of these activities on a larger scale (Turner et al. 2001). Adaptive analysis and integration of ecological information are required to initiate effective plans for the restoration and improvement of urban forests and for the establishment of sustainable management plans for urban areas.

In this study, we clarify the roles of Greenbelt systems in Seoul in prevention of landscape degradation and urban sprawl. We also propose a sustainable management plan for GB based on landscape and restoration ecological principles.

METHODS

Study Area

The study area is the GB areas in the city of Seoul, the capital of Korea, which is located in central Korea, and its surrounding areas. The study area is classified as a cool temperate forest zone. The 30-year mean annual precipitation and temperature in Seoul are 136.9 cm and 12.2℃, respectively. The mean temperature in Seoul is about 0.7℃ higher than that (11.5℃), of the adjacent big cities Incheon, Suwon, and Chuncheon (Korea National Statistical Office 2002). The study area ranges from N37° 6' 4" to N54' 2", and from E126° 33' 7" to E127° 30' 32" and from 10 m to 780 m above sea level. The GB areas surround Seoul and many satellite cities, including Incheon city, with an appearance similar to that of a large donut (Fig. 1). In order to analyze the effects of the GB, the study area was divided into three zones: the interior areas surrounded by the greenbelt (IGB), areas within the GB, and areas on the exterior of the greenbelt (EGB) (Fig. 1). The EGB were determined using GIS software using the buffer function with a 10 km average width of the GB (Park et al. 1996).

Image Processing

The boundaries of the GB were based on 1:50,000 national topographical maps published in 1977. The effects on the quantity and quality of habitat on both sides of the GB was examined using satellite imagery. Quantitative assessment was carried out by analyzing changes in forest cover in IGB, GB, and EGB during the last 30 years. Qualitative changes were assessed by examining landscape fragmentation and the Normalized Difference Vegetation Index (NDVI).

Satellite image interpretation was carried out using ERDAS IMAGINE 8.6 and Arcview GIS 3.3. Satellite images taken in four different years were used for analysis. The earlier images (1975 and 1983) were from Landsat MSS (Multispectral Scanner, Path/Row 124-34 for 1975 and 116/34 for 1983) and those from 1992 and 2001 were from Landsat TM (Thematic Mapper, Path/Row 116-34) and Landsat ETM (Enhanced Thematic Mapper, Path/Row 116/34) data, respectively. Images from 1983, 1992, and 2001 were taken on June 3, and that from 1975 was taken on June 20, so we assumed that plant phenology in those four images was similar. Images were geometrically corrected by TM projection on 1:50,000-scale national topographic maps and resampled to 30 m × 30 m pixel size (the total area differed among the images). The root mean square error was controlled to within one pixel. For each image, we picked >15 ground control points (GCP) obtained from digitalized topographic maps (e.g. play ground, large intersections, peak of Mt. Nam in 1:50,000 topographical map), and constructed subsets for the IGB, GB, and EGB polygons.

Landscape Analysis

Land cover data were produced from each image using a supervised classification method to analyze change in forest area in the approximately 30 years since the GB were designated. Areas were classified into five types of aquatic areas, paddy fields, upper fields, urbanized areas and bare ground, and forest. Greenhouses were

