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Article

Planning Landscape Corridors in Ecological Infrastructure Using Least-Cost Path Methods Based on the Value of Ecosystem Services

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Abstract: Ecosystem service values have rarely been incorporated in the process of planning ecological infrastructure for urban areas. Urban ecological infrastructure is a network system of natural lands and waters that provides ecosystem services. The purpose of this study was to design landscape corridors that maximize the value of ecosystem services in ecological infrastructure planning. We explored the optimal corridors to enhance the connectivity among landscape elements to design an ecological infrastructure for the city of Gwacheon, South Korea, as an example of a small urban area. We calculated the value of ecosystem services using standardized estimation indices based on an intensive review of the relevant literature and employed the least-cost path method to optimize the connectivity of landscape structural elements. The land use type in the city with the highest estimated value of ecosystem services was the riparian zone (*i.e.*, 2011 US$7,312.16/ha). Given areal coverage of all land use types, the estimated value of developed area open spaces was 2011 US$899,803.25, corresponding to the highest contribution to the total value of ecosystem services. Therefore, the optimal configured dispersal corridors for wildlife were found from the riparian zones (source area) to the developed area open spaces (destination area) in the city. Several challenges remain for improving the estimation of the value of ecosystem services and incorporating these ecosystems in ecological infrastructure planning. Nonetheless, the approaches taken to estimate the value of ecosystem services and design landscape corridors in this study may be of value to future efforts in urban ecological infrastructure planning.

Keywords: ecosystem service; value of ecosystem services; least-cost path method; ecological infrastructure; landscape connectivity; landscape structure elements

1. Introduction

The term "ecosystem services" refers to the benefits gained from the complex interactions between the human environment and the functions of an ecosystem, such as carbon sequestration, improvements in air and water quality, microclimate regulation, biodiversity and recreational and cultural and social value [1–6]. Ecosystem services are considered to be a key factor for leading a healthy and prosperous life, and they are significant for the sustainability of human society [7,8]. Balmfor *et al.* [4] suggest that ecosystem services are based on basic ecosystem functions that are crucial for supporting services. Ecosystem functions substantiate ecosystem services, such as the provision of harvested crops, landscape aesthetics and habitats for biodiversity and the regulation of environmental quality [9]. In other words, ecosystem functions represent the capacity of an ecosystem to provide goods and services to indirectly satisfy human needs [10,11]. These ecosystem functions act at the intersection between ecosystem features (e.g., built-up areas and residential functions or forest and timber production) and structures (e.g., landscape diversity, complexity and fragmentation). Ecosystem structures or patterns can affect landscape functions through the composition and configuration of landscape elements [9,12,13], and they can affect ecosystem services indirectly. This statement implies that ecosystem services are expected to fulfill many landscape functions according to the landscape structure. This concept of ecosystem services has become significant among researchers and practitioners in landscape planning and management [14].

The importance of considering ecosystem services when studying landscape planning has been emphasized [14–20]. Previous studies have focused on successful ecological corridor planning in terms of conduits for wildlife [21]. However, simple ecological corridors still lack alternative strategies for addressing the ecological impact of fragmentation and the concept of ecological networks [22]. This concept has recently developed as a popular concept in urban planning, which can be seen as preserving wildlife habitats, as well as contributing to the urban ecosystem's health and resilience. According to Rapport *et al.* [23], the provision of ecosystem services is essential for a healthy urban ecosystem. The ecological networks are necessary to develop approaches that integrate biophysical, economic and sociocultural effects from ecosystem services, in order to propose a better way of landscape planning and management in urban areas.

As rapid urbanization continues, it is assumed that more than 60% of the world's population will live in urban areas by 2030 [24]. With this increased concentration, urban infrastructure has been intensively developed, with little linkage to natural ecosystems [20]. This trend has led to the fragmentation and isolation of urban green spaces, negatively affecting potential ecosystem services [25,26]. There are several ecosystem services available in urban areas [20,24–27] that produce positive biophysical, economic and sociocultural effects. The demand on ecosystem services has continued to increase with population growth [28,29]. Many efforts to factor ecosystem services into landscape planning have been made in the past several decades [14–18]. Recent research shows that an integrated framework, such as ecological infrastructure, is necessary to achieve a systematic and comprehensive assessment of the value of ecosystem services for setting policies and decision making in landscape planning [14–17]. Ecological infrastructure is defined as a network system of natural lands that provides ecosystem services [19]. The development of ecological infrastructure has recently become a practical strategy for providing or supporting ecosystem services to maximize the benefits of the ecosystem. Wetlands are particular practical ecological infrastructures of urban development in the ecological engineering field. Many studies have comprehensively and intensively dealt with constructed wetlands through ecological valuation schemes and a set of indices to evaluate ecosystem services, including the environmental impact and emissions [30–36]. In the field of landscape planning and management, the main challenge has become determining the optimal allocation and management of several different land use types through ecological infrastructure planning [14]. In other words, the large-scale ecological network, which is created by the connection between small or large ecological infrastructure, such as wetlands, has become a major issue of ecological infrastructure in urban areas. This study is also a part of this paradigm.

