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Estimating the Potential Habitat of Breeding Egrets and Herons (Family Ardeidae) for Urban Forest Management in Daejeon Metropolitan City, Korea

Man-Seok Shin[1], Hyun-Ju Cho[2] and Eun-Jae Lee[3]*

[1]Divison of Ecological Information, National Institute of Ecology, Seocheon-gun 33657, Republic of Korea
[2]Dept. Urban Planning and Landscape Architecture, Daegu University, Gyeongsan 38453, Republic of Korea
[3]Sustainability Research Dept., Daejeon Sejong Research Institute, Daejeon 34863, Republic of Korea

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ABSTRACT

Potential breeding habitat of egrets and herons was evaluated using the Maximum Entropy Model (MaxEnt). Model output can help guide management of nuisance egret and heron rookeries in urban forests of Daejeon Metropolitan City, Korea. This study examined 126 locations regarded as breeding sites of egrets and herons at the nationwide census conducted by the National Institute of Environmental Research between 2019 and 2020. In addition, 252 randomly selected locations were used to identify the significant variables among a total of 15 environmental variables within 4 factors (topography, natural environment, distance and climate). Twelve variables were significantly different between the breeding and randomly selected points. The final 10 variables were selected through Pearson's correlation analysis. Using MaxEnt, breeding area was estimated using the 10 selected variables in Daejeon. The area under the receiver operating characteristic curve (AUC) was 0.950, which was the average value through 10-fold cross-validation to estimate the model reliability. The potential breeding habitat for egrets and herons was estimated to be 106.69 km^2 (19.76% of the total area) in Daejeon. Within the estimated potential habitat, 11.82 km^2 (12.46%) were less than 50 m from the residential district while 79.85 km^2 (88.92%) were more than 50m from the residential district. Discriminative management strategies considering the breeding location of egrets and herons should be applied not only to minimize conflicts with residents, but also to maintain stable egret and heron breeding sites in Daejeon, Korea. Also, our study can be used to select suitable alternative breeding habitat for egrets and herons without conflicts in urban forests.

INTRODUCTION

Predicting the distribution of species is central to diverse applications in ecology, evolution, and conservation science (Elith *et al*., 2006). Over the last several decades, the interest in species distribution models (SDMs) of plants and animals has grown dramatically (Guisan and Thuiller, 2005; Franklin, 2010). This has resulted from the growing need for information on the geographical distribution of biodiversity as well as new and improved techniques and data suitable for addressing this need, such as- remote sensing, global positioning system technology, geographic information systems, and statistical learning methods (Franklin, 2010). These methods have been used widely to interpolate sparse biological surveys in space to use the predicted distributions for conservation planning, reserve design, and impact and risk analysis (Franklin, 2010).

Species distribution models are tools that combine observations of species occurrence or abundance with environmental estimates. They include a correlative, process-based, and mechanistic models (Guisan and Zimmermann, 2000; Kleidon and Mooney, 2000). Among them, correlative models, such as the generalized linear model (GLM), generalized additive model (GAM), genetic algorithm for rule-set prediction (GARP), environmental-niche factor analysis (ENFA) and maximum entropy model (MaxEnt) are used widely (McCullagh and Nelder, 1989; Hastie and Tibshirani, 1990; Phillps *et al*., 2006; Kearney and Porter, 2009). These algorithms can be applied in modeling potential habitat for a diversity of species from uplands to wetlands, including water birds (Maleki *et al*., 2016).

* Corresponding author: wildlife@dsi.re.kr
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Long-legged waterbirds, including egrets and herons, are important components of the breeding bird community found in numerous wetlands and woodlands in Korea. Of the 72 egret and heron species recorded in the world, 19 species are observed in Korea (Lee *et al*., 2014). Among them, 6 species, black-crowned night heron (*Nycticorax nycticorax*), cattle egret (*Bubulcus ibis*), great egret (*Egretta alba*), intermediate egret (*E. intermedia*), little egret (*E. garzetta*), and grey heron (*Ardea cinerea*), commonly breed in the urban forests of Korea. In the nationwide monitoring and research for egrets and herons between 2019 and 2020 conducted by the National Institute of Environmental Research, 35,512 nests at 148 breeding sites were recorded in Korea. Also, they preferred small-sized and low-altitude mountains, so urban forests could be one of the suitable breeding sites in Korea (National Institute of Environmental Research, 2021).

