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The Changes in Habitat Suitability for Water Deer and Leopard Cat after Development Projects: a Case of Gyeonggi-do

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Abstract

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Human activity is one of the several factors that have a negative impact on the forest ecosystem. Development activities in the forest ecosystem affect its function as a habitat, leading to a reduction of biodiversity. For the promotion and maintenance of biological diversity, it is necessary to preserve the habitat of species. In South Korea, however, the effects of development activities on the habitat have not been adequately evaluated, and there is a need to establish a process that can predict the impact of development projects on biodiversity and favor sustainable development. A species distribution model predicts the potential distribution of the species on the basis of existing distribution data and habitat variables. Since development projects may cause environmental changes, a predictive model can effectively forecast habitat changes. The purpose of this study was to identify variables that reflect the effects of development projects on habitat by evaluating the potential location and distribution of species following changes in these habitats.

Mammalian species are keystone species in the forest ecosystem. The target species selected for this study were water deer and leopard cat because extensive research on the domestic habitats of these species has already been carried out. Species distribution data were obtained from the National Ecosystem Survey. The constructed environment variables included altitude,

slope, terrain relief, northness, curvature, land cover, forest type, forest age class, road density, distance variables, patch area, area to perimeter ratio and nearest neighbor distance. Development sites in 2008-2012 were selected. The MaxEnt model was used because it showed high sensitivity and accuracy in the domestic study even with a small sample size. The variables were selected on the basis of both their correlation and their independence. Changes in the suitability of potential habitats before and after development were estimated by calculations derived from the maps that were constructed using the model.

The results showed that the habitat suitability changes are greater for the leopard cat than for the water deer because the former is affected by habitat fragmentation. It was also estimated that a relatively small habitat patch area is affected less by new development projects than is a larger one. It was observed that among the environmental variables analyzed in this study, the distance from the road had a strong effect in changing habitat suitability.

Therefore, by considering the attributes of the habitat in the process of determining the location of development projects, one can predict the impact of development projects on those habitats. This research, however, focused exclusively on specific mammalian species, so further research is necessary. Nevertheless, the study remains significant in that it confirmed the potential of the model to forecast the environmental impact of development projects on habitats before the development has begun.

Keyword : Environmental Impact Assessment, Species Distribution model, habitat suitability change, distance to road, patch area

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I. Introduction

Human activity has had an adverse effect on forest ecology worldwide, and is known to have reduced biodiversity. Forest ecosystems have been greatly influenced by land-use change (Gitay *et al.*, 2002). Deforestation, logging, development and other human activities are considered to be some of the factors contributing to the extinction of some sensitive species (Gardner *et al.*, 2009). Linear development, such as construction of roads, may lead to landscape fragmentation and affect natural habitats (Coffin, 2007). Habitat loss and fragmentation cause population decline, extinction, and reduction of species richness. They are also major threats to biodiversity (Brooks *et al.*, 2002; Cushman, 2006; Houlahan and Findlay, 2003).

Therefore, in order to address the issue of biodiversity adequately, it is essential to be able to understand the habitat of the species and its conservation.

In South Korea, however, the impact of development projects on the habitat has not yet been sufficiently considered. Current environmental assessment systems do not evaluate the impacts of development projects on the basis of biodiversity. Rather, the criteria they use are limited to whether legally protected species are present, and which species are present at the time of the assessment. This list is biased, and some protected species do not provide sufficient information about the status of biodiversity and habitats in the ecosystem. In the interest of favoring sustainable development in the process of

environmental assessments, it is necessary to be able to predict the impacts of development projects upon both biodiversity and biological habitat.

Species distribution models create habitat prediction maps of target species and are effective ways to assess the impact of development projects (Chaplin-Kramer *et al.*, 2015; Girardet *et al.*, 2013). These models help estimate the impact of development on potential habitats by using species distribution data and environmental variables. The models also aid in understanding the relationship between environmental changes due to the development and the potential changes in habitat associated with them.

Most studies employing species distribution models have focused only on the variables related to topography and climate (Fourcade *et al.*, 2014; Kwon *et al.*, 2012; Phillips and Dudík, 2008). In order to be able to grasp the impact of development on the habitat, however, it is necessary to account for the factors in the models that pertain to habitat patches, such as their connection (Girardet *et al.*, 2013; Vasas *et al.*, 2009), their size and their proximity (Luque S, 2013). Some studies have shown species distributions by using graphs to measure [habitat patch] connections (Fu *et al.*, 2010; Vasas *et al.*, 2009; Girardet *et al.*, 2013), but no study exists which accounts for all of the characteristics.

This research attempts to show the impact of development projects on the characteristics of the habitat patch. Changes in potential habitat suitability reflect the environmental impacts of development projects. Therefore, this research assesses the impacts of development projects by evaluating changes in

potential habitat suitability. One purpose of the research is to assess the potential probability of occurrence of species in the habitat patch, and the other is to derive the patch attribute associated with changes in potential habitat suitability.

II. Literature Reviews

1. Environmental assessment system

The term Environmental Assessment refers to “the process of predicting, analyzing, and assessing the impact of policies, plans, programs and projects on the environment.” The current environmental assessment system is divided into Strategic Environmental Impact assessment and Environmental Impact Assessment, which investigate the impact of projects on the environment considering biodiversity and habitat with respect to “conservation of biodiversity and habitat” and “flora and fauna”, respectively.

First, Strategic Environmental Impact assessment takes into account biodiversity and habitat when assessing the validity of the location of development projects. In accordance with the guidelines of the Ministry of Environment, an evaluation report should include the following.

- The expected impact on various protected areas such as ecosystem conservation area, wildlife conservation area, and wetland conservation area
- Risk of damage to areas with high ecological conservation value, such as ecological zoning map 1st grade, degree of green neutrality higher than 8th grade, river, or lake
- Potential risk to the habitat of protected wildlife, such as endangered wildlife or main migratory birds
- Potential influence on intertidal zone, dune, estuary, and wetlands, which are areas with high ecological conservation value

Next, the Environmental Impact Assessment report is written as follows:

- Taking into account the type, scale, and the environmental characteristics of the location of target projects, it considers the following elements to assess the state of flora and fauna and ecosystems, and to investigate the taxon state, ecological environment, major species, or individual based on the protection value and the neutrality of the ecosystem.
  - Flora
  - Land fauna
  - Inland water biota
  - Ecological Zoning Map and the current state of ecosystem
  - Other elements necessary for the systematic conservation of biodiversity and natural environment

However, a review of the actual assessment report showed that a majority of the reports contain little or no information on the biodiversity and habitat, thus indicating a problem with the methods used for impact assessment (Kwon, 2006). The cause of these problems is insufficient consideration of the components of the habitats and biodiversity affected by the development projects (Kwon, 2006).

According to previous studies, the ecological model, habitat model, and land use change model were presented to assess the impact of projects in the process of Environmental Assessment (Koo and Lee, 2012). However, the specific discussion has not been made in South Korea.

2. Species distribution model (Habitat suitability model)

The species distribution model (Figure 1) predicts the potential distribution (Phillips and Dudík, 2008) with the environmental variables and species presence data. It is divided into three types, namely prediction by expert judgment, analysis by experience, and empirical and statistical prediction (Song and Kim, 2012).

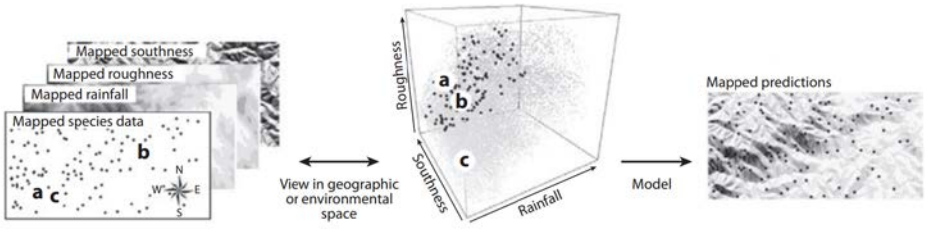


Figure 1 Process of species distribution prediction (Elith and Leathwick, 2009)

In most related studies in South Korea, mammals were the target species. The environmental variables used in 10 studies on habitat suitability of mammals are shown in Table 1. Variables could be named differently by different researchers, but in general, they can be classified as elements related to topography, vegetation, and disturbance.

Table 1 Environmental variables for habitat suitability of mammals

Age class	[1], [2], [5], [9], [10]	**Distance to cropland**	[7], [8]
Canopy density	[1], [3], [10]	**Distance to forest**	[7], [9]
DBH (diameter at breast height) class	[1], [8], [10]	**Distance to inner forest**	[8], [9]
Forest type	[1], [2], [4], [5], [9]	**Distance to grassland**	[7]
NDVI (normalized difference vegetation index)	[9]	**Distance to road**	[1], [2], [3], [5], [6], [7], [9], [10]
Aspect	[1], [2], [3], [4], [7], [9], [10]	**Distance to urban area**	[8]
Elevation	[1], [2], [4], [5], [6], [7], [8], [9], [10]	**Distance to water**	[1], [2], [3], [4], [5], [6], [7], [8], [9], [10]
Slope	[1], [2], [4], [5], [6], [7], [8], [10]	**Distance to wetland**	[3]
Other topographic features	[2], [7], [9], [10]	**Feed supply**	[2], [3]
Land cover	[3], [6], [7], [9]	**Solar radiation**	[2]

Through related research, the discussion of the current Environmental Assessment system and the habitat suitability model was reviewed. Environmental assessment has been carried out in South Korea for the purpose of sustainable development, but information on elements that directly affect the habitat and biodiversity is inadequate. The species distribution model could determine the suitability of habitats using the presence data and the environmental factors, but considering the landscape structure is insufficient.