The design of ecological infrastructure is typically based on connections between "patches" and "matrices" via "corridors", representing the main spatial landscape structure elements of the landscape network [37]. The least-cost path method has been shown to be useful in several studies [38–42] for determining paths to connect landscape structure elements, which are commonly integrated, for example, in geographic information system (GIS) technology. Least-cost path analysis is one of the best methods for achieving the optimal establishment of paths between landscape elements (e.g., large hubs (matrices), smaller sites (patches) and links (corridors)) [43]. This useful method is based on the fact that paths for wildlife movement are affected by the characteristics of landscape, including the land cover, roads and slope [41,44]. Each cell of a raster dataset is allocated a value according to the cost of movement. A value that would incorporate the estimated value of ecosystem services can be assigned based on land cover characteristics, which is easily realized within the raster data cells used for the study. The value of ecosystem services often depends on the maintenance of biodiversity [45,46]. As wildlife species are affected differently by land cover characteristics, including impervious surface and natural green surfaces, the weights of land cover for wildlife habitats contribute to biodiversity [47–49]. The weights of land cover are based on the value of ecosystem services using the least-cost path method. The least-cost path method creates the best travel path according to the composition of the cells that are assigned the shortest distance with the least resistance between two patches of wildlife habitats [38]. Thus, this method can help generate the best theoretical path to connect suitable habitats for wildlife dispersal. In several studies, the least-cost path method has been employed for the analysis of landscape connectivity based on considering wildlife dispersal, which is faster and more convenient for the visualization of landscape connectivity than any other method [50–52], such as random walk modeling [53–55], network analysis [56,57] or gravity models [58]. This approach can also be used to maximize ecosystem services by connecting landscape structure elements in designing corridors for ecological infrastructure. The landscape structure elements may be influenced by ecological processes related to ecosystem services [59].

The purpose of this study is to design landscape corridors that maximize the value of ecosystem services in ecological infrastructure planning. These corridors are meant to serve as connection paths between the main wildlife habitats in the city of Gwacheon. The city of Gwacheon, located in the vicinity of Seoul, South Korea, was chosen for the study. The specific objectives were (1) to calculate the least cost based specifically on ecosystem service values using a least-cost path model and (2) to design a framework demonstrating corridors that serve as the best connection paths between suitable habitats in the city.

2. Methods

2.1. Study Area

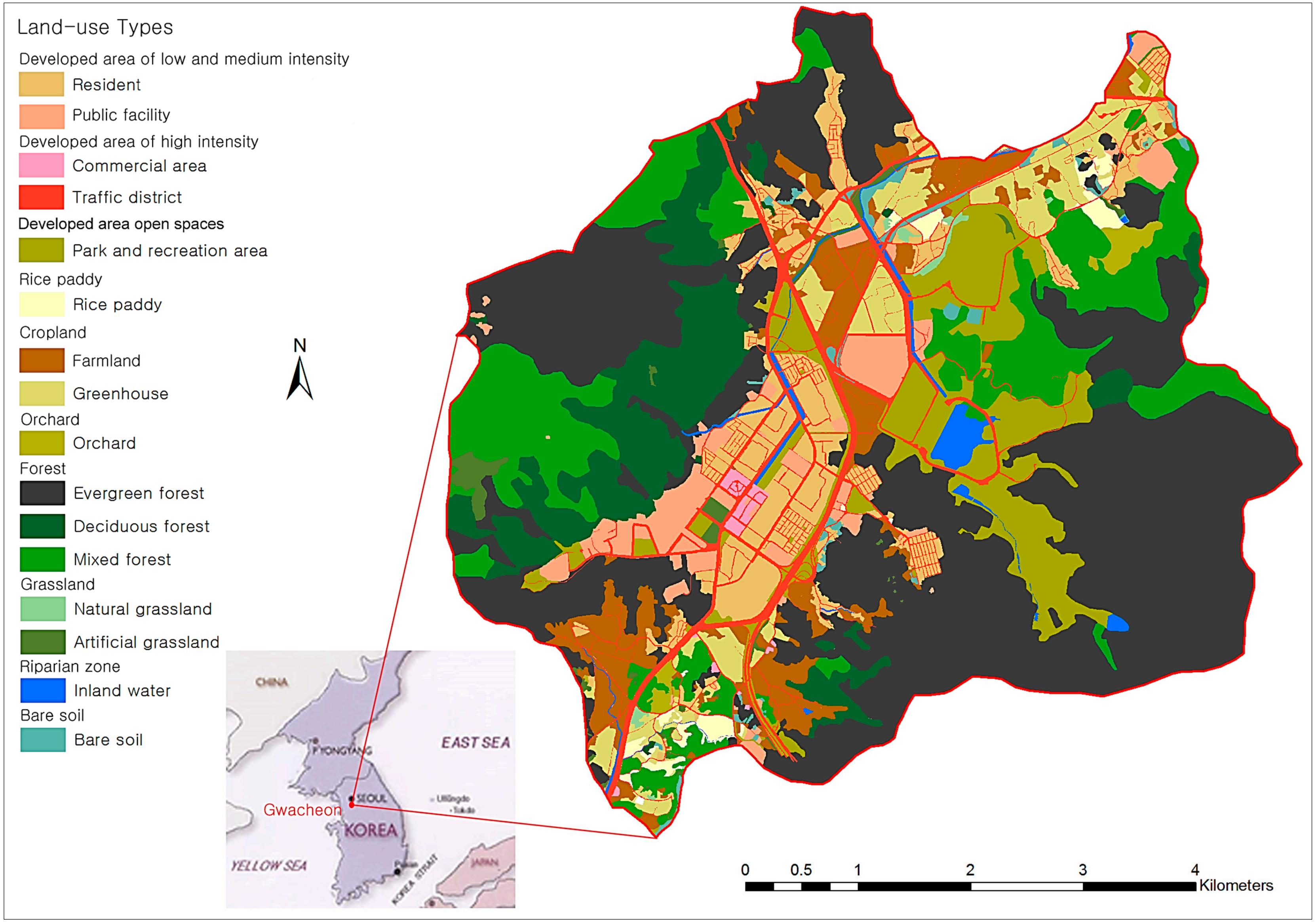
The city of Gwacheon, located in the mid-western region of Gyeonggi-do near Seoul, South Korea, is a medium-scale urban area with considerable green space. The study site is geographically situated at 37°23′53″N to 37°27′52″ and 127°02′52″E to 126°57′52″. The site encompasses an area of approximately 35.86 km^2 and includes 32.45 km^2 of natural areas, such as forest. The climate of Gwacheon is characterized by high temperatures and high humidity in summer and cold, dry conditions in the winter.

