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Use of GIS to Develop a Multivariate Habitat Model for the Leopard Cat (*Prionailurus bengalensis*) in Mountainous Region of Korea

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ABSTRACT: A habitat model was developed to delineate potential habitat of the leopard cat (*Prionailurus bengalensis*) in a mountainous region of Kangwon Province, Korea. Between 1997 and 2005, 224 leopard cat presence sites were recorded in the province in the Nationwide Survey on Natural Environments. Fifty percent of the sites were used to develop a habitat model, and the remaining sites were used to test the model. Fourteen environmental variables related to topographic features, water resources, vegetation and human disturbance were quantified for 112 of the leopard cat presence sites and an equal number of randomly selected sites. Statistical analyses (e.g., t-tests, and Pearson correlation analysis) showed that elevation, ridges, plains, % water cover, distance to water source, vegetated area, deciduous forest, coniferous forest, and distance to paved road differed significantly ($P < 0.01$) between presence and random sites. Stepwise logistic regression was used to develop a habitat model. Landform type (e.g., ridges vs. plains) is the major topographic factor affecting leopard cat presence. The species also appears to prefer deciduous forests and areas far from paved roads. The habitat map derived from the model correctly classified 93.75% of data from an independent sample of leopard cat presence sites, and the map at a regional scale showed that the cat's habitats are highly fragmented. Protection and restoration of connectivity of critical habitats should be implemented to preserve the leopard cat in mountainous regions of Korea.

Key words: Kangwon province, leopard cat, logistic regression, multivariate habitat model, potential habitat map, *Prionailurus bengalensis*

INTRODUCTION

Increasing numbers of wildlife species, especially predators, are threatened with local extinction in mountainous regions of Korea. To protect wildlife species and habitats in mountainous regions, the Korean government has taken a variety of protective measures such as anti-poaching patrols, wildfire control, and the designation of protected areas. Central to such measures is knowledge of the species, its habitat quality and spatial distribution (Gibson et al. 2004). Species-habitat models might be the best approach to organizing species-level data for making wildlife protection decisions (Brennan et al. 1986, Pereira and Itami 1991). Since the late 1980s, habitat models have been developed for game birds and endangered species in mountainous regions (e.g., Mt. Sorak) (Choi 2002, Joo 2002, Rho et al. 2005).

Among predators, the leopard cat (*Prionailurus bengalensis*) may be the top predator in mountainous regions of Korea, but no habitat model has been developed at the regional level (Rho et al. 2005, Lee and Song 2008). The species is designed as an Endangered Species Type II in the Wildlife Conservation Act of Korea. Habitat loss and fragmentation are considered to be essential factors threatening leopard cat populations in mountainous regions. To protect viable populations and critical habitats of leopard cats, it is necessary to identify suitable areas and to determine the extent of habitat fragmentation.

Habitat management decisions should be informed by scientific methods that quantify the relationships between environmental factors and species occurrence. In this study, I used empirical habitat models to identify such relationships. Given appropriate habitat models and environmental data, GIS can be used to estimate habitat suitability (i.e., the probability of a site being used by leopard cat) quickly and cost-effectively (Donovan et al. 1987, Pereira and Itami 1991, Watanabe et al. 2003). In this study, I aim to enhance knowledge about the habitat requirements of leopard cats and to develop a GIS-based

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Table 1. Habitat variables used to develop the leopard cat habitat model in Korea, 1997-2005. Habitat characteristics were determined using GIS technology

Habitat components	Habitat variables	Abbreviation	Literature cited	Data sources
Topographic features	Elevation	ELEV	Lee 2008	Korea DEM data
	Slope	SLOPE	Watanabe et al. 2003	Korea DEM data
	South aspect	S_ASP	Lee 2008	Korea DEM data
	Landform (Ridges)	RIDGES		Korea DEM data
	Landform (Plains)	PLAINS	-	Korea DEM data
Water accessibility	% water cover	STR_DEN	-	Topographic map
	Distance to water source	D_WTR	Watanabe et al. 2003	Topographic map
Vegetation structures	% vegetated area	VGT_PCT	Lee and Song 2008	Actual vegetation map
	Distance to ecotone	EDGE	-	Actual vegetation map
	% deciduous forest	OAK_FRST	Lee and Song 2008	Land-use/land-cover data
	% coniferous forest	PINE_FRST	Rabinowitz 1990	Land-use/land-cover data
	% mixed forest	MIXD_FRST	Rabinowitz 1990	Land-use/land-cover data
Human disturbances	Distance to paved roads	D_RD	Kang et al. 2005	Korea transportation D/B
	Human population density	HPOP_DEN	Lee and Song 2008	Population Census data