Therefore, the present study evaluated the impact of development projects

using the species distribution model that determines habitat suitability based on changing environmental conditions. By providing information that would help to determine the function of habitats in addition to the list of species, it will aid in the assessment of environmental impacts considering the attributes of the habitat patch itself as well as the physical variables.

III. Research Methodology

1. Scope of the study

1.1. Target species

Mammalian species were selected because it was reported that the distance of their habitat from the infrastructure affects their populations l (Benítez-López *et al.*, 2010). In addition, several biodiversity conservation plans use mammalian target species since they are important elements in the ecosystem (Kim *et al.*, 2014). In order to assess species distributions, the habitat characteristics of the target species are required. Water deer (Kwon *et al.*, 2012; Park and Lee, 2013; Song and Kim, 2012) and Leopard cat (Kim *et al.*, 2012; Lee and Song, 2008; Lee *et al.*, 2011) were particularly useful because habitat investigations for these species were already being actively carried out in South Korea.

Water deer is a species endemic to all of South Korea. Since its habitat characteristics are obvious (Song and Kim, 2012), it is expected to be typical of many other species distributions. In the case of Leopard cat, a medium- to large-sized carnivore, it plays a pivotal role in the Korean ecosystem. In addition, it has been designated as an endangered species II group by the Ministry of the Environment and as such, it is legally protected.

1.2. Site

Development activities within the forest were ongoing in Gyeonggi Province. According to the forestry statistics annual report, in 2014 this region had the largest designated forest conversion area (1,806 ha) among seventeen

provinces nationwide. Datasets were constructed for Gyeonggi and the surrounding area. Northern regions that contained the demilitarized zone were excluded.

1.3. Context

To evaluate the changes of potential habitat suitability associated with development activities, data from the species distribution model before and after development were compared. With biogeographical factors utilized in the existing studies, factors for patch are put as input variables to integrate environmental impact on habitat. Variables entered in the species distribution model were used to predict the species occurrence probability in the study area. A subsequent distribution probability map was then extrapolated on the basis of the previous model. The most descriptive variables in the previous model were selected and used in the next model. Finally, the potential habitat suitability was assessed by comparing changes in species distribution probabilities.

2. Methods

2.1. Data collection and analysis

2.1.1. Species presence data

Species distribution data were collected from the Second and Third National Ecosystem Survey. The National Ecosystem Survey is executed by the Ministry of the Environment. The second survey was carried out from 1997 to 2005 and the third survey from 2006 to 2013. Terrain, landscape, vegetation and distributions of animals and plants were parameters included in the surveys (Kim *et al*., 2013).

2.1.2. Environment variables

In this study, there were two types of input variables for the predictive model: biogeographic and landscape structural factors. Biogeographic factors (Table 2) were selected on the basis of previous research performed on the habitat characteristics of mammals (Kim *et al*., 2014; Lee and Song, 2008; Seo *et al*., 2008; Song and Kim, 2012). Landscape structural factors (Table 3) were selected on the basis of the relevant research of habitat patches which affect the occurrence of species (Cattau, 2010; Mapelli and Kittlein, 2009). All environment variables were constructed at 30m spatial resolution using ArcGIS 10.1(ESRI Inc.).

Advanced terrain information such as elevation, slope, terrain relief, northness, and curvature were derived from the digital elevation model and land cover data was obtained from the map of the Ministry of Environment. Forest

type and age class data were extracted from the fourth and fifth type forest maps of the Forest Service. Road density was calculated from the standard transportation network. Some distance variables were constructed on the basis of the stream order map, the standard transportation network and the land cover map. Attributes of habitat patches were calculated using FRAGSTATS 4.2 (McGarigal *et al.*, 2012). FRAGSTATS is an analytical software which calculates indices required to measure the characteristics of the landscape and its components (Lo Papa *et al.*, 2011).

Table 2 Biogeographic variables for species distribution model

Biogeographic variable	Description
Elevation (m)	
Slope (degree)	
Relief	Standard deviation of neighborhood elevation
Northness	Cos {(Aspect*π)/180}, State of being north
Curvature	Slope of the slope
Land cover	7 classes of land cover
Forest type	4 types of forest
Age class	8 classes of age
Road density (km/km^2)	
Distance to river (m)	
Distance to roads (m)	
Distance to mount outside (m)	
Distance to mount inside (m)	
Distance to farmland (m)	
Distance to built-up area (m)	

Table 3 Patch attributes for species distribution model (McGarigal *et al*., 2012)

Patch attribute	Description
Area (ha)	Area of the patch.
Para	Ratio of the patch perimeter to area.
Contiguity	Average contiguity for the cells in a patch minus 1, divided by the sum of the template values minus 1.
ENN (m)	Distance to the nearest neighboring patch of the same type, based on the shortest edge-to-edge distance.

2.1.3. Development sites

Development sites were extracted as a reference for comparison in order to be able to understand the impact of development projects. The development sites that had been carried out from 2008 to 2012 were selected. Regional development projects that were registered for environmental impact assessment were selected and the linear development projects were extracted by comparing the road network data of 2008 and 2012.

2.2. Species distribution model

In this study, a species distribution model was used to predict the occurrence of the target species via species location data and habitat characteristic variables. The prediction was carried out using MaxEnt 3.3.3k (http://www.cs.princeton. edu/~schapire/maxent/), a machine learning algorithm. MaxEnt (Maximum Entropy method) indicates the distribution probability of the species based on the principle of maximum entropy. This model is known to be suitable for predictions with distribution data only (Phillips and Dudík, 2008; Phillips *et al.*, 2006), and its previous species distribution predictions in South Korea showed a high degree of accuracy (Kim *et al.*, 2012; Song and Kim, 2012). In particular, it is efficient in controlling the predictors and their complex interactions (Elith *et al.*, 2011; Jeschke and Strayer, 2008), and it responds well with small samples; therefore MaxEnt is a widely used model (Wisz *et al.*, 2008). The output of the model is displayed as a continuous probability and indicates the relative importance each component variable of the model.

The model simulated the distribution probability of Water deer and Leopard cat using the twenty variables constructed in the previous stage. Thirty percent of the species distribution data was used to validate the accuracy of model prediction. In order to ensure the reliability and consistency of the results, the model was run using ten bootstrap replicates.

A pair of datasets, one collected prior to development and the other following development, were input to the model as variables. In the modeling process,

explanatory power, correlation coefficients, and the result of the Jackknife test of the variables were compared. Then, the variables that best described species distribution were selected since they made the greatest contribution to the model.

Correlation between variables was analyzed and tested using SPSS 21.0 (IBM-SPSS Inc.). If the correlation coefficient *r* is higher than 0.70, the results of the model may tend to be over-fitted (Townsend Peterson *et al.*, 2007). Such variables were excluded from selection (Trisurat and Duengkae, 2011).

Jackknife test is an *a priori* measure to reduce subjective uncertainty in the process of selecting environmental variables and it provides clues about alternative estimation and the independence of variables. Each variable is either excluded in order or used only to build a species distribution model. By comparing the results from all cases, it can extract important and independent variables (Convertino *et al.*, 2012).

In order to assess the performance of the model, the ROC (Receiver Operating Characteristic) curve was used. AUC (Area under the Curve) is a metric to evaluate the accuracy of the model. An AUC value of 0.5 indicates random prediction, while an AUC of 1, the maximum possible AUC value, assumes a perfect prediction (Hirzel *et al.*, 2006).

2.3. Assessment of changes in potential habitat suitability

In order to compare the species distribution before and after development activities, a predictive model of the environment following the development projects is extrapolated from the model of the environment prior to the development project. The same variables were used in the model both before and after the development project. Pairs of maps of the output data, before and after development, were used to estimate the change in the potential habitat suitability.

Since potential habitat suitability is evaluated from the change in species distribution probabilities, each cell in a pair of maps were calculated as follows:

$$\Delta \mathbf{p} = \boldsymbol{p_d} - \boldsymbol{p_0} \qquad \textbf{Equation 1}$$

In Equation 11, p_0 is the probability of the presence of the species before development activities and p_d is its probability after development activities. A result of zero indicates that there was no change in potential habitat suitability. When the output value is negative, the potential habitat suitability has decreased.

