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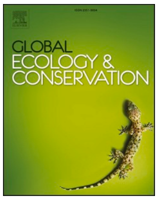

Original research article

Assessing *Corvus frugilegus* (Rook) habitat preferences through flock-size-specific species distribution modeling using citizen science data

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ABSTRACT

Urban environments face significant challenges due to the presence of large bird flocks, such as rooks (*Corvus frugilegus*), which contribute to sanitation issues and property damage. Using citizen science, we gathered extensive data on rook populations in Suwon, South Korea. Over two years, citizens submitted 17,923 photographs of rooks via a smartphone application, including the locations of sightings, enabling the collection of robust datasets without extensive training. Using the MaxENT model, we analyzed rook occurrences while differentiating by flock sizes—small ($\leq$100 individuals), medium (101–1000 individuals), and large ($>$1000 individuals). All models demonstrated high reliability, with AUC values exceeding 0.80. Our analysis revealed that large flocks predominantly occupied urban areas near agricultural lands, with a marked preference for close proximity, while small and medium flocks exhibited a more dispersed distribution. Furthermore, we aimed to analyze how much the Species Distribution Modeling (SDM) run with number of rook observations regardless of the flock sizes either overestimated or underestimated rook occurrence probabilities, when compared to the models run separately for each flock size. Notably, models based on the number of rook observations regardless of flock size significantly underestimated the habitat suitability for large flocks, underscoring the importance of incorporating flock size into predictive modeling. These findings emphasize the need for size-specific management strategies and highlight the utility of citizen science as a scalable tool for urban wildlife management.

1. Introduction

The increasing frequency of interactions and conflicts between humans and large flocks of birds in urban areas has heightened concerns about co-existence between wildlife and humans. Birds such as rooks (*Corvus frugilegus*), feral pigeons, blackbirds, and Canada geese have increasingly adapted to urban environments, forming large congregations that, while visually striking, can lead to property damage, contamination from droppings, and increased risk of disease transmission, posing significant challenges to urban wildlife management (Madge & Burn, 1994; Luniak, 2004).

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Among these species, the rook exhibits a particularly notable behavioral pattern: individuals begin to gather in flocks just before sunset as they move toward communal roosting sites, and before sunrise as they prepare for daily foraging (Höglund, 1985; Hattori et al., 2022). These crepuscular gatherings are typically synchronized and spatially predictable, making them especially relevant for urban planning and habitat modeling. Understanding this temporal dynamic is key for interpreting photographic observation data and structuring analytical procedures such as time-based data filtering

In Suwon, South Korea, large congregations of rooks have caused significant sanitation issues and operational disruptions for local businesses, underscoring the complexities involved in managing wildlife in densely populated urban areas (Kim, 2019). Traditional control measures, such as the laser deterrent method, habitat modification have faced criticism due to their questionable long-term effectiveness (Elbers et al., 2021; Werner and Clark, 2006). These challenges highlight the pressing need for innovative, balanced approaches that prioritize both human welfare and animal rights.

To effectively manage species that interfere with human activities, it is crucial to first identify hotspots where these conflicts are most pronounced (Treves et al., 2006; Broekhuis et al., 2017; Baynham-Herd et al., 2020). This process often relies on large-scale data collection, where citizen science initiatives can play a pivotal role. By encouraging public participation in monitoring bird distributions, citizen science provides valuable presence-absence (P/A) data while fostering community engagement in urban wildlife management. Such data can feed into Species Distribution Models (SDMs) to estimate species occurrence probability (p_occ). While SDMs are effective for estimating potential species occurrences, they do not directly measure population density (N), a critical parameter for designing effective management strategies (Araújo and Williams, 2000; Thuiller et al., 2009).

For broader population trend analyses, camera trapping is a widely used method. A practical approach assumes that the frequency of observations captured by camera traps correlates positively with abundance, offering a proxy for population density that reduces the need for exhaustive manual analysis (Twining et al., 2024; Rowcliffe et al., 2008; Weber et al., 2017; Brodie et al., 2022) However, camera trapping has its limitations when applied at an urban scale, particularly for highly mobile and social bird species like rooks. These limitations include difficulty in achieving spatial coverage representative of the entire urban area and the potential for behavioral adaptations by birds that may avoid or exploit camera trap locations, thus introducing biases in density estimates. Additionally, the complexity of urban environments can exacerbate these limitations by influencing bird movement patterns and habitat use in unpredictable ways.

Furthermore, the intrinsic growth rate of a population is often tied to environmental carrying capacity, which influences population dynamics in response to resource availability (Holt, 1997). In habitats where social behavior significantly affects habitat choice, monitoring local abundance is essential to understanding population dynamics. For semi-colonial or aggregated bird species, combining favorability and abundance models can effectively identify areas of conservation priority or concern (Brodie et al., 2022; Kushlan et al., 2002). Despite the importance of understanding the relationship between site-specific p_occ and population density (N), limited research has explored this across entire urban areas, particularly for bird species with large movement ranges. When spatial capacity is insufficient to support population density, competitive dynamics can alter habitat preferences, potentially decoupling the relationship between P/A models and density models (VanDerWal et al., 2009; Holt and Keitt, 2000). Integrating these models with ecological and demographic data can help bridge gaps in understanding population trends.

To better understand the spatial distribution and habitat preferences of rooks in urban environments, we aimed to analyze the differences between species distribution models (SDMs) based on all observation points and those incorporating flock size classifications (small, medium, and large). Using all observations without considering flock size treats all individuals equally, potentially overlooking critical distinctions in habitat use and population density. This approach can result in overestimation or underestimation of occurrence probabilities in specific areas, leading to inaccurate predictions and ineffective management strategies. Moreover, given the public visibility of the rook problem and high citizen awareness in Suwon, this city offers an ideal environment for implementing citizen science initiatives. Widespread familiarity with rook behavior facilitated untrained public participation in the photographic data collection campaign, which was further supported by national and local institutions.