The landscape of this area has various characteristics in terms of natural resources and cultural attractions. The city is located in a basin surrounded by mountains (Mt. Gwanak, Mt. Cheonggyes and Mt. Umyeon) and includes several streams (Yangjaecheon, Makgyecheon and Galhyeoncheon). The population is distributed along the rivers. Similar to most urban areas, however, it has experienced a rise in population, technology and infrastructure, such as the development of the Government Building and highways connecting the region with Seoul and other surrounding cities. Figure 1 shows the land use pattern in Gwacheon in a land cover map. The urban ecosystems of the city have become highly modified and fragmented.

2.2. Geospatial Data

We collected a geospatial dataset to represent the landscape of Gwacheon by downloading land cover data from the Ministry of Environment and digital topographic maps from the Ministry of Land, Infrastructure and Transport. The current land cover map (2000, with a scale of 1/25,000) and a map of major rivers and traffic districts (2008, with a scale of 1/25,000) were interpreted and modified from aerial photographs (2009). To effectively assign a generalized value of ecosystem services for the study site, the land use types within the study site were reclassified into 10 primary land use types: developed areas of low and medium intensity, developed areas of high intensity, developed area open spaces, rice paddies, croplands, orchards, forests, grasslands, riparian zones and bare soils. Highway and road information was obtained from line data from a topographic map (2007, with a scale of 1/25,000) and aerial photographs. Using a digital topographic map, 30-m digital elevation model (DEM) data were generated from contour lines. The slope was calculated from the 30-m DEM data. The Arcmap 10.1 GIS platform [60] was used for the digitization and analysis of the dataset, then converted to rasters as a 30 × 30-m^2 grid.

Figure 1. Land cover map of Gwacheon.



2.3. Planning Landscape Corridors in the Ecological Infrastructure

This study, aimed at planning landscape corridors, was based on least-cost path methods, where the value of ecosystem services was assessed to determine the best connection among wildlife habitats and to maximize the ecosystem services in Gwacheon. The value of the ecosystem services for each land cover type present in Gwacheon was estimated using synthesis and standardization coefficients for the value of ecosystem services from previous research. We developed least-cost paths for ecological infrastructure planning according to the estimated value of ecosystem services, which were created based on the shortest distance with the least resistance to the movement of the main species in Gwacheon. The resistance encompassed the value of ecosystem services for each land cover type, the density of roads/highways and slopes.

2.3.1. Estimated Value of Ecosystem Services

The value of ecosystem services generally represents the creditable nonmarket value based on efficiency and cost-effectiveness values, including the degree of sustainable use within the complex conditions of the ecosystem and equity for the enhancement of human wellbeing [61]. Identifying and quantifying the value of ecosystem services helps us to better understand the benefits of these services and the provision of ecosystems for human society [62]. In addition, a method for identifying and quantifying the value of ecosystem services could be a valuable tool for the efficient allocation of ecosystem benefits [11,62–64]. Quantifying the value of ecosystems could provide clues about how to achieve the social recognition and acceptance of ecosystem management across multiple geographic scales [65]. The most widely used and best known estimation values for ecosystem services are a set of "generalized coefficients" proposed by Costanza *et al.* [6,66–69]. However, these coefficients are not without limits or constraints on their use [70]. Thus, many researchers made subsequent efforts, which resulted in a range of generalized coefficients that are applicable for estimating the value of ecosystem services for each land use type from varying regions [71–76]. We adopted all of the available values from the existing literature and created our own set or range of coefficients relevant to the land use types included in this study (Table 1).

Table 1. Value estimates for each land use type based on a number of studies.

