Article

Estimating Changes in Habitat Quality through Land-Use Predictions: Case Study of Roe Deer (*Capreolus pygargus tianschanicus*) in Jeju Island

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Abstract: This study predicts future land-use changes and the resulting changes in habitat quality, suggesting a method for establishing land-use management to ensure sustainable wildlife habitats. The conservation effects were verified in terms of wild animal habitat quality according to the designation of protected areas. Land-use change until 2050 was predicted using the Dyna-Conversion of Land Use Change and its effects (Dyna-CLUE) model for Jeju Island, Korea, and the change in the quality of roe deer habitats was predicted using the Integrated Valuation and Environmental Services and Tradeoffs (InVEST) model. Results indicate that, compared to 2030, urbanized area increased by 42.55 km^2, farmland decreased by 81.36 km^2, and natural area increased by 38.82 km^2 by 2050. The average habitat quality on Jeju Island was predicted to decrease from 0.306 in 2030 to 0.303 in 2050. The average habitat quality ranged from 0.477 in 2030 to 0.476 in 2050 in protected areas and 0.281 in 2030 to 0.278 in 2050 outside protected areas. Habitat quality in protected areas was relatively high, and its reduction was limited. Areas with lower habitat quality need approaches such as expanding greenery and improving its quality. By establishing appropriate land-use plans by predicting habitat quality, wildlife habitats can be better maintained and protected, which is a primary goal of green infrastructure.

Keywords: urbanization; protected area; habitat conservation; green space expansion

1. Introduction

Biodiversity is affected by habitat changes, invasive species, climate change, overuse of natural resources, disease spread, nutrient salinity loads, and contamination, among which habitat changes are considered the greatest threats to biodiversity [1]. Jeju Island, which is located in Korea, features high biodiversity, with 7800 species of animals and plants and a natural environment represented by the Halla Mountains, grasslands, the Gotjawal forest, the Oreum volcano, and caves [2]. A total of 4764 land animal species (7 amphibians, 14 reptiles, 4316 insects, 384 birds, and 43 mammals), 155 families, 698 genera, 1841 native plant species, 87 endemic plant species, and endangered wildlife exist in these areas. The biodiversity is excellent, with 122 species of protected wildlife [3].

Currently, the roe deer (*Capreolus pygargus tianschanicus*) is the only mammal living on Jeju Island; it was endangered in the 1980s due to poaching activities [4]. Many major habitats of roe deer are distributed over mid-mountainous areas (200–600 m above sea level); however, more than 16% of such areas have been urbanized, or are planned to be urbanized, with facilities such as tourist complexes (16 km^2), golf courses (9 km^2), amusement parks (11 km^2), district unit planning areas (46 km^2), and promotional district areas (10 km^2) [5]. If the urbanization of Jeju Island continues, the roe deer habitats will be reduced and habitat conditions will further deteriorate owing to the island's spatial restrictions, which may lead to the extinction of roe deer.

Land-use changes are related to various factors such as regional and ecological water cycles, socio–economic conditions, and policy changes; hence, modeling future land use changes is considerably complicated and it involves substantial levels of uncertainty [6–8].

Land-use change modeling is based on understanding the relationship between the spatial patterns of land use and the driving factors by using statistical techniques to examine spatiotemporal changes with respect to variations in socio–economic factors [8–10]. Based on previous research, the changes in land use and the economic impact of these changes can be ascertained by analyzing the correlation between social and economic variables, by studying the changes in agricultural and forest areas according to land use policies, or based on the changes in land use due to market fluctuations [9,11–14]. As a land-use change model, the Cellular Automata (CA) model is the most widely used model in spatial analysis research. Future land-use changes can be predicted by combining it with the Markov chain method [15,16]. The Markov method, which has been used in several studies, offers the advantage of calculating geographic information system (GIS) data based on digital images or grids to suitably reflect the changing trend of current land use [15,17]; however, the probability of transition remains constant and is applicable to all locations over time [18]. The CA model, which is a non-linear dynamic model, also has limitations when applied to different scenarios in terms of representing policies or socio–economic factors; this is because it continuously changes the adjacent grid by applying common changes in the time series results. On the other hand, the Dyna-Conversion of Land Use Change and its effects (Dyna-CLUE) is a model that can predict land-use changes by reflecting environmental and socio–economic changes [8,19–22].

Elderbrock et al. [23], Kim et al. [24], and Benedict et al. [25] defined green infrastructure as an interconnected network of spaces and natural areas that preserves the value and function of natural ecosystems and provide benefits to people and wildlife by maintaining clean air and water. In Europe, green infrastructure is defined as a strategically planned network of areas close to nature, including excellent natural areas designed to protect biodiversity and provide ecosystem services [26]. Green infrastructure is an expanded concept of existing green areas and ecological networks, and it is divided into conservation areas (hubs) and networks (links) [27]. Green infrastructure can afford various functions such as urban climate control, air pollution purification, improvement of water circulation, and provision of living spaces for living organisms.

The purpose of this study was to predict future land-use changes and resulting wildlife habitat quality changes. Based on the results, a method for establishing management directions for providing habitats for wild animals, a primary objective of green infrastructure, is proposed. In addition, the study aims to predict and verify the effects of designated protected areas in terms of habitat quality for wild animals. Thus far, studies focusing on changes in habitat quality according to the change in land-use have estimated changes from the past up to the present [5,28–31]. If changes in the habitat quality for wild animals can be predicted, it is possible to pre-allocate areas where habitat quality is expected to improve and be maintained as conservation-oriented areas, thereby preventing urbanization is such areas in advance. This will ensure a sustainable habitat for wild animals. This study is different from previous studies in that it predicts land-use changes and analyzes the changes in habitat quality for key species in the region, suggesting directions for land-use management to ensure the sustainable inhabitation of wild animals, before any damage to the habitats.

This study attempts to predict the land-use changes in Jeju Island until 2050 and analyze the resulting changes in habitat quality for roe deer. In addition, the study aims to verify the effectiveness of protected areas by analyzing changes in habitat quality by dividing them into areas within and outside protected areas. In addition, the trend of changes in habitat quality was analyzed by subdividing Jeju Island into watershed units. Based on this, we aim to establish a management direction for each watershed.

2. Materials and Methods

2.1. Site Description

Jeju Island is the largest island on the Korean Peninsula. It is a volcanic island with an area of 1848 km² (Figure 1). It was declared a UNESCO Biosphere Reserve in 2002, a World Natural Heritage site in 2007, and a Geological Park in 2010 [32]. From Halla Mountain (1939 m above sea level) at the center of the island to the coastal areas (0 m above sea level), the altitude gradually decreases; this region serves as a habitat for various species depending on the altitude. As such, Jeju Island is an area with high environmental and ecological protection value.
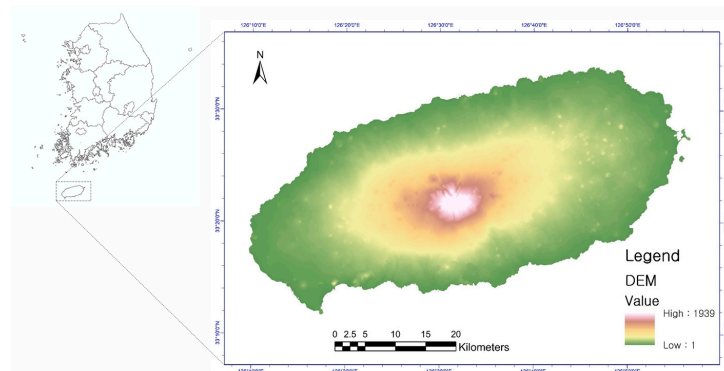

Figure 1. Study Site.

