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Using Citizen Science to Track *Corvus frugilegus* Invading Urban Areas

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위 논문은 서울대학교 및 환경대학원 환경조경학과 학위논문 관련 규정에 의거하여 심사위원의 지도과정을 충실히 이수하였음을 확인합니다.

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Abstract

Using Citizen Science to Track *Corvus frugilegus* Invading Urban Areas

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Urban foraging by synanthropic birds is increasing because of the shelter from predators, mild temperatures, and adjacent food sources offered by cities. Among them *Corvus frugilegus* has reduced crop yields and threatened human health with noise and infrastructure fouling.

While rapid solutions to natural resource management are frustrated by the scale and complexity of urban environments, citizen science can powerfully contribute to in situ studies requiring many samples or simultaneous data collection across the study area. We studied the rook (*Corvus frugilegus*), an increasingly invasive species in South Korean cities. To understand their movements, we developed a citizen science program enabling simultaneous collection of the time and place of individual presence records which can replace previous invasive methods that used GPS devices.

Citizen science data are increasingly analyzed in studies addressing ecological problems. We investigated citizen science data on the invasion of a city by rooks (*Corvus frugilegus*), where they were disruptive and created sanitary−related impacts for urban residents. While several approaches to containing rook invasions exist, effective mitigation measures require knowledge of their preferred habitats and daily movements−data that are difficult to obtain for large areas. To overcome these challenges, we collected 4,523 geolocated areas. As a result we aimed to find the most predictive environmental variables for modeling their distribution during daylight and darkness hours; and develop highly detailed spatial models of rook movements.

The collection of this data facilitated increased opportunities for people to participate in ecological problems directly affecting them. The collected data enabled us to determine rook−favored environmental variables in the city that resembled their preferred environments within the forest, offering safety from external threats, and we were able to identify not only these characteristics but also rook spatial distribution throughout our 24 h dataset.

Our research demonstrated the assemblage patterns of rooks throughout the day using citizen science data acquired independently of any invasive methods. This information can be used to inform strategies to decrease or co−exist with city−invading rooks.

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keywords : Avian monitoring, Rook invasion, Species Distribution Model (SDM), Urban ecosystem

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Chapter 1. Introduction

1. Background and Research purpose

1) Research Background

In the field of ecology, research output depends on our understanding of a wide range of geographical concepts and spatiotemporal patterns. However, conducting large-scale studies with many samples can be challenging (Dickinson et al., 2010). Therefore, in cases requiring investigation over a wide geographic area, such as avian studies, citizen science has been used to overcome spatial and physical limitations and minimize costs (Devitor et al., 2010; McCaffrey, 2005; Brashler, 2009).

Citizen science is a participatory project in which citizens actively collect data for scientific research or policymaking to solve diverse problems and community issues in urban centers with the aid of technology, and modern citizen science has few physical limitations (Silvertown, 2009). Indeed, citizen science, with its numerous advantages, serves as an effective method for locating rare organisms, monitoring invasions, and tracking bird populations (Hochachka et al., 1999). For example, citizen science led to the discovery of ladybug species previously thought to be extinct (Losey et al., 2007). Since 2015, the National Institute of Biological Resources in Korea has actively supported projects allowing citizens to participate in monitoring biodiversity along rivers, especially in relation to climate change indicator species, including plants and birds (Park, 2018). Thus, citizen science is a powerful tool for tackling complex environmental challenges in conservation biology, natural resource management, and environmental protection.

Urbanization poses a major threat to wildlife threats and contributes to extinction (Czech et al., 2000; Sushinsky et al., 2013) by reducing habitats and causing fragmentation, leading to a decrease in biodiversity (Noss, 1991). Therefore, the concept of green connectivity and sustainable urban planning that promotes coexistence with wildlife is gaining attention (Czech et al., 2000; Sushinsky et al., 2013, Kim et al., 2020). Factors such as climate change, habitat fragmentation, and urbanization are increasing the overlap between the ranges of wild animals and humans, leading to various conflicts that necessitate the collection of comprehensive spatiotemporal data. Indeed, urbanization and artificial land use are major contributors to extinction (Czech et al., 2000; Sushinsky et al., 2013., Noss, 1991). Bird species have been impacted by climate change, resulting in changes to their migratory behavior (Sparks, 1999), spring migration patterns (Sokolov and Gordienko, 2006), breeding performance (Crick et al., 1997), fitness components (Sanz et al., 2003), population dynamics (Sæther et al., 2000), and geographical distribution (Thomas & Lennon, 1999). However, broad-scale studies are still required to understand the relationships between changes in environmental factors and the behavioral variation of species.

Previous studies depended on the manual collection of local data or historical data (Whitfield, 2001), but extrapolation of these data to wider regions is limited (Sanz, 2002; Crick, 2004). However, citizen science not only helps in conserving species at a large scale but also serves as an effective tool for identifying and monitoring invasive species across vast geographic regions (Gallo and Waitt, 2011). For example, the Invaders of Texas program trained citizen scientists to track invasive plants in their local area and provide online status updates; consequently, statewide mapping databases were produced, which have helped remediate the environmental damage caused by invasive plants (Gallo and Waitt, 2011).

Notably, urban areas can provide suitable habitats for synanthropic birds species (those that evolve and adapt with humans), which may exhibit increased breeding success and habitat density in urban areas (Mlller, 2014; Jadczyk and Drzeniecka-Osiadacz, 2013). Low temperatures and scarce food resources during migration can lead to high mortality rates among birds traveling to breeding grounds and wintering areas (Newton, 2008), causing them to seek urban areas where food and a warm microclimate are more readily available. Indeed, the number of bird species in urban areas is increasing faster than that in rural areas (Mlller et al., 2014).

An increase in the bird population in urban centers can result in increased noise pollution and decreased hygiene due to bird excrement and the transmission of infectious diseases (Borges et al., 2017). Therefore, analysis and implementation of methods for deterring unwanted bird species from urban centers are required. However, the movement range of birds is vast, both inside and outside urban centers, making their management and eradication challenging. Moreover, despite wild animals commonly inhabiting urban areas and the known threat of urbanization to species conservation, systematic evaluation and management of wild animals in urban centers is insufficient, as is the quantitative evaluation of environmental variables that affect bird habitats (Magle et al., 2012; Song, 2015). However, citizen science is emerging as a solution to overcome the geographic challenges in ecological investigations, enabling simultaneous investigation of the environment and biodiversity (Fink et al., 2014; Sauermann and Franzoni, 2015; Silvertown, 2009).

In Suwon, South Korea, rooks appeared in November 2016 to March 2017 (E Suwon News, 2018), mainly near Gwonseon-gu Office, Dongsuwon Intersection, Ajou University Intersection, Suwon City Hall, and Gwonseon-gu Furniture Street where the rook population is concentrated. Citizen science and data collection were required to investigate the wide geographic range of the rooks while promoting the active interest and participation of citizens in the study of these birds.