In the past, egrets and herons have symbolized peace, integrity, and incorruptibility in Korea. However, these ideals must be balanced with management requirements where these birds strongly conflict with human needs (i.e., urban areas of Korea; Telfair *et al*., 2000). Some heronries (nesting areas of herons, egrets, and other associated colonial nesting waterbirds) are considered nuisances when they are located adjacent to residential areas because of the noise, odor, and concerns about possible health hazards in Korea. Therefore, most urban forests containing heron and egret breeding sites have been thinned to minimize the negative effects for residents in Korea. The large population of egrets and herons have bred at the small forest within Korea Advanced Institute of Science and Technology from 2001 in Daejeon of Korea, but the forest was thinned for the reason of tree regeneration in 2012. After that, the population moved Gunngdong park in 2013, Namsun park in 2014, urban forest within Nedong middle school in 2015, but these breeding sites were all thinned without ecological consideration in Daejeon, Korea.

However, we lack information on the management of egrets and herons to both secure their breeding status while minimizing adverse impacts to human residents in urban forests. In this study, we estimated potential habitats for breeding egrets and herons using the MaxEnt and discussed the implications of the results for the management of breeding egrets and herons in the urban forests of Daejeon, Korea. We hypothesized that areas more than 50m from the residence could be suitable potential habitat for egrets and herons to minimize conflicts with residents in urban forests in Daejeon. Our results could be used for adoption of alternative habitats and city management plan.

MATERIALS AND METHODS

Study area

The study area was Daejeon Metropolitan City (36° 20’ N, 127° 20’ E), located in the central part of South Korea (Fig. 1). The total area of Daejeon is 539.96 km^2 and 56% (301.75 km^2) of the total area is forested. Most of the forested area is located outside of the city and some forested area is distributed randomly in patchy areas in the city. The mean annual temperature is 14.0 □ and the mean annual precipitation is 822.7 mm (www.kma.go.kr).

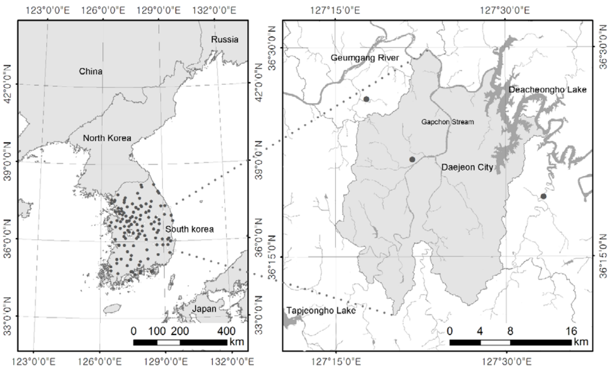

Fig. 1. Location of the study area and 126 breeding colonies of egrets and herons in South Korea.

The topography of Daejeon City is a basin surrounded by mountains on all sides, and the shape of the mountains is clearly visible from the east, west, and south directions (www.daejeon.go.kr). With a population of about 1.5 million, Daejeon City is the 5th most populous city in Republic of Korea. Daejeon City developed rapidly after the establishment of the 5-year national economic development plan in the 1960s, and developed into a science and technology city with the establishment of a research complex in the 1980s and 1990s (Park and Jang, 2020). This led to rapid urbanization and accelerated urban population concentration, which resulted in the spread of urbanized areas and changes in spatial structure (Park and Jang, 2020).

Species data collection

According to the nationwide census conducted by the National Institute of Environmental Research (NIER) between 2019 and 2020, 35,512 breeding pairs of herons and egrets were recorded at 148 sites in Korea (National Institute of Environmental Research, 2021). The NIER had compiled a list of 195 breeding sites for egrets and herons through literature investigation. Through the field survey conducted from March to July 2019-2020, 148 sites were currently used for breeding of egrets and herons. Among them, the observations of 126 colony locations, except for the location points deviating from the extent of variables used (Fig. 1).

