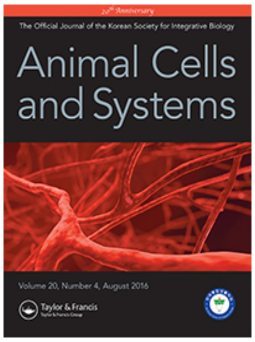

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Developing and testing a habitat suitability index model for Korean water deer (*Hydropotes inermis argyropus*) and its potential for landscape management decisions in Korea

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ECOLOGY, POPULATION BIOLOGY & ANIMAL BEHAVIOR

ABSTRACT

Geographic information system (GIS) and landscape-level data offer a new opportunity for modeling and evaluating the quality of wildlife habitats. Models of habitat quality have not been developed for some species, and existing models could be improved by incorporating updated information on wildlife–habitat relationships and habitat variables. We developed a GIS-based habitat suitability index (HSI) model for the Korean water deer (*Hydropotes inermis argyropus*), which often causes human–wildlife conflicts in the Chungnam Province of Korea because of industrialization and urbanization. The model is based on logistic regression analysis, which addresses the impact of multiple habitat variables, such as habitat components, topographic characteristics, and human disturbances. The model yielded a *p*-value of .289 ($\chi^2 = 9.672$) and 65.4% correct prediction level with the overall observation–prediction comparison data. The model demonstrated that a large portion of the province (61.6%) could be regarded as a poor habitat (mean HSI value of the province = 0.22), while the current habitats of the province could be considered of moderate quality (mean HSI value = 0.31). In addition, the chance of observation of the deer increases as the HSI level increases, which means that the model yields a good predictive power. Lastly, we used the model to produce a habitat suitability map. Our HSI model enabled us to quantify habitat preferences, which could be the basis for decision-making on habitat protection, mitigation, and enhancement of the Korean water deer. The proposed model is also applicable for improving and enhancing the existing management practices, as well as for establishing an effective wildlife protection policy.

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Introduction

Damage by wildlife to field crops is a widespread concern across South Korea, and the assessment and control of this damage to agricultural produce have become important components of wildlife management. Losses caused by wildlife to agriculture have been reported particularly with respect to small grains, corn, vegetables, tree fruits, forest regeneration, and landscape planting. According to nationwide surveys conducted between 2005 and 2009, wildlife-related economic losses in the agriculture industry in South Korea exceed 99.5 million dollars (Cho 2010). Wild boar (*Sus scrofa*), Korean water deer (*Hydropotes inermis argyropus*), and Korean magpie (*Pica pica*) are often considered to be the most common wildlife species that routinely damage agricultural crops (Han et al. 2015). In particular, damage by deer to farm produce creates a serious and potentially confrontational situation between the agricultural community and environmental organizations.

The water deer (*Hydropotes inermis*) is evidently an 'edge' species, and it prefers habitats characterized by shrubs and small trees. It is also found in lowland habitats, specifically along river shores, streams, and coastal areas with reeds and tall grasses, as well as in paddy areas, grasslands on hills, and areas near lakes (Rhim & Lee 2007). The deer is relatively small, ranging in length from 775 to 1000 mm. Both males and females do not have antlers. The males have long upper tusks, which can reach up to 5 cm in length. The adults are relatively small (9–14 kg) and have restricted home ranges (10–25 ha). The water deer is mainly solitary, although stable pairs and even small groups are sometimes observed. The populations have the capacity to increase quickly, as adult females begin to reproduce within the first year and

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can produce 2−5 fawns per litter (Cooke & Farrell 1983; Zhang et al. 2006).

There are two distinct subspecies of the water deer in East Asia: one in China (*Hydropotes inermis inermis*) and the other in Korea (*H. i. argyropus*). The Chinese water deer is on the IUCN Red List, and it is classified as 'Vulnerable' on a world scale; thus, its population density has become a critical issue from the perspective of conservation (IUCN 2001). A similar threat exists for the Korean water deer in certain regions of Korea because of a serious decline in the population due to poaching and habitat destruction (Woo et al. 1990). However, the number of Korean water deer has slightly increased from 1982 to 2011, in part because of reforestation programs, absence of predators, and prohibition of hunting (Kang et al. 2016). The population density of Korean water deer per 100 ha is 7.8, and it varies from 3.7 to 11 (Han et al. 2015). The Korean water deer population has particularly flourished in the modern agricultural landscape, where fragmented mosaic of wood-lots, hedgerows, and cultivated crops seem to be particularly favorable (Kim et al. 2011). Farmers have been appealing to the government for actions to reduce the deer population; however, the government has not yet responded in the light of wildlife conservation, highlighting the necessity for implementing an appropriate species management practice.

To prevent the crop damage caused by the Korean water deer, it is essential to understand its ecology, such as distribution, density, and habitat use. Above all, information on its patterns of habitat use is critical for developing effective management strategies, which would appeal to land managers because it facilitates the understanding of habitat preferences of the deer. The Korean water deer live in fields of tall reeds, rushes along a river, and fields of tall grasses on mountains and cultivated fields. They also inhabit swampy regions and open grasslands. They are adept at hiding, and any cover seems sufficient for shelter. When the cultivated fields that they occupy are cut, they may be found lying in the furrows and hollows of open fields (Brown 1991).