This study aims to address these gaps by (1) identifying preferred habitats for rooks at different flock sizes across an urban scale and analyzing whether population density (N) can be inferred from presence-absence (P/A)data in urban settings. Specifically, this study evaluates (2) whether rook flock sizes display distinct habitat preferences and assesses the reliability of P/A data in reflecting population density within complex urban environments. Additionally, this research highlights the potential of citizen science as a cost-effective and scalable tool to support urban wildlife management, not only by enhancing data quality but also by diversifying data types—such as incorporating population density observations alongside P/A data—thereby enabling more comprehensive and effective modeling approaches.

2. Method

2.1. Study site

We conducted our study in the city of Suwon, Gyeonggi Province, South Korea (37° 17’ 28” N; 127° 0’ 32” E). The total area of Suwon, located in Gyeonggi Province, is 12204 ha. It ranks as the third most densely populated city within the province, accommodating around 0.10 million people per 1 hectare (Suwon, 2019). The western part of Suwon is mainly a rural area where rooks gather to forage, consisting of more than 81.31 % of Suwon’s total agricultural land (1198.56 ha). In contrast, the eastern part of Suwon is an urban area, covering over 45.90 % of total residential area of Suwon (2258.93 ha), also contains mixed residential and business area with urban parks in the surroundings where rooks mainly come to roost (Fig. 1). The arrival of rooks in Suwon begins in November, when the city experiences an average temperature of 7.9°C. During the winter period from November to the following

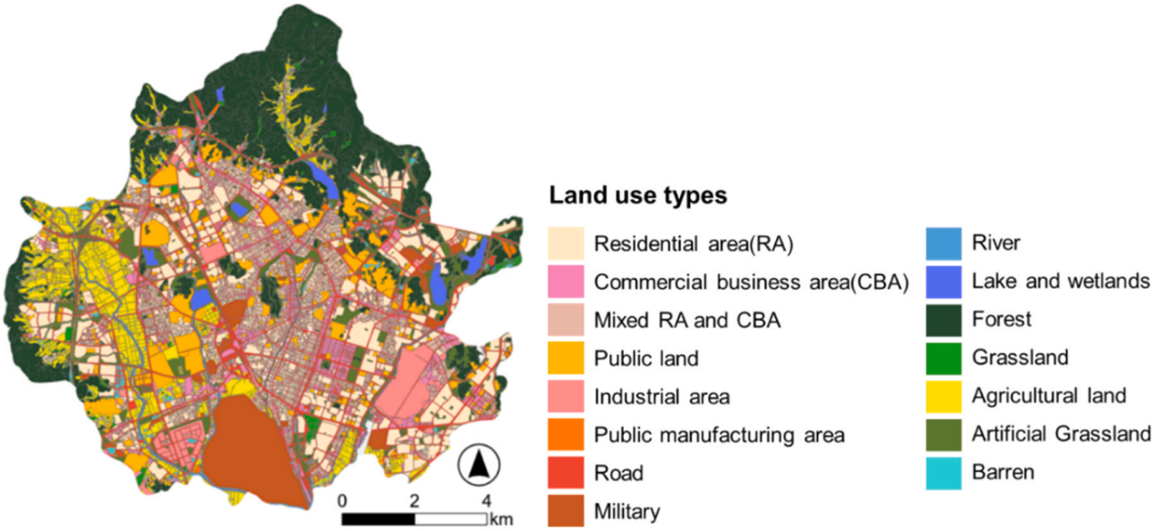

Fig. 1. Land use types of Suwon, South Korea.

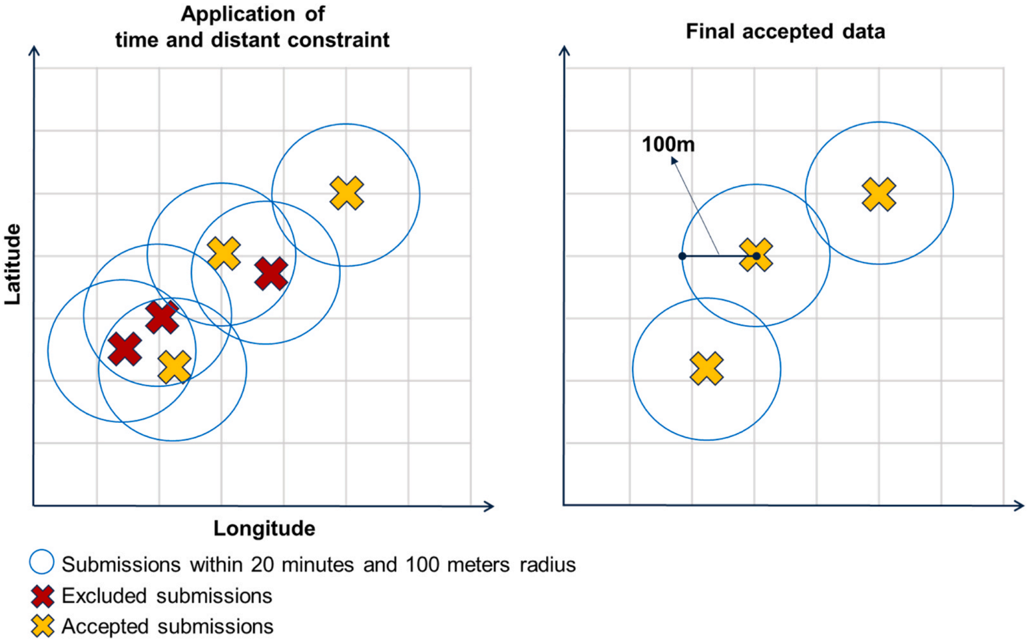

Fig. 2. Process of excluding rook sightings collected within 20 min and 100 m radius.

February, the average monthly precipitation is about 30.8 mm, with a total precipitation of approximately 123 mm for the entire period. (Suwon, 2022).