empirical model for the distribution of leopard cats in mountainous regions of Korea, and to validate the model using independent data. The results can be used to develop broad-scale habitat models to protect wildlife species and critical habitat at a regional level by identifying suitable habitat and determining the extent and nature of habitat fragmentation in mountainous regions in Korea.

MATERIALS AND METHODS

Leopard cat data

Over the 10-year period from 1997 through 2006, field experts from the National Institute of Environmental Research, universities, and research institutes have been conducting survey to acquire species occurrence and spatial distribution data for wildlife species via direct observation, surveys of local people, and field signs such as tracks, feces, and footprints. Species occurrence data were collected in Kangwon Province, a mostly wooded area in Korea, and incorporated as point shapefiles into an ArcView GIS database, including attributes such as the number of observers, and the date of the observation. Half of the data obtained were used to develop a habitat model for the distribution of the leopard cat in mountainous regions of the province, and the other half of the data were used to test the model.

Habitat variables and environmental data

Spatially explicit variables were created to represent habitat characteristics of the leopard cat. Data reflecting these habitat characteristics, including topographic features, vegetation structure and spatial arrangements, water resources, and human disturbance, were derived from previous research and expert opinions. Habitat variables were generated from GIS layers for the study area. Habitat composition was analyzed from land-use/land-cover (LULC), actual vegetation maps, Digital Elevation Models (DEM), topographic maps, transportation databases, and human population census data. After acquiring all the environmental data, thematic maps were re-sampled to a 100-m pixel resolution using the nearest neighboring algorithm.

I then constructed GIS layers for LULC, vegetation, road, stream, and elevation. The LULC data were classified as deciduous forest, coniferous forest, or mixed forest. Reservoirs and stream layers were digitized from topographic maps managed by the National Geographic Information Institute, and DEM was used to calculate elevation, aspect, and degree of slope. To obtain landform categories including ridges, valleys, and high plains, I used the Topographic Position Index Extension for ArcView 3.x (Jenness 2005). The road density (length of ≥2-lane paved road per unit area) was calculated from the National Transportation database, and human population for each county was derived from Population Census data (Table 1).

Habitat model development

My habitat model for the leopard cat incorporated fourteen environmental variables grouped into four categories: topographic features, water accessibility, vegetation patterns and spatial arrangements, and human disturbance. Topographic features such as aspect, altitude, and slope are considered to be major factors affecting the habitat preferences of the species (Lee 2008). Water is a critical element for wildlife and their habitats, and the distance to water is an important factor for evaluating the suitability of habitat for leopard cats. For example, in Thailand, 61% of known leopard cat resting sites are ≤300 m from water sources (Rabinowitz 1990). Leopard cats prefer areas with easy access to different resources, and are usually found in proximity to ecotones between forests and other habitat types (Santiapillai and Supraham 1985, Rabinowitz 1990), so vegetation structure and spatial arrangements should also be included in the model. Leopard cats prefer resting and moving on the ground, utilizing deciduous forest less than evergreen or mixed deciduous forest (Rabinowitz 1990). Human and their artifacts are an integral part of many wildlife habitats and it is essential to understand how their impacts change the quality of wildlife habitat. For example, road construction and high human population densities are thought to be major factors negatively affecting wildlife habitats in Korea (Rho et al. 2005, Lee 2008).

Environmental variables were measured at sites where the presence of the leopard cat was recorded and at an equal number of randomly chosen sites. Since the Nationwide Survey on Natural Environments does not provide information about the complete survey routes, presence/random comparisons are more useful for identification of species-habitat relationships than presence/absence comparisons.

