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EDITED BY
Jie Gao,
Xinjiang Normal University, China

REVIEWED BY
Wenchen Song,
Minzu University of China, China
Xiaoxuan Du,
National Institute of Agricultural Science, Republic of Korea

*CORRESPONDENCE
Jiangshan Lai
lai@njfu.edu.cn
Jiajie Cao
caojiajie@njfu.edu.cn

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Landscape factors influencing bird nest site selection in urban green spaces

Zhenhui Ding[1], Ao Guo[1], Meng Lian[2], Yan Wang[3], Wenjia Ying[1], Hao Jiang[1], Xingyu Zhou[1], Cheng Qian[1], Jiangshan Lai[2]* and Jiajie Cao[1]*

[1]College of Landscape Architecture, Nanjing Forestry University, Nanjing, China, [2]College of Ecology and Environment, Nanjing Forestry University, Nanjing, China, [3]College of Art and Design, Nanjing Forestry University, Nanjing, China

Introduction: Understanding the birds' breeding strategies in urban habitats is vital for ensuring their continued existence. Therefore, more research must be conducted on bird breeding and urban adaptation strategies in urban green spaces. This study aimed to address this gap by investigating the influence of landscape factors on the selection of bird nest sites.

Methods: Data on the presence and absence of magpie (*Pica pica*) and gray magpie (*Cyanopica cyana*) nests were collected through field surveys conducted in the campus of Nanjing Forestry University during the 2023 breeding season. Generalized additive models (GAMs) incorporating landscape variables were employed to assess the effects of these predictors on nest occurrence. The model with the lowest Akaike's information criterion value was selected among the candidate GAMs.

Results: Below is a summary of the main results. Nest tree height (TH), distance from the central lawn (D), and tree coverage (TC) within the sampled area were identified as the primary landscape factors influencing nest site choice. Conversely, factors such as the shortest distance to the water source, herb coverage, shrub coverage, percentage of buildings, and percentage of hard pavement did not significantly impact on nest site selection. Furthermore, the nesting potential of magpies and grey magpies initially increased with tree height, reaching a maximum at ca. TH=25 meters after which it began to decline. The nesting occurrence rate showed an initial decrease tendency with increasing distance from the central lawn, reaching a minimum at D=400 meters, and then increased with further distance. Additionally, nesting potential decreased initially with increasing of TC in the range of 0–20%, fluctuated evenly between 20–60% TC, and decreased rapidly when TC exceeded 60%.

Discussion: This study provides valuable insights into the selection of nest sites by birds in urban habitats, specifically with respect to landscape factors. The understanding of the impact of urban green spaces on urban birds and the underlying mechanisms of their behavior contributes to the conservation of wild birds and promotes the harmonious development of urban areas.

KEYWORDS

landscape factors, magpie and gray magpie, nesting site selection, tree height, urban habitats

1 Introduction

Understanding the impact of the urban environment on wildlife is becoming increasingly urgent and important, as more and more species are settling in urban areas. Urbanization is an inevitable consequence of human economic and social development. The expansion of urban areas is considered to be one of the most important anthropogenic impacts on Earth's ecosystems (Foley et al., 2005), resulting in substantial alterations to natural habitat structure, ecosystem function and biodiversity (Gaston et al., 2010; Gil and Brumm, 2013; Forman, 2014). Numerous life-history strategies of animals have undergone modifications in response to the anthropogenic changes associated with urban environments (Arroyo-Solís et al., 2013; Kivelä et al., 2014). Urbanization presents numerous challenges for organisms due to extensive and dramatic changes in urban habitats, including replacement and fragmentation of natural vegetation, shifts in predators and food resources in communities, and increased human disturbance and pollution (Lowry et al., 2012; Sol et al., 2013). While high-density urbanization provides convenience for humans, high-density built environments have adverse effects on wildlife. Although urbanization often negatively affects some native species and even leads to their extinction (Soulé et al., 1988; McKinney, 2006; Husté and Boulinier, 2007; Sol et al., 2014), there are increasing total abundances of bird species that are successfully occupying and adapting to these new urban environments (Luniak, 2004; Francis and Chadwick, 2012).

The ecological habitats, distribution characteristics, and community structure of birds, as an important indicator species of the urban environment, constitute the main content of basic research on urban birds. Understanding urban birds and exploring the relationship between birds and the urban environment is based on the structure and dynamics of bird communities (Zheng et al., 2008). This study specifically focuses on the bird guild and community structure of cities, bird community surveys, bird community comparisons, and the seasonal or inter annual dynamics of urban bird community structure. A notable research topic is the comparison of bird communities in different urban green spaces or habitats (Zhang and Huang, 2018). Significant differences in bird diversity have been found between habitat types. The richness and diversity of bird communities in cities depend on the richness and diversity of the urban green spaces. The distribution of bird communities in urban green spaces is determined by the bioclimatic area, as well as the type and degree of urbanization (Clergeau et al., 2006). However, it is not necessarily the case that the maximum richness and diversity of bird communities are achieved in less urbanized areas (Jokimäki and Suhonen, 1993; Carbó-Ramírez and Zuria, 2011). Bird communities select habitats of different degrees of urbanization according to their habits. For instance, anthropophilic species take advantage of human activities in highly urbanized areas, while bird species inhabiting agroforestry vegetation are present in low urbanized areas (Burger et al., 2004; Marzluff and Rodewald, 2008; Parker and Nilon, 2012).