2) Research objectives

The rapid expansion of urban centers has increased the number of animals adapted to urban environments (Slabbekoorn et al., 2003). More than 30 species of the family Corvidae have adapted to urban environments (Benmazouz et al., 2021), with such adaptation sometimes leading to problematic interactions with humans. To provide sustainable solutions that benefit the birds and humans (Apfellbeck et al., 2020), better data on the movements and behavior of corvids are needed. Among corvids, the rook Corvus frugilegus is known to reduce crop yields and impact human health through noise pollution and infrastructure fouling (Gorenzel et al., 1995). However, as previously mentioned, the wide movement range of these synanthropic avian species within habitats both inside and outside urban centers complicates research and management practices; therefore, the use of citizen science is necessary to overcome these challenges (Silvertown, 2009).

Gyeonggi-do has a population of 13.41 million people, and Suwon-si has a population of ~1.18 million; thus, Suwon-si is the most populated city in Gyeonggi-do. We studied the rook C. frugilegus, an increasingly invasive species in South Korea, where it is currently designated as harmful (Article 4 of the Enforcement Rules of the Wildlife Protection and Management Act, 2018) because it invades cities at night and damages crops. The migratory behavior of rooks has been altered by environmental change (Sokolov and Gordienko, 2006); since 2016, rooks have appeared in cities such as Suwon seasonally from November to March. The rooks now appear across a wide range of geographical areas in and around Suwon. To understand their movements, we developed a citizen science program enabling simultaneous collection of time and location data for rooks.

Participant-collected data were used to (1) assess the spatial and temporal patterns of dense rook assemblies, (2) identify the most predictive environmental variables for modeling rook distribution during the day and night, and (3) develop spatially detailed models of rook movements in 3 h increments. By investigating the favored habitats of rooks across a large urban environment and within a diurnal cycle, we sought to avoid the limitations of in situ and invasive study methods for avian species while providing insights into rook movements that could inform management strategies.

Chapter 2. Methods

1. Study area and materials

This study was conducted in the city of Suwon, Gyeonggi Province, South Korea (37° 17’ 28“ N; 127° 0’ 32“ E). Suwon comprises four administrative divisions, namely Paldal-gu, Jangan-gu, Yeongtong-gu, and Gwonseon-gu, which include urban areas and surrounding agricultural and natural land (Table 1; Figure 1). Rooks arrive in Suwon in November, when the average temperature is 7.9° C and annual precipitation is 104.2 mm (Suwon, 2022).

[Table 1] The classification of land use and landcover types of Suwon City and the total area of the land use for Gwonseon-gu, Yeongtong-gu, Jangan-gu, and Paldal-gu.

Category	Area(ha)			
	Gwonseon	Yeongtong	Jangan	Paldal
Agricultural land	0.97	0.04	0.17	0.00
Artificial grassland	0.26	0.29	0.16	0.12
Commercial and business area	0.20	0.11	0.10	0.13
Forest	0.35	0.48	1.51	0.08
Grassland	0.11	0.06	0.05	0.00
Inaccessible area	0.61	0.08	0.00	0.04
Industrial area	0.12	0.21	0.04	0.00
Lake and wetlands	0.00	0.07	0.06	0.02
Mixed residential and business area	0.33	0.19	0.25	0.16

Land for public use	0.13	0.09	0.10	0.14
Public manufacturing area	0.01	0.01	0.01	0.00
Residential area	0.71	0.64	0.48	0.31
River	0.12	0.03	0.02	0.01
Transportation facilities areas	0.69	0.41	0.34	0.28
Wasteland	0.10	0.03	0.03	0.01

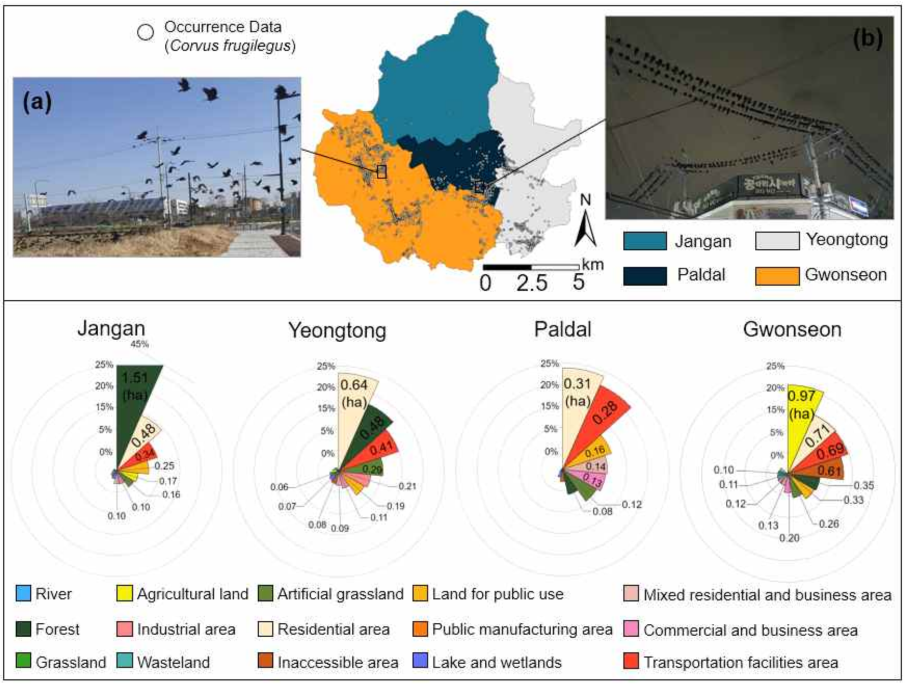

Fig 1. Occurrence data of *Corvus frugilegus* acquired by citizen science and ratio of land use types for all the administrative divisions of Suwon. The areas of each district are Yeongtong: 27.5 km2; Paldal: 12.9 km2; Jangan: 33.3 km2; and Gwonseon: 47.1 km2 (Appendix, Table 1). (a) Gwonseon district has the highest agricultural land area and the picture shows rooks departure from their foraging area, and (b) Paldal district has the highest transportation facilities area, second highest in residential area and the picture shows rooks roosting on the utility pole in the urban area.

2. Study species

The breeding season of rooks occurs mainly during May-June, and the breading areas are Amour, northeastern and southern China, and Mongolia. Rooks winter in Korea, Japan, Taiwan, and east China from November to March. They commonly visit and pass through Korea in spring and autumn and are migratory birds in the southern regions of the country (Won, 1981). The preferred habitats of rooks include flat land, open land, and forests near their roosting areas (Korea National Park, 2018). As previously mentioned, rooks are designated as a harmful species (according to Article 4 of the Enforcement Rules of the Wildlife Protection and Management Act) as they damage crops in groups over a long period. They amass in hundreds or thousands (Madge and Burn, 1994) for roosting after sunset, and begin foraging after sunrise (Hubalek, 2017). Therefore, the preferred habitats of rooks were determined according to the division of sunset and sunrise based on data from December 2020 to February 2021 provided by the Meteorological Administration in Suwon (Table 2).