Statistically significant and ecologically meaningful variables should be selected in model development (Johnson 1981, Rexstad et al. 1990). Habitat variables were passed through three filters before the variables were entered into the model. The first filter determined the significance ($P < 0.01$; using an independent-samples t-test) of individual variables by comparing values between leopard recorded sites and randomly chosen sites. A conservative alpha level ($P < 0.01$) was selected to reduce the number of variables used in the model. To further reduce the variables, I filtered the remaining variables by conducting correlation analysis among the remaining continuous variables and removing correlated variables. If variables were statistically correlated, the least significant variable was omitted in the stepwise logistic regression model (Brennan et al. 1986).

Stepwise logistic regression was used as the final filter and statistical tool to develop the habitat model. The stepwise selection procedures permitted variable inclusion or exclusion based on a variable's relative contribution when additional variables exist in the model. Present/random served as the binary response variable in model. The estimated probability of observing leopard cats in a given habitat was treated as a habitat suitability index for leopard cats. The potential probability of observing leopard cats was calculated using the following equation:

$$\log\left(\frac{P_x}{1-P_x}\right) = \beta_0 + \sum_{i=1}^{n} \beta_i X_i \qquad (1)$$

where, P_x = the probability of a leopard cat using a vector of habitat variable (x)

β = logistic regression coefficient

X = habitat variable

Habitat model validation

The multivariate habitat model was validated using an independent set of data that were not used in model development. I used half of the sites at which leopard cats had been recorded in Kangwon Province to develop the habitat model, and then used the remaining sites for model validation. A habitat type was designated as suitable for leopard cats if the estimated probability of a leopard cat using the site was ≥ 0.5. For the validation using independent data, potential habitat maps were superimposed on species occurrence data.

Habitat map for leopard cats

A potential habitat map for leopard cats was created by applying the parameters of the logistic regression equation from the habitat model to each relevant thematic map. This map predicts the expected probability of occurrence of leopard cats (Osborne et al. 2001, Joy and Death 2004). Such a spatially explicit prediction is restricted to parameters that are available in the study area. In this study, potential habitat map was delineated in Kangwon Province on a regional scale.

RESULTS

Species occurrence

The Nationwide Survey on Natural Environments, conducted by 12 field experts, recorded the presence of leopard cats at 224 locations in Kangwon Province from 1997 through 2005. Among the occurrence data, 112 of the data points were used for model development, and the other 112 data were used for model evaluation.

Habitat variables

To identify habitat characteristics of the sites where the species was observed, I generated a set of 112 random points in Kangwon Province using the Random Point Generator ArcView Extension, for comparisons of habitat variables between presence and random sites. Descriptive statistics were calculated and comparative analyses were conducted for all variables (Table 2). From the t-test

Table 2. Descriptive statistics for habitat variables associated with sites used by leopard cats and at random locations in Kangwon, Korea, 1997-2005.

Habitat variables	Description	Unit	Statistics (mean ± s.e) of presence sites	Statistics (mean ± s.e) of random sites	*P-value*
ELEV	Elevation	m	768.40 ± 31.11	288.92 ± 27.30	0.000
SLOPE	Degree of slope	%	23.19 ± 0.96	21.27 ± 1.00	0.168
S_ASP	% south aspect	%	36.81 ± 1.46	35.63 ± 1.56	0.584
RIDGES	% ridges landform	%	25.76 ± 1.44	17.64 ± 1.38	0.000
PLAINS	% plains landform	%	1.88 ± 0.64	11.65 ± 1.90	0.000
STR_DEN	% water cover	%	0.74 ± 0.18	2.06 ± 0.29	0.000
D_WTR	Distance to water source	m	359.75 ± 23.75	233.43 ± 17.72	0.000
VGT_PCT	% vegetated area	%	72.31 ± 3.20	43.21 ± 3.40	0.000
EDGE	Distance to ecotone	m	648.68 ± 69.90	560.85 ± 100.87	0.476
DEC_FRST	% deciduous forest	%	50.25 ± 3.25	25.59 ± 3.33	0.000
CON_FRST	% coniferous forest	%	20.99 ± 2.48	38.14 ± 2.81	0.000
MXD_FRST	% mixed forest	%	23.25 ± 2.22	16.62 ± 2.19	0.035
D_RD	Distance to paved road	m	2,445.05 ± 131.07	1,419.53 ± 162.07	0.000
HPOP_DEN	Human population density	per/㎢	111.51 ± 13.46	94.73 ± 10.01	0.315

analysis of topographic features, elevation, ridges and plains were significantly different between leopard cat presence sites and random sites, while slope and direction did not significantly differ between presence and random sites. In Kangwon province, the average elevation was 768 m for presence sites and 288 m for random sites. More leopard cats are recorded near ridges than on plains. The area in adjacent to rides is higher in the percentage of the leopard cat presence sites than random sites. However, the slope and percentage of south-facing aspect did not differ between presence and random sites.