2.2. Target Species

There are two species of roe deer: the European roe deer (*Capreolus capreolus*), which are widely distributed over Europe, and the Siberian roe deer *(Capreolus pygargus)*, which are distributed across northern Asia [33], including parts of Siberia, Central Asia, Northeast Asia, and Jeju Island (Figure 2). Currently, their population and habitats are decreasing due to logging and hunting; hence, roe deer have been designated as a species of Least Concern (LC) by the International Union for Conservation of Nature (IUCN) [34], and thus, warrant continuous protection. Currently, Jeju Island is the only place in Korea where roe deer live.

Figure 2. Distribution area of the Siberian roe deer [34].

2.3. Research Method

2.3.1. Prediction of Land Use Changes

The Dyna-CLUE model was applied to predict land-use changes until 2050. The CLUE model is a land-use change model developed at the University of Wageningen in The Netherlands in 1996.

It quantifies the empirical relationship between land-use and driving factors and dynamically simulates the changes in land-use over time and space [8,35]. It was later developed into the CLUE-S model and Dyna-CLUE model [36,37]. The Dyna-CLUE model simulates the changes in land-use through feedback processes that allocate land-use based on the relationship between land-use and driving factors. It also determines land-use changes with respect to the total land-use requirement, considering not only the relationship with the driving factors but also the relationship with the neighboring grids [19].

To drive the CLUE model, a reference map, land-use requirements, location characteristics, spatial policies, restriction data, and land-use type specific conversion settings are required.

The data for driving the land-use change model are shown in Table 1. Land-cover maps produced and distributed by the Ministry of Environment (ME) of Korea were used to calculate the land-use map and land-use requirements. Among the location characteristics data, the DEM provided by the Korea National Geographic Information Institute (NGII) was used as the topographic factor, and the soil map provided by the Ministry of Agriculture, Food and Rural Affairs (MAFRA) of Korea was used as the geological factor. For socio–economic factors, the land-cover map provided by the ME of Korea, digital topographic maps provided by Korea NGII, and the statistical yearbook provided by Jeju Special Self-Governing Province were used.

Table 1. Data sources for driving land-use change model.

Data	File Format	Resolution	Creation Year	Source
Land-cover map	Raster	30 m	1990–2020	Ministry of Environment (ME) of Korea
Digital Elevation Model (DEM)	IMG	30 m	2020	National Geographic Information Institute (NGII) of Korea
Digital topographic map	dxf		2020	National Geographic Information Institute (NGII) of Korea
Soil map	Shape		2020	Ministry of Agriculture, Food and Rural Affairs (MAFRA) of Korea
Statistical yearbook	Excel		2019	Jeju Special Self-Governing Province

The reference map is a base map for simulating land-use changes, and in this study, the 2010 land-cover map provided by the ME of Korea was used (Figure 3).
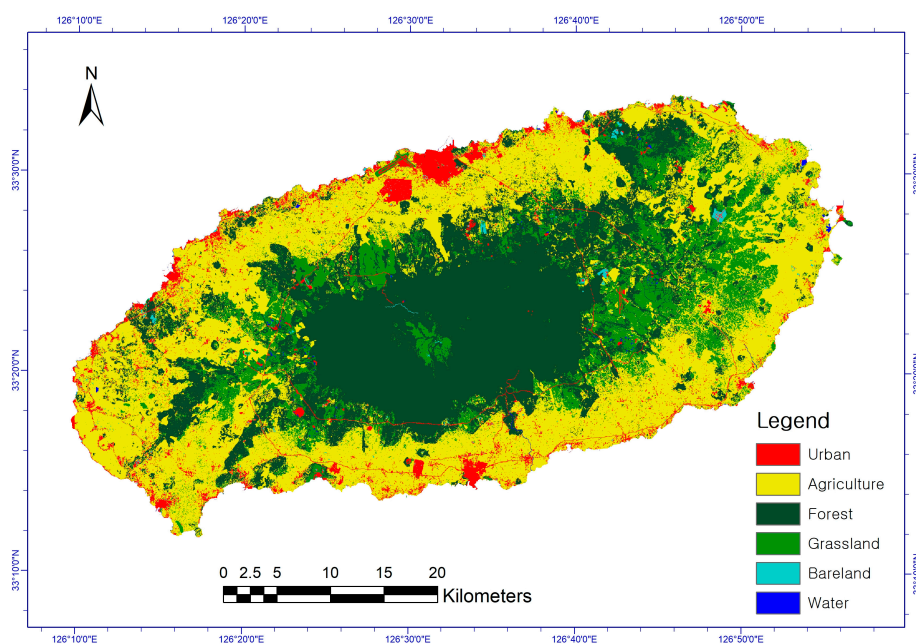

Figure 3. 2010 Jeju Island land-cover map.

Land-use requirements were based on the land-cover map produced by the ME of Korea from 1990 to 2020. According to the trend of change from the past to the present for each land-cover type, the rate of change from the base year (2010) to the land-use area until 2050 was calculated.

Data regarding the location characteristics were obtained based on the relationship between land-use and the land-use change factors, or with the use of the surrounding land. The relationship between land-use and the land-use change factors is represented by a binary logistic Equation (1).

$$\log\left(\frac{P_i}{1 - P_i}\right) = \beta_0 + \beta_1 X_{1,i} + \beta_2 X_{2,i} + \cdots + \beta_n X_{n,i} \tag{1}$$

here, P_i. is the probability that the land-use of grid i will change, $X_{n,i}$ is the land use change factor, and β_n is the regression coefficient for each land-use change factor [8].

Land-use change factors include biophysical factors such as soil, climate, topography, and socio–economic factors, including population, technology, political structure, and economic conditions [36]. In this study, topographical factors such as elevation, slope, and aspect; geological conditions such as effective soil depth, drainage grade, soil character; and socio–economic factors such as distance from streams, distance from roads, distance from cities, distance from the sea, and population density, were set as factors determining the land-use changes (Table 2). The relationship between land-use and the land-use change factors was analyzed based on the current land-cover map. The regression analysis results between each land-use and the land-use change factor were verified based on the Area Under the Curve (AUC) value through Receiver Operating Characteristic (ROC) analyses. ROC analyses are widely used to evaluate the performance of a model [38]. The AUC value lies between 0.5 and 1.0, and the closer it is to 1, the more descriptive the model is [39]. When the AUC value is 0.7 or higher, the model's descriptive power is considered appropriate [40].