Across different ecoregions, the core components of a deer habitat are consistent: water, food, and cover (Fulbright & Alfonso 2006). Cover is defined as either thermal or hiding cover: two habitat components required by deer (Deperno et al. 2003). Thermal cover is the vegetation used by animals to lessen the effects of weather, particularly during winter and summer. Hiding cover is used for security while foraging and moving between areas, and it can provide animals with a sense of security when habitat quality is less than the optimum and vulnerability to harassment and weather is high. The deer favor forest habitats with over 90% canopy cover. The most frequently used bedding sites are located in the areas with high canopy cover, whereas feeding sites are often found in the areas with low canopy cover (0–25%) (Zhang et al. 2006).

The Korean water deer has a four-chambered stomach, but the rumen pillars are poorly developed; this prohibits the deer from efficiently digesting the carbohydrates from plant materials and therefore they select foods low in fiber but high in soluble carbohydrates, proteins, and fats. The Korean water deer is a highly selective feeder, particularly consuming herbs, forbs, and young sweet grasses rather than the coarser and more fibrous mature grasses. Locally, it may browse the tops of root crops in winter when other food sources are in short supply (Cooke & Farrell 1983; Nowak 1991). The Korean water deer drinks free water from ponds, creeks, rivers, springs, and seeps. Besides free water, it obtains water from the food it consumes, and it receives an annual average of 1577 mm of precipitation. The Korean water deer prefers to be within 1 km from open waters (streams, ponds, lakes, etc.), as it uses such areas for feeding and hiding at night (Brown 1991; Congalton et al. 1993; Zhang et al. 2006).

Land managers need to understand how a species will respond to a change in the habitat so that appropriate strategies can be implemented to maintain the species population. One approach that has been successful is the habitat suitability index (HSI) model, which describes large-scale habitat use patterns. HSI modeling is the process of formulating the suitability of a particular habitat on the basis of measurable habitat variables that affect the growth, survival, abundance, distribution, behavior, or other measures of well-being of animals (Brown et al. 2000; Clark et al. 2004). HSIs are generated through the application of wildlife–habitat relationships to relevant geospatial environmental data within a geographic information system (GIS) to develop a composite HSI score with a range of 0.0–1.0 (representing unsuitable to optimal habitat) (Roloff & Kernohan 1999). Using information such as the relevance of the selected habitat variables, availability of geospatial environmental data, and reliability of the applied wildlife–habitat relationships, the HSI model can serve as a robust spatial tool to assist species management via identifying the key habitat areas at a large spatial scale (Margules et al. 2002; Rouget et al. 2006). Although the development of technologies such as GIS and remote sensing has allowed scientists to analyze habitat patterns in detail (Li et al. 2000; Ortigosa et al. 2000; Kim et al. 2014), such indices generally require field data to create an effective model for a species. Many countries, including Korea, have been trying to develop an effective and widespread wildlife census; however, the challenge is to create HSIs with the field data, which can then be leveraged for wildlife management.

The general purpose of this study was to address the fundamental habitat characteristics for the management of the Korean water deer. Specifically, the three goals of the study were to: (1) identify the relevant habitat variables that affect deer distribution, (2) develop an HSI model, and (3) propose how the model can be used to guide management decisions. Further, HSI models enable us to quantify habitat preferences; therefore, this study can be the groundwork to assist decision-making on habitat protection, mitigation, and enhancement for the Korean water deer. In addition, the Korean government would be able to use the model results to improve and enhance current management practices for the deer.

Materials and methods

Study area

Chungnam Province (about 8600 km^2) is located in the middle of South Korea (Figure 1 left) in a temperate monsoon zone characterized by a cold and dry winter and a hot and humid summer. Topographically, the province is flat and low in the west and steep and mountainous in the east, with a maximum elevation of 904 m at the Gyeryongsan National Park. Forests in the eastern mountains are composed of coniferous species, while those in the mountainous areas of the south are composed of mixed deciduous broad-leaved and coniferous trees (Figure 1 right). A wildlife survey (Han et al. 2015) reported that the Korean water deer population in the province has been constantly increasing since the late 1990s, and the province has the highest deer density (11 deer per 100 ha) in South Korea. Substantial losses in agricultural revenue have been estimated in Chungnam Province because of crop damage by the deer, and it has resulted in a rapid increase in agricultural and environmental conflicts.

Habitat variable selection and HSI modeling

To predict the distribution of the water deer in Chungnam Province, we collected existing information on the habitat preferences of the water deer in Korea and China, where it occurs naturally, as well as in the United Kingdom, where it has been introduced. Comprehensive knowledge and understanding of the habitat requirements of the Korean water deer are necessary to accurately assess habitat quality and proactively manage the population through habitat manipulation. It is also necessary to evaluate the relative influence of each habitat variable on habitat suitability (HS) for effective habitat conservation at a large landscape level (Hirzel & Lay 2008). Because the Korean water deer is known to require temporally and spatially diverse habitat components, such as food, water, and cover, key habitat components were incorporated as habitat variables into the model.

The Korean water deer is usually observed at places where two different habitat types meet, for example, forest and meadow; it thrives in an environment where a forested land is adjacent to an open area (Won 1967). Edge areas generally contain more vegetative diversity than either forested or open areas, and many positive attributes of both types are available in these relatively small and readily accessible areas. In other words, woody cover and food requirements can be fulfilled by the associated forested area, and herbaceous food and cover requirements can be satisfied by the associated open place.