2.2. Study species

The study species, is *Corvus frugilegus*, commonly referred to as the rook. Originating from Europe, Asia, and parts of North Africa, rooks possess remarkable sociability, intelligence, and adaptability to various environments (Emery et al.,2007; Seed et al.,2008). Characterized by glossy black plumage and a distinct wedge-shaped tail, rooks exhibit versatile foraging behaviors and are particularly adept at exploiting both natural and anthropogenic food sources (Kasprzykowski, 2003; Höglund, 1985). In urban settings, rooks' plasticity in foraging and nesting strategies contributes to their successful colonization (Kowarik, 2008). Countries such as South Korea, Netherlands, USA(Minnesota) are suffering from large flocks of rooks invading urban areas intruding the city's sanitary issues.

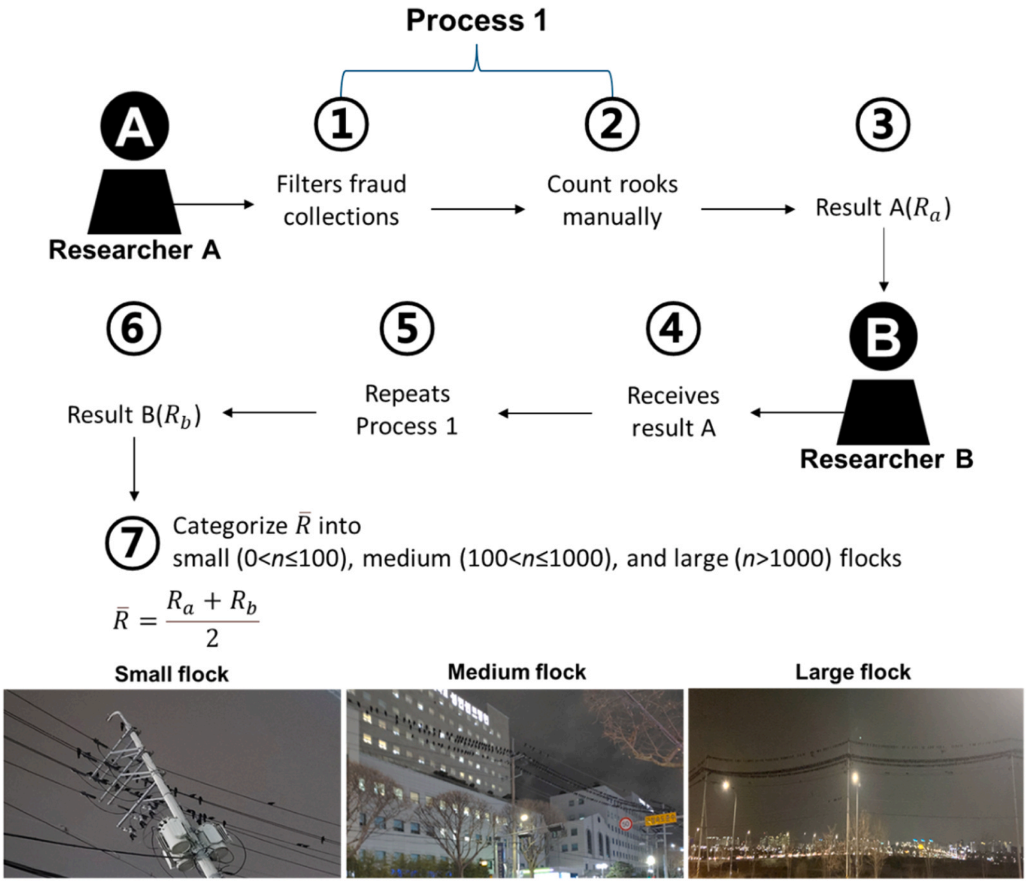

Fig. 3. Process of two researchers categorizing flocks into three flock sizes.

2.3. Citizen science

The issue of rooks disrupting Suwon's urban environment is well-documented and widely recognized throughout South Korea, attracting annual media attention. Images of large rook gatherings and their droppings on parked vehicles highlight the extent of their presence. This situation has persisted for over five years, making rooks a familiar sight to Suwon's residents. The community's familiarity with rook behavior and appearance further negated the need for preliminary training of study participants, enhancing the effectiveness of our citizen science approach. Due to the massive public interest in this issue, the South Korean Ministry of Environment, Suwon City Municipality, and local universities became actively involved in this campaign, lending their support and resources to the study.

We adopted a crowdsourcing approach without any training sessions which citizen scientist just have to take a picture of rooks—the most elementary among the four levels of citizen science which is known to facilitate participation of citizen science and is also one of the levels that requires lowest budget: level 1: crowdsourcing, level 2: distributed intelligence, level 3: participatory science, and level 4: extreme citizen science (Shum et al., 2012). To systematically document rook sightings, the CADA v.1.0.15 smartphone application (Kim, 2020) was employed, which the service location is limited within South Korea.

2.4. Data annotation and validation

To preserve data integrity and minimize redundancy, entries located within a 100 m radius spatial boundary and those collected within 20 min of a preceding report were excluded (Fig. 2).

The 100-meter spatial threshold was chosen to minimize overrepresentation of the same individual or flock due to the high spatial clustering common in urban bird sightings, and aligns with best practices for spatial thinning to reduce autocorrelation in species distribution modeling (Aiello-Lammens et al., 2015). The 20-minute temporal threshold, which is more conservative than the widely used 30-minute cutoff in camera-trap and opportunistic image studies (Sollmann, 2018), was adopted to ensure temporal independence, considering that rooks can traverse several kilometers in much shorter timespans.

A total of 17,923 rook sightings were reported in Suwon, comprising 6314 photographs from March 2020 to December 2021 and 11,609 photographs from March 2021 to December 2022, thereby covering a continuous observation period from March 2020 to

Table 1
Predictor variables used in the study.

