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Using the City Biodiversity Index as a Method to Protect Biodiversity in Korean Cities

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Abstract: This study calculated the ecological network index (City Biodiversity Index 2) of 85 cities in Korea using the Land Cover Map. Based on the values of the index, four types of city were studied, including Miryang (Cluster A), Anseong (Cluster B), Samcheok (Cluster Cluster), and Yongin (Cluster D). Based on the current status of land use and natural green space in urban areas, small and medium-sized cities do not show many disconnected factors and have a positive (+) effect on the ecological network index (ENI) value. In order to promote urban biodiversity, it is necessary not only to expand the green area quantitatively, but also to improve the quality, such as expanding and connecting natural green areas, and reducing linear disconnection factors.

Keywords: biological diversity; ecological network; natural green space; clustering

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1. Introduction

Since the inception of the concept of sustainable development at the 2008 Convention on Biological Diversity (CBD) COP9, city biodiversity has become an issue. The coexistence of human species in harmony with nature in the city is the primary goal. The World Economic Forum (WEF) developed the Environmental Performance Index (EPI) to assess the environmental load, population vulnerability, and social and institutional capacity of each country and the Environmental Sustainability Index (ESI) to assess environmental preservation and ecosystem vitality [1]. The CBD developed the City Biodiversity Index (CBI) [2]. In South Korea, the development of indicators involving domestic cities was based on a review of international indicators to assess sustainability [3].

CBI is a tool designed to monitor and evaluate methods and practices for preserving and strengthening the city biodiversity and ecosystem services. The development of the CBI was initiated in 2008 by the CBD Secretariat in partnership with the local governments internationally on Biological Diversity, The Singapore Government, the Academic Organization Partnership, and the Civil Society. The CBI consists of a total of 23 indicators that are classified into biodiversity, ecosystem services, administration, and management. The method can be used in quantitative evaluation based on the status of ecosystems, management organizations, and operations that changed over a certain period. The CBI draft, designed via an international expert workshop, was approved by 193 CBD member countries through Article X/22 of the Biological Diversity Strategy and Implementation Plan, determined at the 2010 Conference of Parties to the CBD in Nagoya, Japan. Although the application of CBI according to national and urban conditions based on evaluation indices is ambiguous, and the evaluation criteria have yet to be specified, work is underway. At the 2014 Conference of Parties to the CBD held in Pyeongchang, the Ministry of Land, Infrastructure, Transport, and Tourism of Japan released a draft of a Japanese version suitable for their country based on the need, simplification, and applicability of CBI indicators.

In South Korea, studies investigating urban parks, green space networks, and urban ecological networks, have analyzed the construction of networks based on the type of green spaces, such as urban parks and streams [4–6]. Other studies sought to measure landscape connectivity [7]. Yun et al. [3] attempted to develop a Korean-style urban evaluation index for use as an environmental policy by diagnosing environmental challenges independently to improve urban environment and biological diversity. Park et al. [8] analyzed the ecological networks using a biotope map and land cover to determine the ecological network index (ENI) among CBI indicators. A second index known as CBI represents connectivity or ecological networks to counter fragmentation. Fragmentation of natural areas is one of the main threats to sustainable urban biodiversity. Therefore, fragmentation of natural areas affects different species differently. The ENI score was higher when each green space was connected rather than fragmented. However, studies and surveys investigating the actual connectivity of green spaces are unavailable, and the indexation of national ecological networks is inadequate. This study evaluated the ecological network function of cities in Korea and ways to improve them using the city biodiversity index (CBI).

2. Research Methodology

This study involved a total of 85 cities, including special metropolitan cities, large and medium cities, and small towns in South Korea. The 85 cities, including metropolitan cities, were classified into large cities with a population of 500,000 or more, medium cities with a population ranging from 100,000 to 500,000, and small towns with 50,000 to 100,000 residents. Metropolitan cities were classified separately due to the large difference in population size compared with cities classified as large cities. As shown in Figure 1, calculating ENI, classification of cities according to ENI, and defining the characteristics of land use and natural green spaces in representative city clusters were carried out.

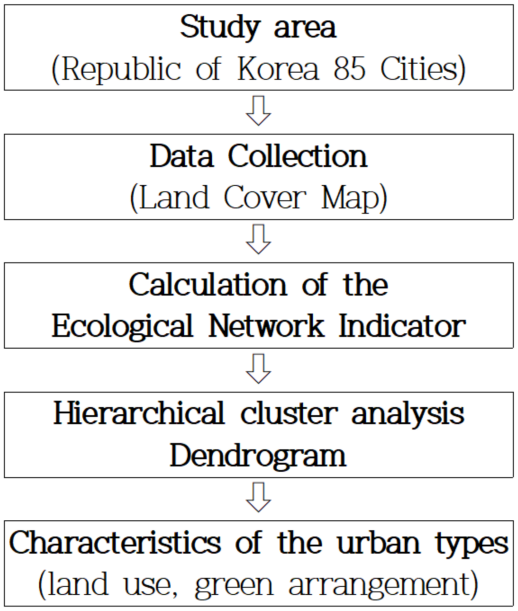

Figure 1. Flowchart outlining the research methodology.