[Table 2] Average time of sunrise and sunset in Suwon

Date	Definition			Type		
	Min	Max	Min	Min	Max	Mean
Dec/2020	07:27	07:46	07:38	17:14	17:24	17:17
Jan/2020	07:36	07:46	07:43	17:25	17:55	17:39
Feb/2021	07:05	07:35	07:21	17:56	18:25	18:11
Mean	07:35			17:41		

3. Citizen science data collected in the CADA application

Advancements in large-scale citizen science have drawn attention to the possible collection of mobile data on bird species across countries or continents (Devictor et al., 2010). Indeed, with advancements in technology, techniques have been developed to manage large amounts of existing data using crowdsourcing methods and collect citizen science data through open-source platforms or applications (Wiggins et al., 2010).

The citizen science method used in the present study did not include training sessions but included a small financial reward (?500) for citizens who recorded C. frugilegus with their smartphones. This is the most basic citizen science data collection method among four levels: (1) crowdsourcing, (2) distributed intelligence, (3) participatory science, and (4) extreme citizen science in which citizens act as sensors (Shum, 2012).

The presence of rooks was recorded using the smartphone application CADA v.1.0.15 (Kim, 2020). The collected data included the address and age of the collector, the longitude and latitude of the location, a photograph, the time of day, and the date of the sighting. Once the smartphone of a participant was registered, our database recorded location data when photos were captured by the participant. We acquired data between December 2020 and March 2021. To minimize the collection of repetitive data within a particular area, location data collected within 20 min and a 200 m radius of a previous record were eliminated. Moreover, images that did not include rooks were removed via (1) a machine learning method and (2) manual inspection.

In total, 6,314 rook location data points were collected via the citizen science participants in Suwon-si, and 5,214 data points were extracted following the removal of inappropriate photos. Data from within the boundaries of Suwon were identified, and 4,523 data points were utilized overall. In total, 2,528 (55%), 1,023 (22%), 963 (22%), and 9 (0%) location data points were collected in Gwonseon, Yeongtong, Paldal, and Jangan, respectively.

Figure 2. Examples pictures of *Corvus frugilegus* collected with citizen science

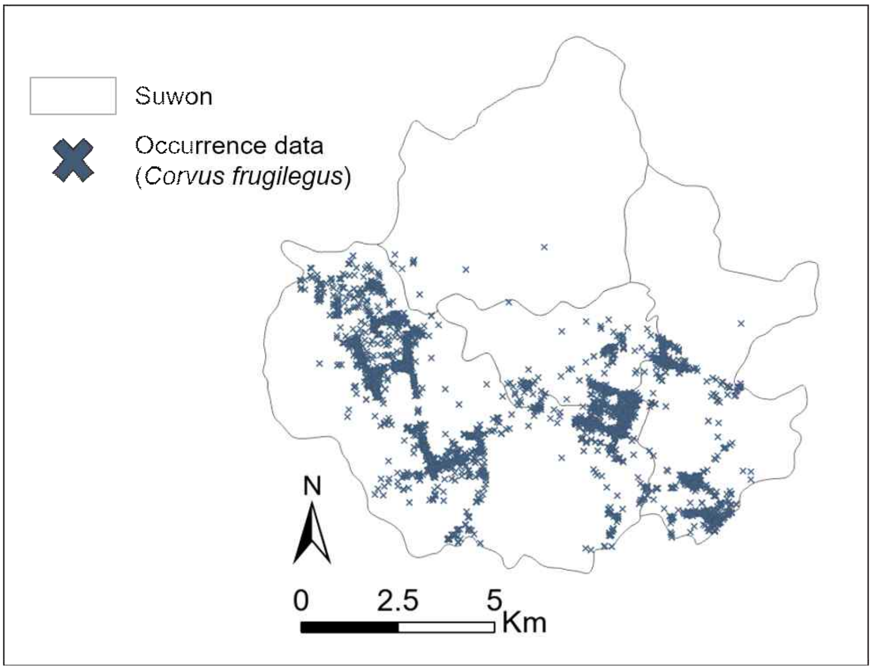

Figure 3. Distribution map of *Corvus frugilegus* picture data collected by citizen science

4. Species distribution model

Species distribution models (SDMs) predict species distribution using environmental covariates associated with appearance records, field exploration, and animal tracking data (Elith et al., 2011; Guillera-Arroita et al., 2015; Pearce and Boyce, 2006). Among such models, MaxENT (Phillips et al., 2006; Phillips and Dudik, 2008) is used to model precise distribution data from large ecological surveys with human-related restrictions related to technical, temporal, or financial issues (Jang, 2015). In the present study, MaxENT version 3.4.4. was used to predict the preferred habitat of rooks according to their occurrence data.

We referenced previous studies to select environmental variables strongly associated with rooks in urban areas; these were primarily artificial influences and structures, such as food supply, mild temperatures, wind shields, and green spaces (Byrkjedal et al., 2012; Ciah et al., 2017; Clewley et al., 2016; Griffin et al., 2000). Among these variables, we combined 15 land-use types from the biotope map with five other rook-favored variables, elevation, euclidean distance from buildings with three different classes of floor numbers (1–5, 6–20, and ≥21 floors), euclidean distance from farmland, euclidean distance from a utility pole, and euclidean distance from a streetlamp (Table 4). Because land cover and land use maps offer practical support when studying natural environments and ecosystems in urban developments, the Ministry of the Environment of South Korea has prepared guidelines for creating “biotope“ maps that have been distributed among local governments. The biotope map of Suwon City (Suwon City Government, 2019) was produced using the following classifications: land use, land cover, green cover ratio, vegetation rate, and landscape data. Within these classifications, we utilized land use and the height (number of floors) of buildings in the Suwon biotope map, which has a native resolution of 5 m2. The distance from a utility pole was determined by eliminating the areas of poles constructed underground provided by the Korea Electric Power Corporation. The area of poles was then placed on top of transportation facilities at intervals of 30 m. Altitude data were extracted with a resolution of 10 × 10 m using a digital topographic map provided by the National Territory Information Platform. The Euclidean distance from streetlamps was determined after acquiring location data on streetlights in Suwon in 2021 from a public data portal (www.data.go.kr).

All variables were weighted over 12 h periods at 3 h intervals according to our MaxENT results. Multicollinearity of environmental variables often leads to statistical problems in terms of depicting a SDM. To minimize inherent collinearity, Pearson correlation analysis was conducted between the environmental variables to exclude those exhibiting high multicollinearity, but we found no such variables.

Two habitat models were created: one each for day and night. MaxENT was used to predict the preferred habitats of rooks from occurrence data. K-fold cross-validation (k = 10) was implemented with a random test percentage of 25%. To correct for uneven sampling, we converted a bias file, i.e., a record of density comprising the population of Suwon (aged ≥18 years) within 5 × 5 m pixels, into a normal distribution to enhance relative gain contributions and provide appropriate weights for areas with lower population rates (Stephanie et al., 2013).