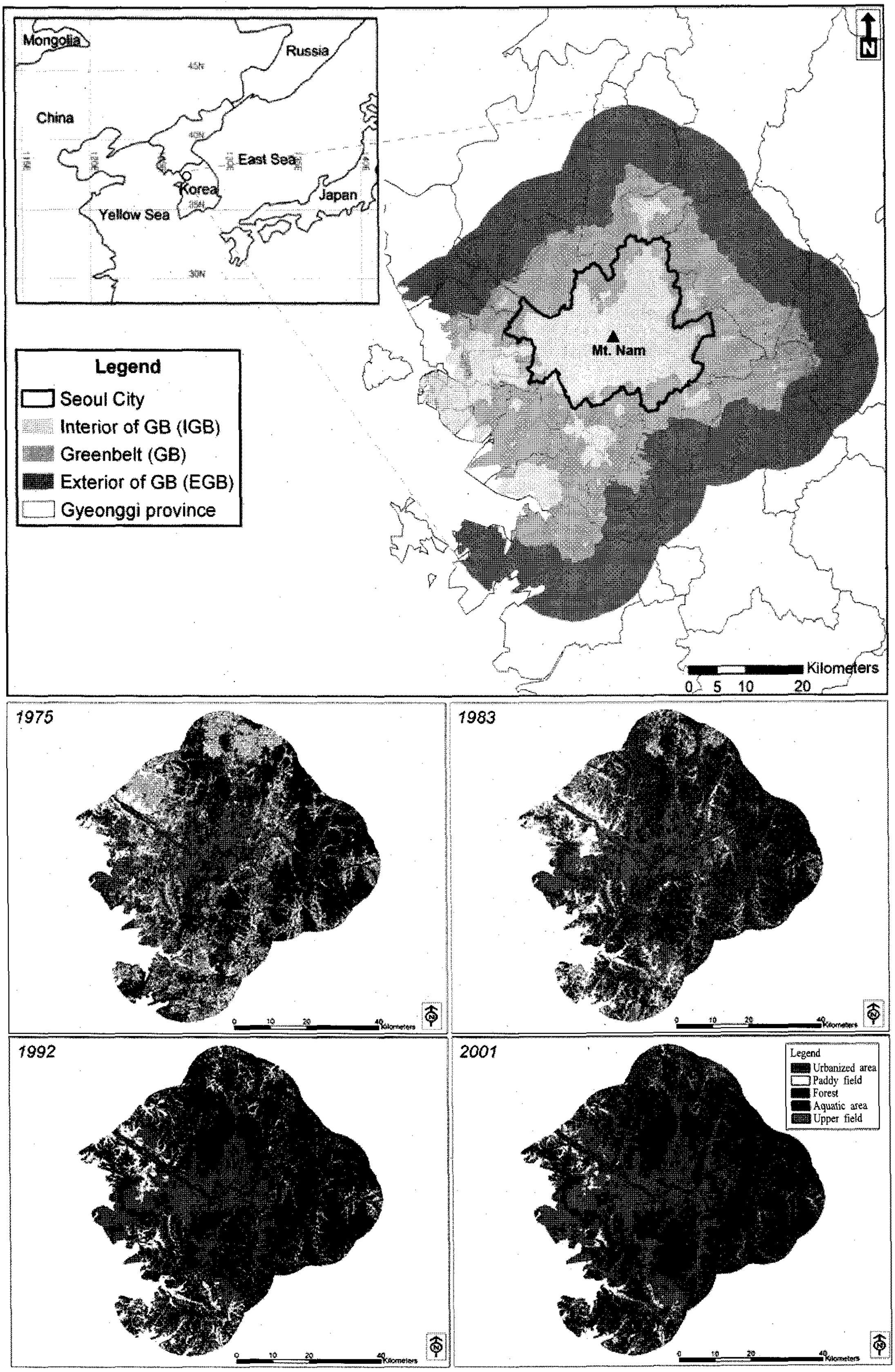

Fig. 1. Map showing the study area (upper) and changes in land cover classes in the study area over ~30 years (lower).

classified into the urbanized class. Cover types were separated by determining the spectral distance between the class signatures. For land cover classification of satellite images, accuracy was verified to > 90% (Lillesand and Kiefer 1994) using 15 ground truth data (e.g., bridges, play grounds, large intersections, the peak of Mt. Nam in 1:50,000 topographical map) per classes. For the images from 1975 and 1983, visual interpretation of the original satellite data by the authors was also used to aid in the classification.

A cohesion index (range between 0 and 1) for the forest cover was obtained using FRAGSTATS 3.3 (McGarigal and Marks 1995). This index is used to determine landscape fragmentation and to measure the degree of aggregation or connectedness of focal patches (Schumaker 1996, Gustafson and Parker 1992, Saura and Martinez-Millan 2001). The equation to obtain the index is as follow (McGarigal and Marks 1995):

$$COHESION = \left[1 - \frac{\sum_{j=1}^{m} p_{ij}}{\sum_{j=1}^{m} p_{ij}\sqrt{a_{ij}}}\right]\left[1 - \frac{1}{\sqrt{A}}\right]^{-1}$$

Where p_{ij} = perimeter of patch ij in terms of number of cell surfaces, a_{ij} = area of patch ij in terms of number of cells, and A = total number of cells in the landscape (McGarigal and Marks 1995).