IV. Results and Discussion

1. Species distribution model

1.1. Potential habitat suitability before development

Datasets of environmental variables before development activities were used to predict species distributions. In the initial model, all of the environment variables were applied. The key variables were identified by repeatedly running the pre-development model. Since it was expected that the development projects changed the land cover and terrain factors, the variables were applied in other periods applied as well. The response curve generated by the model described the relationship between the environmental variables and the species distribution probability. It was assumed that this relationship between the environmental variables and the species distribution probability was the same both before- and after the development projects.

Environment variables at the pre-development period were input to the model several times. The variables which were ultimately selected and used to predict water deer population distributions included contiguity, slope, distance to river, elevation, ratio of the patch perimeter to its area, road density, distance to road and distance to farmland. The contributions of each variable and the Jackknife of the regularized training gain are shown in Table 4 and Figure 2 respectively. The result of the potential habitat suitability is the same as in Figure 3, and the AUC is 0.878.

Table 4 Variable contributions of *Hydropotes inermis*

Variable	Percent contribution	Permutation importance
Contiguity	21.3	19.2
Slope	15.6	15
Distance to river	13.7	10.7
Elevation	12.8	13.1
Patch perimeter to area	11.2	11.1
Road density	10.2	13
Distance to road	8.6	9.4
Distance to farmland	6.6	8.4

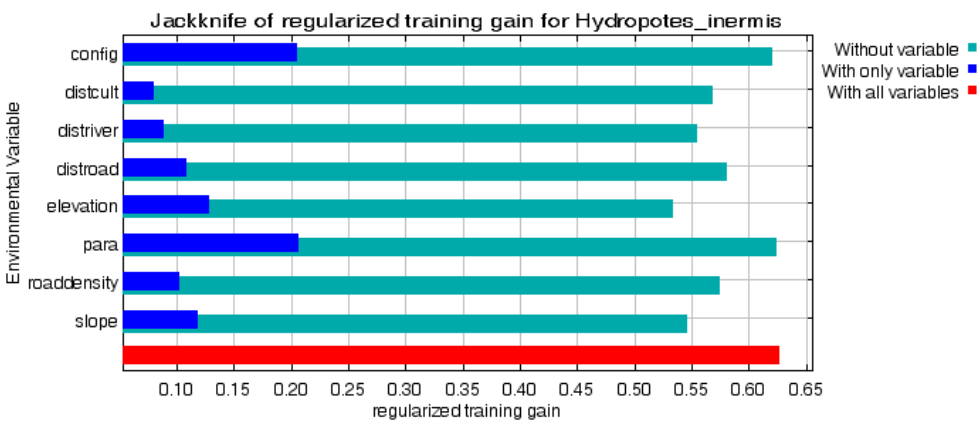


Figure 2 Jackknife of the regularized training gain for *Hydropotes inermis*

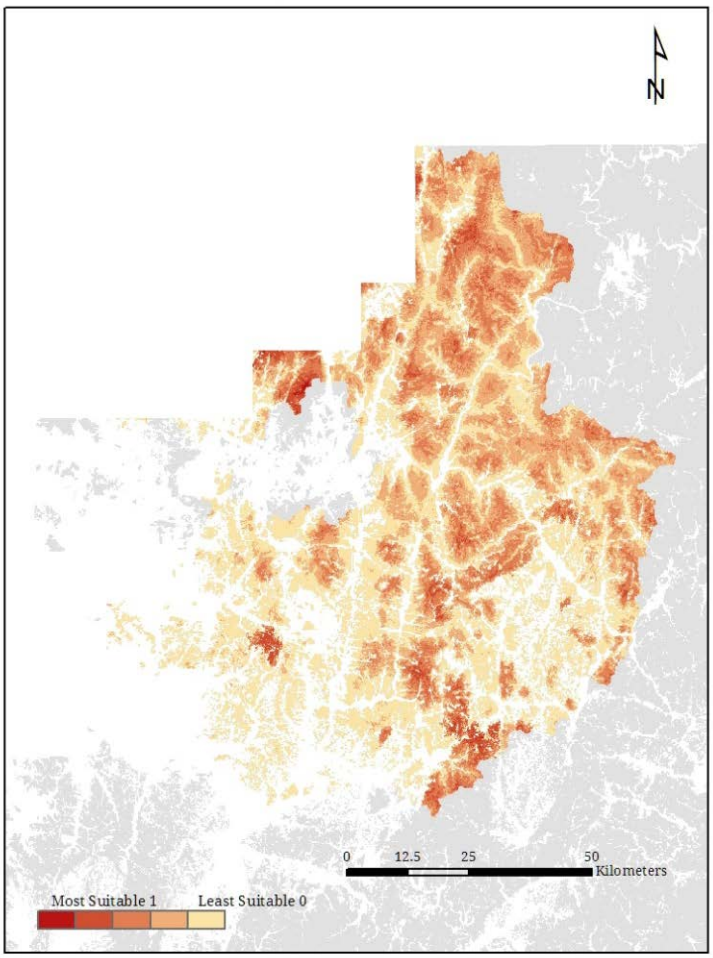


Figure 3 Habitat suitability for *Hydropotes inermis* before development

The variables selected as inputs to the predictive model for Leopard cat population distribution were elevation, distance to farmland, relief, distance to road, forest type, contiguity, distance to river, distance to built-up area, road density, and land cover. Variable contributions and the Jackknife of the regularized training gain are shown in Table 5 and Figure 4 respectively.

Table 5 Variable contributions of *Prionailurus bengalensis*

Variable	Percent contribution	Permutation importance
Elevation	32.5	33.4
Distance to farmland	22.9	14.4
Relief	9.5	12.8
Distance to road	9	8.6
Forest type	8.1	6.4
Contiguity	5.9	9.9
Distance to river	4.4	7.6
Distance to built-up area	3.9	3.2
Road density	3	2
Land cover	0.9	1.6

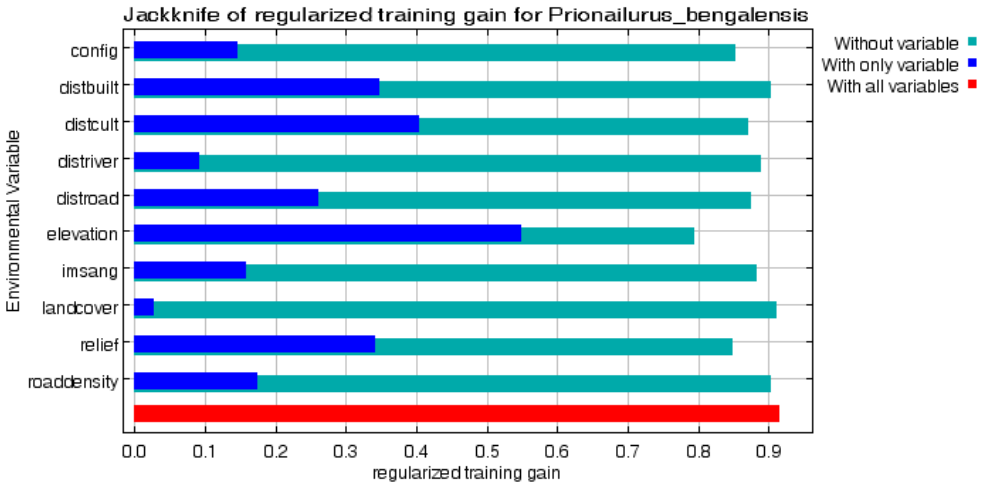


Figure 4 Jackknife of the regularized training gain for *Prionailurus bengalensis*

The result of the potential habitat suitability for the Leopard cat in pre-development conditions are shown in Figure 5, and the AUC is 0.872. In the case of the leopard cat, the contribution of the elevation factor is large, and there is a high probability of detecting the presence of this species at a height of 800 m (Appendix Figure 2).

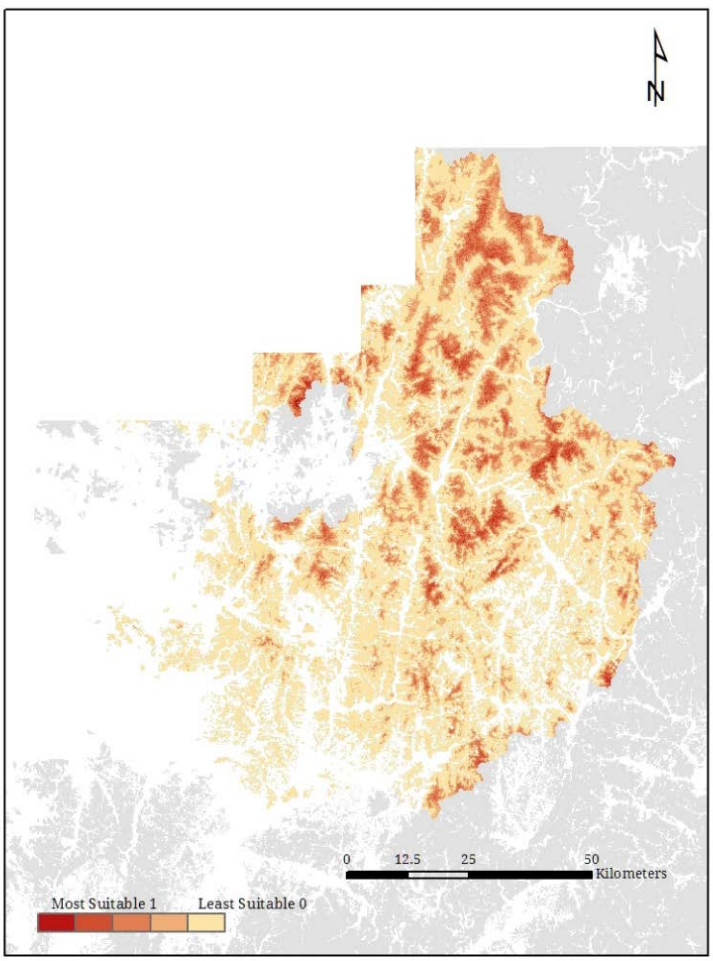


Figure 5 Habitat suitability for *Prionailurus bengalensis* before development

The potential habitat range of the water deer was wider than that of the leopard cat. The leopard cat is well suited to high or elevated habitats, particularly in northern regions. For the water deer, the population distribution maps showed pale red areas around the northern region and dark red areas in the southern region; the latter indicates high potential habitat suitability.