The ecological network analysis indicators were determined using methods presented in the CBI manual, and developed by Secretariat of CBD [9]. The ENI can be used to increase the connectivity of the ecological network or to reduce the disconnectivity. A high score indicates connected rather than fragmented green spaces. The index reflects the current status of natural green space disruption, which is one of the threats to sustainable biodiversity in cities. The artificial elements presented in the manual include roads more than 15 m wide, roads with daily traffic exceeding 5000 vehicles, artificial canals, over-maintained artificial rivers, and artificial structures. Roads may not be an ecosystem-

disrupting element in case of wild birds. However, they affect the mammalian population and negatively affect plant pollination caused by mammals [9]. ArcGIS 10.3 and Excel 2010 software programs were used for the analysis. Land cover of the Environmental Geographic Information Service (EGIS) provided by the Ministry of Environment was also developed. In the case of the EGIS land cover map, all local governments carried unified codes by attributes. The land cover map was divided into large, medium, and small areas, and the medium classification was applied to the 85 cities [10]. During the course of this study, the land cover map on the national unit remained at level 2. Recently, a sub-divided land cover map of the national unit was completed in the 11th round of 2020. For the construction of basic data, natural elements (natural areas) and disconnected elements (transportation areas) were established in the land cover map GIS file. The natural elements were classified into deciduous forests (Code 310), coniferous forests (Code 320), mixed forests (Code 330), natural grasslands (Code 410), inland wetlands (Code 510), natural bare grounds (Code 610), and inland water (Code 710). The classification of disconnected elements was based on transportation areas (Code 150). Using a 50 m buffer centering on the natural element patch, the disconnected element was excluded using the Erase tool. Each area was calculated after merging the fragmented patch. The ecological network value was calculated by dividing the sum of squares of green spaces by the total green space area per patch (Figure 2).

$$\text{IND2 (Ecological Network)} = \frac{1}{A_{total}}\left(A_1^2 + A_2^2 + A_3^2 \ldots + A_n^2\right)$$

$$\text{Ratio of Ecological Network (\%)} = \frac{1}{A_{total}}(\text{EN})$$

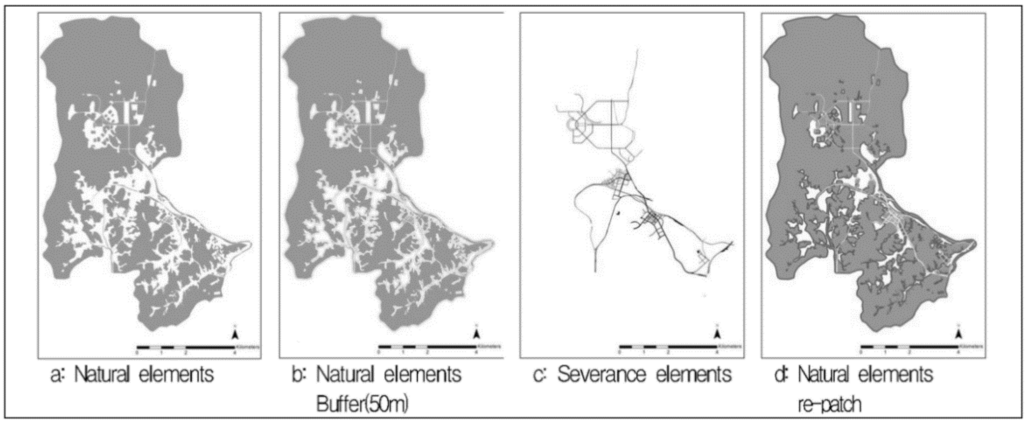

Figure 2. Connectivity measures or ecological networks to counter fragmentation. The map was generated by ArcGIS 10.3 software (http://www.esri.com/software/arcgis/arcgis-for-desktop, accessed on 25 September 2020).

As for the calculation method of the ecological network analysis indicators, the method of calculating the connected green spaces was used as presented in the CBI manual. Green spaces with a distance of less than 100 m in between are regarded as connected, and a 50 m buffer is provided to each polygon of natural green spaces to identify the connectivity [9].

Based on the ENIs of 85 cities, a hierarchical cluster analysis was performed using SPSS (Paws statistics 22.0) and the dendrogram was created to classify the cities. The connections between groups were based on their Euclidean distance squared. Using SPSS (Paws Statistics 22.0), Pearson's correlation of ecological network rates, green spaces rates, natural green spaces, and transportation facilities was performed. Additionally, representative cities were selected from the clustered city groups to delineate the characteristics of the urban environment in each cluster. The characteristics of the natural green space distribution in the cities were compared and analyzed in terms of landscape ecology based on

the shape, size, connectivity, arrangement, and structure of the green patch [11–13]. Mean Patch Size (MPS) and Class Area (CA) were calculated as the indices associated with the natural green patch area. Total Edge (TE) and Mean Patch Edge (MPE) were calculated as the indices associated with edge length.

3. Results and Review

3.1. Calculation of the Ecological Network Index (ENI)

The ratio of natural green spaces in the 85 cities in South Korea ranged from 15.9% to 90.7%. The ratios of the transportation area ranged from 0.7% to 14.4%. Based on the ENI, Yongin-si was selected as the highest city with 55% natural green space, 1.5% traffic area, and an ENI of 304.2. Next, the cities were distributed in the order of Samcheok-si (234.0), Namyangju-si (193.6), and Gangneugn-si (130.3). Among the 85 cities in South Korea, Bucheon-si had the lowest ENI, with 15.9% of natural green space area, 14.4% of transportation area, and an ENI of 0.9, followed by Mokpo-si (1.6), Siheung-si (3.3), and Gwangmyeong-si (4.5).

Regarding spatial distribution, there were 18 cities with less than 10 ENI, including Bucheon-si, Mokpo-si, Guri-si, and Gwangmyeong-si. There were 18 cities with an ENI of 10–20, including Anyang-si, Seoul Special City, Gunpo-si, Asan-si, and Seongnam-si. There were 17 cities with an ENI of 20–40, including Gumi-si, Seosan-si, Sacheon-si, and Gimpo-si. There were 22 cities with an ENI of 40–100, including Chungju-si, Dangjin-si, Gwangju Metropolitan City, and Daejeon Metropolitan City. There were 10 cities with an ENI greater than 100, including Miryang-si, Yeongju-si, Seogwipo-si, and Yangsan-si (Table 1, Figure 3, Appendix A Table A1).