NDVI was used to monitor changes in area of forest cover (Jensen 1996, Lyon et al. 1998, Mass 1999, Woodcock et al. 2001). NDVI is based on the ratio of the maximum absorption of radiation in the red spectral band to the maximum reflection of radiation in the near infrared spectral band. NDVI values range between −1.0 and +1.0 with those approaching +1.0 indicating the presence of dense vegetation cover (closed canopy forest). Mean NDVI values were calculated for forested areas of the IGB, GB and EGB, which were extracted from the land cover data. Because NDVI is affected by daily climate conditions and the acquisition time for the satellite data, we calculated values (%) of the IGB and GB relative to the NDVI of the EGB (referred to as 100%).

Quantitative Evaluation on the Buffering Functions of GB

The buffering function of the vegetation in the GB was evaluated in terms of the capacity for filtering several air pollutants (CO, SO_2, NO_x and CO_2). This evaluation informs us not only about the ecological role of the GB but also may suggest causal factors underlying forest changes in the IGB and some parts of the GB. Source data for air pollutants were obtained from the Korea National Statistical Office (2002). The filtering function of vegetation in the study area were calculated from Lee (2005) by multiplying forest area in 2001 by the absorption capacities per unit area (ha) per year for CO (2.2 ton $ha^{-1} yr^{-1}$), SO_2 (0.24 ton $ha^{-1} yr^{-1}$), NO_x (0.46 ton $ha^{-1} yr^{-1}$) and CO_2 (6.4 ton $ha^{-1} yr^{-1}$) for forests.

RESULTS

Quantitative Landscape Changes

The area of land classified as urbanized continuously increased over time, changing from 45,601.7 ha in 1975 to 178,261.2 ha in 2001 (Table 1). Conversely, agricultural land area (paddy and upper

Table 1. A comparison of land cover changes over the ~ 30 years since GB designation in the GB around the Seoul Metropolitan area and its surrounding areas, the IGB and EGB.

Cover type	IGB (ha)	GB (ha)	EGB (ha)	Total (ha)
1975				
Aquatic area	3,261.3	5,748.4	3,211.7	12,221.4
Paddy field	13,991.9	27,830.7	29,373.5	71,196.0
Upper field	7,843.8	14,792.7	19,309.2	41,945.7
Urbanized area	35,338.6	4,862.3	5,400.8	45,601.7
Forest	18,024.6	101,394.5	147,309.6	266,728.7
Total (ha)	78,460.1	154,628.6	204,604.8	437,693.5
1983				
Aquatic area	2,854.8	6,749.2	3,005.4	12,609.4
Paddy field	7,097.8	18,883.8	22,672.9	48,654.4
Upper field	12,617.3	19,800.4	28,071.2	60,489.0
Urbanized area	41,068.4	8,068.1	7,156.6	56,293.2
Forest	14,821.7	101,127.1	143,698.7	259,647.5
Total (ha)	78,460.1	154,628.6	204,604.8	437,693.5
1992				
Aquatic area	2,554.9	4,503.9	2,811.9	9,870.7
Paddy field	2,413.8	16,790.6	28,860.9	48,065.3
Upper field	620.1	7,082.5	12,072.5	19,775.1
Urbanized area	60,366.0	26,012.0	32,617.1	118,995.1
Forest	12,524.9	100,276.1	128,303.0	241,104.0
Total (ha)	78,479.8	154,665.0	204,665.4	437,810.2
2001				
Aquatic area	2,421.3	3,638.3	1,700.9	7,760.4
Paddy field	589.7	7,811.1	15,369.3	23,770.1
Upper field	184.7	2,152.1	5,478.2	7,815.0
Urbanized area	64,085.1	47,550.8	66,625.3	178,261.2
Forest	11,199.0	93,512.8	115,491.7	220,203.5
Total (ha)	78,479.8	154,665.0	204,665.4	437,810.2

fields) decreased from 113,141 ha in 1975 to 31,585 ha in 2001. The percentage of forest cover and the pattern of forest loss was different in different areas (Fig. 2). The forest cover in the IGB declined from 23.0% in 1975 to 18.9% in 1983, 16.0% in 1992, and 14.3% in 2001, while those in the EGB were 72.0% in 1975, 70.2% in 1983, 62.7% in 1992, and 56.4% in 2001, and only 5% of forested area in the GB was lost over the study period, with forest cover decreasing from 65.6% in 1975 to 60.5% in 2001.