Considering that the water deer is one of the most common mammalian species in the National Ecosystem Survey, water deer habitats occupy larger areas than do those for the leopard cat. In addition, agricultural land occupied large areas in the southern part of Gyeonggi Province (Appendix Figure 3). Research on water deer habitat in Korea has shown that this species prefers farmland or low hills near the cropland (Song and Kim, 2012; Kim, 2009) as the results Figure 3 demonstrate.

1.2. Potential habitat suitability after development

The same variables fed into the predictive model pre-development were also used as inputs for the model post-development. Water deer habitat suitability post-development is illustrated in Figure 6. Leopard cat habitat suitability post-development is illustrated in Figure 7. Regions with high habitat suitability for each species prior to development decreased in suitability following development.

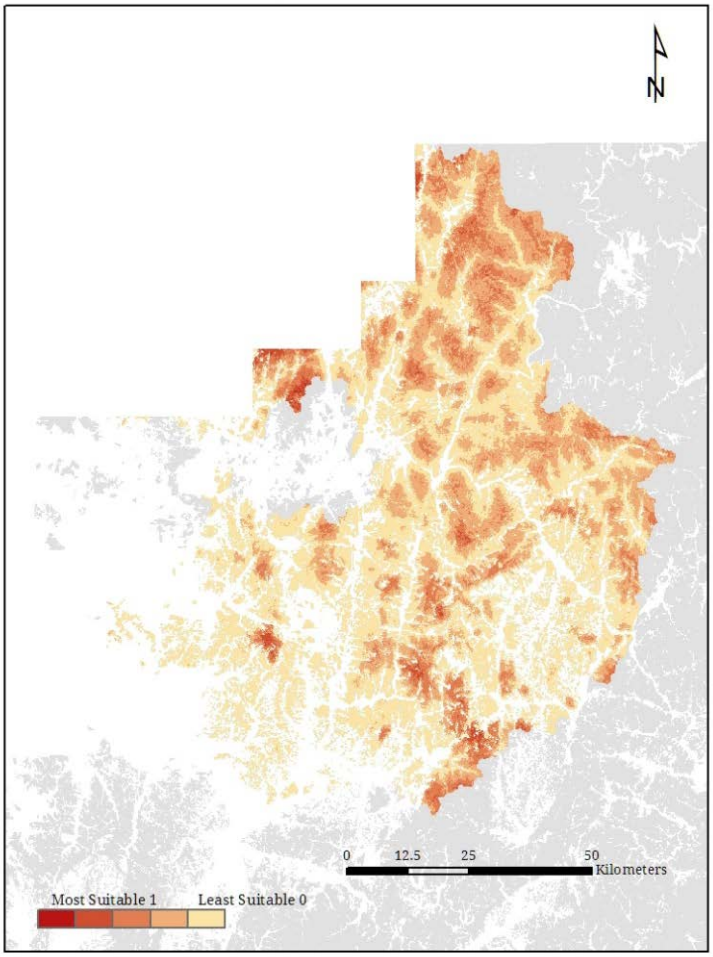


Figure 6 Habitat suitability for *Hydropotes inermis* after development

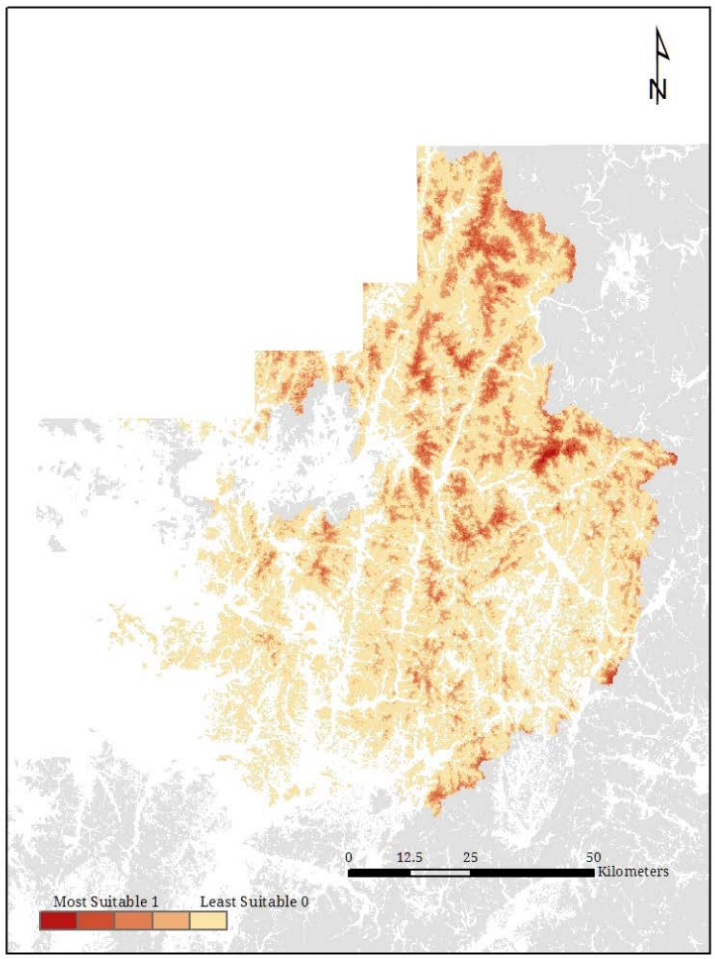


Figure 7 Habitat suitability for *Prionailurus bengalensis* after development

2. Changes in potential habitat suitability

The changes in the potential habitat suitability for water deer and leopard cat are shown in Figure 8 and Figure 9 respectively. Zones shaded in green have negative values, indicating that the species habitat suitability had decreased after development activities. In contrast, zones colored red have positive values that mean that the potential suitability of the habitat increased after development.