Water availability is presumably the most critical factor for the deer. Wild mammals generally require a supply of fresh water around their habitat. In particular, the water deer prefers areas around wetlands or streams. Although the Chinese water deer has been reported to prefer areas that are 200–599 m away from water sources (Zhang et al. 2006), the Korean water deer prefers habitats within 1 km from water (Kim et al. 2011).

In addition, topographic characteristics and human disturbance were considered as habitat variables. Habitat destruction mainly occurs because of the harvest of natural resources for industrial production and urbanization. Habitat losses and fragmentation caused by urban development have become a concern for the recovery and management of species that belong to the family Cervidae (Folk 1991). With an increase in urban development across the province, it is important to understand how Korean water deer are likely to respond to different levels of urbanization pressure. In this study, the effect of human disturbance on habitat quality was considered with two factors, the distance to roads and the distance to urbanized areas. Topographic features such as slope, elevation, and aspect are known to influence the habitat selection patterns of the species (Kim et al. 2011; Zhou & Zhang 2011). In addition, land use was utilized to identify the topographic characteristics of Korean water deer habitats.

Using information on habitat requirements, we defined a function for each habitat variable. An individual habitat variable was represented by a single suitability index (SI). The Korean water deer commonly traverses 1000 m in 24 h; therefore, SI values were assigned within 1000 m. Overall, SI variables based on

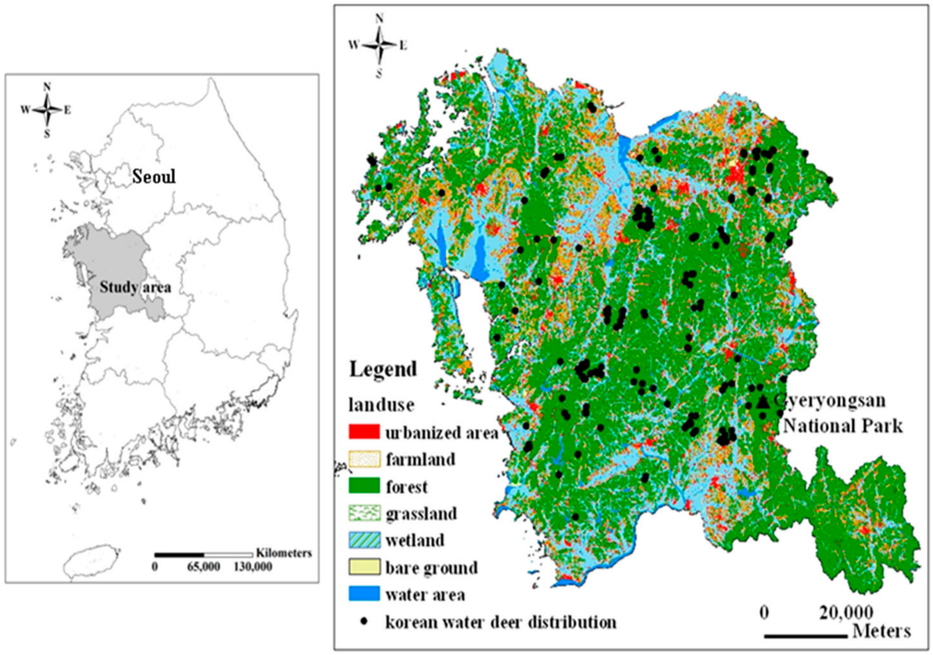

Figure 1. The study area in Chungnam Province (8598 km^2) located 150 km to the south of Seoul, Korea (left). Land use and distribution map for the Korean water deer in the province (right).

the natural history traits were as follows: SI for the distance to water areas (SIv1), canopy cover (SIv2), distance to wetlands (SIv3), slope (SIv4), distance to urbanized areas (SIv5), distance to roads (SIv6), land use (SIv7), aspect (SIv8), and elevation (SIv9) (Figure 2). The government database was used to establish these SI variables. The field data were collected from 1997 to 2006 as part of the Long Term Ecological Research by the Ministry of Environment in Korea. The field data on wildlife were collected for 30−40 days of each season every year in the decade. Observation of Korean water deer was registered at 292 sites, from identification of tracks, droppings, rubbings on trees, and scent markings to other signs of the species' presence in the province. The deer were counted at sites in several sections of the province, and the number at each section was converted into percentage. Then, the SI values were standardized in the range of 0.0–1 by dividing the calculated percentage value for all the sections by the maximum percentage, with 0.0 being the lowest suitability and 1 being the highest. The SI values were then classified into five categories of 0.0–0.2, 0.2–0.4, 0.4–0.6, 0.6−0.8, and 0.8−1, which are categorized as poor, moderate, fair, good, and excellent, respectively, according to the U.S. Fish and Wildlife Service (1981) habitat description.

We developed the HSI model by using the identified habitat variables to predict the distribution of Korean water deer habitats at a landscape level, and we tested the model to validate its application in the province. The HSI model evaluated habitat quality and classified HS in the province, differentiating potentially suitable areas from unsuitable areas. A composite HSI value for a given area was obtained by mathematically combining individual SI values of the habitat variables to generate a composite index of HS on a scale of 0.0–1. If the index was high at a particular location, then the chance of the species to occur was high. We used the following types of spatial data to develop the model: 1/5000 scaled level in the land cover map[1]; vegetation map[1]; digital elevation model[1]; stream map[2]; and the Korean Transport database,[3] which includes national and local roads. Data analysis was performed using ArcView 3.1 and ArcGIS 9 (Environmental Systems Research Institute, Inc. 2000).