Changes in the forested area relative to that in 1975 were also analyzed. The forest cover in the IGB was reduced to 82.2% of the original value in 1983, 69.5% in 1992, and 62.1% in 2001. Those in the EGB declined to 97.5% of the 1975 value in 1983, 87.1% in 1992, and 78.4% in 2001 (Fig. 3), whereas the decrease in the GB was slight: 99.7% of the original value in 1983, 98.9% in 1992, and 92.2% in 2001.

Changes in the Landscape and Vegetation Qualities

Changes in the cohesion index, by which the degree of landscape fragmentation can be evaluated, were marked in the IGB, but negligible in the GB and EGB (Fig. 4). The NDVI increased for about ten years after GB designation but has tended to decrease since 1983 (Fig. 5). The value of the NDVI in the IGB relative to that in the EGB was 53.5% in 1975, 71.0% in 1983, 67.2% in 1992, and 53.7% in 2001. The value of the NDVI in the GB relative to that in the EGB has remained >90%: it was 90.2% in 1975, 93.1% in 1983, 90.5% in 1992, and 91.9% in 2001.

Buffering Function of GB

The absorption capacities of forests for various pollutants generated in Seoul are shown in Table 2. There was insufficient vegetation in the IGB to absorb pollutants, resulting in a severe imbalance between sources and sinks of pollution, indicated by negative values. The imbalance was most pronounced for CO_2.

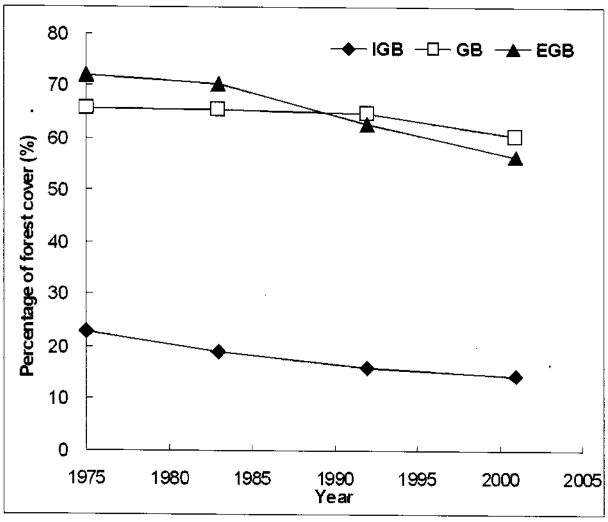

Fig. 2. Changes in the forest cover ratio in the greenbelt interior (IGB), exterior (EGB) and in the greenbelt itself (GB) around Seoul in the last three decades.

DISCUSSION

Long-term changes in spatial land use patterns and the resulting biotic and abiotic responses such as changes in forest cover, forest fragmentation, NDVI and the buffering function of forests were analyzed in the GB and the surrounding areas in the Seoul metropolitan area. Integration of such ecological information into urban

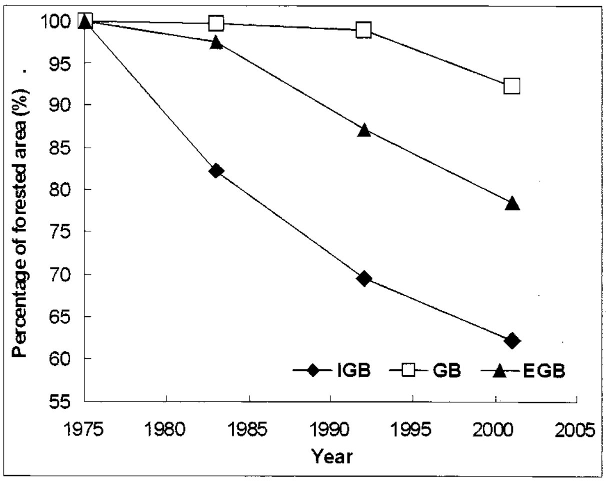

Fig. 3. Changes in the forested area compared to that of 1975 in the greenbelt interior (IGB), exterior (EGB) and the greenbelt itself (GB) around Seoul in the last three decades.