Land Use Typology [a]	Definition [b]	Total of Service Means Values (2011 US$/ha/Year)	Total SD of Means (2011 US$/ha/Year)	Source
Developed areas of low and medium intensity	Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20%–79% of the total cover.	0	0	[6,67,72]
Developed areas of high intensity	Includes highly developed areas where people reside or work in high numbers. Impervious surfaces account for 80%–100% of the total cover.	0	0	[6,67,72]

Table 1. *Cont.*

Land Use Typology [a]	Definition [b]	Total of Service Means Values (2011 US$/ha/Year)	Total SD of Means (2011 US$/ha/Year)	Source
Developed area open spaces	Includes areas with a mixture of constructed materials, but mainly contains vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of the total cover.	2130.67	1189.36	[6,77]
Rice paddies	Areas where perennial herbaceous vegetation accounts for more than 80% of the vegetative cover and the soil or substrate is periodically saturated with or covered with water, such as rice paddies.	5131.91	1540.98	[6,68,78–82]
Croplands	Areas being used for the production of crops other than rice. Plantations with cash crops, such as herbal teas or horticultural products.	413.07	162.33	[6,68,83–85]
Orchards	Areas being used for food production by planting trees and shrubs, such as *Malus pumila* Mille, *Pyrus serotina* Rehder and *Diospyros kaki*.	594.80	16.48	[6,67]
Forests	Includes natural forest plantations. Lands with tree-canopy cover account for more than 20%. The trees should be able to reach a minimum height of 5 m.	1937.03	1719.01	[6,67,78,85–103]
Grasslands	Includes infertile or degraded land where no trees or shrubs grow.	315.19	65.96	[6,67,68,83]
Riparian zones	All areas of open water, including riparian buffer zones, generally with less than 25% vegetation or soil cover	7312.16	5836.06	[6,68,91,104–110]
Bare soils	Areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Vegetation generally accounts for less than 15% of the total cover.	25.98	0.00	[6,68]

[a] The land unit typologies consisted of the land cover types present in Gwacheon; [b] source: [111].

Peer-reviewed articles from 15 journals were collected, synthesized and combined to develop a well-defined estimated value of ecosystem services. All of the potential data on such values were screened using the keywords “ecosystem service”, “value of ecosystem service” and “ecosystem services value”. Data were extracted from studies that provided a monetary value for a given ecosystem service attached to a specific land use type and a specific time period. The values of ecosystem services were applied to enable the conversion of monetary values to per-hectare values. Because the values of ecosystem services have been reported in many different metrics and currencies for different time periods, locations and price levels, it was necessary to organize these values in a standardized form to reduce generation errors. We developed estimation indices for the existing values of ecosystem services based on this literature review to find well-defined coefficients. The estimation indices entailed obtaining economic estimates for the value of nonmarket services that are not directly traded in markets for environmental resources [75]. Several of the coefficients used to estimate the value of ecosystem services exhibited a central tendency [71,112,113].

In the review of 37 studies, the estimated values of ecosystem services were taken as averages of the existing estimated values (Table 1). The average of all collected values was estimated using a range of approaches [78]. To aid in the direct comparison and aggregation, the collected ecosystem service values were standardized to common spatial, temporal and currency units, namely, international dollars per hectare per year ($/ha/year) for 2011 (Table 1). When necessary, the estimates were converted into the official local currency. The values were then adjusted to 2011 values using the nominal GDP per capita of each country. The official exchange rates and nominal GDP per capita were determined according to MeasuringWorth.com [114]. The sum of all ecosystem service values constituted the total service mean values (Table 1). The total of service mean values included three types of ecosystem services (regulating, provisioning and cultural services), and the three types of ecosystem services were composed of 10 ecosystem functions (gas and climate regulation, disturbance regulation, water regulation, waste treatment, water supply, food production, pollination, refugia, recreation and cultural) [6,20] (Table 1).

This study used the assessment method developed by [66] to calculate the value of ecosystem services for each land cover type. The formula for calculating the values is as follows:

$$[\text{Vaue of ecosystem services } = \sum(A_k \times V_k)] \tag{1}$$

where A_k is the area (ha) of the corresponding cover type, V is the annual value of the land cover per hectare and k is the land cover type. Each value for each ecosystem service category was estimated by calculating the estimated value for each land use type.

2.3.2. Least-Cost Path Method

The least-cost path method using GIS-based analysis supported the best corridors for connecting landscape patches to be adopted in ecological infrastructure planning for Gwacheon. The least-cost path method is based on cost-distance analysis. Two GIS layers (the source layer and the resistance layer) are used as inputs in the least-cost path method. The source layer represents the landscape patches from which connectivity is calculated according to the cost benefits of ecosystem services related to changing ecological infrastructure into urban infrastructure. The resistance layer represents resistance values assigned by summarizing the weight values of the relative costs of traveling through each land use type and geographical position. The weight values are formed by each cell (30 m × 30 m) in the grid based on the value of ecosystem services according to the land use-type attributes. In addition, the relative cost of traveling is based on the consideration of the main wildlife in Gwacheon, which includes medium–large-sized mammals, such as *Hydropotes inermis* and *Prionailurus bengalensis,* and their movement according to the land use type and geographical position, including the density of roads/highways and slopes. To increase connectivity between landscape patches based on the composition and configuration of the landscape structure, a weight value for each land use type was inversely calculated in proportion to the lowest ecosystem service value for a land use type according to the value of ecosystem services for each land use type. The weights were calculated as follows, where w is the computed weight of ecosystem services for a land use type:

$$[w_i = \frac{\sum_{i=1}^{n} a_i - a_i}{\sum_{i=1}^{n} a_i} \times 100, \text{ for all values of ecosystem services } i = 1,2,\ldots, \text{n}] \qquad (2)$$

The weight value for the geographical position was set to one within a cell, which reflects a minimum cost movement [115,116]. The resistance value was ultimately assigned to the cost-surface raster by summarizing the relative weight cost of each land cover using the Calculation Cost Surface Tool in ArcToolbox. The resistance value for each cell indicates the path to the source, measured as the least cost involved in moving over the resistance layer.