3.2. Clustering of Cities Based on Ecological Network Analysis

Based on ENI, a total of 4 clusters were created. Cluster A includes 12 cities, including Chuncheon-si, Suncheon-si, and Pohang-si, whereas Cluster B includes 70 cities, such as Bucheon-si, Mokpo-si, and Guri-si. Cluster C includes 2 cities (Namyangju-si and Samcheok-si), and Cluster D involves Yongin-si. Based on the analysis of ecological networks, most of the cities in the study were classified as Cluster B (Table 2).

In Cluster A, the average ratio of natural green space areas was 69.3%, the average ratio of transportation areas was 1.5%, the average ENI was 105.9, and the average ratio of green space areas was 78.9%. In Cluster B, the average ratio of natural green space areas was 51.1%, the average ratio of transportation areas was 3.1%, the average ENI was 26.0, and the average ratio of green space areas was 68.1%. In Cluster C, the average ratio of natural green space areas was 80.0%, the average ratio of transportation areas was 1.2%, the average ENI was 213.8, and the average ratio of green space areas was 91.8%. In Cluster D, the ratio of natural green space areas was 55.4%, the ratio of transportation areas was 1.5%, the ENI was 304.2, and the ratio of green space areas was 82.7% (Table 3, Appendix A Table A2.

Table 1. Calculation of ecological network index (ENI) of 85 cities in South Korea (summary of major cities).

City Number	City	Ratio of Natural Green Space (%)	Ratio of Transportation Area (%)	Ecological Network Index	Rank	City Number	City	Ratio of Natural Green Space (%)	Ratio of Transportation Area (%)	Ecological Network Index	Rank
2	Ansan-si	70.6	3	15.4	61	46	Jeongeup-si	44.6	1.2	27.3	40
4	Anyang-si	49.2	9.6	10.1	67	54	Namyangju-si	69.3	1.6	193.6	3
7	Bucheon-si	15.9	14.4	0.9	85	58	Pocheon-si	69.4	0.8	64.4	19
11	Cheongju-si	52.5	2.3	47.6	28	61	Sacheon-si	59.5	1.7	24	47
15	Daejeon Metropolitan City	56.6	4.6	42.1	29	62	Samcheok-si	90.7	0.7	234	2
19	Gangneung-si	79.8	1	130.3	4	66	Seongnam-si	52.6	4.9	14.4	63
24	Gimpo-si	36.4	1.5	24.6	46	67	Seosan-si	38.5	1.4	23.4	48
27	Gumi-si	59.4	2	21.7	49	68	Seoul Special City	28.1	12.1	10.4	66
28	Gunpo-si	45.2	8.1	10.8	65	69	Siheung-si	28.9	6.7	3.3	83
30	Guri-si	41.8	5.1	3.4	82	80	Yangsan-si	76.8	1.6	118.7	7
34	Gwangmyeong-si	36.4	7.4	4.5	81	83	Yeongju-si	64.7	1.2	109	9
50	Mokpo-si	24	6.7	1.6	84	85	Yongin-si	55.4	1.5	304.2	1

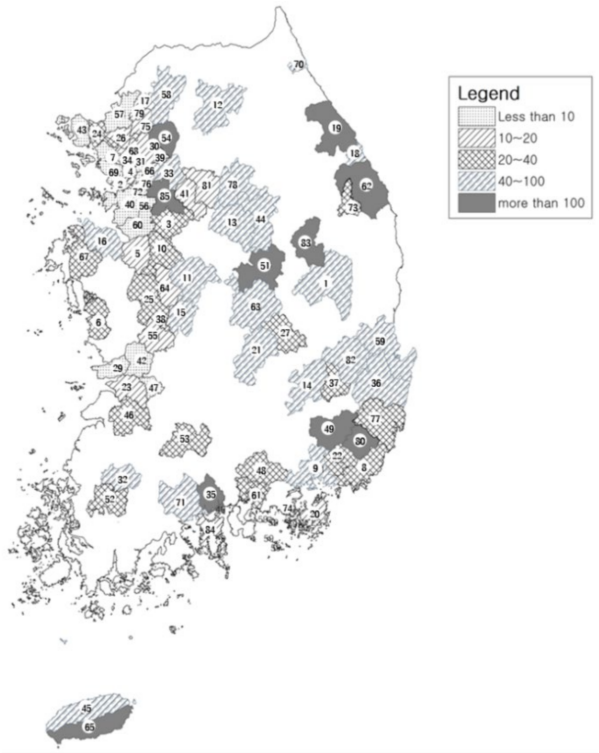

Figure 3. ENI Map covering 85 cities in South Korea. The map was generated by ArcGIS 10.3 software (http://www.esri.com/software/arcgis/arcgis-for-desktop, accessed on 25 September 2020).

Table 2. Clustering of cities based on ecological network analysis.

Types	City Number *
Cluster A (12 cities)	1, 9, 12, 19, 35, 49, 51, 59, 65, 71,80, 83
Cluster B (70 cities)	2–8, 10, 11, 13–18, 20–34, 36–48, 50, 52, 53, 55, 56–58, 60, 61, 63, 64, 66–70, 72–79, 81, 82, 84
Cluster C (2 cities)	54, 62
Cluster D (1 city)	85

* Refer to Appendix A for City Number.

In contrast to ENI, the analysis was performed based on a clear classification of natural green spaces, excluding artificial factors. However, the comparison of urban green space rates, the areas of the green spaces, and the green space rate in the city were calculated based on the green spaces containing artificial elements, such as rice paddies, fields, and artificial lakes. Based on the ranking of the ENI between cities and the ranking of the ratio of green space areas, Seogwipo-si, Chuncheon-si, and Jeju-si were identified as the representative cities with a low green space ratio and high ENI. The representative cities with a high green space ratio and low ENI were Dongducheon-si, Ansan-si, and Tongyeong-si. Thus, in addition to quantitative green space area expansion to enhance biological diversity within the city, specified green space area management plans for reducing linear disconnect elements, such as natural green space area expansion and connection, as well as transportation facilities are needed to improve the ENI.