Table 2. Land-use change factors.

Division	Change Factors	Source
Topography	Elevation Slope Aspect	Digital Elevation Model (DEM)
Geology	Effective soil depth Drainage grade Soil character	Soil map
Social economy	Distance from streams Distance from roads Distance from cities	Land-cover map
	Distance from sea Population density	Digital topographic map Statistical yearbook

As spatial policies and restriction data, protected areas data were used (natural parks, natural monuments protected areas, wetland protected area, and public forest) (Figure 4).

Specific conversion settings of the land-use type are used to determine the conversion elasticity and conversion matrix. Conversion elasticity is a coefficient that quantifies the degree to which conversion can occur for each land-use; it has a value ranging from 0 to 1. The closer the value is to 1, the lower is the probability of conversion. The conversion matrix determines whether a conversion is possible for each land type; it can have a value of 0 or 1. A value of 0 means that no conversion between land uses is possible, whereas a value of 1 means that conversion is possible. The conversion elasticity was established by analyzing the degree of change with respect to land-use type between 1990 and 2020 (Table 3). Compared to other land-use types, the changes in bare land were relatively more numerous; bare land had the highest conversion probability (0.2), followed by farmland (0.5), grassland (0.7), forest (0.9), urban area (0.9), and water body (1.0), respectively.
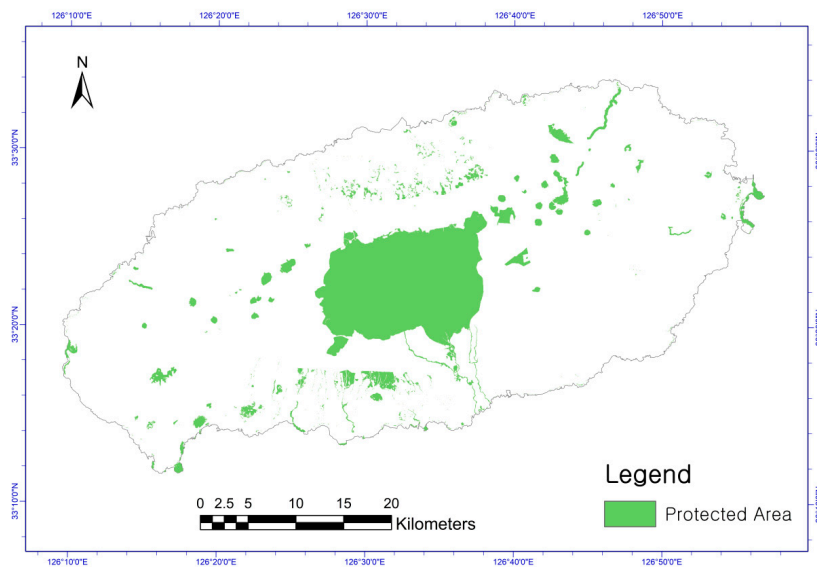
Figure 4. Jeju protected area map.

Table 3. Default values of conversion elasticity.

	Farmland	Urban	Forest	Grassland	Bare Land	Water
Value	0.5	0.9	0.9	0.7	0.2	1.0

The conversion matrix distinguishes whether conversion is possible for each land type and has values of 0 and 1. The conversion matrix was established by analyzing the changes in land-use types over the last 30 years (Table 4). For instance, in the case of farmland, changes from farmland to other land-use types over 30 years were analyzed, and the land-use type to which the farmland was converted was set as the convertible (1); if it was not converted to any other land-use type, the value in the conversion matrix was set as 0. The urban, forest, grassland, and bare land were set up using the same approach. As the water body was assumed to remain unchanged, it was set that only water body could be converted.

Table 4. Default values of the conversion matrix.

	Farmland	Urban	Forest	Grassland	Bare land	Water
Farmland	1	1	0	1	1	0
Urban	0	1	0	0	1	0
Forest	1	1	1	1	1	0
Grassland	1	1	1	1	1	0
Bare land	1	1	0	0	1	0
Water	0	0	0	0	0	1

Land-use allocation is determined through the following Equation (2):

$$Ptot_{i,t,lu} = Ploc_{i,t,lu} + Pnhb_{i,t,lu} + ELAS_{lu} + COMP_{t,lu}. \tag{2}$$

here, $Ptot_{i,t,lu}$ is the total probability that land-use lu exists in grid i, $Ploc_{i,t,lu}$. is the location fit probability according to the land-use change factor, $Pnhb_{i,t,lu}$ is the probability of fit according to the surrounding grid, $ELAS_{lu}$ is the transition characteristic value, and $COMP_{t,lu}$ is the competitive advantage value.

The land-use with the highest total probability is allocated for each grid, and the value of $COMP_{t,lu}$ is repeatedly calculated depending on whether the land-use demand for each land-use is satisfied (Figure 5).
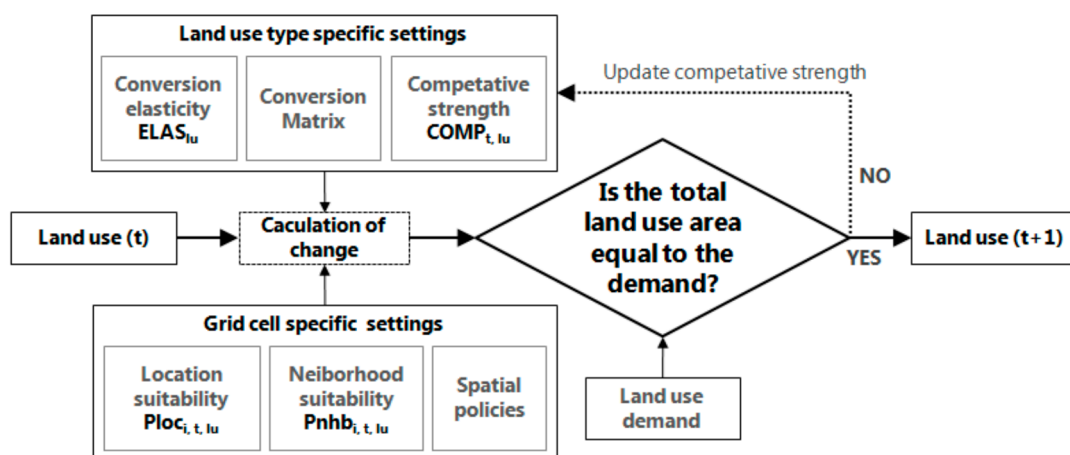
Figure 5. Land-use allocation process [36].

Land-use changes were predicted from 2020 to 2050. The predicted land-use map for 2020 was analyzed for accuracy by cross-validating with the 2020 land-cover map produced by the ME of Korea.

2.3.2. Analysis of Change in Roe Deer Habitat Quality According to Land-Use Change

The InVEST model was used to analyze the changes in quality of roe deer habitats. The InVEST model is one of the most widely used models owing to its high field applicability and user convenience; it has been applied in many studies [5,28–31]. It is a suitable tool for analyzing changes in the quality of habitat in terms of ecosystem service evaluation items, tradeoff analysis, economic valuation, stakeholder engagement, flexibility, and user convenience.