Variable	Definition	Source
Land use type	Land use types 1. Residential area (RA) 2. Commercial and business area (CBA) 3. Mixed RA and CBA 4. Public land 5. Industrial area 6. Public manufacturing area 7. Road 8. Military 9. River 10. Lake and wetland 11. Forest 12. Grassland 13. Agricultural land 14. Artificial grassland 15. Barren	Suwon City Government. (2022) GIS dataset provided upon request
Building (low, medium, high)	Category of building floors low: 1–5 floors medium: 6–20 floors high: 21 floors and above	
Agricultural land	Euclidean distance from agricultural land	
Streetlamp	Euclidean distance from streetlamp	Data portal(www.data.go.kr)
Utility pole	Euclidean distance from utility pole	Korea electric power corporation
Elevation	Elevation	National territory information platform

December 2022. Rooks typically congregate in large groups of hundreds or thousands, making them easily distinguishable from other bird species even to untrained observers. Of these records, 2242 and 1792 observations from the first and second periods, respectively, were excluded due to being collected outside the administrative boundaries of Suwon. An additional 1653 records were filtered out through a two-step validation process: initial classification using a machine-learning model trained to detect rook, followed by manual review by two trained researchers. This procedure ensured the removal of irrelevant or low-quality data, including photographs depicting non-avian subjects (e.g., turtles, dogs), undetectably small or blurry individuals, or scenery images devoid of birds. In total, 5687 records were excluded from the final species distribution modeling data set to preserve data integrity. All remaining observations were verified to contain visible and confidently identified rooks. While mixed-species gatherings occasionally occur, empirical evidence suggests that such interspecific mingling does not significantly bias flock size categories (small, medium, large) (Jolles et al., 2013) This distinctive behavior significantly reduced the likelihood of misidentification and eliminated the need for participant training.

Rather than merely using the data collected through citizen science as presence data, this study utilized photographs to classify the flock size of the rooks, thereby allowing for the use of more sophisticated data. Due to the rooks' tendency to appear in urban areas at night and their black feather color, it was challenging to ensure counting their exact population. Therefore, in this study, two researchers were involved in manually classifying the rooks flock size in each photo to achieve accurate results. Each photograph was categorized into one of three flock size classifications: small ($0 < n \leq 100$), medium ($100 < n \leq 1000$), and large ($n > 1000$) (Haramis et al., 1985). The two evaluators who filtered out photos without rooks also categorized the flock sizes based on the pictures by manually counting them and as a result, each picture contained an average number of two counted data (Fig. 3).

2.5. *Processing maximum entropy model*

Building on existing literature, we identified a series of environmental factors responsible for the attraction of rooks to urban settings. Rooks primarily centered around human-introduced elements such as food accessibility, utility poles that enables them to gather and roost, wind shielding around the buildings, and the prevalence of green spaces (Byrkjedal et al., 2012; Ciach, Fröhlich, 2017; Clewley et al., 2015; Griffin et al., 2000, Yun et al., 2024). Based on the literature, we focused on 15 land use types and introduced an additional five variables. These included elevation, Euclidean distances from building floors (stratified into three categories: 1–5 floors, 6–20 floors, and 21 floors and above), and distances from agricultural lands, utility poles, and streetlights (Table 1).

To model these preferences, we employed the MaxENT software (version 3.4.4), using observed rook occurrences. To ensure the robustness of our model, we initiated a k-fold cross-validation process, with 'k' set to 10, and reserved a random 25 % subset of the data for testing in each cycle. Anticipating potential collinearity within our chosen environmental variables, we undertook a Pearson correlation analysis. This was designed to highlight and, if necessary, remove variables that displayed marked multicollinearity; however, none were identified in our dataset in the threshold $r = 0.08$. Addressing potential sampling biases, we implemented Suwon citizen's population density bias file for individuals aged 18 and above, spread across 5 × 5 m sectors in Suwon. Through this, we successfully optimized the model's sensitivity to areas with varied citizen densities (Kramer-Schadt et al., 2013).

Based on this methodology, species distribution model (SDM) results were derived for small, medium, and large populations of