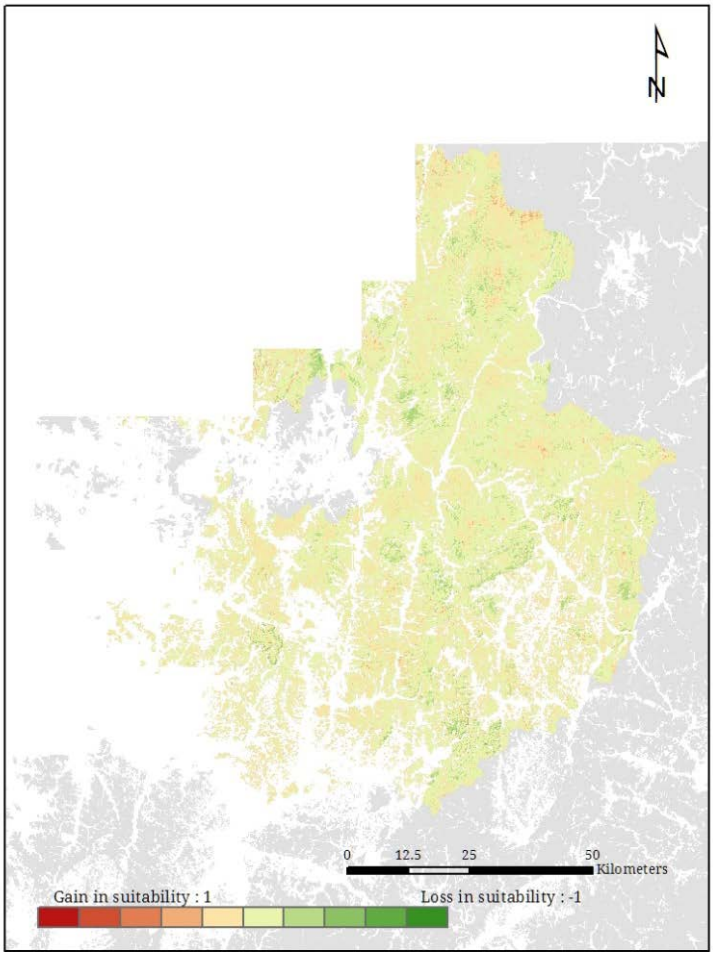


Figure 8 Habitat suitability change for *Hydropotes inermis*

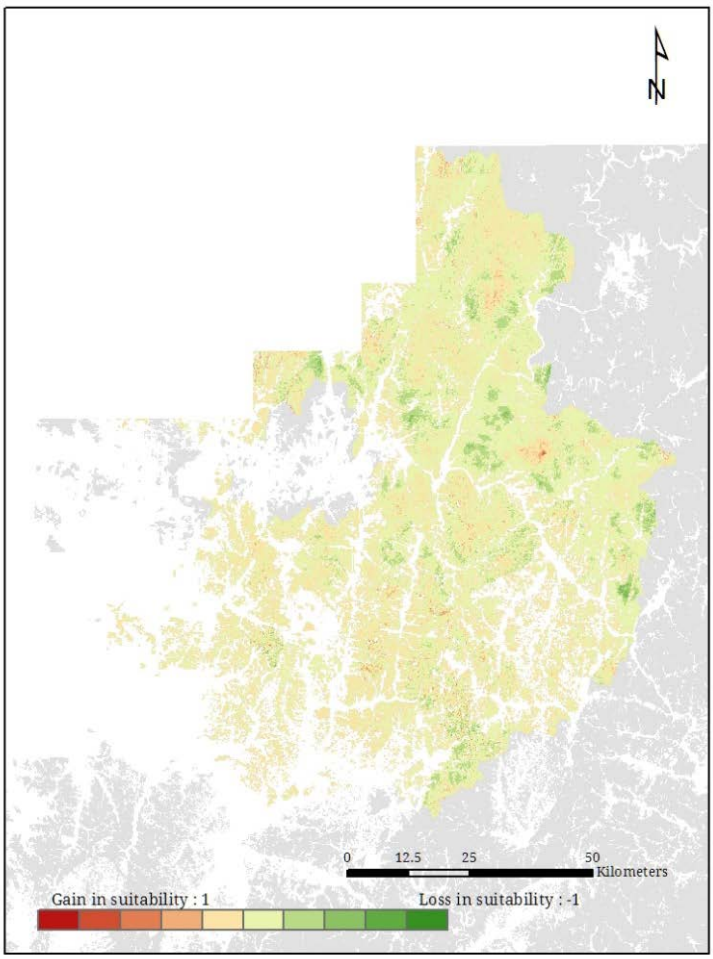


Figure 9 Habitat suitability change for *Prionailurus bengalensis*

Comparison of the maps for the two species revealed that the change in potential habitat suitability for the leopard cat was greater than that for the water deer. The main habitat of the leopard cat is mountainous terrain, and this species is more sensitive to habitat fragmentation than the water deer (Kang *et al*., 2005).

3. Development sites and changes in habitat suitability

Development sites that occupy larger areas affect land-use conditions, namely land cover and distance from the forest, cropland, or built-up areas. On the other hand, linear developments such as roads or railroads affect not only road-related conditions such as the density of the road and the distance from the road, but also the habitat patch attributes as a result of cutting into them. Figure 10 shows the area and linear development from 2008 to 2012.

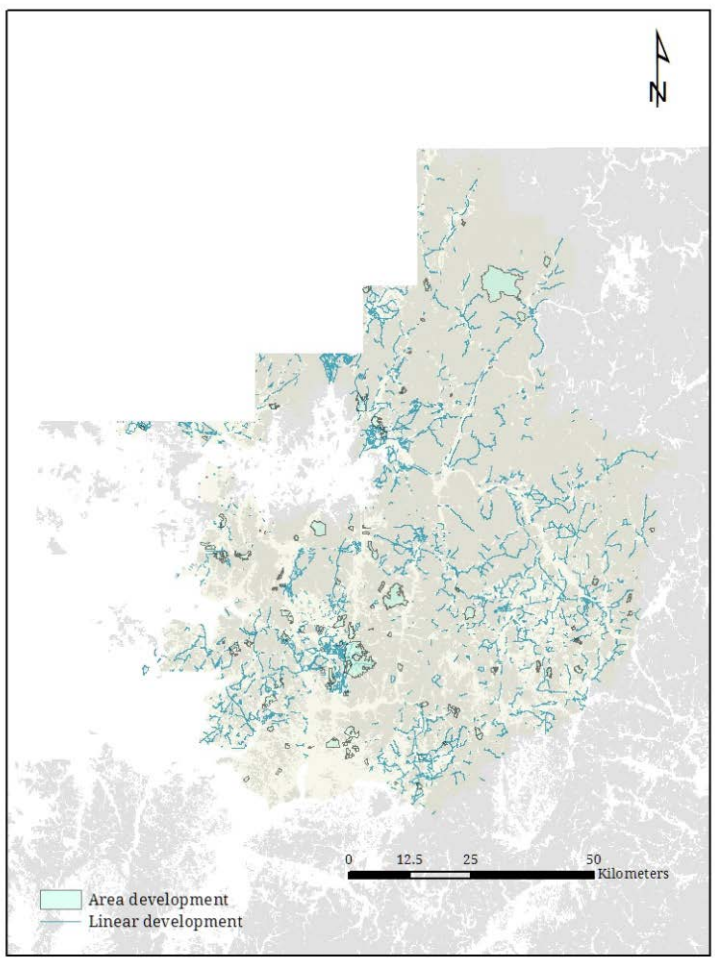


Figure 10 Development site

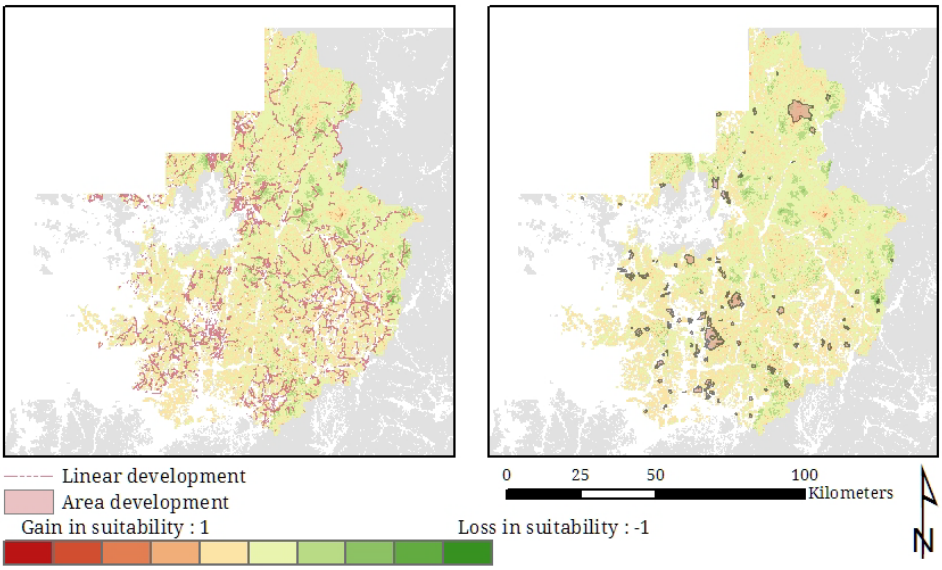


Figure 11 Habitat suitability change for Prionailurus *bengalensis* with development site

Figure 11 shows the change in habitat suitability for the leopard cat; development project sites are shown in overlay. As can be seen from the maps above, the area development projects, mainly in the southwestern region, did not significantly change habitat suitability for this species.

A possible explanation for this phenomenon might be that the area of the patches is a critical factor. In the southwestern region, which encompasses Siheung, Gwacheon, Suwon, and Yongin, the potential habitat suitability of the pre-development period was already low since the habitat patches had already been fragmented by previous urban and farmland developments. In contrast, there are large forest patches in the northeastern region with relatively higher potential habitat suitability (Figure 12). This observation might be explained by the fact that there were comparatively few development projects to change

habitat suitability in the provinces of Gapyeong, Yangpyeong and Namyangju in the northeastern region. Taken together, these results suggest that even though the area of the habitat patch was not considered as an input variable it had a large influence on habitat suitability change. In addition, The development projects which divide the patch into smaller size have high potential to decrease the habitat suitability.