There are four steps in the least-cost path method to find the best paths for ecological infrastructure planning: assignment of the source area; creation of a cost-surface raster; assignment of the destination area; and creation of potential least-cost paths between each source/destination pair. The source area and destination were assigned to calculate and generate a cost-weighted surface. The cost-weighted surface is the cost value related to movement in each grid, which can be generated through superposition of the cost raster, source area and destination. The geospatial data included the land cover map, comprising the land use type and geographical position in Gwacheon. In addition, all of the values of ecosystem services for different land use types were estimated to create a cost-surface raster. All of the geospatial data were analyzed using Arcmap 10.1 [61] for each 90 m^2 grid.

3. Results and Discussion

3.1. Ecosystem Service Estimates for the City of Gwacheon

Table 1 shows the estimated ecosystem service values calculated per land use unit, garnered from a number of studies. The total mean service values were calculated from each value of ecosystem services within each land use unit typology (Table 1). The statistical means were calculated with medians from the minimum, maximum or single values available in the literature, summed as the total mean value for all studied ecosystem services. The total standard deviation shows the range of the total mean service values.

The developed areas of low and medium intensity and developed areas of high intensity did not present any anticipated ecosystem service value. These land use types include residential (mainly suburban) and commercial (mainly urban) areas where paving materials are present, without biomes. Most land use types based on natural resources, such as forests, water and vegetation, show a capacity to provide ecosystem services. For the developed area open spaces, recreation services appear to be the main ecosystem service provided; thus, there is a need to assess more detailed values of recreation services, because this land use type is similar to natural resources as a form of ecological infrastructure at the center of the urban ecosystem.

The total value of riparian zones ranked first at $7312.16 (Table 1). This result implies that riparian zones must be a main consideration in the ecological infrastructure of urban areas. Riparian zones are highly valuable in urban ecosystems for a range of environmental, social and economic reasons [117]. Most major cities have been built along rivers, which play roles in transportation, are related to industrial functions and provide a natural environment for people, as well as a stable drinking water supply [118]. To protect urban riparian areas, many river commissions have been established for planning and management purposes [119]. In the same vein, riparian zones are an important landscape patch in the ecological infrastructure, because they provide many valuable ecosystem services to society.

The total value of rice paddies ranked second at $5131.91, and developed area open spaces ranked third at $2130.67 (Table 1). Rice paddies not only produce rice for use as food, but also provide multiple ecosystem services as artificial freshwater wetlands. According to the OECD [120], rice paddies exhibit a vast potential to supply multiple ecosystem services, including food security, maintenance of the viability of rural communities, environmental protection, sustainable management of renewable natural resources, preservation of biodiversity and aesthetic landscapes, despite also having features with negative services, such as high methane emissions. Developed area open spaces received the top ranking, because they include parks, recreation areas and small urban green areas, which could be part of the ecological infrastructure for enhancing societal wellbeing.

The total value of ecosystem services for each land use unit typology in Gwacheon is presented in Table 2. Synthesized and standardized ecosystem service values were used to calculate and estimate the total value of ecosystem services. The total value of ecosystem services was estimated to be $5,673,026.83. The value of forests was highest ($4,132,227.36), followed by the value of developed area open spaces ($899,803.25). Forests are located on the edge of town in Gwacheon, occupying over 60% of the area (2133.28 ha). Because urban ecological infrastructure planning focuses on urban areas, the main patch is riparian zones, not forests, due to their geographical location. The value of not only developed area open spaces ($899,803.25), but also riparian areas ($297,678.04) are located in one of the most densely populated regions of Gwacheon, which has around 42% of the total population (11,069 persons) according to the 2009 population census. As a high economic value of ecosystem services depends on a high residential population [121], the value of riparian zones seems to be influenced by residential population in the city. Those values indicate that such highly populated areas show great potential to improve human wellbeing and provide benefits from ecosystem services in urban areas.

Table 2. Land use types and annual value of ecosystem services per land use type in Gwacheon.

Land Use Type	Component	Estimated Value (2011 US$/ha)	Area (ha)	Value of Ecosystem Services (2011 US$)
Developed areas of low and medium intensity	Residential		235.36	0.00
Developed areas of high intensity	Commercial/traffic district/parks and recreation		198.36	0.00
Developed area open spaces	Public facilities	2130.67	422.31	899,803.25
Rice paddies	Rice paddy	5131.91	34.03	174,638.90
Croplands	Farmland/greenhouse	413.27	342.06	141,363.14
Orchards	Orchard	594.80	22.39	13,317.57
Forests	Evergreen/deciduous/mixed	1937.03	2133.28	4,132,227.36
Grasslands	Natural/artificial	315.19	42.2	13,301.02
Riparian zones	Inland water	7312.16	40.71	297,678.03
Bare soils	Bare soil	25.98	26.85	697.56
Total		17861.01	3497.55	5,673,026.83