HSI modeling

The HSI model directly incorporated habitat variables (SIv*n*) regarded as critical in evaluating HS. For HSI modeling, a backward stepwise logistic regression was applied (Hosmer & Lemeshow 2000; Menard 2002). All habitat variables for either analysis of variance or bivariate analysis at a significance level of .05 or less were included in the initial logistic regression model.

The probability that a particular habitat is selected by the species was assumed to be taken in the form of the logistic regression model. A binary response variable (y) was defined for each observation, such that $y = 1$ if observed and $y = 0$ if not. It is similar to a linear

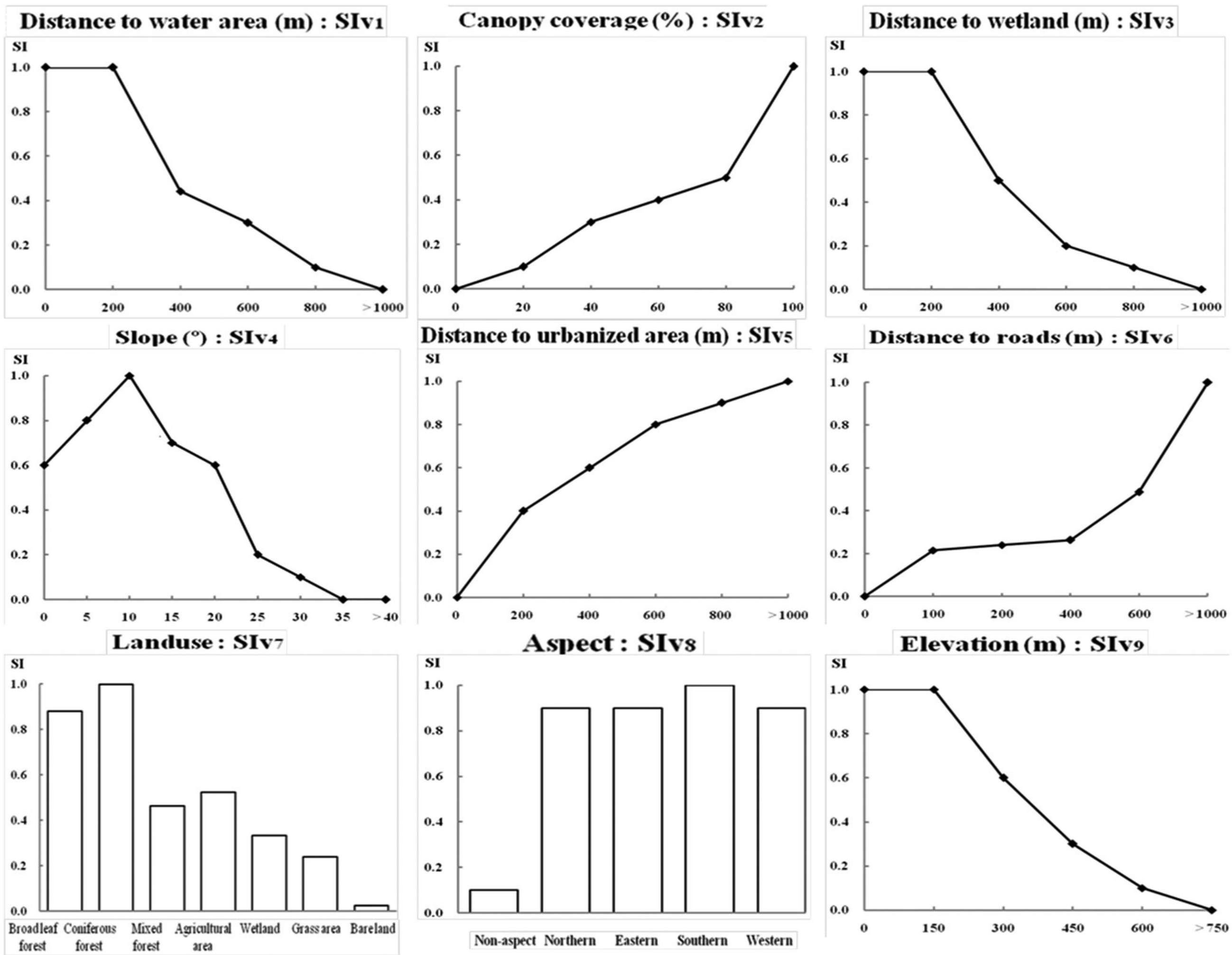

Figure 2. SI for the habitat variables: Distance to water area (SIv1), canopy cover (SIv2), distance to wetland (SIv3), slope (SIv4), distance to urbanized area (SIv5), distance to roads (SIv6), land use (SIv7), aspect (SIv8), and elevation (SIv9).

regression model but is suited to a case where the dependent variable is dichotomous. The logistic regression equation estimates the probability that $y = 1$ if the sample region is the most suitable habitat, while $y = 0$ if not. This predictive probability was regarded as the HSI value, differentiating potentially suitable areas from unsuitable areas in the province. The HSI model describing the probability of use conditioned on habitats was defined as follows:

$$P(y = 1|x) = \frac{\exp\ (\beta'_x)}{1 + \exp\ (\beta'_x)}, \qquad (1)$$

where $\beta' = (\beta_0, \beta_1, \ldots, \beta_n)$ is a vector of coefficients relating the probability of use to the habitat covariates via the relationship $\beta'_x = \beta_0 + \beta_1 \mathrm{SIv1} + \ldots + \beta_n \mathrm{SIv}n$. The HSI model is intrinsically bound within the interval from 0 to 1. Model parameters were estimated by maximizing the log likelihood proposed by Hosmer and Lemeshow (2000). Development of the model was performed using SPSS ver. 13.