The movement of rooks to foraging and roosting areas is dependent on light intensity (Swingland, 1976). Based on data from December 2020 to February 2021 provided by the Meteorological Administration in Suwon, sunrise and sunset times in Suwon were 07:35 and 17:41, respectively. Civil twilight lasts 20–30 min, starting from sunset and sunrise, such that an evident shift in radiance begins at 08:00 and 18:00, respectively (Andre and Owens, 2021). The day and night weightings of rook predictor variables were determined and applied to the sighting records in eight 3 h intervals (Table 3), including the sunrise and sunset periods, enabling “real-time“ rook population tracking across the region during the daily cycle.

[Table 3] Citizen science data collected every 3 h

Counts of citizen science data								
Hours	24-03	03-06	06-09	09-12	12-15	15-18	18-21	21-24
Count	182	47	626	574	496	685	1162	750

[Table 4] Predictor variables used in the study.

Variable	Definition
Land use	Land use types 1: Residential area 2: Commercial and business area 3: Mixed residential and business area 4: Land for public use 5: Industrial area 6: Public manufacturing area 7: Transportation facilities area 8: Inaccessible area 9: River 10: Lakes and wetlands 11: Forest 12: Grassland 13: Agricultural land 14: Artificial area 15: Wasteland
Building 1,2,3	Euclidean distance from building floors 1: 1-5 floors 2: 6-20 floors 3: 21 floors and above
Farmland	Euclidean distance from agricultural land
Streetlamp	Euclidean distance from streetlamp
Utility pole	Euclidean distance from utility pole
Elevation	Elevation

Chapter 3. Results

1. MaxENT results

1) Model performance

MaxENT AUC values of ≥0.70 are considered useful (Phillips and Dudik, 2008). The AUC values of rook distribution in the periods after sunrise (08:00–18:00) and after sunset (18:00–08:00) were ≥0.87 and ≥0.87, respectively; therefore, they indicated that the models had sufficient explanatory power (Figure 4).

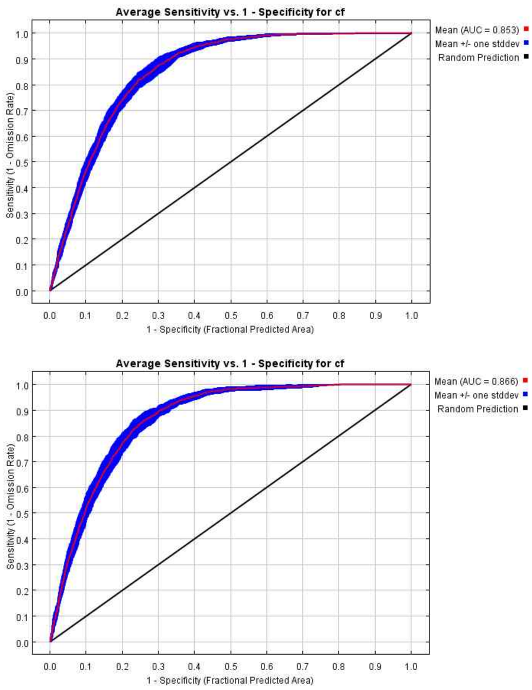

Figure 4. The receiver operating characteristic (ROC) curve for training and test data with the area under the curve (AUC) after sunrise and sunset

2) Species distribution map of *Corvus frugilegus*

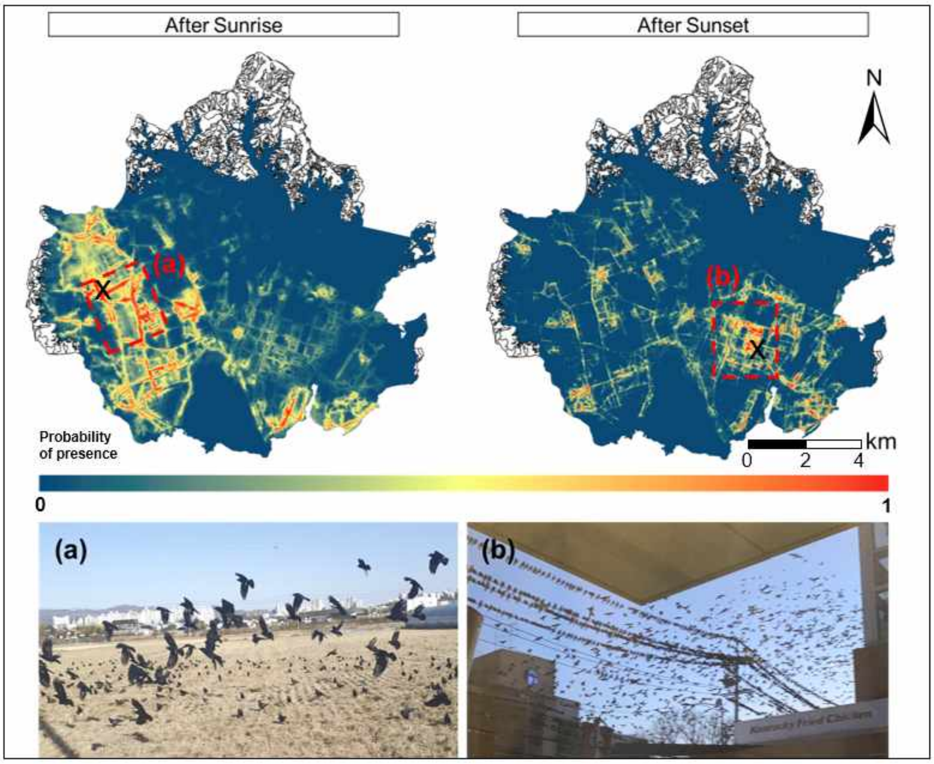

Figure 5. MaxENT results of *Corvus frugilegus* throughout Suwon after sunrise (08:00~18:00) and sunset (18:00-08:00), the locations of the pictures are marked as black “x“s: (a) sample crowd-sourced photograph collected on December 25, 2020 at 14:33 in the Gwonseon district, and (b) sample crowd-sourced photograph collected on January 3, 2021 at 07:23 in the Paldal district.

Suitable areas for rooks to inhabit after sunrise (08:00-18:00) near their foraging area were identified. Specifically, it was possible to predict the presence of rooks with high probability around cultivated land, traffic facilities, and streetlamps in east Suwon. In the period after sunset (18:00-08:00), the presence of rooks was predicted with high probability near Suwon City Hall, located in Ingye-dong, Paldal-gu, southwest of urban areas distant from their foraging area, and another suitable area was identified at the intersection near Suwon Station located in Maesan 1-ro, Paldal-gu, near the center of Suwon.