3.2. Planning Landscape Corridors within the Ecological Infrastructure

The planning of landscape corridors in the ecological infrastructure was conducted by finding the best paths for improving connectivity between landscape patches constituting suitable habitats for wildlife based on the value of ecosystem services. We created a potential dispersal corridor for continuous wildlife habitats in the urban area of Gwacheon. This corridor linked the highest value of ecosystem services per hectare, which occurred in riparian zones. The least-cost path method contributed to the search for an appropriate linkage corridor in ecological infrastructure planning. Based on the value of ecosystem services per land use type, connecting riparian zones and developed area open spaces could be a suitable strategy for maximizing ecosystem services in Gwacheon. Under these circumstances, the least-cost path method was applied in four steps. Spatial data were collected from a land cover map, and the value of ecosystem services was assessed.

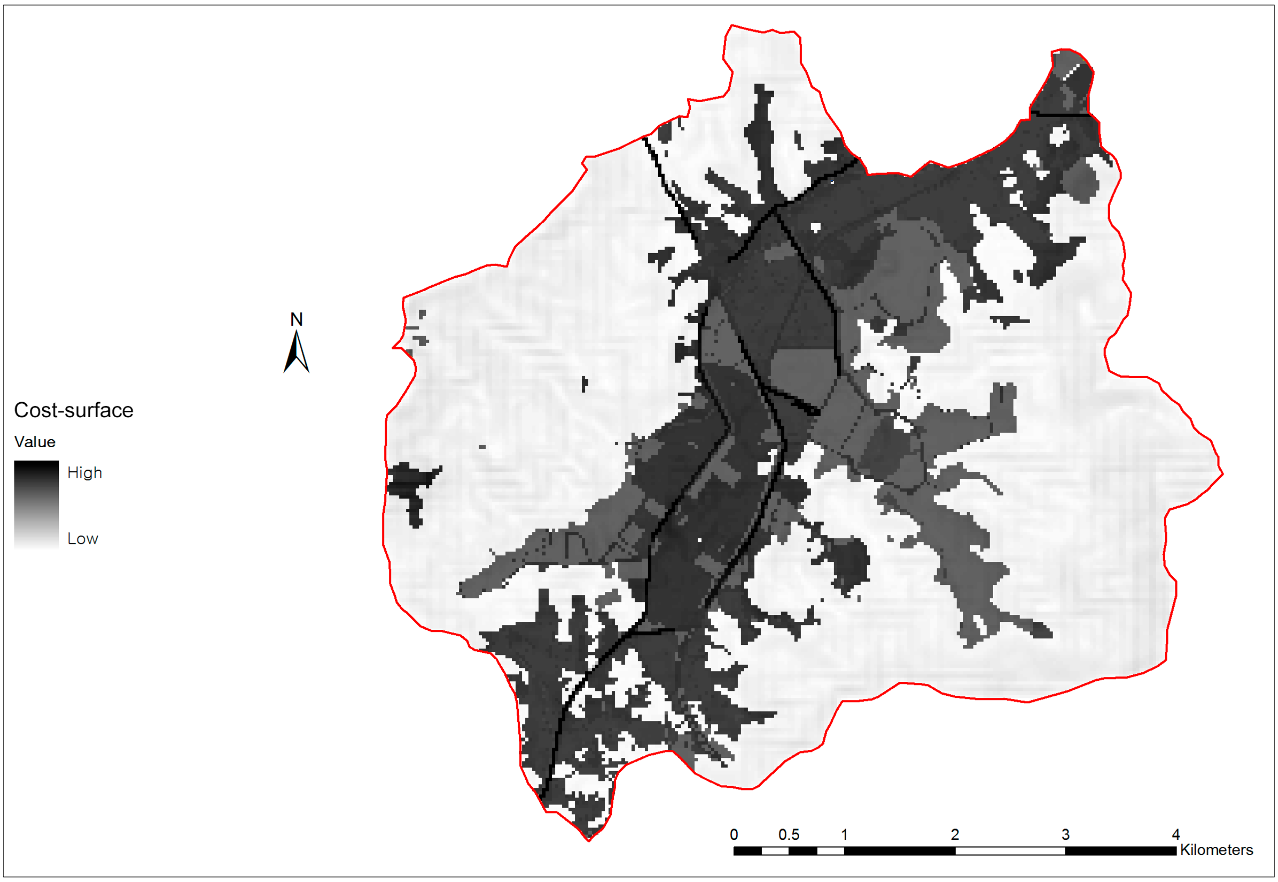
First, source areas were assigned to calculate and generate a cost surface. A source area represents a large hub linking the ecological infrastructure, which in this case relates to the riparian zones, *i.e.*, Yangjaecheon and Makgyecheon (Figure 1). These riparian zones are representative of high-value ecosystem service areas among the landscape elements present in Gwacheon. Riparian zones have also been assigned as nature conservation and environmental protection areas by the Ministry of the Environment in Korea. This land use type, which includes the interface between terrestrial and aquatic components of the landscape, provides useful food resources with large amounts of nutrients to wildlife habitats.