Table 3. Clustering of cities according to ecological network index (summary of major cities).

City Number	City	Average Ratio of Green Space Area	Average Ratio of Transportation Area	ENI	EN Rank	Ratio of Green Space Area (%)	Ratio of Green Space Area (Rank)	City Number	City	Average Ratio of Green Space Area	Average Ratio of Transportation Area	ENI	EN Rank	Ratio of Green Space Area (%)	Ratio of Green Space Area (Rank)
	Cluster A	**69.3**	**1.5**	**105.9**	**-**	**78.9**	-	68	Seoul Special City	28.1	12.1	10.4	66	49.2	74
19	Gangneung-si	79.8	1.0	130.3	4	83.9	21	66	Seongnam-si	52.6	4.9	14.4	63	72.9	45
80	Yangsan-si	76.8	1.6	118.7	7	90.8	6	69	Siheung-si	28.9	6.7	3.3	83	59.1	66
83	Yeongju-si	64.7	1.2	109.0	9	87.8	15	2	Ansan-si	70.6	3.0	15.4	61	89.7	8
	Cluster B	**51.1**	**3.1**	**26.0**	**-**	**68.1**	-	4	Anyang-si	49.2	9.6	10.1	67	68.7	53
34	Gwangmyeong-si	36.4	7.4	4.5	81	43.7	79	46	Jeongeup-si	44.6	1.2	27.3	40	61.9	58
30	Guri-si	41.8	5.1	3.4	82	50.5	73	11	Cheongju-si	52.5	2.3	47.6	28	76.4	37
27	Gumi-si	59.4	2.0	21.7	49	63.9	55	58	Pocheon-si	69.4	0.8	64.4	19	86.1	19
28	Gunpo-si	45.2	8.1	10.8	65	53.4	72		**Cluster C**	**80.0**	**1.2**	**213.8**	**-**	**91.8**	**-**
24	Gimpo-si	36.4	1.5	24.6	46	62.1	57	54	Namyangju-si	69.3	1.6	193.6	3	88.1	14
15	Daejeon Metropolitan City	56.6	4.6	42.1	29	80.2	31	62	Samcheok-si	90.7	0.7	234.0	2	95.5	2
50	Mokpo-si	24.0	6.7	1.6	84	53.4	71		**Cluster D**	**55.4**	**1.5**	**304.2**	**-**	**82.7**	**-**
7	Bucheon-si	15.9	14.4	0.9	85	37.4	82	85	Yongin-si	55.4	1.5	304.2	1	82.7	25
67	Seosan-si	38.5	1.4	23.4	48	59.2	65		**Total**	**54.4**	**2.8**	**45.0**	**-**	**70.4**	**-**

Pearson's correlation analysis was conducted to identify the correlation between natural green spaces, transportation facilities, green spaces rate, and ecological network rate, which are the primary variables in this study (Table 4). Natural green space covers broad-leaved forests, coniferous forests, mixed forests, natural grasslands, inland wetlands, natural lands, and inland trees. Green space refers to green areas including rice paddies, fields, facility cultivation, orchards, artificial grasslands, and artificial areas that contain natural green spaces and additional artificial elements. The ecological network showed a significant positive correlation with the natural green spaces rate (r = 0.508, $p < 0.01$) and green space rate (r = 0.421, $p < 0.01$), and a significant negative correlation with transportation area rate (r = −0.366, $p < 0.01$).

Table 4. Results of correlation analysis.

Classification	Pearson's Correlation Coefficient			
	(1)	(2)	(3)	(4)
Natural green space rate (1)	1			
Transportation area rates (2)	−0.491 **	1		
Ecological Network (3)	0.508 **	−0.366 **	1	
Green space rate (4)	0.836 **	−0.436 **	0.421 **	1

** Significant correlation coefficient ($p < 0.01$; two-tailed).

3.3. Characteristics of Land Use and Distribution of Natural Green Space in the Representative Cities

3.3.1. Land Use

After selecting representative cities most similar to the average value of the ENI within the cluster, the characteristics of land use and natural green space distribution of the cities were identified. The average ENI for Cluster A was 105.9, and Miryang-si (107.8) was selected as the representative city. The average ENI for Cluster B was 26.0, and Anseong-si (26.0) was selected as the representative city. Samcheok-si (234.0) was selected as the representative city for Cluster C. A single city, Yongin-si, was classified as group D (304.2)

Land use in Miryang-si was in the order of coniferous forests (30.4%), mixed forests (17.6%), deciduous forests (14.8%), and field (7.4%), and the transportation area constituted 1.1%. Land use in Anseong-si was in the order of rice paddies (25.2%), coniferous forests (19.3%), and fields (11.1%), and the transportation area was 1.1%. Land use in Samcheok-si was in the order of deciduous forests (43.6%), coniferous forests (37.5%), fields (4.7%), and mixed forests (4.3%), and the transportation area was 0.7%. Land use in Yongin-si was in the order of coniferous forests (22.9%), deciduous forests (16.9%), rice paddies (13.3%), and mixed forests (12.3%), and the transportation area was 1.5%. Compared with the other three cities, Anseong-si was characterized by a wider distribution of cultivated land than forested areas, and the ENI was not determined by including the cultivated land in natural green space, so it had no influence on the ENI (Table 5, Figure 4).

3.3.2. Spatial Distribution

A comparison of the average ENI by cluster revealed the results as B < A < C < D. It can be stated that Yongin-si had a better connection with natural green space than other representative cities. The number of green patches ranged from 1170 to 1341, and was similar for all the clusters except for Cluster C. The comparison of the mean patch size by cluster revealed the result as B < D < A < C, and comparison of the mean patch edge of natural green space revealed the result as B < A < D < C (Table 6, Figure 5). Thus, in the case of ENI, small and medium-sized cities with several natural elements do not carry many disconnected elements. The potential for connection between natural elements is high, so the area of natural elements has a positive (+) effect on the value of the ENI, while big cities carrying fewer natural elements contain numerous disconnected elements, so the numbers and areas of fragmented natural green spaces have a negative (–) effect on the value of the ENI. In order to improve the ENI, it is important to secure the area of natural

green areas, and create interconnected green areas and minimize disconnection due to artificial elements.