3) Environmental contributions to the presence of rooks after sunrise according to MaxENT results

1. Jackknife test results for the period after sunrise

According to Jackknife test variable importance, among the evaluated predictive models for the period after sunrise, the environmental variable with highest gain (i.e., the most useful variable) when used in isolation was Euclidean distance from farmland. The environmental variable that decreased the gain most when omitted was elevation, which apparently provides information that is not provided by other variables (Figure 6).

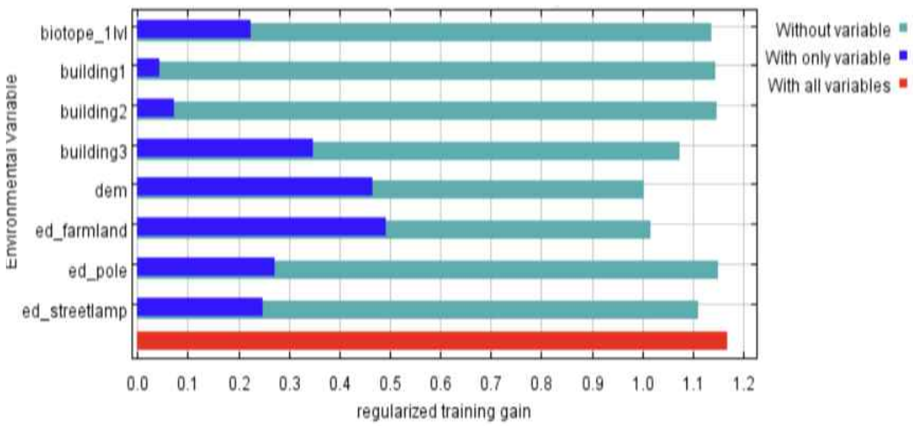

Figure 6. Results of jackknife test after sunrise of individual environmental variable importance for MaxEnt model.

2. Importance of environmental variables in the period after sunrise

The relative contributions of the top three environmental variables, i.e., Euclidean distance from agricultural land, elevation, and Euclidean distance from streetlamps, to the MaxENT model for the presence of rooks in the period after sunrise were 31.5%, 29.1%, and 12.8%, respectively.

[Table 5] Analysis of variable contributions of MaxENT after sunrise

Variable	Percent Contribution	Permutation Importance
Farmland	31.5	31.1
Elevation	29.1	42
Streetlamp	12.8	9.3
Building3	10.9	5.1
Pole	5.2	6
Building2	4.5	2.2
Land use	3.7	3.9
Building1	2.3	0.4

The probability of the appearance of rooks according to the Euclidean distance from farmland increased sharply to >60% at 0–100 m and 3,000–3500 m. Considering elevation, the probability of the appearance of rooks was ≥ 50%–55% between 25 and 30 m. Among the 15 land types, farmland had the highest contribution rate to the presence of rooks, which might be related to rooks moving to foraging areas after sunrise, which in Suwon were areas around agricultural land located in the west. The appearance of rooks after 08:00 decreased significantly to <15% when the distance from farmland was >100–500 m. Regarding the elevation, the probability of the appearance of rooks decreased to <45% in areas of >40 m, and the probability decreased to zero at >80 m. Therefore, rooks prefer a lower elevation range of <40 m.

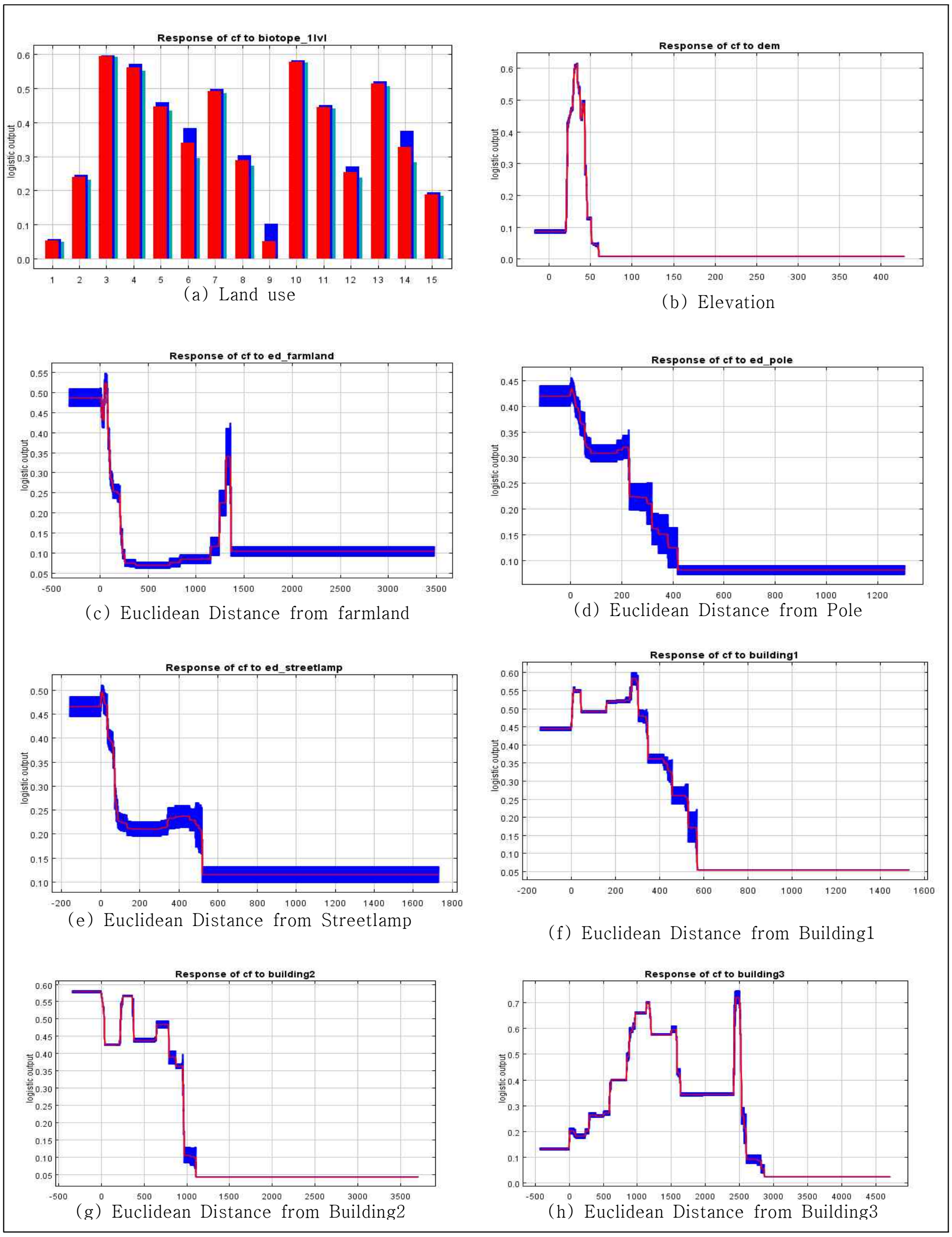

Figure 7. The response curves of environmental variables after Sunrise for *Corvus frugilegus* habitats distribution model.