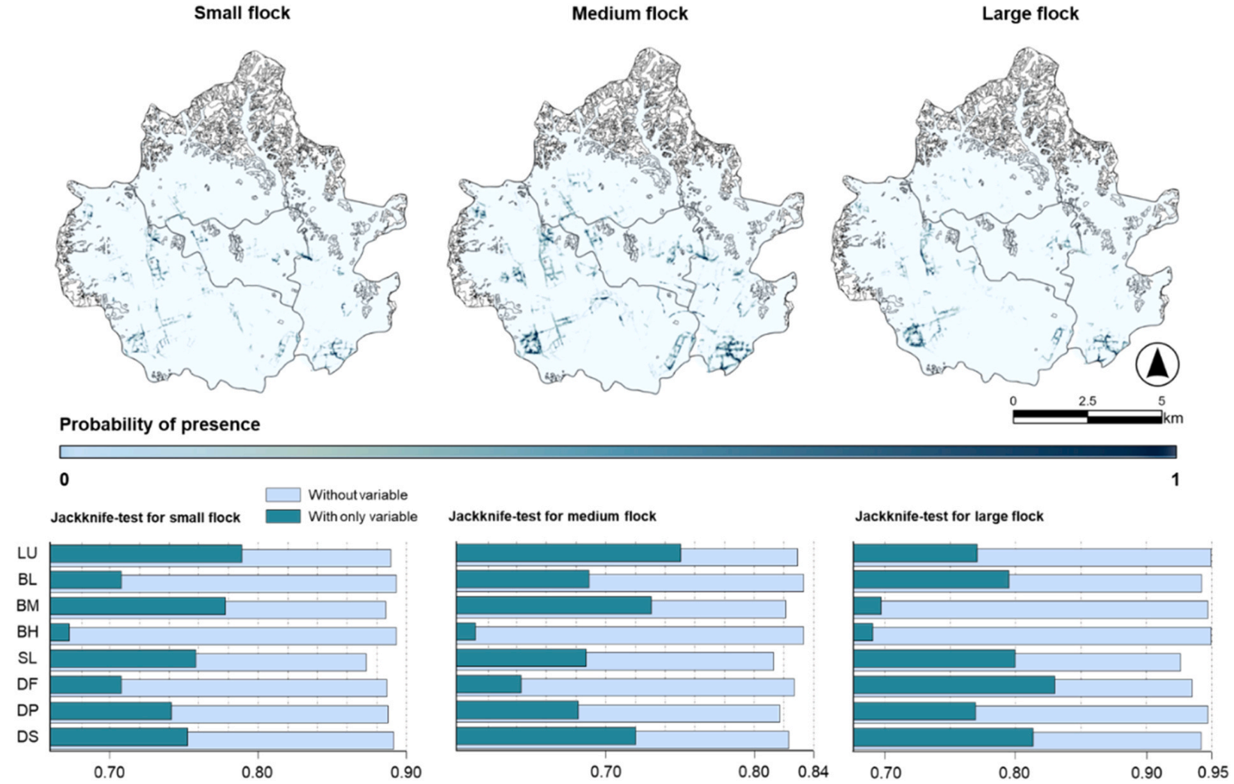

Fig. 4. MaxENT results and jack-knife test based on AUC results of different flocks of rooks (LU: Land use, BL: Building(low), BM: Building (Medium), BH: Building (High), SL: Elevation, DF: Distance from agricultural land, DP: Distance from utility pole, DS: Distance from streetlamp).

rooks (SDMs, SDMm, SDMl). An additional SDM using all observation points without flock size classification (SDMa) was also generated for comparison.

To assess the difference between the general model and the size-specific models, we subtracted the SDM result for each flock size (SDMs, SDMm, SDMl) from the all-observation SDM result (SDMa) to derive delta SDM (dSDM) values (Eq. 1). A positive dSDM value indicates that the size-specific SDM predicted higher probability than the general SDMa, implying that SDMa may underestimate rook presence in that area. Conversely, a negative dSDM indicates overestimation. Areas with dSDM values ≥ 0.5 were considered underestimated areas, and those with values ≤ -0.5 were considered overestimated areas.

$$dSDM = \text{SDM probability result with individual flock size} - \text{SDM probability result with all observation points} \qquad (1)$$

2.6. Analysis of differences in MaxENT results based on population and point count

To examine the occurrence probability differences between a species distribution model run with three population classifications and another model run based on the total point count, we calculated the dSDM and compared the differences in species occurrence probabilities between the overall point-based results and those derived from the three separate population clusters. We aimed to analyze how much the SDM run with all observation points either overestimated or underestimated rook occurrence probabilities when compared to the models run separately for each flock size.

To derive these results, we subtracted the occurrence probabilities generated for each flock size from those generated using the total points across Suwon City. We defined areas as underestimated if the probability increased by 0.5 or more when running the model with total points compared to individual flock sizes, and as overestimated if the probability decreased by 0.5 or more under the same conditions. This threshold of 0.5 was chosen based on its significance in species distribution modeling (SDM). In MaxENT models, the output probabilities typically range from 0 to 1, with 0.5 often serving as a neutral threshold to distinguish between high and low occurrence probabilities (Phillips et al., 2006). Probabilities above 0.5 generally indicate a higher likelihood of species occurrence, while values below 0.5 suggest the opposite (Liu et al., 2005). By using this threshold, we aimed to identify regions where occurrence probabilities were either substantially underestimated or overestimated, reflecting meaningful ecological differences.

Additionally, we employed two methods: kernel density estimation (KDE), which yields values based on geographical distribution of point and its density, and inverse distance weighting (IDW) interpolation, which produces results based on the attributes of the

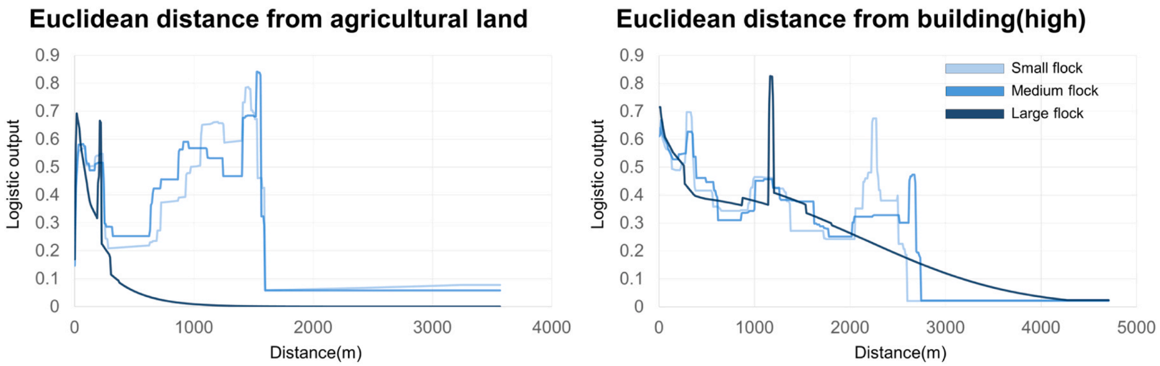

Fig. 5. Variables that showed the highest difference on logistic output of occurrence probability between small, medium and large flocks.

points (such as the population size of rooks). By comparing KDE and interpolation results after standardization, we can identify areas where the density (or probability of species occurrence) significantly differs based on these attributes. After standardizing both types of results, we subtract standardized KDE from standardized interpolation (DV) (Eq.2). We focused our analysis on areas where the DV values were most significant.

$$DV = standardized\ interpolation - standardized\ kernel\ density\ estimation \quad (2)$$

3. Result

3.1. Model performance

The AUC curve for the small flock is 0.895, for the medium flock is 0.846, and for the large flock is 0.950, which verifies the reliability of the model (Fig. 4).