For the percentage of water cover, there was a statistical difference between leopard cat presence site and random site. Both the percentage of water cover for the area and the distance to water sources significantly differed between presence sites and random sites. Generally, leopard cats were observed within 359 m of water sources and in areas with 0.74% of water cover for the area, whereas random sites averaged 233 m from water sources and had 2.06% of water cover for the area.

Percentages of vegetated area, deciduous forest and coniferous forest significantly differed between leopard cat presence sites and random sites. The percentage of vegetated area was 72.31% in presence sites and 43.21% in random sites. Leopard cats were more frequently observed in deciduous forest than coniferous forest: the percentage of deciduous forest was 50.25% in leopard cat presence sites, and 25.59% in random sites, while the percentage of coniferous forest was 20.99% in presence sites, and 38.14% in random sites.

The distance to paved roads was significantly different between presence sites (2,445 m) and random sites (1,419 m). However, human population density did not statistically differ between leopard cat presence and random sites. Therefore, a total of nine variables are selected as statistically significant in model development and used in further analyses: ELEV, RIDGES, PLAINS, STR_DEN, D_WTR, VGT_PCT, DEC_FRST, CON_FRST, D_RD.

Logistic regression analysis

Before developing the multivariate habitat model for leopard cats, I examined correlations among habitat variables using 112 leopard cat presence sites and an equal number of random locations. ELEV, VGT_PCT, DEC_FRST and CON_FRST are highly correlated with each other. The Pearson correlations for DEC_FRST are 0.623 (with ELEV), 0.498 (with VGT_PCT), and -0.681 (with CON_FRST). Seven variables including RIDGES, PLAINS, D_WTR, D_RD were used as independent variable in logistic regression analysis. Selection of ecologically meaningful variables is another challenge in the development of habitat models. Water resources are believed to be fundamental resources for the survival of wildlife species (Lee 2008, Rabinowitz 1990), but in Kangwon Province, water resources are not a limiting factor because the maximum distance to water resources is 2,148 m, which is below the daily travel distance of the species. As previous studies have shown (Rabinowitz 1990, Kang et al. 2005, Lee 2008), topographic features, vegetation, and human disturbance are the most important factors affecting habitat suitability for the leopard cat. In this study, the stepwise logistic regression showed that RIDGES, PLAINS, DEC_FRST, CON_FRST and D_RD affected habitat suitability and suggested the following habitat model for leopard cats:

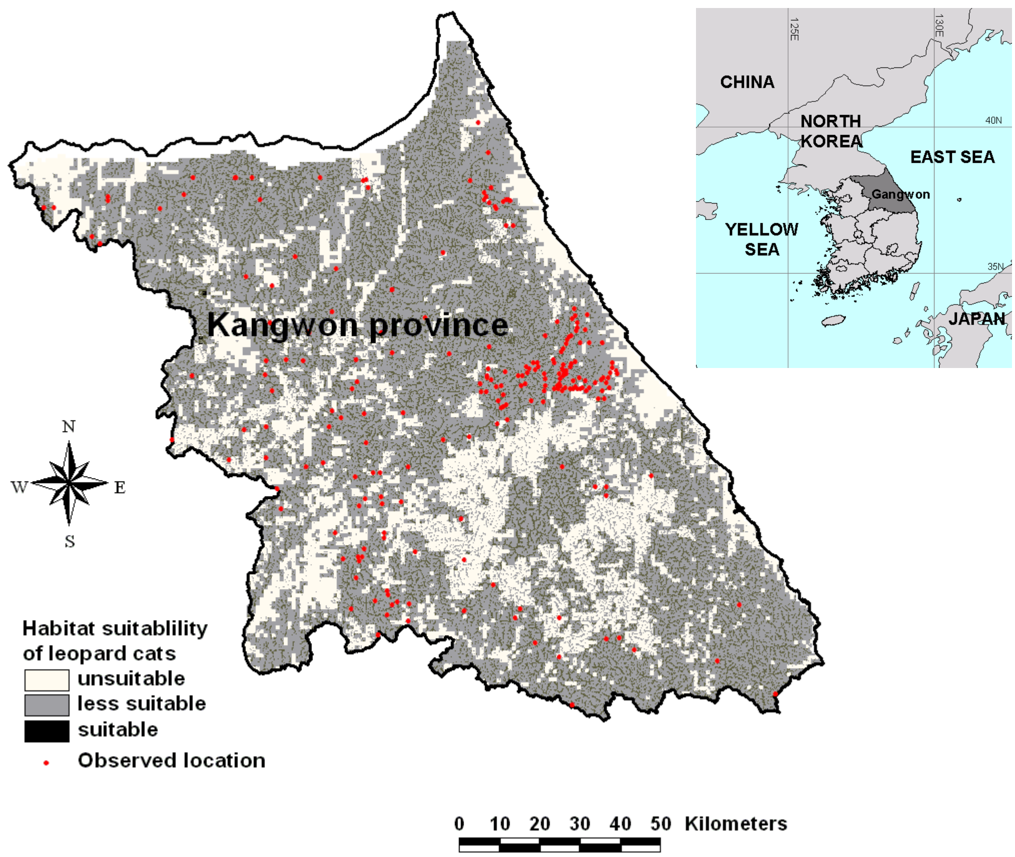

Fig. 1. Potential habitat map of the leopard cat in Kangwon province of Korea delineated using GIS and a habitat model. Grid cells having a <0.2 suitability value were designated as 'unsuitable habitat,' cells with values of 0.2-0.5 habitat suitability were designated as 'less suitable habitat,' and cells with values ≥ 0.5 were designated as 'suitable habitat'. The red circles represent actual observations of the species from 1997-2005.

$$Y = 0.093RIDGES - 0.175PLAINS + 0.096DEC\_FRST - 0.167CON\_FRST + 0.175D\_RD - 0.160 \quad (2)$$

The coefficients of RIDGES, DEC_FRST, and D_RD have positive values, indicating that leopard cats are likely to be observed in areas near ridges, in or near deciduous forest, and far away from paved roads. Conversely, the probability of leopard cat presence decreased as the proportion of plains and coniferous forest increased. The result of the regression shows that leopard cat habitat selection was influenced by topographic features, vegetation, and human disturbance.

Potential habitat map

Based on the logistic regression, I delineated a potential habitat map for leopard cats and overlay it with species occurrence data (Fig. 1). The darker areas have a higher probability of habitat suitability than the lighter areas. Cutoff values to distinguish 'suitable,' 'less suitable,' and 'unsuitable' habitats were derived from the probability distribution function. In this study, the mean and standard deviation of habitat suitability derived from logistic regression were 0.34±0.14, suggesting 0.2 and 0.5 as appropriate cutoff values. The label 'unsuitable habitat' is assigned to sites where the probability of leopard cat presence is 0.0-0.2, 'less suitable habitat' is assigned to sites where the probability is 0.2-0.5, and 'suitable habitat' is assigned to sites with values of 0.5-1.0. Approximately 965,177 hectares (59.08%) of the area was classified as 'less suitable habitat' and only 252,798 hectare (15.40%) was classified as suitable habitat. The area of suitable habitat was also severely fragmented.

Model evaluation

To evaluate the habitat model, I calculated the predicted probability of leopard cat presence at 112 leopard cat presence sites that had not been used in model development. The habitat suitability values for leopard cat presence sites averaged 0.43, which is much higher than the mean value of 0.34 in the entire province. This indicated that the habitat model identified suitable habitat of the species well. In my evaluation of the habitat model, 105 of 112 sites not used in model development were classified as suitable habitat from the model, suggesting that the habitat model has good predictive value.