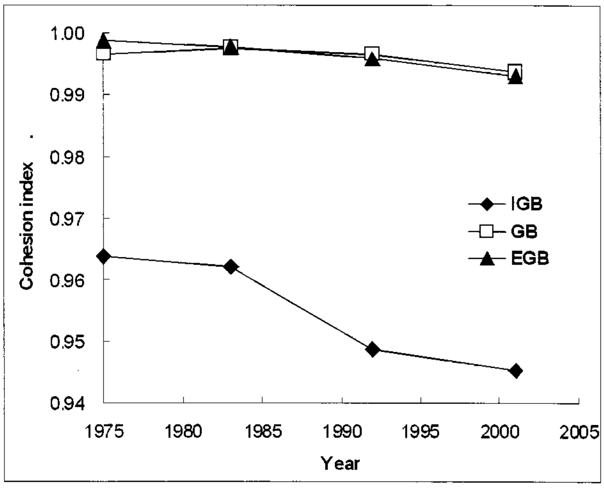

Fig. 4. Changes in the cohesion index for forest cover in the greenbelt interior (IGB), exterior (EGB) and the greenbelt itself (GB) around Seoul in the last three decades.

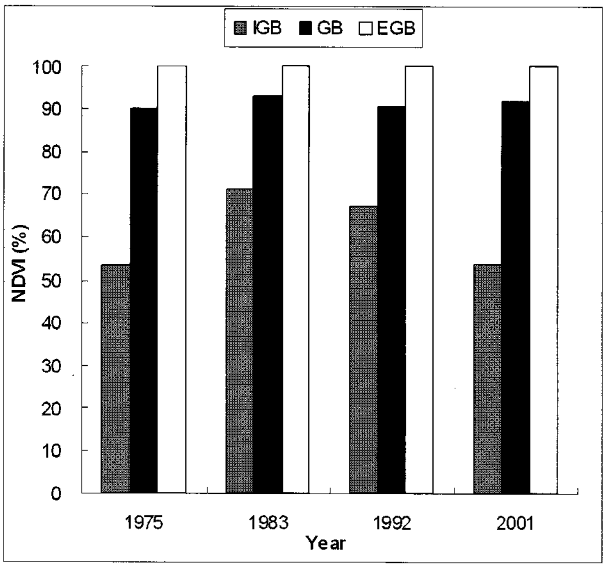

Fig. 5. Comparisons of the relative NDVI of the greenbelt interior (IGB), exterior (EGB) and the greenbelt itself (GB) around Seoul by the period at about 10-year intervals.

policy, planning, design, and management strategies is complex, but from a landscape ecological point of view, integration of ecological data into urban policy is one of the key management and research priorities (Wu and Hobbs 2002).

Effects of the Greenbelt System on a Landscape Level

In the IGB and EGB, forest cover has decreased continuously and substantially during the 30 years since GB designation. Forest loss in the IGB was due to expansion of the existing urban area and forest loss in the EGB was to construction of new cities. Change of forest cover in the EGB revealed a movement of urban functions, such as residence and industry, to the urban outskirts. Those land-use changes are closely associated with environmental problems, and this trend has been notable in the Seoul Metropolitan area in recent years (Kwon et al. 2004, You 1998).

Forest cover in the GB decreased less than that in the IGB and EGB during the study period. Conservation of forest in GB was usually due to restrictions on construction to essential public facilities, such as highways and local roads, and to public services including educational establishments, etc. (Park et al. 1996). A shift in agricultural techniques from conventional farming in paddy and upper fields to modernized farming using greenhouses was also notable.