3.2. Environmental variables influencing the occurrence probability of different sizes of rooks

The species distribution models were run separately for each flock size category, the most influential environmental variables affecting rook occurrence probability were found to differ across these models. Especially, the overall result of jack-knife test was similar between small and medium flock, whereas large flock showed distinguishing results. The presence of mid-rise buildings independently resulted in a high value for both small and medium flocks, indicating that this variable had a strong influence on predicting the distribution of these flock sizes. However, for large flocks, the presence of mid-rise buildings did not show significant importance. Conversely, the distance from high-rise buildings and agricultural land exhibited a high importance for large flocks, but it was not particularly influential for small and medium flocks. Moreover, when all variables were included in the model, the exclusion of the distance from agricultural land had the greatest impact on the species distribution results for large flocks after elevation. (Fig. 4).

Among the most notable differences were the distance from agricultural land and the presence of high-rise buildings. For small flocks, the highest occurrence rate (above 83.23 %) was observed at distances between 1000 and 2000 m from agricultural land. In contrast, large flocks showed higher occurrence rates (up to 69 %) at closer distances to agricultural land, with occurrence probabilities dropping below 50 % when the distance exceeded 80 m. Regarding high-rise buildings, large flocks exhibited a high probability of occurrence (over 80 %) at distances between 1000 and 2000 m. However, for medium and small flocks, the probability of occurrence ranged between 40 % and 70 % at distances between 2000 and 3000 m (Fig. 5), highlighting that large flock of rooks shows distinguishing preference over locations near agricultural land with high-rise buildings.

When the model was run by classifying the number of rooks into different flock sizes, the preferred environmental variables varied significantly across flock sizes. The jackknife test and variable contribution analysis revealed that the environmental preferences of small, medium, and large flocks were distinct (Fig. 4) and large flocks exhibited considerable shifts in variable importance compared to the smaller flocks (Fig. 5).

3.3. Comparison of species distribution model results

The SDM results based on the number of photos (data points) showed significant differences in rook occurrence probabilities when compared to the model using the number of individuals (flock sizes). Difference between occurrence probability was observed over 583 ha when comparing the results generated using only small flocks. Within this area, 582 ha were overestimated, while just 1 hectare was underestimated. The medium flock when compared to the SDM result run by the number of photos, showed differences across approximately 32 ha (Fig.6b-1). In contrast, the large flock exhibited a much larger discrepancy, with a significant difference

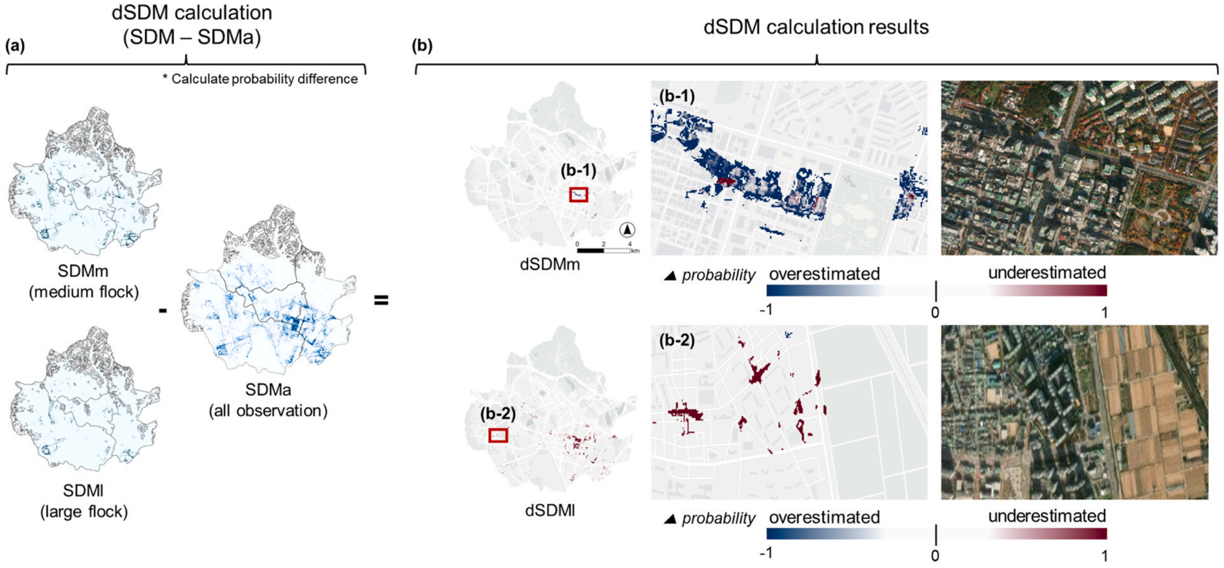

Fig. 6. dSDM calculation results using SDMm, SDMl and SDMa for under and overestimation analysis. (a) dSDM calculation method (SDM – SDMa); (b) dSDM calculation results. The areas that are closer to red color indicate regions where the existence probability were underestimated, and blue for overestimated; (b-1) overestimated of possibility of probability regions; (b-2) underestimated of possibility of probability regions.