The HSI model was statistically developed by comparing its distribution predictions with the actual distributions of Korean water deer in the province on the basis of the field data (total, 292 observations; 1997–2006). The low number of observations is due to the nocturnal habits, secretive nature, and small size of the species, as well as its tendency to avoid roads and people. To confirm the distribution of the SI values, we divided the province into two parts: Kernel and non-Kernel, where 'Kernel' is the region around each point location containing some likelihood of animal presence. The technique using Kernel is regarded as the most robust approach to determine probabilistic distributions of wildlife (Hooge et al. 1999). The output of the Kernel home range displayed 75% probability regions, calculated with the default smoothing parameter value ($h = 1$) in the Animal Movement Extension of Arcview (Rodgers & Carr

1998) (Figure 3). The 75% contour had the maximum variation from random space use and was the area most intensely used by the species. We determined 300 random points outside the 75% Kernel areas and then created a square buffer around each of the 292 observation points and 300 random point features (25 ha units). The outputs of the buffering operation for observation and random points were used as habitat and non-habitat samples, respectively.

HSI model validation

Logistic regression analysis was performed to determine the best fitting model that effectively described the relationship between the HSI values and a set of habitat variables. The Hosmer–Lemeshow test was performed to determine the goodness of fit of the model. Moreover, the model predictive accuracy was validated using a test habitat and a non-habitat sample data set based on the kappa statistic (Scott et al. 2002). The classification ratio is another method to evaluate the predictive accuracy. To make comparisons between observed and predicted data, the continuous probability generated by the HSI model should be converted to a binary one, that is, habitat versus non-habitat. For this purpose, a threshold was set to 0.5, so that the predicted probability was reclassified into habitat (over 0.5 probability) or non-habitat (below 0.5). Parameters for the model evaluation – sensitivity (the ratio of correctly predicted habitat to the total number of habitats), specificity (the ratio of correctly predicted non-habitat to the total number of non-habitats), and correct classification rate (the ratio of correctly predicted habitats and non-habitats to the total number of sampling sites) – were estimated from a confusion matrix to assess agreement between the observed and predicted distributions. A *t*-test was also conducted to test the differences between the two groups: actual habitats where the water deer were observed and non-habitats chosen at random on the basis of the regression estimates.

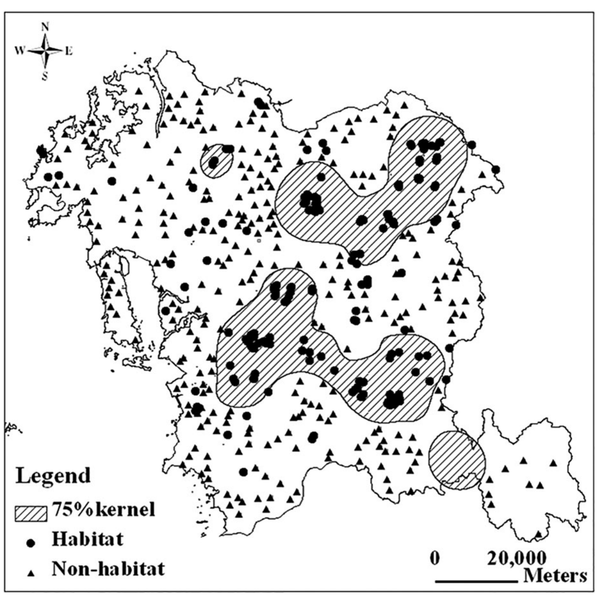

Figure 3. Habitats and non-habitats for the Korean water deer in Chungnam Province.

Results

The HSI model for Korean water deer

After overlaying habitat variables on the habitats and non-habitats with 25 ha units, 465 sub-region sample data (habitat = 180 and non-habitat = 285) were obtained out of 592 because of some overlaps. We applied this approach to identify the distribution of potential habitats at a higher resolution (25 ha), which provided us with feasibility to directly map the target species. Using the stepwise method with 465 sample data, the significant logistic regression model with −2 log-likelihood values (−2*LL*) of 577.37 and overall accuracy of 65.4% emerged (Table 1). The resulting equation for the habitat variable data is as follows:

$$\ln\{Y/(1-Y)\} = 0.268\text{SIv1} + 0.501\text{SIv2} + 1.550\text{SIv3} + 1.988\text{SIv4} + 0.695\text{SIv5} + 1.118\text{SIv6} + 0.011\text{SIv7} - 2.627. \quad (2)$$

The predicted value, *Y*, denotes the probability of observing Korean water deer in the area, ranging from 0.0 to 1. In this study, the predicted values were regarded as HSI values, describing suitability of given habitat by combining the interactions of all key environmental variables. The significance of each habitat variable was measured using the Wald statistic ($p < .05$). Of all the habitat variables, SIv3, SIv4, and SIv6 had the largest impact on the HSI model, indicating that these three components are major contributors to the HSI and particularly effective at predicting Korean water deer occurrence. It also implied that the deer tend to avoid roads and prefer wetlands and forest areas.