Table 5. Land use of representative cities based on cluster analysis.

Classification	Cluster A (Miryang-si)		Cluster B (Anseong-si)		Cluster C (Samcheok-si)		Cluster D (Yongin-si)	
	Area (ha)	Ratio (%)	Area (ha)	Ratio (%)	Area (ha)	Ratio (%)	Area (ha)	Ratio (%)
Residential	2046	2.6	2344	4.2	510	0.4	4140	7.0
Industrial	189	0.2	911	1.6	89	0.1	1539	2.6
Commercial	116	0.1	298	0.5	125	0.1	778	1.3
Culture–Sports–Recreation	26	0.0	15	0.0	25	0.0	203	0.3
Transportation	867	1.1	622	1.1	860	0.7	869	1.5
Public Facility	123	0.2	271	0.5	152	0.1	818	1.4
Rice Paddies	11,359	14.2	13,986	25.2	1091	0.9	7846	13.3
Fields	5916	7.4	6139	11.1	5538	4.7	4115	7.0
Greenhouse	1352	1.7	84	0.2	47	0.0	165	0.3
Orchards	2310	2.9	1260	2.3	135	0.1	72	0.1
Other cultivated land	193	0.2	1017	1.8	49	0.0	823	1.4
Deciduous forests	11,882	14.8	3445	6.2	50,964	43.6	9999	16.9
Coniferous forests	24,432	30.4	10,694	19.3	43,855	37.5	13,571	22.9
Mixed forests	14,131	17.6	9415	17.0	5026	4.3	7253	12.3
Natural grasslands	483	0.6	910	1.6	3913	3.3	403	0.7
Artificial grasslands	974	1.2	1634	2.9	516	0.4	3731	6.3
Inland wetlands	706	0.9	495	0.9	763	0.7	554	0.9
Natural bare grounds	42	0.1	51	0.1	926	0.8	14	0.0
Artificial bare grounds	985	1.2	797	1.4	1556	1.3	1314	2.2
Inland water	2105	2.6	1042	1.9	548	0.5	1001	1.7
Ocean water	0	0.0	0	-	129	0.1	0	-
Total	80,237	100.0	55,431	100.0	116,817	100.0	59,209	100.0

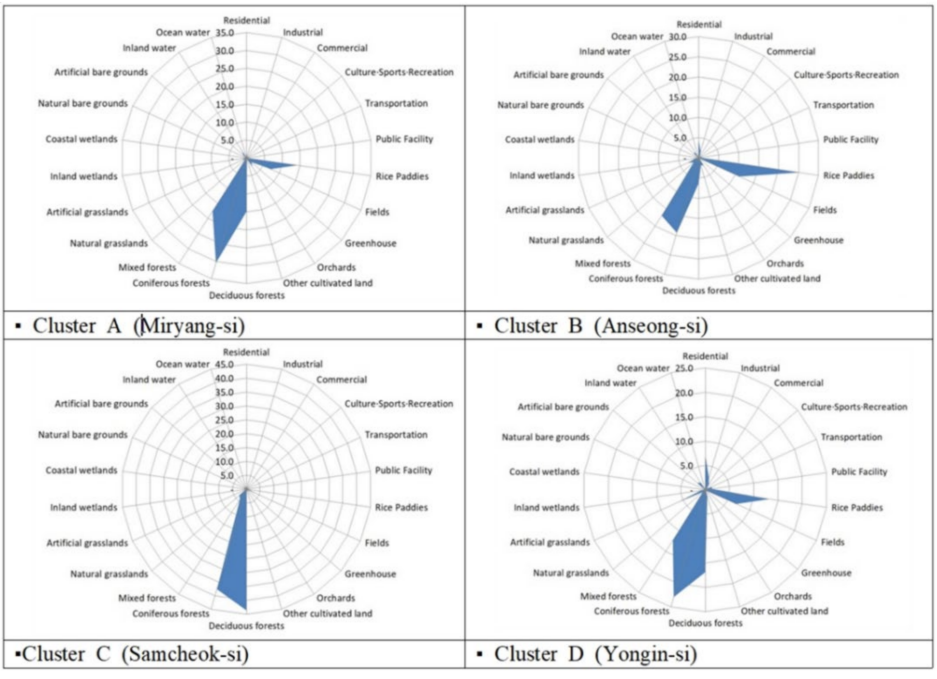

Figure 4. Land use of representative city by cluster.

Table 6. Spatial distribution of representative city by cluster.

Indices	Cluster A (Miryang-si)	Cluster B (Anseong-si)	Cluster C (Samcheok-si)	Cluster D (Yongin-si)
Number of patch	1224	1341	814	1170
Total area (m^2)	651,569,856	385,300,663	1,116,009,948	489,816,806
Mean patch size (m^2)	532,328	287,323	1,371,019	418,646
Total edge (m)	6,892,049	6,710,013	6,708,513	7,413,621
Mean patch edge (m)	5630	5003	8241	6336
EN (ecological network)	107.8	26.0	234.0	304.2
Ratio of green space (%)	81.2	69.5	95.5	82.7