Patterns of fragmentation of forest cover over the last ~30 years corresponded well with the observed decreases in forest cover. Landscape fragmentation affects abundance and spatial patterns of native habitats, and often results in additional habitat loss and fragmentation (Skole et al. 1994, Turner et al. 1994, Sinclair et al. 1995, Matlack 1997, Cooperrider et al. 1999). The GB and EGB showed little habitat fragmentation during the study period, but in the IGB, fragmentation of natural forested areas was severe as the total forested area decreased to about 60% of total area. Lee et al. (2008) suggested a restoration plan to address the urban environmental problems occurring due to the uneven distribution of green space. The plan seeks to connect remnant forest patches using linear landscape elements, such as restored urban rivers or streams and footpaths along roadsides by applying restoration ecological principles.

Increases in forest cover during the early part of the study period were due to vegetation growth resulting from government nature

Table 2. Quantitative comparisons between air pollution sources in Seoul (2000) and the absorption capacities of greenery spaces in the GB and its surrounding areas, the IGB and EGB

Environmental factors		Sink (ton / ha^{-1} yr^{-1})		
		IGB (S1)	IGB+GB (S2)	IGB+GB+EGB (S3)
CO		24,637.8	230,365.8	484,447.7
SO_2		2,687.8	25,130.8	52,848.8
NO_x		5,207.5	48,691.0	102,394.6
CO_2		71,673.6	670,155.2	1,409,302.3
Balance between source and sink	Source (ton/yr, S)	S1 - S	S2 - S	S3 - S
CO	156,955.0	−132,317.2	73,410.8	327,492.7
SO_2	7,091.0	−4,403.2	18,039.8	45,757.8
NO_x	83,762.0	−78,554.5	−35,071.0	18,632.6
CO_2	30,881,541.0	−30,809,867.4	−30,211,385.8	−29,472,238.7

conservation policies, and the subsequent decrease is probably due to various environmental stresses related to urban expansion. The NDVI of the GB, which remained at ~about 90% of that of the EGB, hardly changed during the study period. However, the NDVI of IGB has declined as low as ~70% of that of EGB. The NDVI of the IGB increased until 1983 but has been decreasing continuously since then. Increases in the NDVI in the early 1980s are attributable to the recovery of degraded forests since the 1970s (Lee et al. 2001). The subsequent reduction in the NDVI since the 1980s is probably due to urban expansion and to reductions in forest vitality caused by chronic air pollution and acid rain since the 1980s (Kim 2005, Ryu and Lee 1992). Additionally, the heat island effect and temperature inversions due to the lack of green space in the urban center compared with that in the suburbs and beyond, and the trapping of air pollutants related to the microclimatic changes (Miller 1997, Lee et al. 2008) may also have led to decreases in the NDVI. Conversely, the NDVI in the GB was sustained at a consistent proportion of that of the EGB during the study period. From this result, it can be inferred that the GB and the EGB are within the same range in terms of urbanization effects. Patterns of long-range transport of air pollutants such as NO_x, SO_x, and O_3 also support that inference (Cox et al. 1975, Apling et al. 1977).

Environmental degradation resulting from urbanization affects the public functions of forests, such as air filtering, water retention, etc. Imbalances between sources of air pollutants and the filtering or public functions of forest (i.e., as a pollution sink) is severe in the Seoul metropolitan area (Table 2). An increased number of sources and a concurrent decrease in the environmental capacity of forests in urban environments to absorb pollutants causes various problems such as heat island effects, forest decline, climate change and human disease. In addition, such imbalances can result in unexpected effects in other ecosystem components in urban and surrounding areas. Without alternatives to this undesirable situation, truly sustainable management for urban ecosystems is still far away.

The establishment of GB areas has succeeded in its original goals, which include preventing uncontrolled urban expansion and preserving natural environments from various environmental stresses in suburbs. If properly managed, GB could also contribute to improving the urban environment via the performance of diverse ecological functions.

Implications for Natural Resources Management

One of the most critical steps in preserving biological communities is the establishment of legally designated protected areas. Protected areas can be established in a variety of ways, but the two most common mechanisms are government action (often at a national level but action can also occur at a regional or local level) and purchases of land by private individuals and conservation organizations (Primack 1995).