Application of the HSI model to Chungnam Province

The mean HSI value for the province was 0.22, with a range from 0.02 to 0.88. Only 414.91 km^2 (4.8% of the province) had HSI values ranging from 0.6 to 1,

Table 1. HSI model summary for the Korean water deer.

Model	−2LL	Cox and Snell R^2	Nagelkerke R^2	Hosmer–Lemeshow test			Correct classification ratio		
				Chi-square (χ^2)	df	Sig.	Specificity	Sensitivity	Overall accuracy
Null model (Only constant)	620.711	–	–	–	–	–	–	–	–
HSI model	**577.367**	**0.089**	**0.121**	**9.672**	**8**	**0.289**	**85.3%**	**33.9%**	**65.4%**

Note: −2*LL* = −2 log likelihood. HSI model = 0.268SIv1 + 0.501SIv2 + 1.550SIv3 + 1.988SIv4 + 0.695SIv5 + 1.118SIv6 + 0.011SIv7 − 2.627, where SIv1 = SI for the distance to water area; SIv2 = SI for canopy cover; SIv3 = SI for the distance to wetland; SIv4 = SI for slope; SIv5 = SI for the distance to urbanized area; SIv6 = SI for the distance to roads; and SIv7 = SI for land use.

whereas 748.07 km^2 (8.7%) had values from 0.4 to 0.6 and 7467.41 km^2 (86.5%) had values from 0.0 to 0.4. Majority of the studied areas were unsuitable as Korean water deer habitats; therefore, 61.6% of the province could be regarded as a poor habitat (Table 2). Most deer were observed in the mountainous areas, and high HSI values were largely concentrated in the forest areas (Figure 4); this indicated that the forest provides quality habitats that can offer food and shelter. This is particularly true for the national parks, which have been well managed and provide a canopy cover of suitable density. The HSI model yielded significantly larger HSI values where the Korean water deer were actually observed, relative to randomly generated non-habitat areas in the same province (mean HSI value = 0.31). The areas with HSI values greater than 0.6 had a relatively higher percentage of habitats (11.5%) than non-habitats (1.3%; Table 2). The average SI value for every habitat variable considered was significantly higher in the actual habitats or sites in which the Korean water deer were observed than the average values for those not observed or non-habitats ($p < .001$; Table 3). The average SI values for four habitat variables, SIv2, SIv3, SIv4, and SIv7, all exceed 0.6 (over 50% of the habitat areas), indicating good quality as habitat components. In addition, the average SI values for three habitat variables, SIv1, SIv5, and SIv6, were in the range of 0.4–0.6. The SI for SIv1 had a lower average (SI = 0.46) than the entire province (SI = 0.56), suggesting that it is not easy for the deer to access water.

Table 2. Distribution of HSI values for habitat, non-habitat, and the entire province (unit: km^2) and the observation possibility in the HSI ranges.

HSI range	Habitat	Non-habitat	Chungnam Province	Observation possibility
0.0–0.2	17.68 (38.0%)	65.11 (83.5%)	5317.17 (61.6%)	38.0/61.6 = 0.6
0.2–0.4	15.54 (33.4%)	9.67 (12.4%)	2150.24 (24.9%)	33.4/24.9 = 1.4
0.4–0.6	7.98 (17.1%)	2.22 (2.9%)	748.07 (8.7%)	17.1/8.7 = 2.0
0.6–0.8	4.51 (9.7%)	0.80 (1.0%)	363.21 (4.2%)	9.7/1.0 = 9.7
0.8–1.0	0.84 (1.8%)	0.22 (0.3%)	51.70 (0.6%)	1.8/0.6 = 3.0
Mean (SD)*	0.31 (0.20)	0.14 (0.11)	0.22 (0.17)	
Min–Max	0.02–0.88	0.02–0.88	0.02–0.88	

*Significant difference at $p = .001$.

Validation of the HSI model for Korean water deer

The model was validated to estimate the accuracy of model prediction when compared with a set of observations. Classification accuracy was assessed using sensitivity, specificity, and overall accuracy with a modest set of observations, allowing us to predict where there would be concentrations of Korean water deer in the province.

The predictive performance of the model was determined by comparing the HSI mean values between the habitats and non-habitats. The results of the *t*-test for the predicted values of the logistic regression model indicated that there were distinct differences between the habitat (mean = 0.31) and non-habitat sites (mean = 0.14) (p-value < .001; Table 2). The distribution of the deer could also be compared visually to the map for HS (Figure 4). The deer were observed in areas with both high HSI values and high SI values for roads (SIv6). They tend to be observed in areas with high-density forests and far from roads. One exception is in the far northwest of the province, which apparently has a suitable habitat despite a lack of observations.