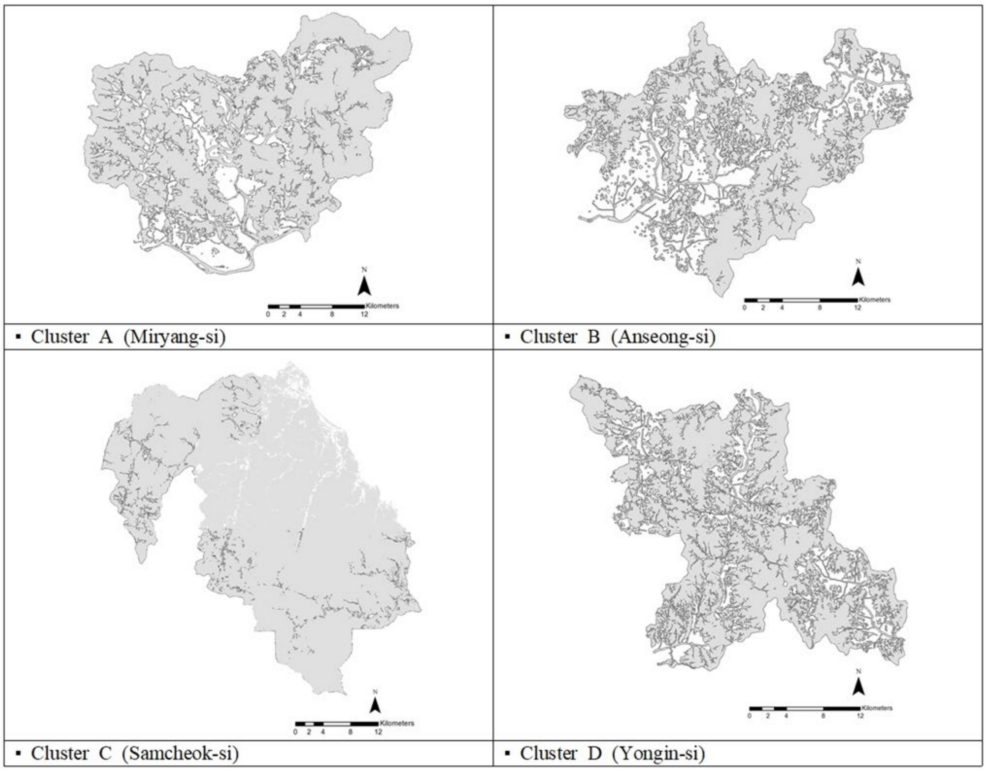

Figure 5. Spatial distribution of representative city by cluster. The map was generated by ArcGIS 10.3 software (http://www.esri.com/software/arcgis/arcgis-for-desktop, accessed on 25 September 2020).

4. Conclusions

Eighteen cities scoring an ENI less than ten showed poor ecological connectivity between natural green spaces, including Bucheon-si, Mokpo-si, Siheung-si, Guri-si, and Gwangmyeong-si. Ten cities with an ENI greater than one hundred showed high ecological connectivity between natural green spaces, including Miryang-si, Yeongju-si, Seogwipo-si, and Yangsan-si. Based on the ENI, a total of four clusters were classified. Cluster A included a total of 12 cities, such as Chuncheon-si, Suncheon-si, and Pohang-si. Cluster B included 70 cities, such as Bucheon-si, Mokpo-si, and Guri-si. Cluster C included two cities (Namyangju-si and Samcheok-si), while Cluster D included one city (Yongin-siin).

Miryang-si, Anseong-si, Samcheok-si, and Yongin-si were selected as the representative cities, to illustrate the characteristics of land use and natural green space distribution. Thus, based on ENI, small and medium-sized cities carrying many natural elements do not show large disconnected features. The potential for connection between natural elements is high, so the area of natural elements has a positive (+) effect on the value of the ENI. In contrast, high-density cities with fewer natural elements carry numerous disconnected elements, and thus the number and areas of fragmented natural green spaces have a

negative (−) effect on the value of the ENI. In addition to quantitative expansion of green space to enhance biological diversity within the city, specific strategies for green space area management are needed to reduce linear disconnected elements, such as natural green space area expansion and transportation facilities to improve the ENI.

The land cover map displays the status of the surface using a satellite or aerial survey. This study utilized a level 2 land cover map (22 classification codes, 5 m resolution). The 2020 sub-divided land cover map contains 41 classification codes (resolution 1 m). Accordingly, the ecological network rate that accurately reflects the current status of each city should be calculated. In the future, a suitable model for calculating the domestic ENI in South Korea should be developed via expansion of the investigated target area reflecting the characteristics of each city.

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Appendix A

Table A1. Calculation of ENI of 85 cities in South Korea.