The GB system, designated by government decree in 1971, has two major purposes: prevention of uncontrolled urban expansion and preservation of the environment in the suburbs. The IUCN (The World Conservation Union) has developed a system of classification for protected areas, ranging from minimal to intensive use of the habitat by humans (IUCN 1984, McNeely 1995): strict nature reserves and wilderness areas, national parks, national monuments and landmarks, managed wildlife sanctuaries and nature reserves, protected landscapes and seascapes, resource reserves, natural biotic areas and anthropological reserves, and multiple-use management areas. In this classification system, GB zones are roughly equivalent to "protected landscapes and seascapes" or "resource reserves." That is, they occupy an intermediate position between truly protected areas and managed areas (Primack 1995).

For sustainable management, 1) GB can be divided into three zones-the core area, a buffer area and a transition area-by imitating a Multiple Use Module (MUM) (Noss and Harris 1986). Enhancement of the connectedness of green space is also a desirable goal for future GB management.

In GB areas in this study, there was less loss of forest as a natural landscape element over the last 30 years than in IGB and EGB areas (Fig. 3), which shows that the GB designation contributed to quantitative conservation of green space. However, based on the NDVI, the quality of green space in the GB is worse than that in the EGB, which is undoubtedly due to the effects of a big city, Seoul. Moreover, several new cities were constructed newly in the EGB, which contributed to fragmentation of the GB. Air pollutants from those cities will also influence the GB and EGB and are likely to cause forest decline in GB as the case in IGB.

Both ecological functions and environmental carrying capacity should be considered when planning for the conservation of functions in GB areas. The GB and its surrounding areas are composed of various landscape elements that are natural or semi-natural, such as plantation areas, and artificial elements. Each component has its own natural or socio-economical functions and needs. Therefore, suitable management plans that consider its function are required (Groom et al. 2006). The uses of core areas of GB, which are generally composed of natural areas including *Q. mongolica* and *Pinus densiflora* forests on the upper slopes, ridges and peaks (Lee et al. 2001), should be limited to activities such as climbing and hiking.

Buffer areas surrounding the core areas consist of various plantations and are usually established in lower elevations at the feet of mountains. The ecological importance of plantations is generally lower than that of natural forests. However, conversion of plantations to natural forests via succession is ongoing in Korea in recent years. This vegetation change has been achieved by a kind of passive restoration, as opposed to unassisted restoration (Lee et al. 2002, 2004), but enrichment planting designs may considerably hasten the natural process in plantations in low areas. Therefore, in the future, the ecological functioning of the buffer areas may reach that of the core areas.

Agricultural fields in lower and hilly areas, an element of the transition zone in the GB that has received high development pressure, perform various ecological functions, such as diminishing edge effects by increasing the physical distance from industrial or residential areas and connecting remnant lowland forest patches. Agricultural landscape elements prevent isolation of natural landscape elements, which are embedded in artificial landscapes as remnant patches. Unfortunately, the conversion of traditional agriculture to greenhouse agriculture prevents agricultural lands from performing these functions (Lee et al. 2001, Lankoski 2003, Lee et al. 2008).

Control of landscape development and improvement of landscape connectedness by connecting green landscape elements within the GB and among the IGB, GB, and EGB are essential elements of landscape management plans designed to improve ecological functioning within metropolitan landscapes, and restoration planning on a landscape level is necessary (see Lee et al. 2008). The ecological quality of the GB will be determined by the ecological balance in the urban area, including the GB. The primary step to enhance the ecological function of the urban space would be reintroduction of green space in the urban center, which lacks vegetation. Accordingly, we recommend that a network of green space be introduced to recover a balanced ecological structure and functioning in the metropolitan area. Atmospheric sources of air pollution must also be reduced, and management plans should consider the loss of forest cover in the EGB in the process of construction of new cities, which also discharge pollutants.

GB areas play critical roles as a kind of buffer zone that helps to restrict urban sprawl. However, in this study, the GB had a lower NDVI than the EGB and the area near to the urban center displayed symptoms of forest decline or adaptation of plant communities to environmental changes (Lee et al. 2008). In order to prevent expansion of the damaged area, additional buffer zones are needed around both existing urban areas in the IGB and newly constructed cities in the EGB. Reduction of the NDVI in the IGB and GB (Fig. 5) due to excessive forest use, various pollutants discharged from the many satellite cities constructed in the EGB, and isolation of the GB by urban expansion in the EGB and the IGB indicate the need for the introduction of a system such as MUM for sustainable management of the area.

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