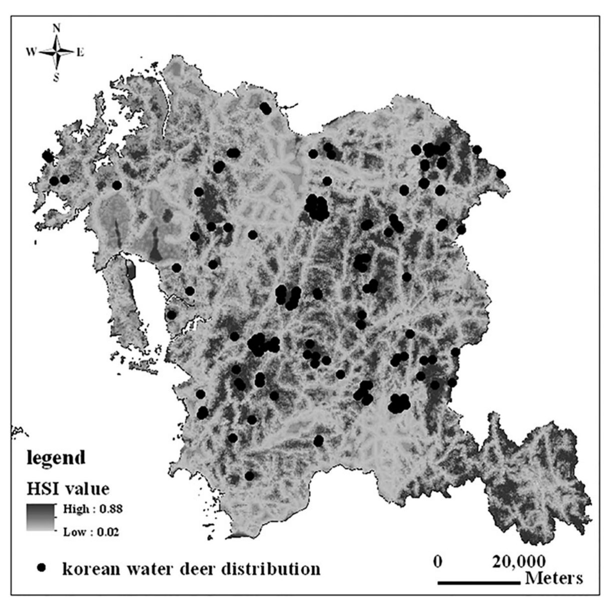

Figure 4. The HS map for the Korean water deer in Chungnam Province.

Table 3. Habitat variables (SIvn) for the HSI model and distribution of the SI values for habitat, non-habitat, and the entire province (unit: km^2).

Habitat variables (SIvn)	SI range	Habitat	Non-habitat	Chungnam Province
Distance to water area (SIv1)*	0.0–0.2	10.99 (23.6%)	26.32 (33.7%)	1734.57 (20.1%)
	0.2–0.4	6.10 (13.1%)	9.86 (12.6%)	640.52 (7.4%)
	0.4–0.6	7.02 (15.1%)	10.77 (13.8%)	1013.80 (11.7%)
	0.6–0.8	8.87 (19.0%)	9.68 (12.4%)	1451.71 (16.8%)
	0.8–1.0	13.58 (29.2%)	21.38 (27.4%)	3789.80 (43.9%)
	Mean (SD)	0.46 (0.35)	0.40 (0.37)	0.56 (0.36)
Canopy cover (SIv2)*	0.0–0.2	5.40 (11.6%)	44.47 (57.0%)	3160.49 (36.6%)
	0.2–0.4	4.55 (9.8%)	9.52 (12.2%)	976.54 (11.3%)
	0.4–0.6	5.59 (12.0%)	8.37 (10.7%)	953.94 (11.1%)
	0.6–0.8	7.77 (16.7%)	5.75 (7.4%)	985.01 (11.4%)
	0.8–1.0	23.26 (50.0%)	9.92 (12.7%)	2554.42 (29.6%)
	Mean (SD)	0.67 (0.34)	0.30 (0.29)	0.47 (0.37)
Distance to wetland (SIv3)*	0.0–0.2	9.02 (19.4%)	47.35 (60.7%)	3600.16 (41.7%)
	0.2–0.4	0.64 (1.4%)	0.19 (0.2%)	31.99 (0.4%)
	0.4–0.6	0.83 (1.8%)	0.33 (0.4%)	77.71 (0.9%)
	0.6–0.8	2.63 (5.7%)	1.10 (1.4%)	224.42 (2.6%)
	0.8–1.0	33.43 (71.8%)	29.06 (37.2%)	4696.11 (54.4%)
	Mean (SD)	0.78 (0.40)	0.39 (0.48)	0.57 (0.47)
Slope (SIv4)*	0.0–0.2	1.68 (3.6%)	0.43 (0.6%)	158.56 (1.8%)
	0.2–0.4	3.12 (6.7%)	0.90 (1.2%)	283.51 (3.3%)
	0.4–0.6	15.88 (34.1%)	57.76 (74.0%)	4858.09 (56.3%)
	0.6–0.8	16.21 (34.8%)	11.90 (15.3%)	2086.70 (24.2%)
	0.8–1.0	9.66 (20.8%)	7.03 (9.0%)	1243.54 (14.4%)
	Mean (SD)	0.71 (0.23)	0.46 (0.14)	0.59 (0.19)
Distance to urbanized area (SIv5)*	0.0–0.2	13.44 (28.9%)	47.90 (61.4%)	4011.37 (46.5%)
	0.2–0.4	12.61 (27.1%)	19.33 (24.8%)	2336.58 (27.1%)
	0.4–0.6	7.87 (16.9%)	6.67 (8.6%)	1078.11 (12.5%)
	0.6–0.8	3.69 (7.9%)	2.08 (2.7%)	541.56 (6.3%)
	0.8–1.0	8.95 (19.2%)	2.0 (2.6%)	662.78 (7.7%)
	Mean (SD)	0.46 (0.35)	0.20 (0.37)	0.31 (0.32)
Distance to roads (SIv6)*	0.0–0.2	4.13 (8.9%)	17.53 (22.5%)	1125.22 (13.0%)
	0.2–0.4	8.47 (18.2%)	31.46 (40.3%)	2339.14 (27.1%)
	0.4–0.6	5.99 (12.9%)	12.76 (16.4%)	1226.10 (14.2%)
	0.6–0.8	10.45 (22.5%)	11.82 (15.1%)	1701.52 (19.7%)
	0.8–1.0	17.51 (37.6%)	4.45 (5.7%)	2238.41 (25.9%)
	Mean (SD)	0.56 (0.37)	0.26 (0.24)	0.45 (0.35)
Land use (SIv7)*	0.0–0.2	2.32 (5.0%)	14.37 (18.4%)	917.23 (10.6%)
	0.2–0.4	1.15 (2.5%)	1.73 (2.2%)	148.20 (1.7%)
	0.4–0.6	17.94 (38.5%)	44.02 (56.4%)	4449.70 (51.6%)
	0.6–0.8	10.42 (22.4%)	4.14 (5.3%)	1068.61 (12.4%)
	0.8–1.0	14.73 (31.6%)	13.76 (17.6%)	2046.68 (23.7%)
	Mean (SD)	0.69 (0.31)	0.44 (0.33)	0.56 (0.34)

*Significant difference at $p = .001$.