City Number	City	Ratio of Natural Green Space (%)	Ratio of Transportation Area (%)	Ecological Network Index	Rank	City Number	City	Ratio of Natural Green Space (%)	Ratio of Transportation Area (%)	Ecological Network Index	Rank
1	Andong-si	73.8	0.9	83.3	15	44	Jecheon-si	77.5	1.1	68.9	17
2	Ansan-si	70.6	3	15.4	61	45	Jeju-si	42.1	1.8	58.3	23
3	Anseong-si	47	1.1	26	45	46	Jeongeup-si	44.6	1.2	27.3	40
4	Anyang-si	49.2	9.6	10.1	67	47	Jeonju-si	33.7	5.1	8.7	70
5	Asan-si	40.7	1.5	12.1	64	48	Jinju-si	62.7	1.5	27	41
6	Boryeong-si	58.4	1.3	26.7	43	49	Miryang-si	67	1.1	107.8	10
7	Bucheon-si	15.9	14.4	0.9	85	50	Mokpo-si	24	6.7	1.6	84
8	Busan Metropolitan City	49.6	5.8	26.9	42	51	Mungyeong-si	77.7	0.8	130	5
9	Changwon-si	59.4	3.1	88	14	52	Naju-si	39.6	0.9	28.2	39
10	Cheonan-si	50	2.3	33.3	38	53	Namwon-si	63.8	1	33.6	37
11	Cheongju-si	52.5	2.3	47.6	28	54	Namyangju-si	69.3	1.6	193.6	3
12	Chuncheon-si	83.5	0.8	89.1	12	55	Nonsan-si	40.6	1.3	19	50
13	Chungju-si	68.3	1.5	40.1	32	56	Osan-si	33.5	3.3	8.4	72
14	Daegu Metropolitan City	57.6	4.1	58.1	24	57	Paju-si	49.2	2.1	8.9	69
15	Daejeon Metropolitan City	56.6	4.6	42.1	29	58	Pocheon-si	69.4	0.8	64.4	19
16	Dangjin-si	33.3	1.2	40.2	31	59	Pohang-si	69.8	1.5	89	13
17	Dongducheon-si	70.6	3	15.4	60	60	Pyeongtaek-si	19.6	2.7	8	75
18	Donghae-si	75.8	2.3	59.9	22	61	Sacheon-si	59.5	1.7	24	47
19	Gangneung-si	79.8	1	130.3	4	62	Samcheok-si	90.7	0.7	234	2
20	Geoje-si	69.7	1.7	17.5	53	63	Sangju-si	66.1	0.8	47.8	27
21	Gimcheon-si	70.1	1	48.7	26	64	Sejong Metropolitan Autonomous City	54.5	1.6	16	59
22	Gimhae-si	52	2.4	35.1	36	65	Seogwipo-si	42	1.5	112.4	8
23	Gimje-si	19.4	1	16.1	58	66	Seongnam-si	52.6	4.9	14.4	63
24	Gimpo-si	36.4	1.5	24.6	46	67	Seosan-si	38.5	1.4	23.4	48
25	Gongju-si	67	1.1	39.9	34	68	Seoul Special City	28.1	12.1	10.4	66
26	Goyang-si	38.6	5.5	16.6	55	69	Siheung-si	28.9	6.7	3.3	83

Table A1. *Cont.*

City Number	City	Ratio of Natural Green Space (%)	Ratio of Transportation Area (%)	Ecological Network Index	Rank	City Number	City	Ratio of Natural Green Space (%)	Ratio of Transportation Area (%)	Ecological Network Index	Rank
27	Gumi-si	59.4	2	21.7	49	70	Sokcho-si	75.6	1.2	69.4	16
28	Gunpo-si	45.2	8.1	10.8	65	71	Suncheon-si	69.3	1.3	89.1	11
29	Gunsan-si	23.9	3.5	6	80	72	Suwon-si	25.9	7	8.2	73
30	Guri-si	41.8	5.1	3.4	82	73	Taebaek-si	87.8	0.9	39.6	35
31	Gwacheon-si	59.8	4.7	9	68	74	Tongyeong-si	62.4	2.3	7.6	76
32	Gwangju Metropolitan City	40.5	3.9	41.9	30	75	Uijeongbu-si	57.1	5.4	6.9	77
33	Gwangju-si	70.5	0.9	52.1	25	76	Uiwang-si	59.4	5.8	8.2	74
34	Gwangmyeong-si	36.4	7.4	4.5	81	77	Ulsan Metropolitan City	64.9	2.5	39.9	33
35	Gwangyang-si	68.3	2.7	123.8	6	78	Wonju-si	74.3	1.5	62	20
36	Gyeongju-si	69.1	1.2	65.4	18	79	Yangju-si	57.8	1.7	16.1	57
37	Gyeongsan-si	56.9	2	26.1	44	80	Yangsan-si	76.8	1.6	118.7	7
38	Gyeryong-si	68.8	2.5	17.7	52	81	Yeoju-si	51.3	1.2	18.4	51
39	Hanam-si	58.2	2.3	17	54	82	Yeongcheon-si	69.8	0.9	60.5	21
40	Hwaseong-si	33.4	1.9	6.7	78	83	Yeongju-si	64.7	1.2	109	9
41	Icheon-si	34.9	1.2	15.1	62	84	Yeosu-si	57	2.3	16.6	56
42	Iksan-si	21.1	1.6	6	79	85	Yongin-si	55.4	1.5	304.2	1
43	Incheon Metropolitan City	38.5	4.6	8.6	71			-			

Table A2. Clustering of cities according to ecological network index.

City Number	City	Average Ratio of Green Space Area	Average Ratio of Transportation Area	ENI	EN Rank	Ratio of Green Space Area (%)	Ratio of Green Space Area (Rank)	City Number	City	Average Ratio of Green Space Area	Average Ratio of Transportation Area	ENI	EN Rank	Ratio of Green Space Area (%)	Ratio of Green Space Area (Rank)
	Cluster A	**69.3**	**1.5**	**105.9**	**-**	**78.9**	**-**	63	Sangju-si	66.1	0.8	47.8	27	83.1	24
19	Gangneung-si	79.8	1.0	130.3	4	83.9	21	67	Seosan-si	38.5	1.4	23.4	48	59.2	65
35	Gwangyang-si	68.3	2.7	123.8	6	74.5	42	68	Seoul Special City	28.1	12.1	10.4	66	49.2	74
51	Mungyeong-si	77.7	0.8	130.0	5	90.9	5	66	Seongnam-si	52.6	4.9	14.4	63	72.9	45
49	Miryang-si	67.0	1.1	107.8	10	81.2	27	64	Sejong Metropolitan Autonomous City	54.5	1.6	16.0	59	80.6	29
65	Seogwipo-si	42.0	1.5	112.4	8	54.7	69	70	Sokcho-si	75.6	1.2	69.4	16	88.6	11
71	Suncheon-si	69.3	1.3	89.1	11	88.2	13	72	Suwon-si	25.9	7.0	8.2	73	32.8	83
1	Andong-si	73.8	0.9	83.3	15	92.5	3	69	Siheung-si	28.9	6.7	3.3	83	59.1	66