Second, to generate a cost surface, which is the map-represented cost value associated with the movement in each grid (90 m^2), this study considered three components related to the cost: land use types, roads/highways and slopes. Land use types were categorized based on the value of ecosystem services. Table 3 shows the resistance values obtained from the weight value for land use types based on the value of ecosystem services as a function of Equation (2) and the weight of the other elements (roads/highways and slopes) to create a cost-surface raster. The cost-surface raster was created according to the integration of four components (land use type, density of road, highway, slope) by summarizing the relative weight cost of each land cover. Passing the values of ecosystem service through a land use type is a significant factor in linking the ecological infrastructure to increase the total value of an ecosystem in urban planning (Table 3). Roads and highways were represented as density values, and the slope represented the resistance value related to wildlife movement. These factors are associated with the concept of landscape permeability, which evaluates landscape connectivity and describes the ability of wildlife to pass through certain environments. The cost-surface raster was generated using weights for these components referring to the literature [115,116]. To understand the concept of landscape permeability, the weight values for different land use types were calculated adversely using the value of ecosystem services in the land use types present in Gwacheon. Furthermore, the cost-surface raster can aid in the configuration of land use types according to the value of ecosystem services. A cost-surface raster map was created based on the shortest distance with the least resistance, as shown in Figure 2. This map shows the results for the distance cost of the resistance values for the source area in gray scale. The increasing cost values (darker colors) toward the riparian area, in the center of Gwacheon, demonstrate the effect of the distance from the source area (Figure 2).

Table 3. Weight per land unit, density of roads/highways and slopes for resistance values.

Component		Weight	Value
Land use type	Developed areas of low and medium intensity	100.00	0.65
	Developed areas of high intensity	100.00	
	Developed area open spaces	84.14	
	Rice paddies	96.92	
	Croplands	97.51	
	Orchards	99.77	
	Forests	27.16	
	Grasslands	99.77	
	Riparian zones	94.75	
	Bare soils	99.99	
Density of road	0–1 km/km^2	1	0.15
	1–2 km/km^2	2	
	2–4 km/km^2	5	
	4–6 km/km^2	7	
	More than 6 km/km^2	10	
Highway	Less than eight lanes	100	
	More than eight lanes	200	
Slope	10(1.0—(1.0/1.0 + e(-(slope-30)/7)))		0.2

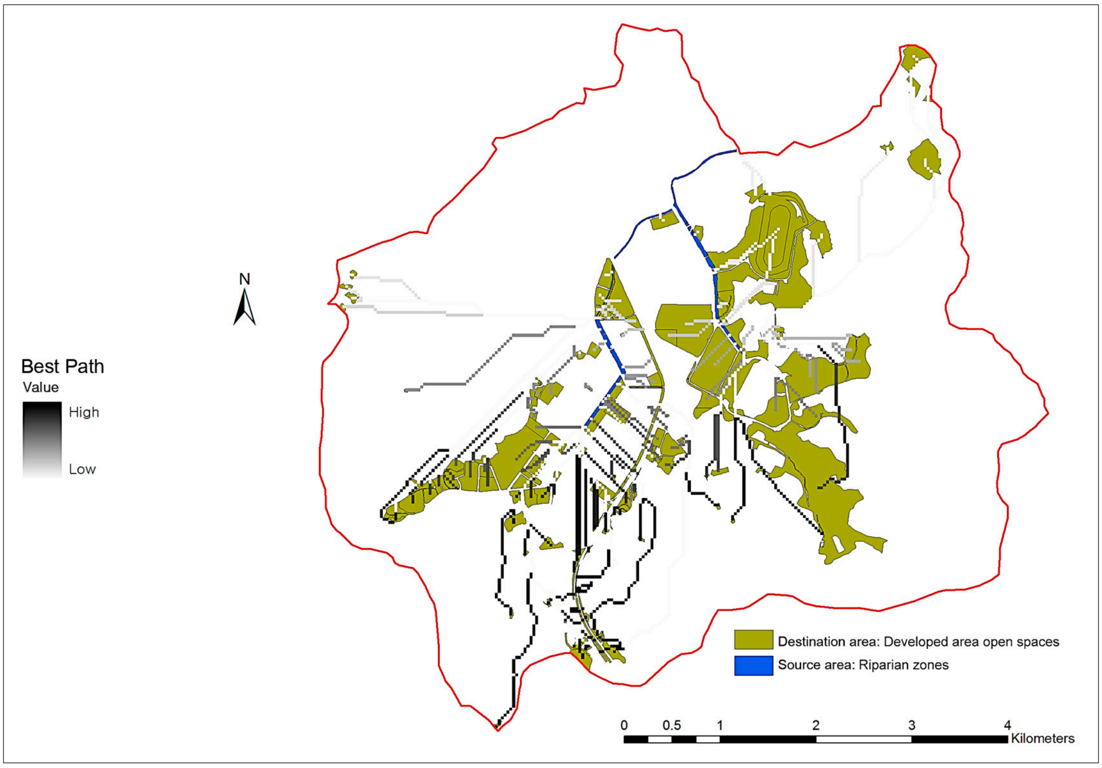
Figure 2. Cost-surface raster map for determining the connectivity of landscape elements.



Third, destination areas were selected where there were developed area open spaces. These areas are fragmented natural habitats in an urban area (Figure 1). To increase the connectivity of each habitat, a developed area open space was selected as the destination area.