Among the InVEST models, the habitat quality assessment model relies on the proximity of habitats to human land-use and the intensity of land-use [41,42]. Habitat quality is affected by habitat suitability, threats due to habitat quality reduction factors, habitat sensitivity to reduction factors, and access to the habitat. The habitat quality is expressed as a value between 0 and 1; the higher the value, the higher the evaluated quality of the habitat is [43].

The formula for calculating habitat quality is as follows (3) [44]:

$$Q_{xj} = H_j \left[1 - \frac{D_{xj}^z}{D_{xj}^z + k^z} \right] \tag{3}$$

here, Q_{xj} is the habitat quality of grid x in habitat type j, and habitat suitability H_j represents the degree of suitability as a habitat for different types of habitats. The value of habitat suitability ranges between 0 and 1. The larger the value, the higher the suitability is. D_{xj} refers to the degree of reduction in the quality of the habitat in grid x and habitat type j; k is a half-saturation constant, which is half of the maximum reduction degree, and z is a normalized constant (usually 2.5).

By reviewing existing references [4,5,28–31], the threats to habitats, maximum impact distance, and weights for each factor were derived (Table 5). The main threats to the Jeju roe deer were urban land, farmland, and bare land, which can be termed human activity areas. The roads were designated as a separate threat category, especially because roads were the biggest threat due to accidents with vehicles. According to [4], the maximum impact distance for each factor was set to 200 m, by investigating the response of deer with respect to distance. The averages of the values presented in existing references were used as the weights.

Table 5. Threats to roe deer.

Threat Factors	Maximum Impact Distance (km)	Weight	Decreasing Trend with Distance
Urban	0.2	0.814	Exponential
Roads	0.2	0.465	Linear
Farmland	0.2	0.68	Linear
Bare land	0.2	0.7	Exponential

In addition, habitat suitability was calculated based on the rate of discovery of individual roe deer and the habitat traces for each habitat type surveyed in existing reports [45]. Habitat sensitivity was used as the average of the values presented in existing references [5,28–31] (Table 6).

Table 6. Sensitivity of habitat to threats.

Habitat Type	Habitat Suitability	Threat Factors			
		Urban	Road	Farmland	Bare Land
Urban	0.029	0.000	0.000	0.000	0.000
Farmland	0.273	0.482	0.263	0.240	0.400
Forest	0.524	0.850	0.530	0.765	0.700
Grassland	0.155	0.550	0.408	0.415	0.500
Bare land	0.004	0.326	0.150	0.250	0.350
Water	0.014	0.856	0.513	0.738	0.650

To classify the degree of accessibility to the habitat, the designation of protected areas was used. It was applied differentially from 0 to 1 according to the degree of legally protected area designation for each grid. The change in the habitat quality for Jeju roe deer from 2030 to 2050 was analyzed.

2.3.3. Spatial Management for Improving and Maintaining Roe Deer Habitats According to Land-Use

Wild animals prefer to have their own habitats, and they mainly survive within these areas. In the case of large mammals, a watershed was applied as an ecological unit for habitat management [46]. Therefore, in this study, Jeju Island was subdivided into areas according to watersheds (Figure 6). By analyzing the changes in habitat quality based on ecological units by 2050, space management efforts needed to focus on continually suppressing urbanization and preserving greenery in areas where habitat quality is expected to improve and be maintained. In areas where habitat quality is low, space management efforts should focus on continuously expanding and improving greenery.
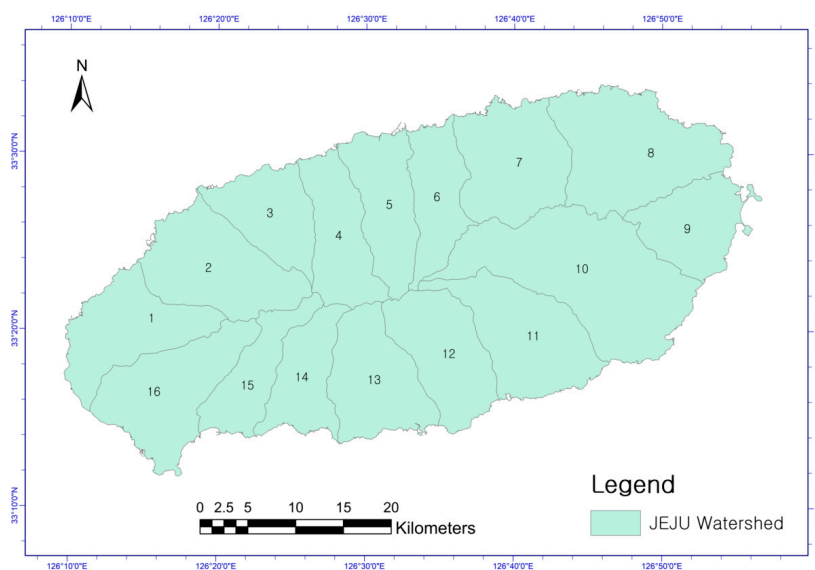

Figure 6. Jeju Island watershed map.

3. Results

3.1. Land-Use Change Prediction

The rate of change from the past to the present for each type of land-cover was calculated from the base year of 2010 up to 2050, according to the trend of land-use change (Table 7, Figure 7). In 2050, as compared to 2010, urbanized areas increased by 79.5%, farmland areas decreased by 27.3%, and natural areas increased by 1.6%. Jeju Island is a volcanic island, and during rainfall, accumulated water drains quickly. Hence, water bodies do not form. As a result, the area of the water body is extremely small compared to the total area (0.3% of the total area). Therefore, it is assumed that the water body does not change.

Table 7. Area by land-use type from 2010 to 2050 and rate of change by type in 2010.

Year	Urbanized (Urban + Bare Land)		Farmland		Natural (Forest + Grassland)	
	Area (km^2)	Change Rate (%)	Area (km^2)	Change Rate (%)	Area (km^2)	Change Rate (%)
2010	116.6		733.1		950.2	
2020	139.8	19.9	683.1	−6.8	954.0	0.4
2030	162.9	39.7	633.0	−13.6	957.9	0.8
2040	186.1	59.6	583.0	−20.5	961.7	1.2
2050	209.3	79.5	533.0	−27.3	965.5	1.6

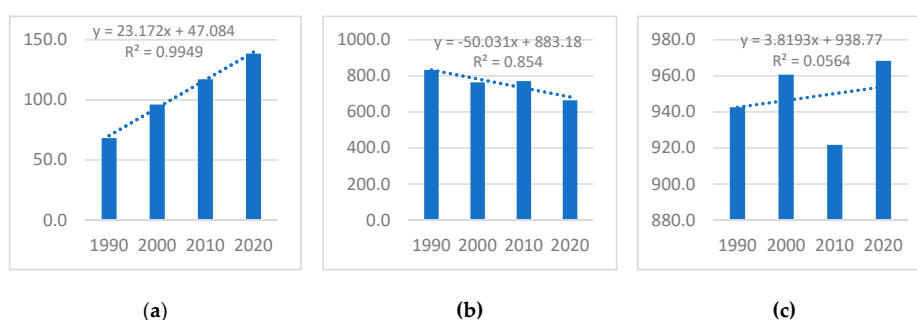
(a) (b) (c)

Figure 7. Land-use trend analysis graphs in (**a**) Urbanized areas, (**b**) Farmland, and (**c**) Natural areas.