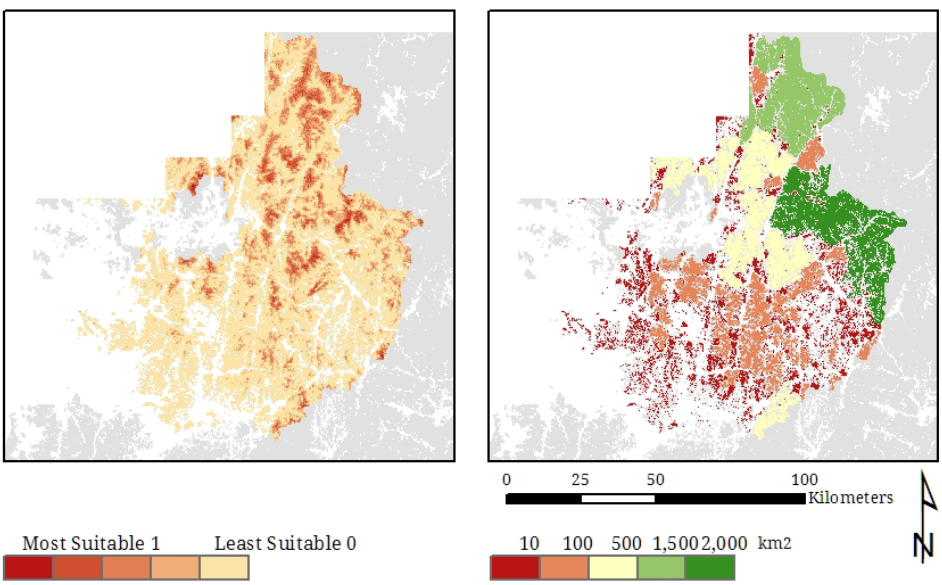


Figure 12 Habitat suitability for *Prionailurus bengalensis* before development, and habitat patch area

From Table 4 and Table 5, it can be seen that topographical elements such as elevation and slope contribute much to habitat suitability predictions. Nevertheless, the differences in topographical variables between the two periods were slight. In order to identify the key factor contributing to the

change in habitat suitability, the differences in each environment variable between the two periods (pre- and post-development) were compared in the northeastern region alone. As a result, the distance from the road was observed to be strongly correlated to the habitat suitability changes. Figure 13 illustrates the changes in habitat suitability and affected areas more than 1 km from the road.

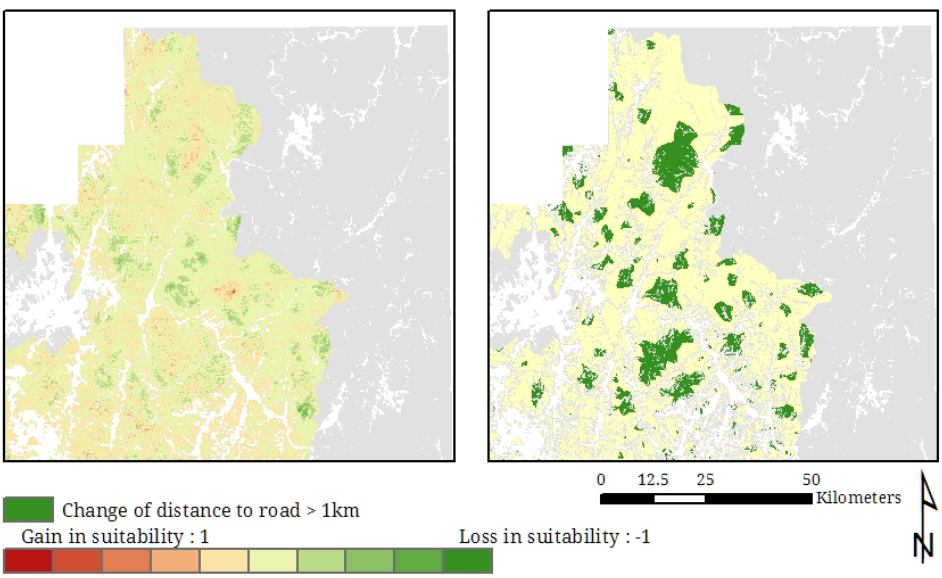


Figure 13 Habitat suitability change for *Prionailurus bengalensis* and the affected areas more than 1 km from the road

V. Conclusion

The existing species distribution models primarily account for biogeographic factors but do not adequately explain the impact of development on habitat. This research, therefore, was designed to assess the impact of development on habitat function using species distribution probabilities. The attributes of habitat patches were used as input variables for species distribution model. Changes to these attributes were then examined by comparing species distribution probabilities before and after development projects. Patch attributes such as contiguity and the ratio of patch perimeter to area served as explanatory variables.

The species distribution probability extrapolated from the previous model shows that the potential habitat suitability changed after development projects. Water deer had a wider range of possible habitats than did leopard cats, and potential habitat suitability for leopard cats tended to change more than they did for water deer. In addition, it was estimated that large habitat patches are more affected by new development projects than are smaller ones. The pattern of distance from the road mirrors that of the changes in habitat suitability.

The research has shown that habitat patch attributes could be used as variables in species distribution models, and that changes in habitat suitability depend upon the size of the existing habitat patches. Therefore, predicting the impact of development upon habitats and determining project locations can be facilitated by accounting for habitat patch attributes in the species distribution

model.

Since the scope of this research was limited to studying the impact of development on the habitats of a few large mammals, it was not possible to generalize the results for all species. More research with various species is required to increase the applicability of the methodology. Moreover, further studies need to be carried out in order to assess the environmental impact of particular development projects. This study suggests that the attributes of habitat patches could be integrated into a species distribution model, and environmental assessment systems can predict the impact of development on habitat. Although continued research is needed to make the findings more practicable, the findings of this study support the idea that environmental assessments should consider the impact of habitat function on biodiversity.

Bibliography

Benítez-López, A., Alkemade, R., and Verweij, P.A. (2010). The impacts of roads and other infrastructure on mammal and bird populations: A meta-analysis. Biol. Conserv. *143*, 1307–1316.

Brooks, T.M., Mittermeier, R.A., Mittermeier, C.G., Da Fonseca, G.A.B., Rylands, A.B., Konstant, W.R., Flick, P., Pilgrim, J., Oldfield, S., Magin, G., et al. (2002). Habitat Loss and Extinction in the Hotspots of Biodiversity. Conserv. Biol. *16*, 909–923.

Cattau, M. (2010). Using the ecosystem service value of habitat areas for wildlife conservation: implications of carbon-rich peatswamp forests for bornean orang-utan, *pongo pygmaeus*. Duke University.

Chaplin-Kramer, R., Sharp, R.P., Mandle, L., Sim, S., Johnson, J., Butnar, I., Canals, L.M. i, Eichelberger, B.A., Ramler, I., Mueller, C., et al. (2015). Spatial patterns of agricultural expansion determine impacts on biodiversity and carbon storage. Proc. Natl. Acad. Sci. *112*, 7402–7407.

Coffin, A.W. (2007). From roadkill to road ecology: A review of the ecological effects of roads. J. Transp. Geogr. *15*, 396–406.

Convertino, M., Welle, P., Muñoz-Carpena, R., Kiker, G.A., Chu-Agor, M.L., Fischer, R.A., and Linkov, I. (2012). Epistemic uncertainty in predicting shorebird biogeography affected by sea-level rise. Ecol. Model. *240*, 1–15.

Cushman, S.A. (2006). Effects of habitat loss and fragmentation on amphibians: A review and prospectus. Biol. Conserv. *128*, 231–240.

Elith, J., and Leathwick, J.R. (2009). Species Distribution Models: Ecological Explanation and Prediction Across Space and Time. Annu. Rev. Ecol. Evol. Syst. *40*, 677–697.

Elith, J., Phillips, S.J., Hastie, T., Dudík, M., Chee, Y.E., and Yates, C.J. (2011). A statistical explanation of MaxEnt for ecologists. Divers. Distrib. *17*, 43–57.

Fourcade, Y., Engler, J.O., Rödder, D., and Secondi, J. (2014). Mapping species distributions with MAXENT using a geographically biased sample of presence data: A performance assessment of methods for correcting sampling bias. PLoS ONE *9*.

Fu, W., Liu, S., Degloria, S.D., Dong, S., and Beazley, R. (2010). Characterizing the "fragmentation–barrier" effect of road networks on landscape connectivity: A case study in Xishuangbanna, Southwest China. Landsc. Urban Plan. *95*, 122–129.