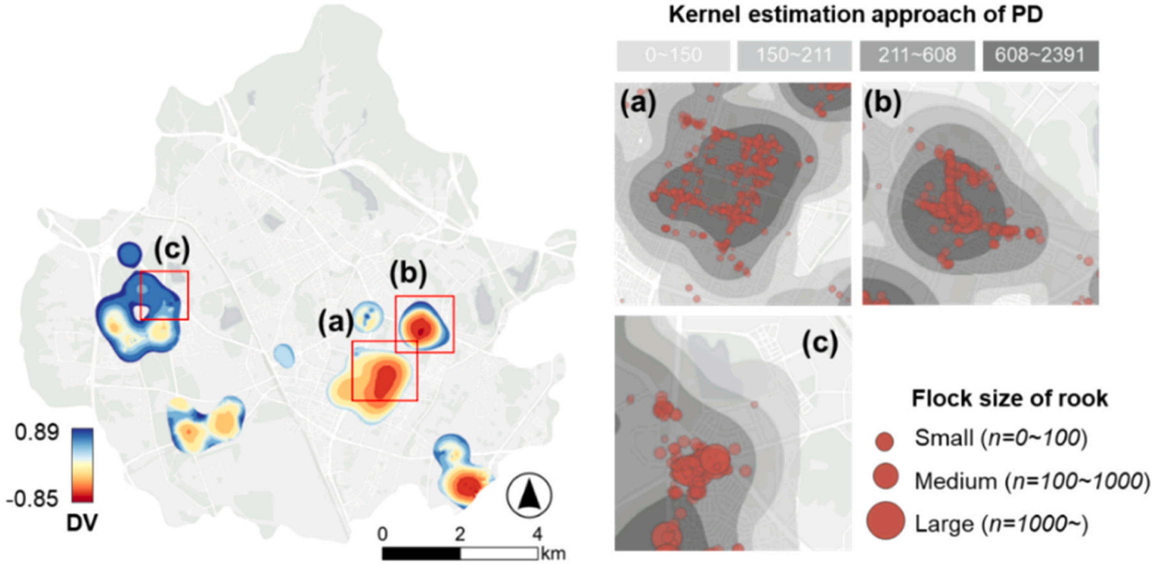

Fig. 7. Difference between standardized interpolation(IDW) of rook flock size and standardized kernel density(KDE) of presence-only data (DV = standardized IDW − standardized KDE).

spanning 2310 ha. Of these, 13 ha were overestimated, and the remaining 2297 ha—primarily located near agricultural land—were underestimated (Fig.6b-2).

The SDM results reveal that using the total number of photos (data points) compared to flock size-based models leads to notable differences in occurrence probabilities. Small and medium flocks showed relatively minor discrepancies, while large flocks displayed substantial underestimations in areas near agricultural land.

The total area where the occurrence probability of rooks was either underestimated or overestimated—when comparing the SDM results using the total occurrence data to those run for medium and large flocks—ranged from 500 to 2000 ha (Fig. 6). When we analyzed these regions, we examined both the actual number of rook observation points and the flock sizes represented by those points to identify patterns, we found a mismatch (warmer colors indicate areas where interpolated flock size (IDW) exceeds presence-only density (KDE), whereas cooler colors indicate the opposite) (Fig. 7). Specifically, areas that were overestimated had a large number of rook data points (608–2391 points), but the actual flock sizes within these points were smaller than expected (around 100–1000

Table 2
Correlation between distance from agricultural land and flock sizes of rook.

	Small	Medium	Large
Correlation analysis	0.07	0.06	−0.19
$\rho - value$	$\rho > 0.05$	$\rho > 0.05$	$\rho > 0.01$

individuals). On the other hand, in areas like the western part of Suwon, which is predominantly agricultural land, the underestimated regions had fewer rook data points (211−608), but these points represented much larger flock sizes (above 1000 individuals), consistent with the findings of the variable contribution analysis (Table 2, Fig. 7c).

This indicates that in some areas, although there were many observation points, the actual number of rooks in those photos was smaller, leading to overestimation in the model. Conversely, in regions where fewer points were collected, the flock sizes were significantly larger, leading to underestimation of rook occurrence.

4. Discussion

4.1. The necessity of division in flocks when managing large flocks of rooks

Our findings demonstrate that treating all rook observations equally can obscure critical differences between small and large flocks. Models based on total occurrence points tended to overestimate rook presence in areas with many small-group sightings, while underestimating it in areas where only a few sightings represented very large flocks (Fig. 6c) (Phillips et al., 2006). For example, predominantly agricultural regions in our study had relatively few observation points but harbored exceptionally large flocks (often >1000 birds per sighting), leading a unified model to under-predict rook occurrence there.

Conversely, urban areas with numerous sightings of small flocks were over-predicted by a non-stratified model. These biases underscore the importance of dividing data or weighting observations by flock size. In general, incorporating group size into species distribution models improves their accuracy, as it ensures that a single sighting of 1000 rooks contributes more to habitat suitability estimates than a sighting of 10 rooks (Kramer-Schadt et al., 2013). By separating our analyses by flock size classes, we revealed distinct habitat preferences that would otherwise be masked (Fig. 7), thereby providing a more reliable basis for management decisions.

From a management perspective, large congregations of rooks warrant special attention because of their unique ecological and social impacts. Large flocks have different resource needs and behaviors compared to scattered individuals or small groups (Newton, 1998). For instance, rooks breeding in cities can partially rely on urban food sources (lawns, waste), allowing small urban colonies to persist with less dependence on farmlands. In contrast, sustaining a flock of several hundred or thousand rooks requires extensive foraging habitat, which typically means nearby agricultural land (Hagemeijer & Blair, 1997; Tryjanowski et al., 2005).

These differences imply that management strategies should be flock-size specific. A “one-size-fits-all” approach might fail: measures effective for mitigating issues with solitary birds or small groups may be inadequate for large flocks that can overwhelm resources or cause significant crop damage (Redpath et al., 2013). Indeed, large rook flocks in farmlands have historically led to human–wildlife conflicts such as crop depredation and noise nuisance, prompting control measures like culling and nest removal in some regions (Benskin et al., 2009). Identifying and monitoring the sites of large rookeries or roosts is therefore crucial for proactive management. Our analysis supports this need by showing that flock size-specific modeling captures where these high-impact congregations occur, allowing wildlife managers to target interventions more effectively. In summary, dividing observations by flock size is not only statistically necessary for accurate modeling but also practically necessary for tailoring management to the scale of rook aggregations.