The probability of the appearance of rooks according to the number of floors in a building increased to >62% around high-rise apartments (≥20 stories), indicating that a high number of high-rise apartments were located around agricultural land. However, more specific research is needed to determine whether rooks prefer cultivated land with high-rise buildings or the environmental variable of building height itself increased the probability of rooks appearing.

4) Environmental contributions to the presence of rooks after sunset according to MaxENT results

1. Jackknife test results for the period after sunset

The environmental variable with highest gain in predicting the presence of rooks after sunset was land use, which was the most useful variable when used in isolation. The environmental variable that most decreased the predictive gain when omitted was ed_pole, which appears to provide information not provided by other variables. Although many environmental variables were associated with the preferred habitat of rooks after sunset, the presence of a utility pole had the most influence on the probability of rooks appearing (Figure 8).

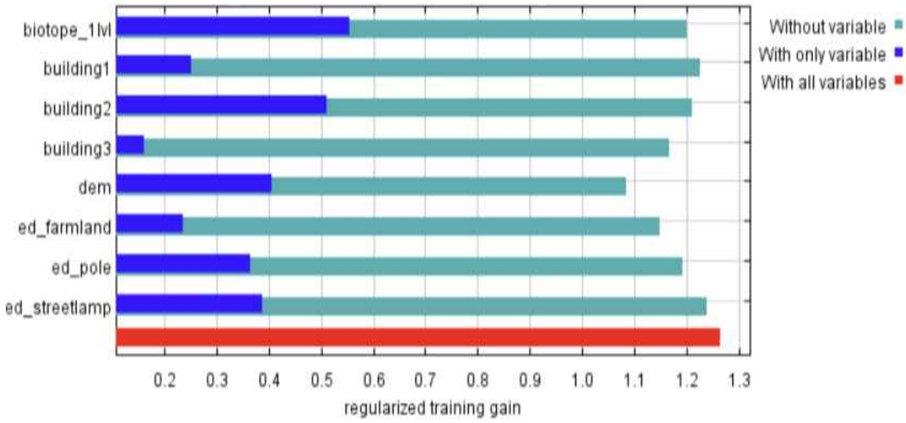

Figure 8. Results of jackknife test after sunset of individual environmental variable importance for MaxEnt model.

2. Importance of environmental variables in the period after sunset

The relative contribution rates of the top four environmental variables, i.e., Euclidean distance from buildings with 6-20 floors tall, land use, elevation, and Euclidean distance from a utility pole, to the MaxENT model for the appearance of rooks after sunset were 20.7%, 19.4%, 19.0%, and 14.5%, respectively (Table 6).

[Table 6] Analysis of variable contributions of MaxENT after sunset

Variable	Percent Contribution	Permutation Importance
Building2	20.7	12.2
Land use	19.4	11.7
Elevation	19	34.3
Pole	14.5	15.8
Farmland	9.7	7.5
Building3	7.9	4.5
Streetlamp	5.9	11.5
Building1	2.9	2.6

Among the 15 land use types, residential areas and mixed complex areas contributed >50% to predicting the presence of rooks. The probability of rooks appearing within 0–10 m of a utility pole was ≥55%, and the probability of rooks appearing decreased to ≤20% at a distance of >100 m (Figure 9). Unlike the preferred environmental variable for the presence of rooks after sunrise, distance from a utility pole was more important than the distance from a streetlamp, and the contribution percentage of the former

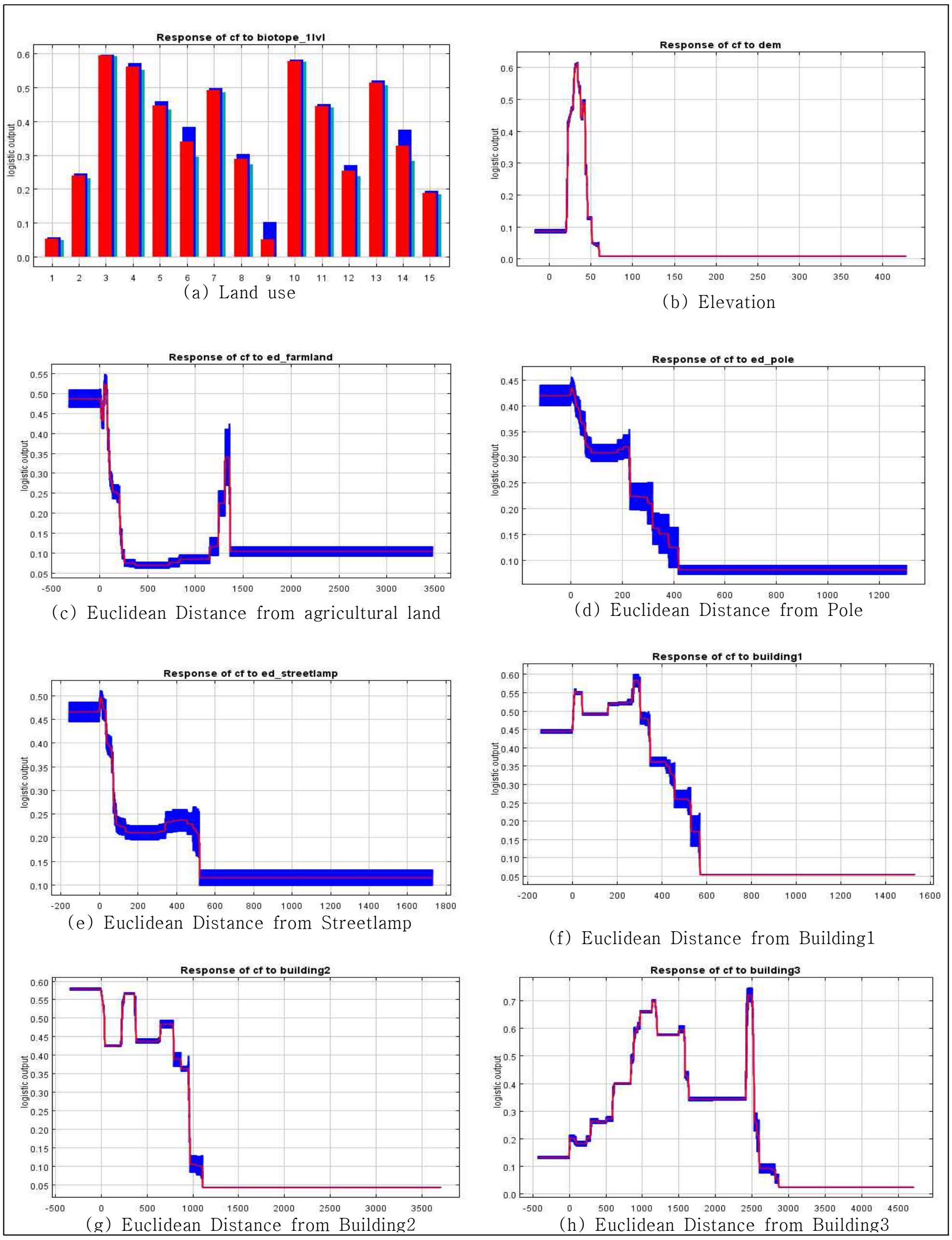

Figure 9. The response curves of environmental variables after Sunset for *Corvus frugilegus* habitats distribution model.

suggests that utility poles are crucial environmental variables for rooks. Previous studies have revealed that electric poles are often used by birds, including rooks and owls, that appear in urban areas to hunt (Dwyer et al., 2014), especially in areas with large areas of open space and few forests.