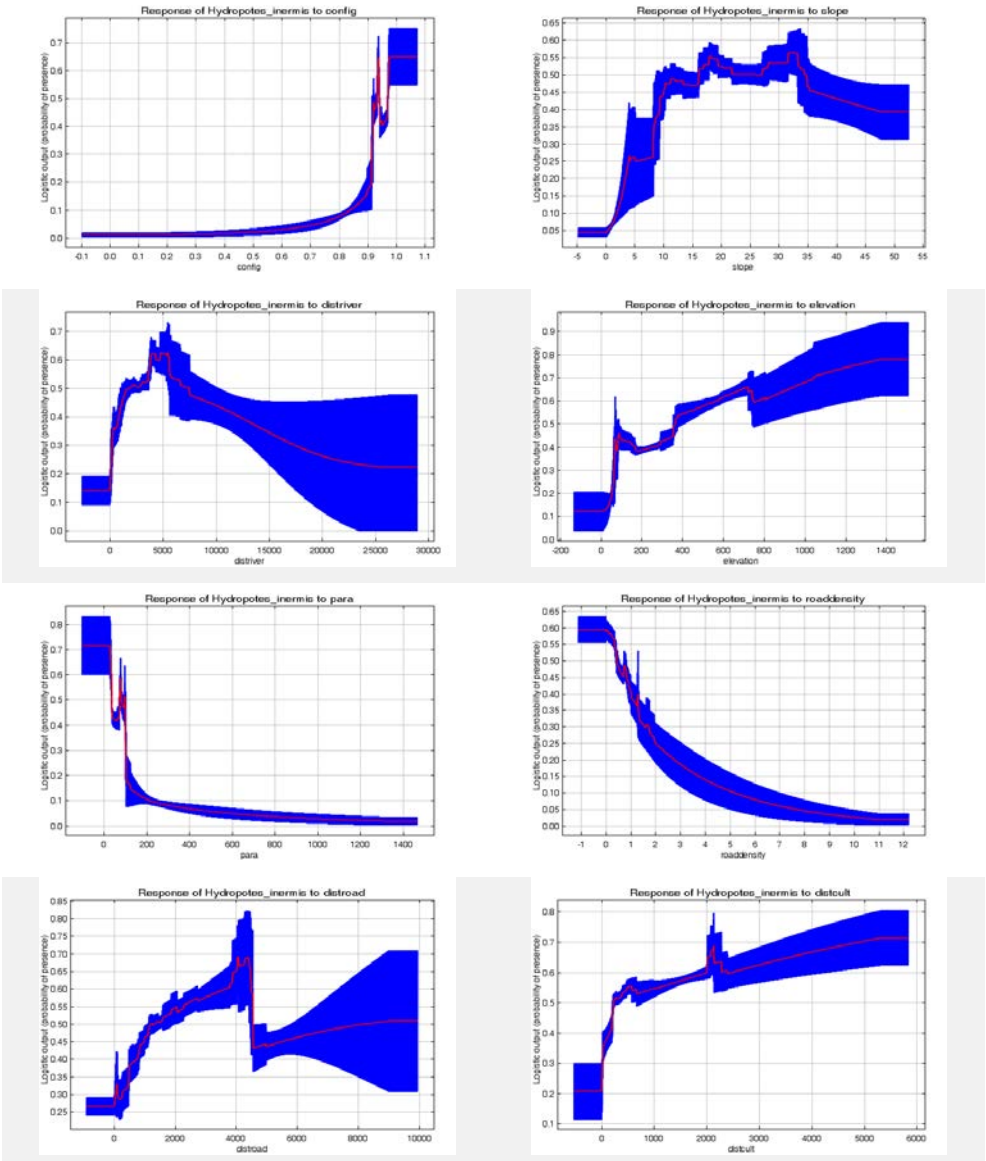
Gardner, T.A., Barlow, J., Chazdon, R., Ewers, R.M., Harvey, C.A., Peres, C.A., and Sodhi, N.S. (2009). Prospects for tropical forest biodiversity in a human-modified world. Ecol. Lett. *12*, 561–582.

Girardet, X., Foltête, J.-C., and Clauzel, C. (2013). Designing a graph-based approach to landscape ecological assessment of linear infrastructures. Environ. Impact Assess. Rev. *42*, 10–17.

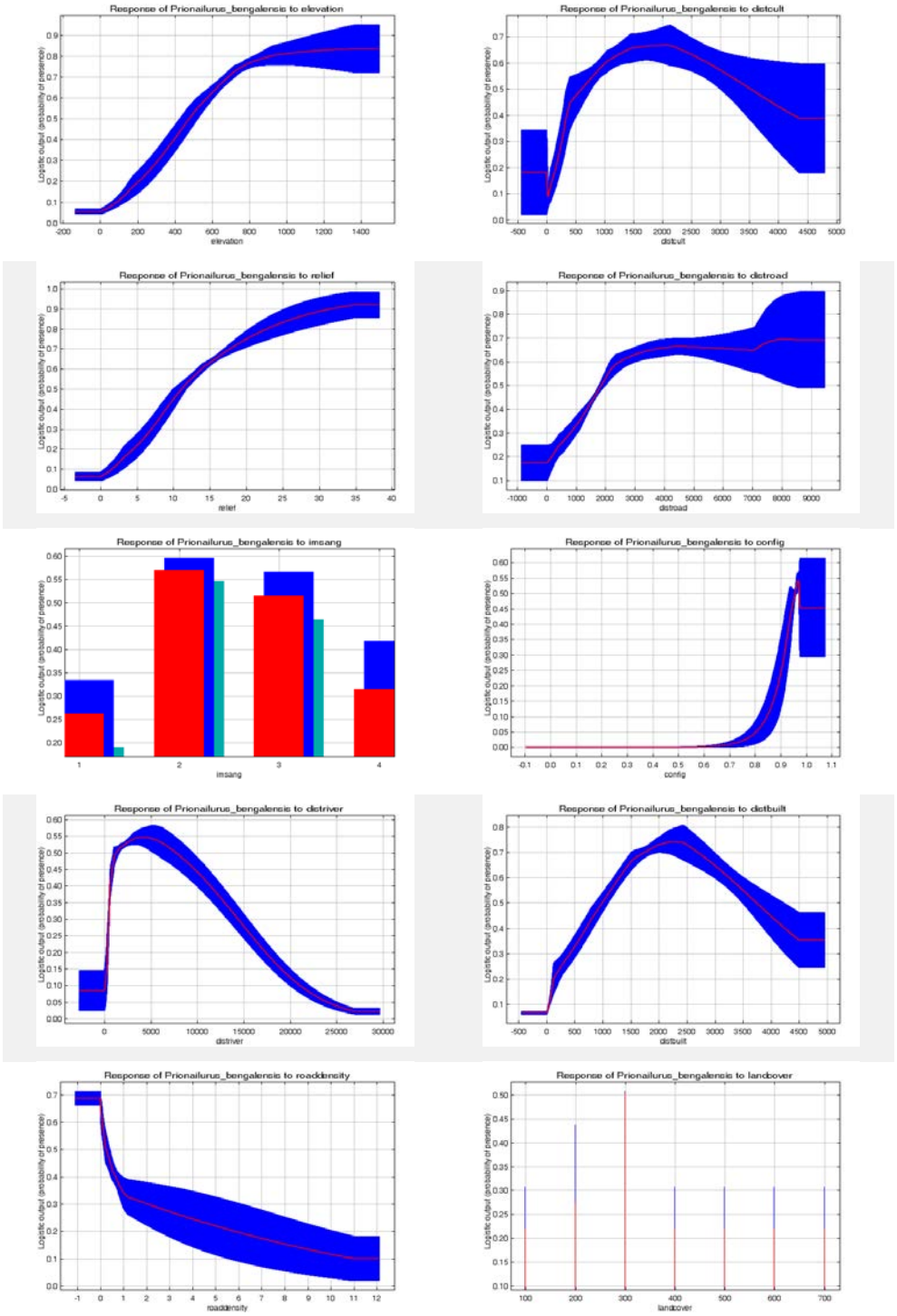
Gitay, H., Suárez, A., Watson, R.T., and Dokken, D.J. (2002). Climate change and biodiversity (Intergovernmental Panel on Climate Change Geneva,, Switzerland).
Hirzel, A.H., Le Lay, G., Helfer, V., Randin, C., and Guisan, A. (2006). Evaluating the ability of habitat suitability models to predict species presences. Ecol. Model. *199*, 142−152.
Houlahan, J.E., and Findlay, C.S. (2003). The effects of adjacent land use on wetland amphibian species richness and community composition. Can. J. Fish. Aquat. Sci. *60*, 1078−1094.
Jeschke, J.M., and Strayer, D.L. (2008). Usefulness of bioclimatic models for studying climate change and invasive species. Ann. N. Y. Acad. Sci. *1134*, 1−24.
Kang, H., Kim, J.-Y., and Park, K. (2005). Habitat Connectivity between Soraksan and Odaesan National Parks with a Consideration of Wildlife Home Range. Korean J. Environ. Eology *19*, 150−161.
Kim, W. (2009). Study on the optimal management for sustainable use of Korean water deer population (National Institute of Environmental Research).
Kim, C.-H., Kang, J.-H., and Kim, M. (2013). Status and Development of National Ecosystem Survey in Korea. J. Environ. Impact Assess. *22*, 725−738.
Kim, J., Seo, C., Kwon, H., Ryu, J., and Kim, M. (2012). A Study on the Species Distribution Modeling using National Ecosystem Survey Data. J. Environ. Impact Assess. *21*, 593−607.
Kim, J., Kwon, H., Seo, C., and Kim, M. (2014). A nationwide analysis of mammalian biodiversity hotspots in South Korea. J. Environ. Impact Assess. *23*, 453−465.
Koo, M., and Lee, D.-K. (2012). A Study on the National and International Research Trend of Biodiversity Assessment method and Its Application of Environmental Impact Assessment. J. Environ. Impact Assess. *21*, 119−132.
Kwon, Y.H. (2006). The Introduction of the Biodiversity Item in Environmental Assessment (Seoul: Korea Environment Institute).
Kwon, H.S., Seo, C.W., and Park, C.H. (2012). Development of Species Distribution Models and Evaluation of Species Richness in Jirisan region. J. Korean Soc. Geospatial Inf. Syst. *20*, 11−18.
Lee, D.-K., and Song, W.-K. (2008). A Study on the Analytic Unit of Habitat Suitability Assessment and Selection in Conservation Areas for Leopard Cat (Prionailurus bengalensis)-Focus on Chungcheong Province Area. J. Korean Inst. Landsc. Archit. *36*, 64−72.
Lee, D., Baek, G., Park, C., and Kim, H. (2011). Spatial Planning of Climate Adaptation Zone to Promote Climate Change Adaptation for Endangered Species. J. Korea Soc. Environ. Restor. Technol. *14*, 111−117.
Luque S, D.P. (2013). Landscape Structure Indicators as a Key Feature in Habitat Selection: an Operational Approach to Conservation Planning. J. Biodivers. Endanger. Species *01*.
Mapelli, F.J., and Kittlein, M.J. (2009). Influence of patch and landscape