DISCUSSION

Topographic features, vegetation characteristics, and intensity of human disturbance had more significant effects on leopard cat habitat preferences than water accessibility. The habitat model selected topographic features such as elevation, ridges, and plains in mountainous region as significant factors affecting the suitability of habitat for leopard cats. In particular, areas with many ridges are favored by the leopard cat. Other studies have also found that high ridges are frequently used by leopard cats during both day and night for catching prey (Kang et al. 2005). Rajaratnam et al. (2007) reported that visibility and ease of movement are important for leopard cats and may increase their hunting success. In Korea, leopard cats prefer to use ridges in mountainous areas for catching prey. Open forests with a dense cover of shrubby plants near high ridges are good places to search for and capture prey due to their surface visibility and ease of passage. Thus, areas near ridges are assumed to be suitable habitat for leopard cats.

The major threats to wildlife in Korea are human-wildlife conflict and scarcity of food resources. Leopard cats usually roam in interior forests such as mountain tops and high ridges, away from the human-populated and roadside areas at low altitude. In this study, the distance to paved road was significantly different between presence sites and random sites. Watanabe et al. (2003) reported that the dependence of feral cats on humans and the expansion of their distribution into the habitats of wild cats may increase competition for prey in Iriomote Island. As in Japan, feral cats have expanded their range in Korea and their population density increases near human-populated areas; therefore, it may be difficult for leopard cats to find prey near populated places and roadsides dominated by feral cats. However, human population density was not statistically different between presence and random sites in this study, which may be due to the fact that the human population density data were only analyzed at the county level. Human population density for each block in the study area should be analyzed to further explore the effects of human population density on leopard cat occurrence.

The comparative analysis showed that deciduous forest is habitat for leopard cats than coniferous forest, which is probably related to the feeding habits of the species. The diet of leopard cats consists of small rodents, birds, hares, lizards, and snakes (Rabinowitz 1990). Temperate deciduous forests are considered to be important habitats for many wildlife species as they provide several high-quality food resources (e.g., acorns, nuts, seeds and berries). Rhim et al. (2003) identified deciduous forest as the primary habitats for small rodents in Korea, which suggests that the preference of leopard cats for deciduous forests may be related favorable hunting conditions in these forests. Kang et al. (2005) also reported that leopard cats prefer deciduous forests over mixed or conifer forests in Korea due to the highest species richness and diversity in deciduous forests, which generate more food and cover resources for leopard cats than other habitat types.

My potential habitat map for leopard cats is based on a GIS-based habitat suitability model, a method which is useful for elusive carnivores such as leopard cats. As dense vegetation and the rugged landscape in Kangwon Province makes direct observation of the species very difficult, field survey-based habitat models are difficult to develop. Therefore, expert knowledge and GIS-based habitat models are alternative approaches for leopard cats, but these models should be evaluated with field data. My potential habitat map can serve an important role in helping decision-makers to identify areas important to wildlife that should be given high conservation priority, and to assess impacts of potential land development projects on the area.

Habitat models based on GIS data and satellite imagery can enhance the accuracy and efficiency of field data collection. Using potential habitat maps, field surveys might be effectively designed to focus on appropriate field sites containing suitable habitat, which is especially important when attempting to find elusive, solitary predators such as leopard cats. In this study, five habitat variables related to topography, vegetation, and human disturbance emerged as essential factors affecting my landscape-level habitat model for leopard cats. The potential habitat map shows the area of the region divided into cells that are scored by assigning a grade indicating the estimated habitat suitability, from the least suitable to the most suitable. Most of the area in the province was unsuitable or less suitable habitat for the leopard cat. Relatively small areas were classified as suitable habitat, and these areas were highly fragmented even in the most mountainous regions. An ecological and habitat network should be established to maintain a minimum viable population of leopard cats in Korea (Kang et al. 2005).

GIS-based approaches to the development of habitat suitability models are currently limited by insufficient knowledge about wildlife-habitat relationships. The empirical model used in this study suggested that topography, vegetation, and human disturbance affect habitat quality for the leopard cat. In particular, landform type, forest type, and distance to paved roads are important factors affecting habitat quality for the leopard cat. Further fine-scale studies about the associations between physical variables and habitat quality should be conducted to develop a more effective habitat model.

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