A logistic regression analysis between each land-use type and land-use change factor was performed to derive the regression coefficient β. To determine the suitability of the derived regression analysis results, the AUC value was obtained using the ROC curve (Table 8). The AUC value of all cover types was 0.8 or higher, indicating that the model was reliable.

Table 8. Regression analysis results between each land-use type and land-use change factors (β values).

Land-Use Change Factor	Land-Use Type					
	Urban	Farmland	Forest	Grassland	Bare Land	Water
Aspect	0.000246	0.000313	0.000339	-	0.000374	−0.000995
Slope	−0.054018	−0.062016	0.113731	−0.073059	−0.030213	−0.188145
Elevation	0.003425	−0.005112	0.000876	-	−	0.002451
Distance from roads	−0.023111	−0.002209	0.001042	-	−0.001137	-
Distance from streams	−0.000230	0.000381	0.000189	-	−0.000463	−0.005207
Distance from cities	−0.008269	−0.001199	0.001129	-	−0.002053	−0.000670
Distance from sea	−0.000148	−0.000036	0.000098	0.000176	0.000041	−0.000170
Population density	0.023501	−0.044447	−0.008532	−0.001005	0.007420	-
Effective soil depth	0.096881	0.266295	−0.218660	−0.152839	−0.049740	-
Drainage grade	-	−0.151377	-	-	0.076155	0.193253
Soil character	−0.037741	-	0.110120	0.226939	-	-
Constant	0.187266	1.267142	−2.986911	−3.212232	−3.182950	−2.830859
Area Under the Curve (AUC) value	0.915	0.921	0.931	0.823	0.819	0.858

The land-use change in Jeju Island from 2030 to 2050 was predicted (Figures 8 and 9, Table 9). The urbanized area increased by 42.55 km^2 (2.35% compared to the area of Jeju Island) by 2050 compared to that in 2030; the farmland decreased by 81.36 km^2 (4.50% compared to the area of Jeju Island), and the natural area increased by 38.82 km^2 (2.15% compared to the area of Jeju Island).
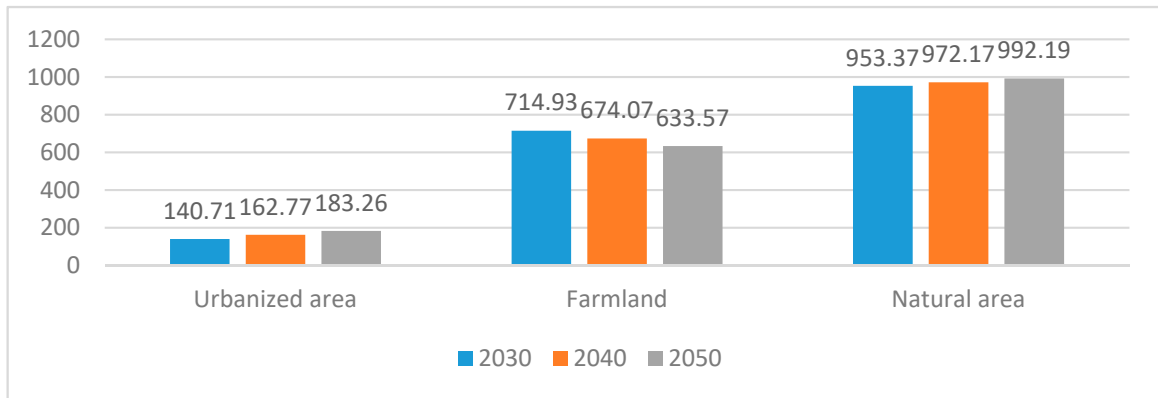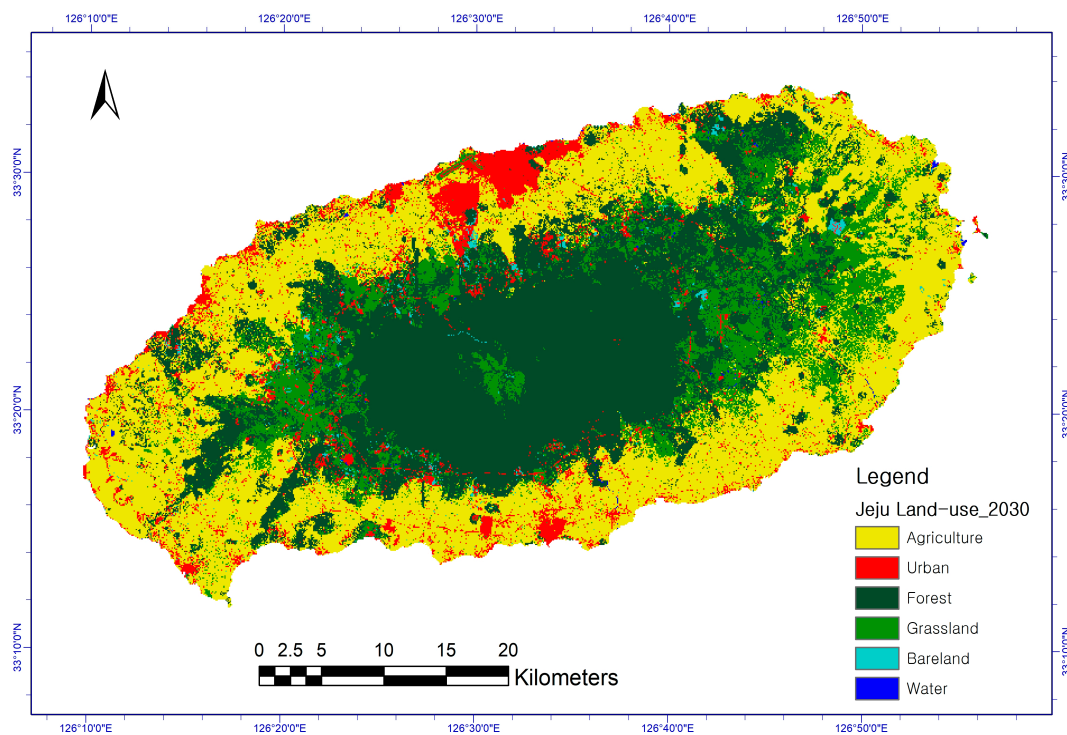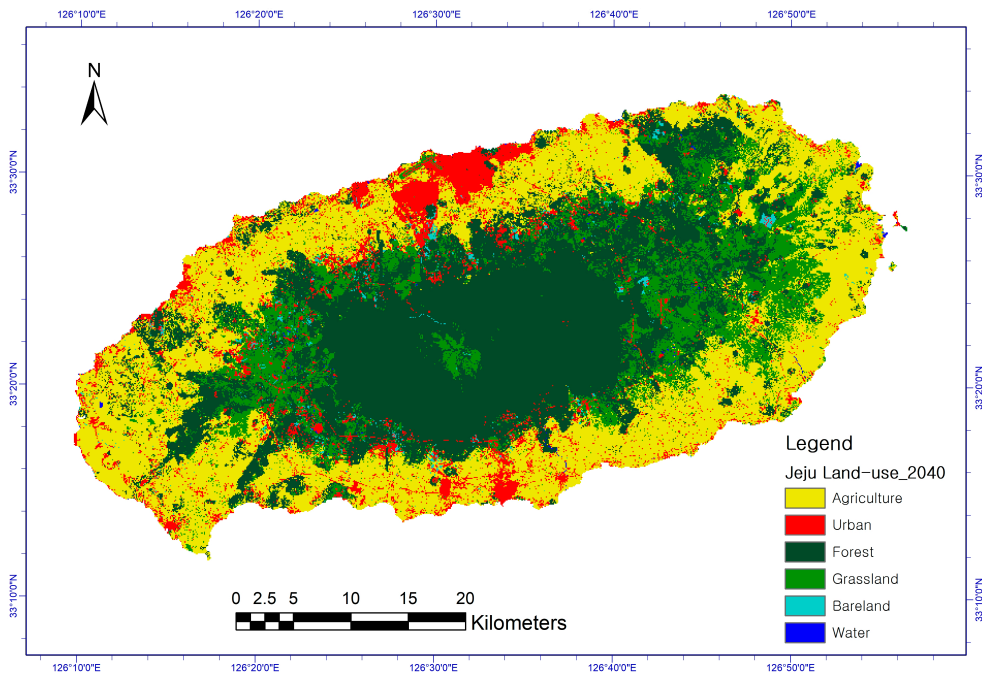