characteristics on the distribution of the subterranean rodent Ctenomys porteousi. Landsc. Ecol. *24*, 723−733.
McGarigal, K., Cushman, S.A., and Ene, E. (2012). FRAGSTATS v4: spatial pattern analysis program for categorical and continuous maps. University of Massachusetts, Amherst. Comput. Softw. Program Prod. Authors Uni-Versity Mass.
Lo Papa, G., Palermo, V., and Dazzi, C. (2011). Is land-use change a cause of loss of pedodiversity? The case of the Mazzarrone study area, Sicily. Geomorphology *135*, 332−342.
Park, H.M., and Lee, S.D. (2013). Habitat use pattern of Korean Waterdeer based on the land coverage map. J. Wetl. Res. *15*, 567−572.
Phillips, S.J., and Dudík, M. (2008). Modeling of species distributions with Maxent: new extensions and a comprehensive evaluation. Ecography *31*, 161−175.
Phillips, S.J., Anderson, R.P., and Schapire, R.E. (2006). Maximum entropy modeling of species geographic distributions. Ecol. Model. *190*, 231−259.
Seo, C.-W., Park, Y.-R., and Choi, Y.-S. (2008). Comparison of Species Distribution Models According to Location Data. J. Korean Soc. Geospatial Inf. Syst. *16*, 59−64.
Song, W., and Kim, E. (2012). A Comparison of Machine Learning Species Distribution Methods for Habitat Analysis of the Korea Water Deer (Hydropotes inermis argyropus). Korean J. Remote Sens. *28*.
Townsend Peterson, A., Papeş, M., and Eaton, M. (2007). Transferability and model evaluation in ecological niche modeling: a comparison of GARP and Maxent. Ecography *30*, 550−560.
Trisurat, Y., and Duengkae, P. (2011). Consequences of land use change on bird distribution at Sakaerat Environmental Research Station. J. Ecol. Field Biol. *34*, 203−214.
Vasas, V., Magura, T., Jordán, F., and Tóthmérész, B. (2009). Graph theory in action: evaluating planned highway tracks based on connectivity measures. Landsc. Ecol. *24*, 581−586.
Wisz, M.S., Hijmans, R.J., Li, J., Peterson, A.T., Graham, C.H., and Guisan, A. (2008). Effects of sample size on the performance of species distribution models. Divers. Distrib. *14*, 763−773.

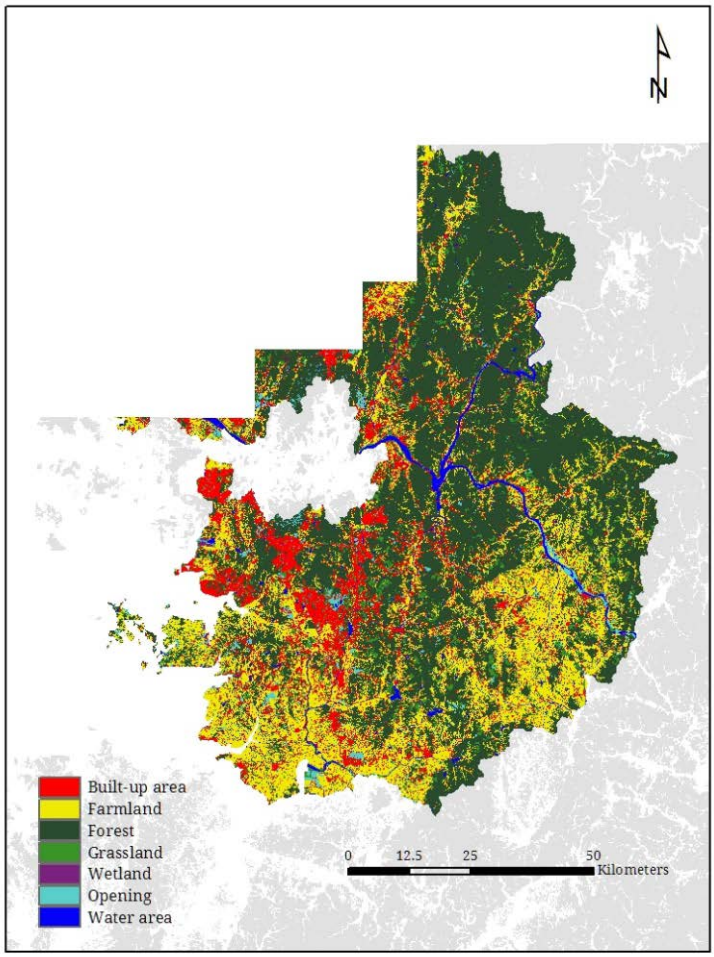
Appendix



Appendix Figure 1 Response curve for *Hydropotes inermis*



Appendix Figure 2 Response curve for *Prionailurus bengalensis*



Appendix Figure 3 Land Cover Map

국문초록

인간 활동은 산림과 산림 생태계에 부정적인 영향을 미치는 원인들 가운데 하나이다. 산림에서 이루어지는 개발 활동은 특히 산림의 서식지 기능에 영향을 미치며 생물다양성의 감소를 초래한다. 생물다양성의 유지와 증진을 위해 생물의 서식지를 보존해야 한다. 그러나 우리나라의 경우 개발 활동에 의한 서식지의 영향이 충분히 고려되지 못하고 있다. 생물다양성에 관한 개발 사업의 영향을 예측하고, 지속적인 발전을 충족시킬 수 있는 영향 예측 과정을 확립할 필요가 있다. 종 분포 모형은 기존의 출현 자료와 서식 환경 변수에 따라 생물의 잠재적인 분포를 예측한다. 개발 사업은 환경 변수를 변화시키며, 종 분포의 예측을 통하여 효과적으로 서식지의 변화를 예측할 수 있다. 본 연구의 목적은 생물종의 잠재적인 분포와 서식지 변화를 정량화하고 이를 통하여 개발 사업에 따른 서식지의 영향을 반영하는 변수를 식별하는 것이다.

생태계의 핵심종인 포유류 중에서도 국내의 서식 환경에 대해 광범위한 연구가 이루어진 고라니와 삵을 연구의 대상 종으로 선정하였다. 종의 위치 자료는 전국자연환경조사의 분포 자료를 활용하였다. 전국 시도 가운데 산림 전용 면적이 가장 넓은 경기 지역을 대상으로 환경 변수들이 구축되었다. 구축된 환경 변수에는 고도, 경사도, 지형기복, 북사면율, 곡률, 토지피복, 임상, 영급, 도로밀도 및 거리 변수들, 패치

면적, 면적 대 둘레 비율, 인접성 및 최인접거리 등이 포함된다. 2008년부터 2012년까지 시행된 개발 사업지를 선택하였다. 종 분포 모형 가운데 작은 샘플 크기에서도 높은 민감도를 가지고 국내 연구에서 높은 정확도를 나타낸 MaxEnt 모형을 사용하였다. 설명 변수는 상관성과 독립성을 고려하여 선택되었다. 개발 전후의 서식지 예측 모형을 통해 구축한 두 지도를 계산하여 잠재적인 서식지 적합성의 변화를 추정하였다.

연구 결과, 일반종인 고라니에 비하여 서식지 단편화의 영향을 크게 받는 삵의 서식지 적합성 변화가 더 높게 나타났다. 또한 상대적으로 기존의 패치 면적이 컸던 곳이 새로운 개발 사업의 영향을 크게 받는 것으로 추정되어다. 또한 본 연구에서 분석한 환경 변수 중 '도로에서의 거리' 변수가 서식지 적합성 변화에 큰 영향을 미친다는 것을 관찰하였다.

따라서 개발 사업의 입지를 결정하는 과정에서 서식지의 속성을 고려함으로써 개발 사업에 따른 서식지의 영향을 예측할 수 있다. 그러나 본 연구에서는 대상종이 일부 포유류에 한정되어 있고, 개발 사업의 특성을 반영하지 못하였으므로 추가적인 연구가 필요하다. 하지만 개발 사업을 시작하기 전에 개발 활동의 환경 영향을 예측하기 위한 모형의 가능성을 확인하였다는 점에서 의의가 있다.