Generation and selection of habitat variables

Variables for modeling were selected by considering previous literature and ecological characteristics of egrets and herons in Korea (Kim, 2004; Park, 2012). Variables were classified into four factors (topography, natural environment, distance and climate) and constructed using a 30×30m cell size. Each variable with different resolution was resampled to 30×30m cell size. The DEM (Digital Elevation Model) of the National Geographic Information Institute, Republic of Korea was used to generate topography in 2011. Altitude variable were used as DEM. Aspect and Slope variables were generated using the Surface tool in the Spatial Analyst extension. Relief variable was calculated from the elevation difference between the highest and lowest pixels in the surrounding eight pixels. The age class, diameter class, and density of forest were generated using a map of the forest types maintained by the Korea Forest Service and land cover map made supplied by the Ministry of Environment, Republic of Korea. Age class variable was classified into 10 years using the average receipt of the upper dominant tree. Diameter variables was classified into four grades according to chest diameter of upper dominat tree. Density variables were divided into three stages according to the crown-area of tree. Land cover variable was divided into 5 as shown in Table II. Roads, forests (all forest areas), water (open water, river, stream etc.), city (urban area), farmlands and open terrain were extracted from the land cover map and distance variables were generated using the Euclidean Distance tool in the Spatial Analyst extension of ArcGIS Desktop 9.3 (ESRI, Redlands, California). Climate variables used included Bio8 (Mean Temperature of Wettest Quarter) and Bio16 (Precipitation of Wettest Quarter) of WorldClim (www.worldclim.org).

Table I. Mann-Whitney results comparing breeding colonies of herons and egrets (n=126) and random points (n=378) as related to habitat variables in South Korea.

Factors	Habitat variables (Acronym of variables)	Units	p value	Sources
Topography	Aspect	degree	0.170	DEM: Digital Elevation Model (National Geographic Information Institute, Republic of Korea)
	Altitude	m	0.000	
	Slope	degree	0.388	
	Relief	m	0.071	
Natural environment	Age class of forest (Age)	years	0.003	Forest type map (Korea forest service)
	Diameter class of forest (Diameter)	cm	0.000	
	Density of forest (Density)	%	0.001	
	Land cover	-	0.000	Land cover map (Ministry of Environment, Republic of Korea)
Distance	Distance from road (D. road)	m	0.000	
	Distance from forest (D. forest)	m	0.000	
	Distance from water (D. water)	m	0.000	
	Distance from city (D. city)	m	0.000	
	Distance from farmland and open terrain (D. farm)	m	0.000	
Climate	Mean temperature of wettest quarter (BIO08)	°C	0.003	World Clim (www.worldclim.org)
	Precipitation of wettest quarter (BIO16)	mm	0.024	

Table II. Classification criteria of land cover.

Class of land cover	Kind of land cover
0. Unclassified areas	Unclassified areas (e.g. demilitarized zone)
1. artificial areas	Residential area, manufacturing area, traffic area, commercial area, public establishment
2. cultivation areas	Rice paddy, farm, other cultivated land
3. forest areas	Broadleaf forest, coniferous forest, mixed forest
4. hydrological environment areas	Inland wetland(river, stream etc), coastal wet land(mud flat, salt pond)
5. other areas	Grassland, bare land

Before using variables as input data for the MaxEnt model, we conducted a variable reduction process (Kwon *et al.*, 2012; Seo *et al.*, 2008). We randomly generated 252 points (two times the number of breeding points), to compare to the breeding points (n=126). The random (absence) to breeding points (presence) ratio was 2:1 with reference to the previous study (Seo *et al.*, 2009; Kvamme, 1985). A Mann-Whitney U test was conducted in SPSS 20.0 (SPSS Inc., Chicago, Illinois) to clarify the difference in variables between the breeding points and randomly selected points. Variables that varied significantly at the $\alpha = 0.05$ level between breeding and random points were retained for use in the model. To the next step, We used Pearson's r correlation on pairs of variables to eliminate the weaker predictors which showed high correlations (> 0.70) with another variable (Seo *et al.*, 2009). The categorical variable, Land use, was excluded from the Pearson's r correlation analysis.

The MaxEnt model provides the variable importance in two ways. First, this model provides the percent contribution of each variable to the final model. Second, jackknife approach, this approach excludes one variable at a time when running the model (Baldwin, 2009). We estimated the importance of the variables through the two methods provided in this model.