2. Differentiation in assemblage locations according to “real-time“ tracking data from citizen science participants

1) Assemblage pattern of *Corvus frugilegus*

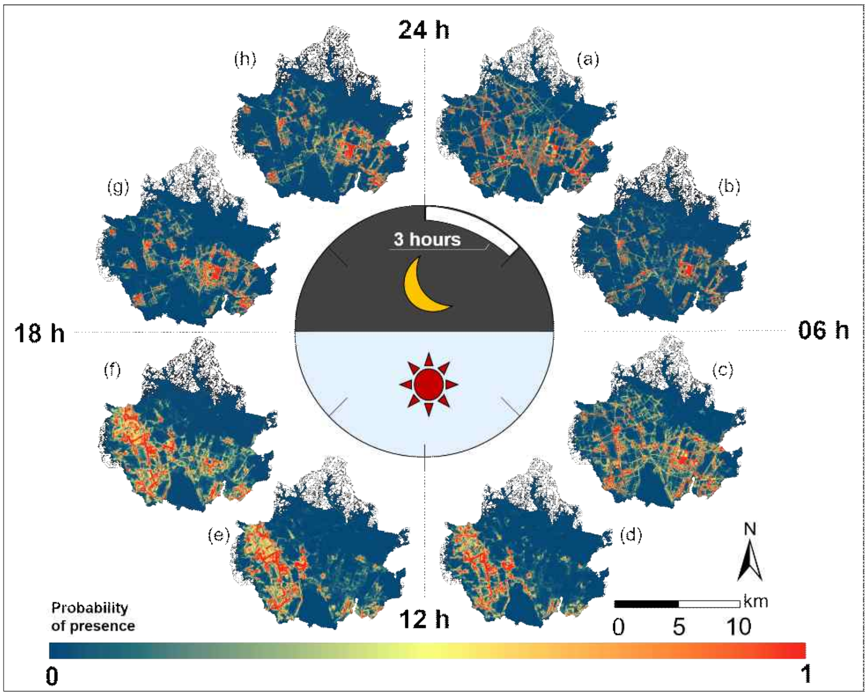

Figure 10. MaxENT-derived three-h interval distribution of Corvus frugilegus (a) 24:00-3:00, (b) 03:00-06:0, (c) 06:00-09:00, (d) 09:00-12:00, (e) 12:00-15:00, (f) 15:00-18:00, (g) 18:00-21:00, (h) 21:00-24:00 (AUC < 0.85).

Daily citizen science data from November to February indicated that rooks began moving to foraging areas in the Gwonseon district after 06:00. Agricultural land comprises 20.7% of this region in western Suwon (Figure 10c). After 09:00, presence probabilities of >0.8 were concentrated mainly in this agricultural land where rooks settled to forage until 18:00 (Figure 10d–f). Movement to urban areas occurred after 18:00 in the Paldal and Yeongtong districts, located in eastern Suwon, where mixed residential and business land use represents >20% of land use (Figure 10g–b).

Over 24 h, the habitat suitability map exhibited a gradual change in the location of rooks. Rooks assembled around arable land located west of Suwon after civil twilight faded, i.e., after sunrise (08:00) and gradually moved to the urban area located in the eastern part of Suwon after sunset (18:00) (Andre and Owens, 2021). The timing of rooks settling at foraging and roosting areas is mainly affected by light intensity, especially during winter (Swingland, 1976). Light levels in the afternoon stimulate the flight of rooks to their primary assemblage points (Harker, 1960). Moreover, departure from feeding areas occurs earlier under lower light intensity, which triggers rooks to gradually change their location after sunrise (Swingland, 1976).

Chapter 4. Discussion

1. Application of citizen science for tracking bird species in a noninvasive manner

Citizen science-derived data are often related to ecological problems in cities or those that directly affect citizens, thereby motivating the participation of citizens in science projects (Gallo and Waitt, 2011). Using citizen science, we collected 4,523 data point on the occurrence of rooks. These data enabled us to determine the favored environmental variables of rooks in Suwon, which resembled those in forests environments, i.e., they offered safety from external threats. We not only identified these variables but also the spatial distribution of rooks over 24 h. In traditional studies, such data could be acquired only using invasive methods, such as attaching GPS devices to birds (Byrkjedal et al., 2012; Ciach et al., 2017; Griffin et al., 2000).

The assemblage of rooks was limited to within 50-100 m of agricultural land after sunrise. The assemblage of rooks near agricultural land during the day is a well-known phenomenon, and their foraging area is dependent on the size and abundance of available resources (Griffin et al., 2000). Rooks favor foraging areas adjacent to streetlamps (i.e., at distances of 50-100 m) because artificial lighting improves their ability to detect food and increases foraging opportunities in illuminated areas (Clewley, 2016). Additionally, urban spaces, including commercial and domestic areas, are warmer environments, which are favored by rooks. For example, we observed a high probability of rooks appearing near Paldal in the southeast of Suwon, which is dominated by residential areas (Dwyer et al., 2014). After sunset, the distance from a utility pole was more important than the distance from streetlamps. Utility poles provide a long perching area that can accommodate a large population of rooks; thus, rooks prefer utility poles over streetlamps after sunset (Dwyer et al., 2014). Locations near buildings with 6-20 floors were favored by wintering rooks because such areas provide good protection from the wind (Gorenzel and Salmon, 1995). Rooks are known to favor rookeries close to forging areas; in the present study, the foraging area was most typically within a radius of 0.5-1.5 km from the rookery.

Our 24 h habitat suitability map revealed gradual changes in rook locations over time. Rooks assembled around agricultural land located west of Suwon after the remaining civil twilight faded. As mentioned previously, light intensity affects the timing of rooks settling behavior at their foraging and roosting areas, especially during winter (Andre and Owens, 2021).