The model had a correctly classified rate of 65.4%, with a sensitivity of 33.9% and specificity of 85.3% (Cox–Snell $R^2 = 0.089$; Nagelkerke $R^2 = 0.121$; Table 1). In addition, chances of observation increase throughout the province with the increase in the HSI values. This indicates that the deer would be found in the areas with high HSI values, and the model proves the high overall prediction accuracy (Table 2).

Discussion

This study was conducted to understand the habitat requirements for the Korean water deer on the basis of HSI modeling for Chungnam Province, Korea. The HSI model was developed by leveraging the environmental geographic information and ecology of the water deer in Korea, China, and the United Kingdom. This HSI modeling could provide information on the types of habitat favored by the Korean water deer. Of all the habitat variables considered, three components of the model (wetland accessibility, slope, and distance from roads) are particularly effective in predicting the presence of the Korean water deer. Cooke and Farrell (1983) reported that the water deer prefers watery areas or nearby. However, water features in the province have received developmental pressures for many years, resulting in the interference of the approach of the Korean water deer to the water areas. Thus, habitat variables for the water areas could not be used as the habitat indicators for the region strongly affected by anthropogenic factors, and sufficient evidence regarding the existence of water deer will be required to assess the level of their accessibility to water.

The water deer and other Korean ungulate species (or subspecies) are facing the risk of anthropogenic disturbances such as roadkill, lack of habitat, or habitat fragmentation, especially in or near large cities (Kim et al. 2011). High levels of some types of human activity indeed limit deer abundance, implying that the deer tend to avoid roads and prefer wetland and forest areas. In addition, local topographic features, such as the slope and aspect, play a crucial role in a number of morphological, ecological, and hydrological processes (Vico & Porporato 2009). However, the studied area is relatively low and flat with a maximum elevation of 904 m above sea level (a.s.l.). The distribution of Korean water deer in areas below 300 m a.s.l. does not appear to be affected by local differences in elevation. In addition, there are almost no significant differences in aspect. Given the geographical conditions, the variables of aspect and elevation could be less important than other habitat variables for the province.

The proposed model is particularly useful in the case where a wildlife habitat has not been previously identified in a broad area. It allows us to predict the concentration of Korean water deer at a large scale. It demonstrates that only 13.5% of the province can be considered as a high-quality habitat (HSI values > 0.4), mainly in forest areas. Because the forest areas in parks have been well managed and they offer a forest canopy cover of suitable density, most deer have been observed in mountain areas close to cultivated or open areas (Figures 1 and 4), indicating that the field crops can be damaged or destroyed by the deer. The deer are more likely to stay and rest in the forest or a dense vegetation area during daytime and feed on the farmlands at night.

The HS map was created by fitting the logistic regression to the environmental and species distribution data. However, the species distribution data were not sufficient and complete at a high spatial resolution and large spatial extent. Constructing a distribution model by using the species data could cause an issue related to the model accuracy if the species has not been recorded at all the sites that are actually suitable (Tyre et al. 2003; Guisan & Thuiller 2005). With respect to the presence/absence data for the Korean water deer, the absence information was generated at random. We randomly selected 300 sites outside 75% of the Kernel areas to compare with the observation sites as the presence information. The Kernel density estimation based on the available field data provides a probabilistic measure of how the animals use space and allows us to distinguish between areas with different intensities of use. Calculating a core area (area of 50% Kernel contour) and an area of active use (area of 90% Kernel contour) will help to clarify the assessment of preferences and qualities of habitats for the Korean water deer.

To identify all suitable locations, long-term location data on changes in the deer population with respect to the environment may be required (Welk 2004; Herben et al. 2006). Historical records of population may correspond to sites where the species' habitat has been subsequently destroyed or changed. For the past few decades, areas near streams or wetlands have undergone substantial changes because of development projects, such as building a residential or industrial complex. Although Korean water deer prefer this lowland habitat, habitat modification would cause them to migrate to forested areas and locations at a higher elevation.

Another limitation is that, because of the lack of data on shrubs and herbs, certain key food variables that probably affect habitat quality could not be fully considered in the model. Since the feeding pattern of the deer is known to selectively increase the abundance of unpalatable species (Suzuki et al. 2008), in the future, we would like to investigate the impact of the deer on vegetation. The HSI model is also limited in terms of information on dispersal, competition, niche issues of single species, and interaction with other species.

Despite these limitations, the HSI model shows that the population of Korean water deer increases as the level of HSI values increases (Table 2). The model enables us to identify key environmental variables that can be used to predict the distribution of Korean water deer as well as the focus areas where the habitat should be managed. It also allows us to identify areas that may or may not have a significant population of the deer but have suitable habitats. In addition, the model could provide guidance to government officials who are required to protect the wildlife species and to farmers whose crops are often being damaged by the species. We believe it is important to implement actions that achieve a better coexistence between humans and wildlife, and this study could be an initial step in that effort.

Notes

1. The source of the data set is the Ministry of Environment, Korea.
2. The source of the data set is the Korea Water Resources Corporation.
3. The source of the data set is the Korea Transport Institute.

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Disclosure statement

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