Model application

A Maximum Entropy Model 3.3.3k (MaxEnt; Phillips and Dudík, 2008) was used to predict the potential breeding habitat of egrets and herons. The model version is freely downloadable (http://www.cs.princeton.edu/~schapire/MaxEnt/). MaxEnt model was developed using software what was descrived and tested in detail in past publications (Phillips *et al.*, 2006). The model is generally used to obtain effective results with relatively small amounts of data for the presence-only species distribution (Phillips *et al.*, 2006). We used default parameters for MaxEnt model (i.e., no random subsampling, regularization multiplier = 1500 maximum iterations, 10,000 background points, convergence limit= 10−5). We used Maxent's *k*-fold cross-validation routine to verify the model reliability. We used 10-fold cross-validation, which holds out 10% of the data as a testing set at each of 10 iterations, building the model on the remaining 90% of the data in each iteration. The model reliability was evaluated by the area under the receiver operating characteristic (ROC) curve, known as the AUC. The MaxEnt predicts the suitability of the area for egrets and herons as a continuous ratio. This was transformed into binary suitable/unsuitable area by applying the maximum training sensitivity plus specificity logistic threshold, an available output of MaxEnt. We chose this threshold because it is considered a superior method to transform continuous probabilities of species occurrence to binary presence/absence occurrence (Hof *et al.*, 2017; Liu *et al.*, 2005).

To determine management strategies for the breeding habitat of egrets and herons in Daejeon, the potential habitat model was divided into less than and greater than 50 m from the residential district derived from a land cover map by the Ministry of Environment.

RESULTS

Generation and selection of habitat variables

Twelve environmental variables (altitude, age class of forest, diameter class of forest, density of forest, land cover, distance from road, forest, water, city, farmland and open terrain, mean temperature of the wettest quarter, and precipitation of the wettest quarter) showed significant differences (p-value < 0.05) between breeding points and randomly selected points (Table I). Pearson's r correlation on pairs of variables results showed high correlation between age class of forest, diameter class and density of forest (Tables II, III). We chose age class of forest of three variables. We finally selected 10 variables that were retained for model input.

Model application

The total area of South Korea was conferred using the 10 selected variables and the 126 breeding point locations of egrets and herons. Model reliability, as estimated from the mean AUC value, was 0.950. Test AUC values ranged from 0.899 to 0.975. The contribution ratios reflecting the model variables were described in descending order as: distance from the city (49.8%), land cover (32.2%), altitude (3.9%), distance from the water (3.4%), distance from the road (3.1%), distance from the farmland and open terrain (2.3%), distance from the forest (2.2%), precipitation of the wettest quarter (1.4%), age class of the forest (1.4%) and mean temperature of the wettest quarter (0.2%). The Two response curves for habitat variables that contributed the most to the MaxEnt model predictions for breeding habitat of egrets and herons were distance from the city and land cover variable (Fig. 2). Based on these response curves, breeding habitat of egrets and herons prefers a place close to the city however, it is not within the city (Fig. 2). Forest area is suitable for breeding site in land cover variables (Fig. 2). In the Jackknife procedure result, distance from the city and distance from the farmland and open terrain provided the most useful and unique information for breeding habitat of egrets and herons (Fig. 3).

The threshold between potential habitat and non-habitat as determined by the maximized sum of sensitivity and specificity was 0.184. The model threshold produced a

Table III. Pearson's correlations on a paired habitat variables.

	Aspect	Altitude	Slope	Relief	Age	Diameter	Density	D. road	D. forest	D. water	D. city	D. farm	BIO08	BIO16
Aspect	1.000													
Altitude	0.100	1.000												
Slope	0.212	0.595	1.000											
Relief	0.191	0.595	0.908	1.000										
Age	-0.161	-0.346	-0.584	-0.551	1.000									
Diameter	-0.177	-0.412	-0.642	-0.608	0.981	1.000								
Density	-0.131	-0.350	-0.531	-0.501	0.920	0.913	1.000							
D. road	0.029	0.504	0.375	0.375	-0.232	-0.283	-0.223	1.000						
D. forest	-0.257	-0.317	-0.455	-0.441	0.377	0.407	0.333	-0.180	1.000					
D. water	0.083	0.609	0.383	0.384	-0.224	-0.270	-0.222	0.471	-0.184	1.000				
D. city	0.030	0.687	0.479	0.480	-0.287	-0.351	-0.289	0.616	-0.203	0.537	1.000			
D. farm	0.033	0.564	0.372	0.376	-0.179	-0.235	-0.194	0.444	-0.069	0.428	0.653	1.000		
BIO08	-0.097	-0.879	-0.492	-0.497	0.273	0.328	0.303	-0.444	0.273	-0.575	-0.633	-0.517	1.000	
BIO16	0.062	0.432	0.220	0.224	-0.106	-0.139	-0.110	0.207	-0.124	0.331	0.280	0.327	-0.452	1.000