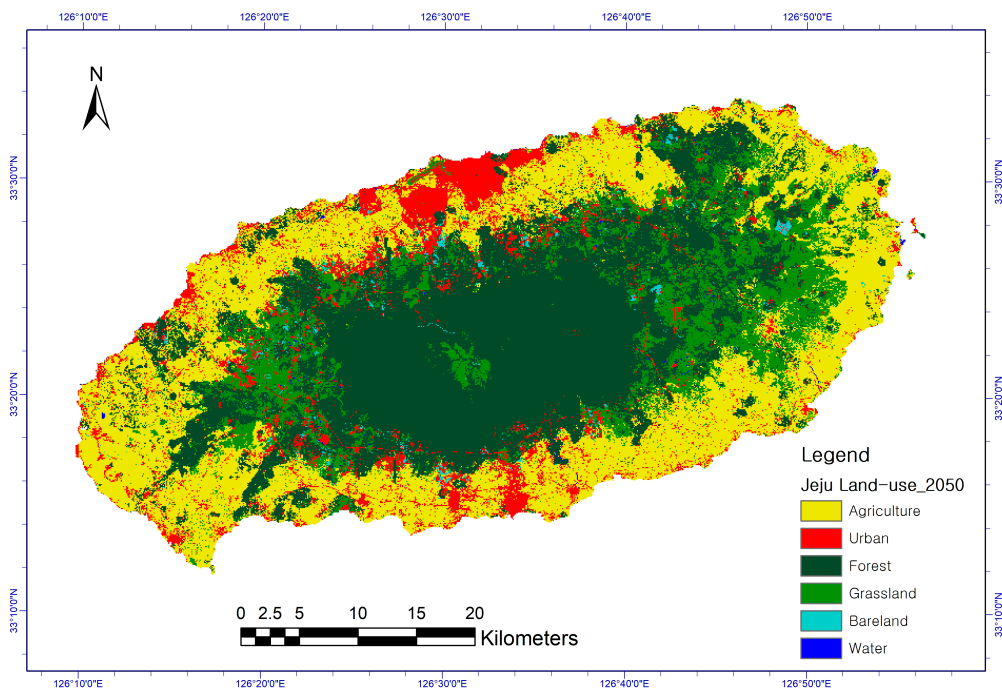**Figure 8.** Area change by land-use type in 2030–2050 (unit: km^2).

(**a**) 2030

Figure 9. *Cont*.

(**b**) 2040

(**c**) 2050

Figure 9. Land-use maps in (**a**) 2030, (**b**) 2040, and (**c**) 2050.

Table 9. Area and ratio of land-use by 2030, 2040 and 2050.

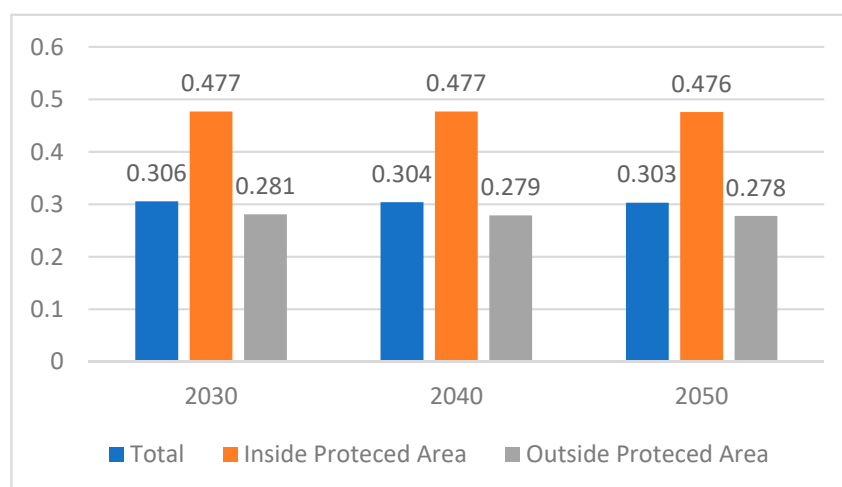| Land-Use	2030		2040		2050	
	Area (km^2)	Ratio (%)	Area (km^2)	Ratio (%)	Area (km^2)	Ratio (%)
Urbanized Area	140.71	7.78	162.77	9.00	183.26	10.13
Used Area	127.13	7.03	146.90	8.12	165.51	9.15
Barren	13.58	0.75	15.87	0.88	17.76	0.98
Farmland	714.93	39.52	674.07	37.26	633.57	35.02
Natural Area	953.37	52.70	972.17	53.74	992.19	54.85
Forest	670.85	37.08	684.50	37.84	698.46	38.61
Grassland	280.21	15.49	285.36	15.77	291.41	16.11
Water	2.31	0.13	2.31	0.13	2.31	0.13