Finally, least-cost paths were created from the cost-surface raster map (Figure 3). The cost-surface raster map was obtained using the cost distance, and the direction raster began at the source area and ended at the destination. Figure 3 shows the results of all calculations connecting the source area and destination area to assess the connectivity of landscape patches in Gwacheon. A darker path color indicates a stronger landscape patch connection (Figure 3). As the least-cost path is based on the cost surface calculated in the preceding step, the least-cost path is the best potential linear dispersal corridor for improving ecosystem services. This result could be useful in the planning of ecological infrastructure to increase the value of ecosystem services in Gwacheon.

Figure 3. Best potential dispersal corridor from the source areas (riparian areas) to destination areas (developed area open spaces) in ecological infrastructure planning to enhance ecosystem services in Gwacheon. Ecological infrastructure is defined as a network system of natural lands that provides ecosystem services.



The lengths and widths of the corridors were not considered when dispersal corridors from the main habitats were occupied by species, as this planning approach is sufficiently capable of producing a conceptual plan for ecological infrastructure planning by allocating the arrangement and location of corridors to achieve landscape connectivity. Landscape connectivity arises from not only the movement of organisms, but also their spatial distribution [122,123]. The extension of the area of a land use type affects the value of the ecosystem services of that land use type, which was reflected in the least-cost path analysis using the resistance value for the shortest distance of corridors. Concerning the aspects of the spatial distribution in landscape connectivity, the value of the ecosystem services of a land use type focused on determining the characteristics of each land use type rather than the pattern of landscape patches. The results are integral to understanding the processes involved in the interface between ecosystem functions and structures from the viewpoint of the value of ecosystem services.

The appropriate types of ecological infrastructure could be determined through assessing the value of ecosystem services in the riparian zones. Because the planning of ecological infrastructure targets the riparian zones in urban areas, the appropriate ecological infrastructure along the best corridor must be considered based on the results of the assessment of ecosystem service values. Water regulation, waste treatment and recreation values are ranked highly in riparian zones. Therefore, the selected ecological infrastructure must maximize these ecosystem service values. For example, a wetland shows excellent water regulation and waste treatment capabilities [71,88]. Greenways could also be suitable for enhancing recreation services. A greenway is a representative ecological infrastructure that provides opportunities for recreation for urban dwellers [124]. However, because ecosystem services rely on different ecological processes and spatial patterns, ecological infrastructure planning should be considered a specific ecosystem service and ecological target. In the case of riparian habitats (e.g., floodplain wetlands), the connectivity might need to be limited for the ecosystem service of biodiversity [125].

4. Conclusions

In this study, we investigated the best corridors for enhancing connectivity among landscape elements to design an ecological infrastructure for the city of Gwacheon, South Korea. The generated least-cost path provides dispersal corridors from riparian zones to developed area open spaces, which present a high ecosystem service value via providing suitable wildlife habitats. This set of corridors passes through residential areas containing more green cover, as well as through agricultural areas, such as rice paddies, croplands and orchards. Implementing corridors scattered between patches of urban areas in Gwacheon would clearly be favorable for landscape connectivity. The aim of ecological infrastructure planning is to promote ecosystem and human health in urban areas. Our planning of landscape corridors using the least-cost path method demonstrated the possibility of applying the value of ecosystem services in the ecological infrastructure, which means that the outcomes of planning contribute to human health through providing healthy wildlife habitats in urban areas.

The challenge of synthesizing the estimated values of ecosystem services was at least partially surmounted through using values from databases generated in previous studies, translated for application to the present work. However, there are a number of limitations to the applicability of these data. There is a possibility for the overestimation or underestimation of the results. In addition, the literature values did not correspond to most of the literature addressing assessments of the value of ecosystem services per land use type, focusing on ecosystem services in Europe and South America, whereas our study site was in South Korea. In addition, the quantity of available data was insufficient. Thus, estimation indices for the value of ecosystem services must be developed in consideration of the environment of South Korea. Future studies must focus on creating a database for estimation indices based on regional environmental characteristics. Nevertheless, the planning landscape corridors within ecological infrastructure planning were well supported by identifying the estimated value of ecosystem services. Our study was intended to review all possible ecosystem services to explore the opportunistic benefits of ecosystem services that may be supported by creating landscape connectivity in urban planning.

The outcome of the study may seem preliminary in that it did not relate the specific type of ecosystem service regarding the ecological corridor or the connectivity being designed in the landscape.

Our findings have the following implications for planning. First, the approach taken to estimate the value of ecosystem services in this study provided a useful example of assembling these values from a variety of spatial contexts. Second, the study represents not only an exploratory step toward a better understanding of the ecological infrastructure planning process, but also a novel landscape corridor design that supports landscape connectivity. Finally, the small urban planning case explored in this study could help create and improve policies for a sustainable urban ecosystem. In most small urban areas, local governments can promote land use policies that would provide sustainable living environments for humans.

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Author Contributions

Jung A Lee contributed to the development of the idea and participated in all phases. Jinhyung Chon also contributed to development of the idea and helped perform the analysis with constructive discussions. Jinhyung Chon and Changwoo Ahn provided guidance for writing this paper. Changwoo Ahn helped improve the figures and manuscript. All of the authors made contributions to the work in this paper.

Conflicts of Interest

The authors declare no conflict of interest.

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