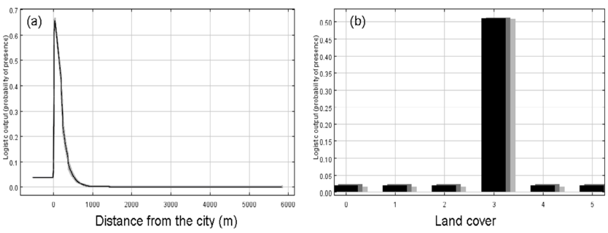

Fig. 2. Response curves showing the relationships between the probability of breeding colonies of egrets and herons and two top habitat variables (Distance from the city, Land cover). The curves show the mean response of the 10 replicate model runs (black) and the mean +/- one standard deviation (light gray, two shades for Land cover variables).

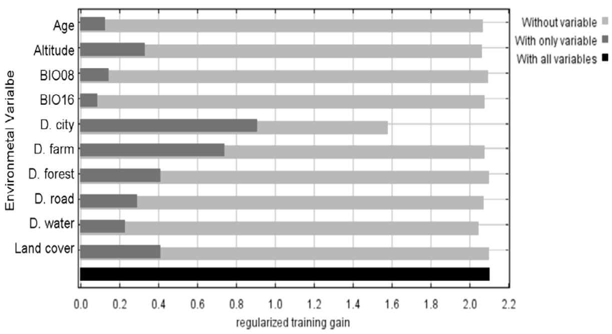

Fig. 3. The results of the jackknife test of variable importance. Values shown are averages over 10 replicate runs.

binary result indicating the estimated potential habitat for breeding of egrets and herons was 106.69 km^2 (19.76% of the total area) in Daejeon (Fig. 4). The estimated potential habitat for breeding contained 109 of the total 129 breeding sites on the Korean peninsula.

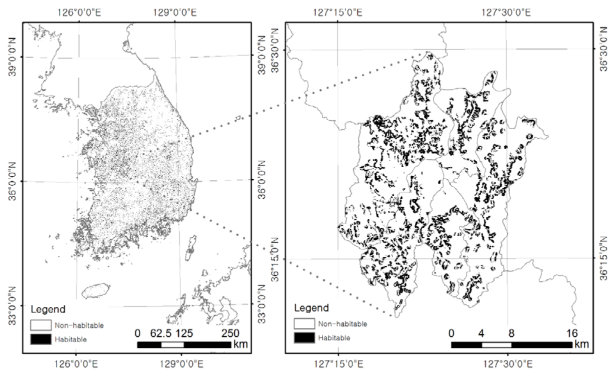

Fig. 4. Maps for displaying the probability and prediction of breeding egrets and herons by MaxEnt in Daejeon, South Korea.

For management purposes of breeding egrets and herons in urban forests of Daejeon Metropolitan city, the potential habitat was divided into two groups of less than and greater than 50 m from the residential district. Results of the division indicated that 11.82 km^2 (12.46% of the potential habitat) and 79.85 km^2 (88.92% of the potential habitat) were less than and greater than 50 m from the residential district, respectively (Fig. 5).