To verify the accuracy of the land-use prediction results, the 2020 prediction results were obtained according to the current change trend and the 2020 land-cover map cross-validation was conducted (Table 10). The verification indicated an accuracy of 71%. In previous studies, modeling results were deemed valid if the accuracy exceeded 70% [7]; hence, this model was considered valid.
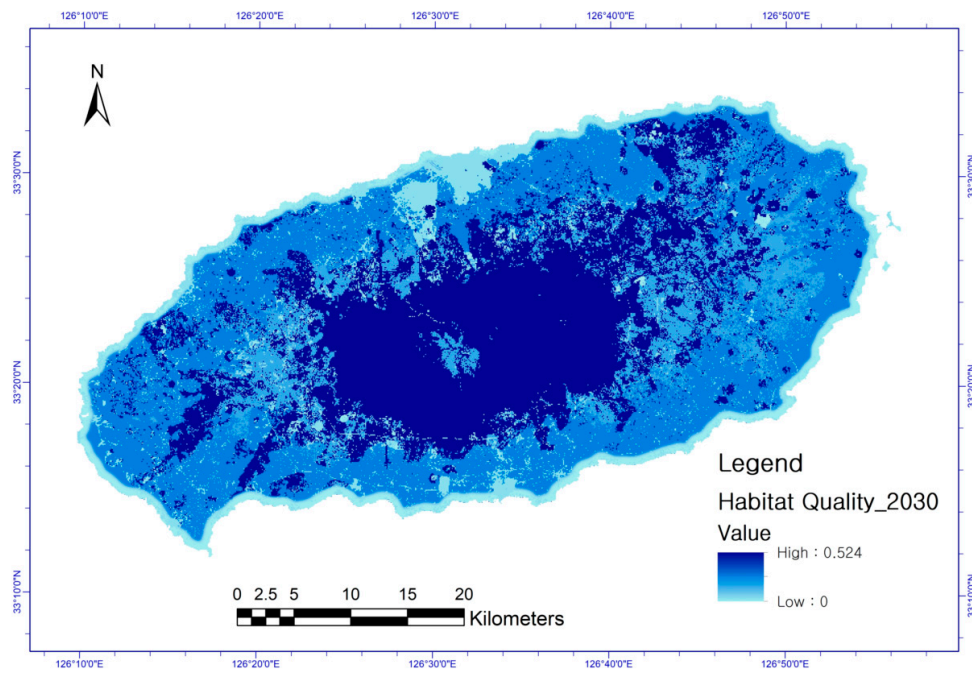
Table 10. 2020 Cross-verification result of 2020 land-use change model results and land-cover map.

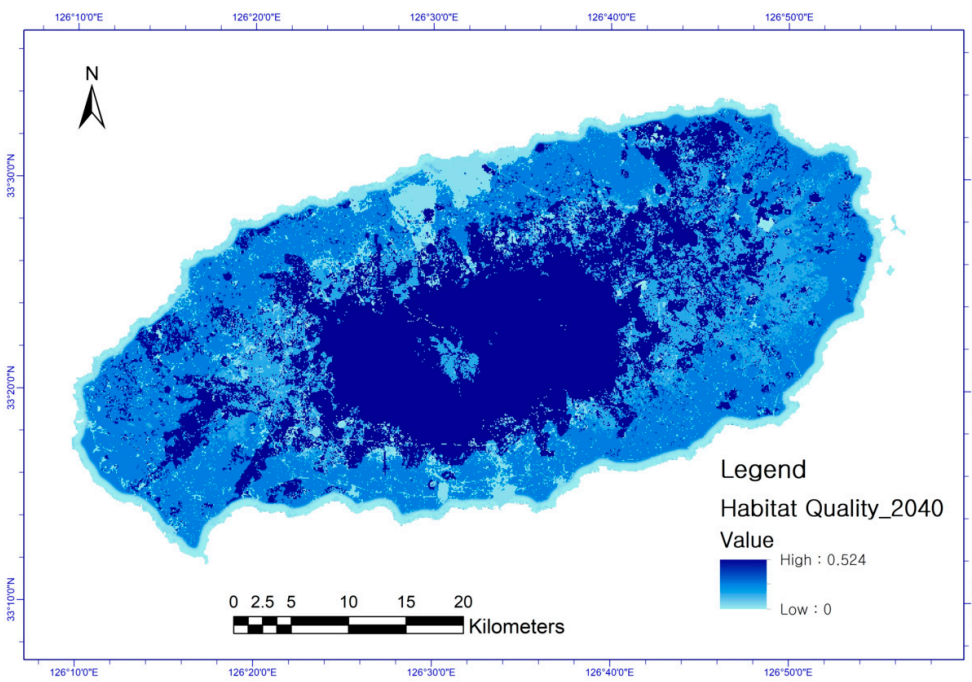|	Total	Farmland	Urban	Forest	Grassland	Bare Land	Water
Accuracy (%)	71.0	86.3	41.5	76.8	48.9	12.0	39.6

3.2. Jeju Roe Deer Habitat Quality Changes

The results of the habitat quality of roe deer in Jeju Island from 2030 to 2050 are shown in Figures 10 and 11 and in Table 11. Habitat quality values are assigned to each grid and displayed as a continuous value. Therefore, to analyze the change in habitat quality, the average habitat quality with respect to the period was calculated. The average value of the habitat quality of Jeju roe deer was predicted to decrease from 0.306 in 2030 to 0.303 in 2050. Habitat quality was predicted from 2030 to 2050 inside and outside the protected areas. It was predicted that the habitat quality within the protected area was high (0.477–0.476), whereas the habitat quality outside the protected area was low (0.281–0.278). Within the protected area, it was noted that the habitat quality was maintained better than that outside the protected area, and the extent of reduction was limited (reduction in protected area: 0.001; reduction outside protected area: 0.003). This shows that the designation of a protected area leads to a relatively high quality of habitat and a small decline in quality.

Figure 10. Changes in roe deer habitat quality by space for 2030–2050 (average value).
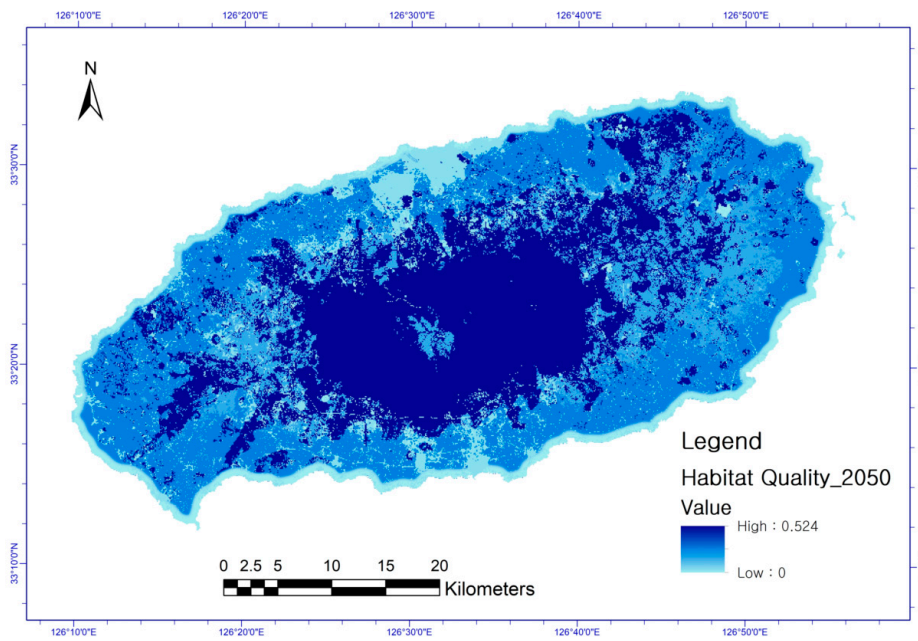
(**a**) 2030

(**b**) 2040

Figure 11. *Cont.*

(**c**) 2050

Figure 11. Jeju deer habitat quality map for (**a**) 2030, (**b**) 2040, and (**c**) 2050.