Table A2. *Cont.*

City Number	City	Average Ratio of Green Space Area	Average Ratio of Transportation Area	ENI	EN Rank	Ratio of Green Space Area (%)	Ratio of Green Space Area (Rank)	City Number	City	Average Ratio of Green Space Area	Average Ratio of Transportation Area	ENI	EN Rank	Ratio of Green Space Area (%)	Ratio of Green Space Area (Rank)
80	Yangsan-si	76.8	1.6	118.7	7	90.8	6	5	Asan-si	40.7	1.5	12.1	64	61.4	59
83	Yeongju-si	64.7	1.2	109.0	9	87.8	15	2	Ansan-si	70.6	3.0	15.4	61	89.7	8
9	Changwon-si	59.4	3.1	88.0	14	71.2	49	3	Anseong-si	47.0	1.1	26.0	45	69.5	51
12	Chuncheon-si	83.5	0.8	89.1	12	44.8	76	4	Anyang-si	49.2	9.6	10.1	67	68.7	53
59	Pohang-si	69.8	1.5	89.0	13	86.5	17	79	Yangju-si	57.8	1.7	16.1	57	81.7	26
	Cluster B	**51.1**	**3.1**	**26.0**	**-**	**68.1**	**-**	84	Yeosu-si	57.0	2.3	16.6	56	81.2	28
20	Geoje-si	69.7	1.7	17.5	53	73.4	44	81	Yeoju-si	51.3	1.2	18.4	51	75.6	38
37	Gyeongsan-si	56.9	2.0	26.1	44	61.3	61	82	Yeongcheon-si	69.8	0.9	60.5	21	86.4	18
36	Gyeongju-si	69.1	1.2	65.4	18	72.8	46	56	Osan-si	33.5	3.3	8.4	72	59.4	64
38	Gyeryong-si	68.8	2.5	17.7	52	77.4	36	77	Ulsan Metropolitan City	64.9	2.5	39.9	33	83.5	23
26	Goyang-si	38.6	5.5	16.6	55	43.9	78	78	Wonju-si	74.3	1.5	62.0	20	91.0	4
25	Gongju-si	67.0	1.1	39.9	34	69.0	52	76	Uiwang-si	59.4	5.8	8.2	74	78.9	32
31	Gwacheon-si	59.8	4.7	9.0	68	62.5	56	75	Uijeongbu-si	57.1	5.4	6.9	77	78.0	35
34	Gwangmyeong-si	36.4	7.4	4.5	81	43.7	79	41	Icheon-si	34.9	1.2	15.1	62	60.0	62
32	Gwangju Metropolitan City	40.5	3.9	41.9	30	47.3	75	42	Iksan-si	21.1	1.6	6.0	79	42.2	81
33	Gwangju-si	70.5	0.9	52.1	25	75.2	39	43	Incheon Metropolitan City	38.5	4.6	8.6	71	64.9	54
30	Guri-si	41.8	5.1	3.4	82	50.5	73	47	Jeonju-si	33.7	5.1	8.7	70	54.4	70
27	Gumi-si	59.4	2.0	21.7	49	63.9	55	46	Jeongeup-si	44.6	1.2	27.3	40	61.9	58
29	Gunsan-si	23.9	3.5	6.0	80	31.7	84	45	Jeju-si	42.1	1.8	58.3	23	42.2	80
28	Gunpo-si	45.2	8.1	10.8	65	53.4	72	44	Jecheon-si	77.5	1.1	68.9	17	90.5	7
23	Gimje-si	19.4	1.0	16.1	58	21.7	85	48	Jinju-si	62.7	1.5	27.0	41	84.5	20
21	Gimcheon-si	70.1	1.0	48.7	26	72.3	47	10	Cheonan-si	50.0	2.3	33.3	38	72.0	48
24	Gimpo-si	36.4	1.5	24.6	46	62.1	57	11	Cheongju-si	52.5	2.3	47.6	28	76.4	37
22	Gimhae-si	52.0	2.4	35.1	36	73.7	43	13	Chungju-si	68.3	1.5	40.1	32	87.4	16
52	Naju-si	39.6	0.9	28.2	39	58.0	68	73	Taebaek-si	87.8	0.9	39.6	35	96.8	1
53	Namwon-si	63.8	1.0	33.6	37	83.8	22	74	Tongyeong-si	62.4	2.3	7.6	76	88.2	12
55	Nonsan-si	40.6	1.3	19.0	50	59.8	63	57	Paju-si	49.2	2.1	8.9	69	75.2	40
16	Dangjin-si	33.3	1.2	40.2	31	58.5	67	60	Pyeongtaek-si	19.6	2.7	8.0	75	44.3	77
14	Daegu Metropolitan City	57.6	4.1	58.1	24	75.0	41	58	Pocheon-si	69.4	0.8	64.4	19	86.1	19
15	Daejeon Metropolitan City	56.6	4.6	42.1	29	80.2	31	39	Hanam-si	58.2	2.3	17.0	54	78.2	34
17	ongducheon-si	70.6	3.0	15.4	60	89.7	9	40	Hwaseong-si	33.4	1.9	6.7	78	61.4	60
18	Donghae-si	75.8	2.3	59.9	22	88.8	10		**Cluster C**	**80.0**	**1.2**	**213.8**	**-**	**91.8**	**-**
50	Mokpo-si	24.0	6.7	1.6	84	53.4	71	54	Namyangju-si	69.3	1.6	193.6	3	88.1	14
6	Boryeong-si	58.4	1.3	26.7	43	78.5	33	62	Samcheok-si	90.7	0.7	234.0	2	95.5	2
8	Busan Metropolitan City	49.6	5.8	26.9	42	70.5	50		**Cluster D**	**55.4**	**1.5**	**304.2**	**-**	**82.7**	**-**
7	Bucheon-si	15.9	14.4	0.9	85	37.4	82	85	Yongin-si	55.4	1.5	304.2	1	82.7	25
61	Sacheon-si	59.5	1.7	24.0	47	80.6	30		**Total**	**54.4**	**2.8**	**45.0**	**-**	**70.4**	**-**

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