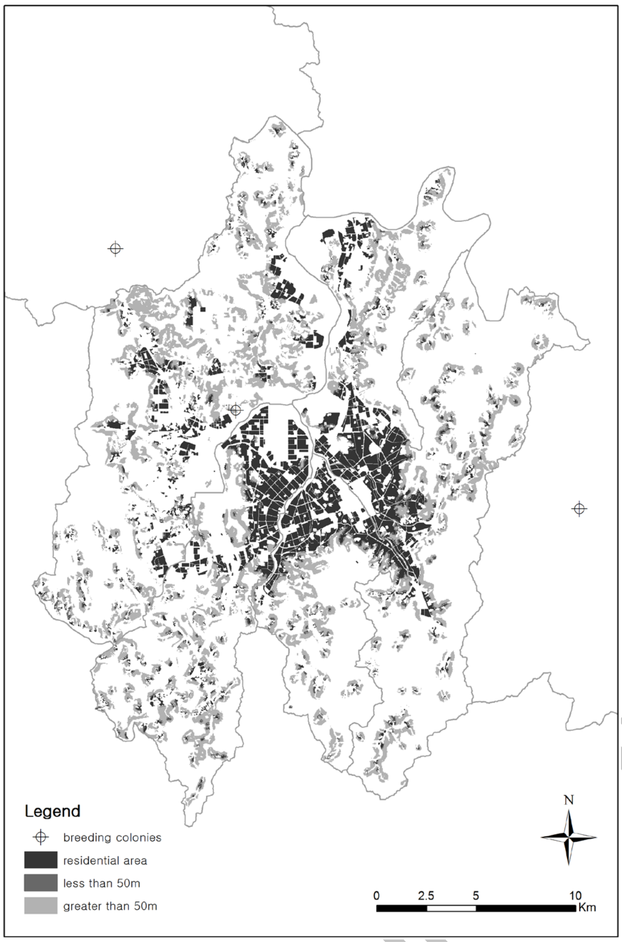

Fig. 5. Distribution of the potential habitat for breeding egrets and herons less than and greater than 50m from residential areas in Daejeon, South Korea.

DISCUSSION

When using SDMs for applications such as conservation planning, it is necessary to consider potential noise that could confound model results (Elith and Leathwick, 2009). To minimize model uncertainty, the location points deviating from the extent of variables used and environmental variables (e.g., aspect, slope and relief) that showed statistically no significant differences between breeding and non-breeding points were removed prior to building the model in this study. The Pearson's correlation analyses among 14 habitat variables identified five variables, slope, relief, age class of forest, diameter class of forest and density of forest, with strong correlation among them (> 0.70). In particular, forest-related variables had very strong correlations with each other (Table III). Finally we removed the variable with high correlation.

According to suggested guidelines, one could distinguish among non-informative (AUC=0.5), less accurate (0.5 < AUC ≤ 0.7), moderately accurate (0.7 < AUC ≤ 0.9), highly accurate (0.9 < AUC ≤ 1), and perfect tests (AUC=1) (Greiner *et al*., 2000; Swets, 1988). Therefore, our potential habitat model for breeding egrets and herons could be considered highly reliable with an AUC of 0.953.

Variable importance of MaxEnt model can be determined in two ways. First, as a result of the percent contribution, distance from city and land cover were the most important variables. In the second method, result of jackknife approach, distance from the city and distance from the farmland and open terrain were seen most useful variables. The suitability of breeding site decreased sharply with increasing all distance of variables (road, forest, water, city, farmland and open terrain). In the response to the land cover variable, breeding site responded only to the forest area (Fig. 2). In South Korea, the ratio of urbanization is very high, thus forests and urban area are often adjacent. Based on this, it is estimated that breeding site of egrets and herons prefers a wide spread area adjacent to forest area. For example, as shown in Figure 5, it can be seen that the breeding site of egrets and herons is very close to urban area in Daejeon city.

Approximately 20% of the total Daejeon area was estimated to be potential habitat for breeding egrets and herons in this study. Some estimated potential habitats were within isolated inner urban forests, whereas most of them included the outer perimeter of Daejeon. In addition, most of the potential habitat was located more than 50m from a residential district. Only a few cities around the world have had problems with egret and heron breeding sites. In Japan during the mid-1990s, some egrets and herons were killed because they were considered harmful (http://www.env.go.jp/nature/choju/docs/docs2.html). On the other hand, heronries in urban forests are managed differently in the USA. For example, the bird species typically associated with nuisance heronries in Texas, USA are protected under both state and federal laws (Telfair *et al*., 2000). In addition, they suggested that the best way to prevent the establishment of a heronry is through public awareness and early detection. If detected early when the birds first move in, they become nervous and can be moved on easily using a range of scaring methods, such as screamers, rope-fire crackers, propane cannons, and eye-spot balloons (Booth, 1994; Dusi, 1983). All birds, including nuisance heronries, are not designated as harmful animals and are therefore protected under the national laws in Korea. On the other hand, there has long been conflict between heronries in urban forests and residents in many cities including Daejeon in Korea. Therefore, this paper proposes that the nuisance heronries be prevented from breeding in urban forests adjoining the residential districts in their early establishment stage to minimize the resident damage in Korea. To achieve this, daily monitoring in the early breeding season (February to April) should be conducted to detect the establishment of heronries at potential habitats less than 50 m from residential districts. In addition, habitat allurement efforts, such as decoy displays (Dusi, 1985; McIllenny, 1936; Pullin, 1983) and the production of natural or constructed alternatives (Harrison *et al*., 2010) are needed for the stable inhabitation of egrets and herons more than 50m from residential districts in Daejeon, Korea.

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Statement of conflict of interest

The authors have declared no conflict of interest.

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