Table 11. Average value of Jeju roe deer habitat quality.

Region	2030			2040			2050		
	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
Total	0	0.524	0.306	0	0.524	0.304	0	0.524	0.303
Within protected area	0	0.524	0.477	0	0.524	0.477	0	0.524	0.476
Outside protected area	0	0.524	0.281	0	0.524	0.279	0	0.524	0.278

3.3. Results of Spatial Management for Improving and Maintaining Roe Deer Habitat Quality

The results of the spatial management for each watershed are shown in Figure 12 and Table 12. As a result of setting management goals of improving and maintaining habitat quality of watersheds for roe deer inhabitation, it was predicted that the habitat quality of the eastern watershed (WS 8, 9, 10, 11), where grassland and forests developed, will be maintained. In addition, it was predicted that the habitat quality will be maintained in the western watershed (WS 16), where forests developed. Other watersheds will require green space management to improve habitat quality.
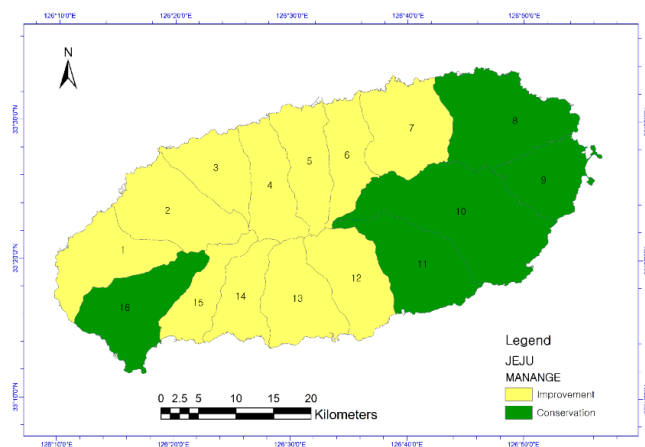

Figure 12. Classification of management directions by watershed.

Table 12. Average habitat quality results and management direction for each watershed.

Region	2030	2040	2050	Habitat Quality Change	Management Direction
Total	0.306	0.304	0.303	Decrease	Improvement
WS 1	0.255	0.254	0.252	Decrease	Improvement
WS 2	0.292	0.291	0.291	Decrease	Improvement
WS 3	0.273	0.267	0.263	Decrease	Improvement
WS 4	0.343	0.342	0.341	Decrease	Improvement
WS 5	0.302	0.298	0.295	Decrease	Improvement
WS 6	0.353	0.349	0.346	Decrease	Improvement
WS 7	0.314	0.310	0.308	Decrease	Improvement
WS 8	0.273	0.273	0.274	Increase	Conservation
WS 9	0.216	0.217	0.217	Increase	Conservation
WS 10	0.310	0.312	0.314	Increase	Conservation
WS 11	0.334	0.334	0.334	Maintain	Conservation
WS 12	0.382	0.380	0.376	Decrease	Improvement
WS 13	0.345	0.338	0.331	Decrease	Improvement
WS 14	0.337	0.335	0.334	Decrease	Improvement
WS 15	0.336	0.335	0.335	Decrease	Improvement
WS 16	0.258	0.259	0.259	Increase	Conservation

4. Discussion

The results of this study revealed that urbanized and natural areas increased, whereas farmland areas decreased. Urbanization is expected to further accelerate if existing land-use patterns continue. Nevertheless, natural areas are expected to be maintained because many areas are currently designated and managed as protected areas. However, if this protected status is revoked and urbanization is permitted in these areas, the natural area in Jeju Island is expected to decrease rapidly.

Based on the prediction results of land-use change, the habitat quality of roe deer was found to decrease over time. By analyzing changes in the habitat quality within and outside protected areas, it was found that habitat quality within the protected area was high and the rate of decline over time was limited. Therefore, the designation of protected areas is effective in improving and maintaining habitat quality for wildlife. To prevent a decline in habitat quality, designating protected areas can be an alternative solution.

Habitat quality was predicted according to the watersheds in order to establish management directions for each watershed to promote roe deer inhabitation. In the watershed where forests and grasslands developed, habitat quality is predicted to be improved and maintained, although the current green areas need to be continuously preserved and maintained. However, the watersheds where habitat quality decreases require expansion and improvements in the quality of greenery.

It is essential to actively utilize the method of evaluating habitat quality through land-use change predictions when establishing a green infrastructure plan. By using modeling techniques to predict long-term changes in land-use and predict the changes in the habitat quality of key species in cities, long-term green infrastructure plans can be established from the perspective of wildlife inhabitation. This can help land management policy makers develop sustainable land-use plans whereby wildlife and people can co-exist.

This study is meaningful in that it predicts land-use changes, analyzes habitat quality changes, and suggests spatial management directions for improving biological habitats, one of the primary goals of green infrastructure. In the future, if habitat quality changes are predicted and analyzed by considering the environmental factors of various species, a more specific sustainable spatial management direction can be suggested from the perspective of biological habitat preservation and maintenance.

5. Conclusions

This study proposed a method for establishing the direction of land-use management to ensure sustainable wildlife inhabitation in the future. If future land-use changes and the resulting changes

in habitat quality are predicted, rather than evaluating habitat quality based on current or past land-use, it becomes possible to prevent the urbanization of areas with good habitat quality in advance. This study predicts the land-use changes in Jeju Island until 2050, which is the largest island in Korea, featuring a high ecological diversity; the study also predicts the changes in habitat quality for roe deer in Korea, which are only found on Jeju Island.

Based on the predicted land-use changes, it was found that urbanized areas and natural areas increased, whereas farmlands decreased. By predicting the changes in the habitat quality of roe deer in accordance with these land-use changes, it was determined that the quality of habitats on Jeju Island, as a whole, would decrease. The changes in habitat quality within and outside protected areas indicated that habitat quality within protected areas was high and the rate of decline over time was limited. To improve and maintain roe deer habitat quality in Jeju Island, conservation is necessary, primarily in watersheds with forests and grasslands. Watersheds with low habitat quality require continuous expansion and quality improvements for green spaces.

This study suggested that in land-use management, it is possible to establish a management direction for sustainable wildlife inhabitation by predicting the changes in the habitat quality in accordance with land-use changes. In addition, this study suggested that the designation of protected areas is effective in terms of habitat quality conservation of wildlife.

Long-term green infrastructure management will be possible if land-use management measures, such as designating protected areas or expanding green spaces, are implemented based on predicted changes in the habitat quality, which was the aim of this study.

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