4.2. Distance of agricultural land being the most influential variable of large sized flocks of rooks

Among the environmental variables evaluated, distance to agricultural land emerged as the most influential factor determining the presence of large rook flocks in our study. Euclidean distance from streetlamp and utility pole maintained as a variable that influenced all the flock sizes and were shown to be the most important variable that influenced the occurrence probability when omitted in the past studies (Yun etal., 2024). However, large flocks exhibited a strong preference for areas close to farmlands, whereas small and medium flocks showed little to no relationship with this variable (Fig. 5; Table 2). This pattern was evident both in the jackknife test and in the MaxEnt model’s internal metrics (Phillips et al., 2006). The occurrence probability of large flocks increased as distance to farmland decreased, suggesting a strong spatial link between agricultural foraging grounds and large aggregations.

This result is consistent with existing ecological knowledge of rooks as farmland-dependent species. Previous studies have demonstrated that rook colonies are commonly located near pastures and spring crops, with larger colony sizes sustained in landscapes offering extensive and productive farmland (Griffin et al., 2000; Tryjanowski et al., 2005; Siriwardena et al., 2000). These habitats provide access to invertebrates and seeds, which are critical for supporting large numbers of individuals. Thus, distance to agricultural land in our model can be interpreted as a proxy for food availability, especially relevant for large flocks whose energetic demands are higher.

Additionally, the historical decline of rook populations in parts of Europe has been linked to changes in land use and the loss of traditional farming practices (Newton, 2004). Our finding reinforces that large roosting aggregations in urban settings are supported by the nearby availability of farmlands. Without such areas, large flocks may decline or disperse (Hattori et al., 2022).

Temporal patterns in our data also support the ecological importance of agricultural proximity. Large flocks appeared in urban

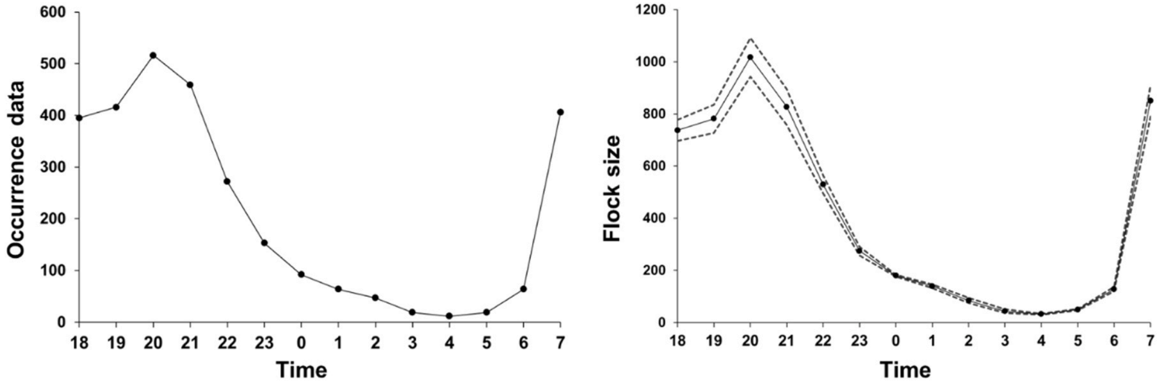

Fig. 8. Hourly collected number of occurrences point data of rook (left); mean number of rook individuals (right).

areas near farmland shortly after sunset and again at dawn, suggesting daily commuting between feeding and roosting sites (Fig. 8). Notably, by 10 PM, the flock sizes in urban areas far from agricultural land had reduced, confirming that large flocks prioritize areas near their feeding sites before dispersing. This behavior is well-documented in corvids, with rooks traveling several kilometers to forage during the day and returning to urban roosts at night (Homan & Linz, 2008; Hattori et al., 2022; Yun et al., 2024). Therefore, conservation and management plans should account for both the spatial and temporal dimensions of rook activity when addressing their impacts and habitat needs.

These findings not only highlight the importance of agricultural land proximity but also reveal the time of day when large flocks occupy specific regions. The synchronization of their movement with feeding and roosting schedules adds another layer of understanding to the management of large rook flocks, as their habitat preferences and movement patterns are influenced by both environmental and temporal factors.

5. Conclusion

This study successfully demonstrated the utility of citizen science in addressing challenges in urban wildlife management, focusing on the distribution and habitat preferences of large flocks of rooks in Suwon. By analyzing 17,923 citizen-reported sightings, the research provided an advanced understanding of flock-specific habitat preferences. The MaxENT model revealed that large flocks (over 1000 individuals) are predominantly found in urban areas adjacent to agricultural lands, with occurrence probabilities peaking above 0.69 at close distances. Additionally, the comparison of species distribution models (SDMs) revealed significant underestimations in the habitat suitability and occurrence probabilities for large flocks when using total observation points, emphasizing the importance of incorporating flock size into predictive modeling for more accurate urban wildlife management.

These findings underscore the critical need for population size-based species distribution models to enhance the management of large wildlife flocks in urban environments. By integrating ecological and demographic data, these models provide a more nuanced approach to targeting management efforts effectively. For example, this approach allows urban planners and wildlife managers to identify key conservation or intervention zones, enabling better resource allocation and minimizing human-wildlife conflicts by taking into account population size and the scale of associated impacts.

Ultimately, this study highlights the potential of combining citizen science with advanced modeling techniques to create scalable, cost-effective frameworks for urban wildlife management. By incorporating flock-specific data and refining the granularity of analysis, such methods can significantly enhance the management of large wildlife populations, ensuring both ecological balance and urban sustainability.

CRediT authorship contribution statement

Jiweon Yun: Writing – review & editing, Writing – original draft, Visualization, Methodology, Data curation, Conceptualization. **Youngkeun Song:** Writing – review & editing, Methodology, Conceptualization.

Declaration of Competing Interest

We, the authors, hereby declare that:

The work described in this manuscript has not been published previously in an academic thesis, or a registered report.

The manuscript is not under consideration for publication elsewhere.

The publication of this manuscript is approved by all co-authors as well as by the responsible authorities where the work was carried out.

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Data availability

Data will be made available on request.

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