2. Combining citizen science-based data on rooks with a laser deterrent method

We identified the daily assemblage patterns of rooks using citizen science data acquired without using invasive methods, and our data could be used to inform strategies for deterring corvids from cities or coexisting with these invading birds. In Suwon, rooks are discouraged from roosting in the city using the laser pointer method, an approach that was tested in Sunnyvale, California to counter rook invasions in urban areas (Kim, 2019; Picon, 2022). The laser pointer method disperses rooks via a green laser, which imitates the eye color of their predators. In Rochester, Minnesota, USA, researchers used laser pointers combined with recorded crow calls and an athletic starter gun to discourage American crows (*Corvus brachyrhynchos*) from roosting in downtown areas (Richert, 2019). In several other cities, including Sacramento and Hanford, California, USA, trained Harris's hawks (Parabuteo unicinctus) are guided by laser pointers to disperse groups of roosting crows. To develop an efficient eradication plan, several eradication priorities should be considered simultaneously. The inter-relationship between the predicted appearance of rooks and their actual appearance should be confirmed. Nevertheless, we postulate that combining citizen science data on the "real-time" occurrence of rooks over 24 h, analysis of environmental variables to predict the favored locations of rooks, and the laser pointer deterrence method will be an effective approach for eradicating rooks from an urban center.

Appendix

MaxENT percentage contribution and permutation importance for *Corvus frugilegus* for 3 hours interval (C: percent contribution, I: permutation importance).

	3-hour interval															
	24-03		03-06		06-09		09-12		12-15		15-18		18-21		21-24	
Variable	C	I	C	I	C	I	C	I	C	I	C	I	C	I	C	I
Land use	24.3	17.1	28.9	15.6	21.5	13.9	3.4	2.9	3.3	4.3	5.1	4.8	18.7	7.3	18.4	23.2
Building1	0.7	0.7	1.2	4.3	0.9	3.1	3.9	1.5	1.5	0.3	1.3	1.4	2.1	1.7	2.6	2.1
Building2	21.4	17.8	4.6	10.6	7.4	4.2	3.9	1.7	4.4	0.9	3.7	1.9	26.6	20.3	25.4	20.3
Building3	4.7	7.3	2.7	2.6	7.4	6.1	10.7	6.4	10.9	9.4	11.5	6	8.2	4.4	9.5	7.2
Elevation	18.4	15.9	15.1	13.6	20.7	44.5	25.5	37.6	26.9	35.1	30.5	46.2	18.7	32.7	16.1	28
Farmland	11	11.3	9.6	4.3	7.3	6.9	32.3	35.7	31.5	40.3	22.1	21.5	7.3	9.7	6.5	4.7
Utility pole	17.2	26.1	20.4	40.2	9.1	8.5	5.1	3.6	6.3	2.7	11.6	10.1	12.2	16.8	18	23.2
Streetlamp	2.4	3.8	17.3	8.7	25.7	12.9	15.2	10.5	15.3	7.1	14.2	8.2	6.2	7.1	3.5	3.9

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초 록

시민과학을 활용한 도심지에 출몰하는 떼까마귀 추적

윤 지 원

도심지가 제공하는 온난한 기후, 먹이원과의 높은 근접성, 포식자로부터의 안전한 환경 등의 조건들로 인해 도심지에 출몰하는 야생동물의 수가 매년 증가하고 있다. 이러한 야생동물 중 떼까마귀는 일몰 이후 시간대에 도심지로 출몰하여 전신주에 앉아 주차되어 있는 차량들 위에 배설물을 떨어트리는 등 소음과 위생적인 이유로 피해를 끼치고 있다. 수원시는 11월부터 3월까지 한국에 도래하는 떼까마귀(*Corvus frugilegus*)에 의한 피해가 증가하고 있다. 수원시에 2016년에 처음 나타나기 시작한 유해조류 떼까마귀는 소음과 배설물에 의한 지속적인 피해를 주고 있지만 선호하는 서식처에 대한 기초적인 자료가 부족한 실정으로, 본 연구에서는 수원시에 서식하는 떼까마귀의 구체적인 선호 서식처와 시간대별 이동 패턴 분석을 진행하고자 했다.

시민과학자는 과학조사의 일환으로 데이터를 수집 혹은 처리하는 자원봉사자의 개념으로, 이러한 시민과학자들이 참여하는 시민과학 프로젝트는 데이터 수집을 동일한 목표를 가지고 많은 사람들이 협업하여 만들어 내는 결과다. 최근에는 이러한 시민과학의 분야가 생태계와 환경과학 분야에서 관심이 급증하고 있는데, 이런 시민과학은 광범위한 지리적 지역에서의 자연 환경과 생물을 동시다발적으로 모니터링 할 수 있게하고 조사자가 겪는 물리적 한계와 지리적 범위에서의 경계를 극복시켰다. 지역 시민들의 경험지에

근거하는 시민과학 프로젝트는, 지역의 실질적인 환경 정책 결정과 실행에 직접적으로 도움을 주고 있고 이러한 데이터 구축을 통해 수원시 전역에 출현하는 떼까마귀의 위치를 동시다발적으로 파악하여 물리적, 지리적 범위를 극복할 수 있는 시민과학(Citizen Science)를 활용하였다. 시민과학의 4가지 단계 중 연구 비용과 연구 범위를 극대화할 수 있고, 시민들의 관심 고양과 교육을 촉진할 수 있는 '기여형 시민과학'을 적용하였다.

이러한 비침습적인 방법으로 취득된 떼까마귀의 출현 데이터는 3개월간 총 6,414장 의 사진이 수집되었으며, 이 중에 떼까마귀가 사진에 없어 부적합으로 판단된 데이터를 검수하여 총 5,214건이 추출되었다. 이후 수원 외곽지역의 산림의 경우 시민과학 데이터의 저조한 수집율을 고려하여 산림지역을 포함한 수원 이외의 지역에서 수집된 데이터를 제외하고 총 4,523점의 유효한 결과를 취득하였다. 결과적으로 떼까마귀는 수원 도심지로 일출을 맞춰 취식지로 이동하며, 도심지 출현은 일몰에 맞춰 이동하는 것으로 파악되었다. 또한 구축된 환경변수 중 층건물(6~20층)으로부터의 거리, 고도, 토지유형, 전신주의 유무가 중요한 변수로 파악되었다.

본 연구에서는 생태연구의 시공간 및 물리적 한계점을 극복하고자 시민과학의 자료를 활용하여 수원시의 떼까마귀 레이저 퇴치 우선지역 도출과 레이저 퇴치의 효율성을 입증하고자 했다. 시민과학을 통해 보존 가치가 높은 생물종을 연구하는 비중이 높지만, 본 연구를 통해 유해조수를 관리하는 방안으로도 제언이 가능함을 확인할 수 있었다. 향후, 시민과학의 활용 범위의 폭이 넓어짐에 따라 도심지역에서 나타나는 생태 현상에 대해 시민들과 해결방안을 함께 도출하며 이러한 참여율 증가는 장기적인 시민과학 데이터 취득으로 이어져 다양한 생태적 현상을 시민들과 함께 규명할 수 있을 것으로 기대된다.

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주요어 : 시민과학, 떼까마귀, 종분포모델, 도시생태, 조류 추적
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