The design and management of urban green spaces play a vital role in determining the diversity and richness of bird communities. Two key factors that affect these communities are the composition and structure of the vegetation within these spaces (MacGregor-Fors and Schondube, 2011). On the one hand, the composition of plant communities is closely related to bird diversity (James and Wamer, 1982; Huang et al., 2015). The researchers found significant correlations between the heterogeneity and abundance of trees with the richness and density of birds. This study also revealed a positive correlation between bird diversity and richness of flowering plants (Blinkova and Shupova, 2017). On the other hand, the volume and density of plants in urban green areas positively impact bird richness and diversity (Savard et al., 2000; Mella and Loutit, 2007). Therefore, thinning of trees and shrubs is counterproductive (Camprodon and Brotons, 2006). Inappropriate vegetation structure in urban green spaces can also lead to a further reduction in bird diversity (Ge et al., 2005; Xu et al., 2007; Yang et al., 2015). Therefore, by providing suitable microclimates, refuges, abundant food resources, and nesting areas with reduced competition and predation, urban green spaces offer birds agreeable living conditions (Magre et al., 2019).

Among these elements, trees are considered as one of the most important elements to increase bird richness and diversity in urban green spaces (Palomino and Carrascal, 2006; Yang et al., 2015; Weaving et al., 2016). Tree canopies provide sheltering, nesting sites and feeding opportunities (Munyenyembe et al., 1989). Specially, birds use dense tree canopies, tree trunk with holes and branches that produce fruits or seeds. The presence of these resources for bird' refuge, nesting and breeding promotes the access of adjacent flora and fauna into the urban green spaces (Boada and Sánchez, 2012). In summary, promoting urban green management actions that lead to a suitable composition and structure of vegetation in cities can potentially enhance the diversity and richness of birds residing in these areas (Camprodon and Brotons, 2006; Shanahan et al., 2011).

Urbanization has brought about changes in the resources upon which birds depend, such as habitat types and availability (Camprodon and Brotons, 2006; Ibáñez-Álamo and Soler, 2010). To survive and breed successfully in urban environments, birds have had to adapt to trade-offs between the pressures specific to urban settings and the benefits that these new habitats offer (Grinnell, 1924; Wang et al., 2015). Species living in urban environments have to adapt their behavior and life histories to the new environment. Urbanization has resulted in differences in genetic, reproductive and ecological characteristics of bird populations compared to those found in natural habitats (Luniak and Mulsow, 1988; Partecke et al., 2004; Wysocki, 2004; Partecke et al., 2006). Breeding, as the most critical stage in a bird's life history, is an important issue for birds in adapting to the disturbances of the urban environment and successfully breeding their offspring (Meillère et al., 2015). Adaptations in nesting behaviour reflect the ability of birds to adapt to urban ecosystems and have been demonstrated in a variety of bird species (Luniak, 2004; Wang et al., 2009). Nest site selection is a significant aspect of breeding as it minimizes the impact of natural predators, disturbance from similar species, and other factors, thus enhancing breeding success. It is an important means by which birds can adapt to a complex and changing environment (Lack,

1969). Various environmental features can influence nest site selection, which in turn affects bird survival, breeding, and adaptation (Kivelä et al., 2014; Sepp et al., 2018).

Despite the increasing knowledge about urban nesting behavior, there is still relatively little understanding of the predictability of nesting behavioral shifts in urban areas. Most studies on the richness and diversity of birds in urban environments primarily focus on investigating e breeding success by analyzing nest depredation rates. These studies have shown that nest depredation rates tend to be higher when nests are associated with specific mammals and predatory birds (Miller et al., 1998; Matthews et al., 1999; Jokimäki and Huhta, 2000; Phillips et al., 2005; Reale and Blair, 2005; Bakermans and Rodewald, 2006; Burhans and Thompson, 2006; Smith-Castro, 2008). In Mediterranean cities, cats (Stracey, 2011) and magpies (Bonnington et al., 2015) are the main cause of nest depredation. However, the only magpie species found in urban areas (*Pica pica*) actually prefers nearby rural areas (Andren, 1992). Other studies conducted in peri-urban areas have found that nests located at low heights experience higher rates of depredation due to the influx of domestic animals (Miller et al., 1998), while those at higher heights remain better conserved (Smith-Castro, 2008). Nonetheless, research on the effects of specific landscape factors on bird nesting in urban green spaces is limited.

The main objective of this paper is to test the influence of various landscape factors associated with urban habitats on the selection of nest sites for magpie and gray magpies in green spaces on the campus of Nanjing Forestry University. A field survey was conducted during the 2023 breeding season, resulting in a collection of 152 presence–absence data points. Generalized additive models (GAMs) (Hastie and Tibshirani, 1987; Wood, 2004) were employed to assess the effects of landscape variables on the occurrence of nests. The possibilities of bird nest site selection were compared and analyzed in relation to different landscape factors. These models incorporated various predictor variables related to the surrounding landscape. To determine the best model, several candidate GAMs were employed, considering all significant predictor variables and selecting the model with the lowest Akaike's information criterion (AIC) value. The findings of this study may serve as a valuable tool for urban green managers and technicians aiming to enhance urban biodiversity. Furthermore, the study contributes to a deeper understanding of the mechanisms through which birds adapt to urbanized habitats.

2 Materials and methods

2.1 Study sites

Nanjing, residing in the southwestern part of Jiangsu Province, at the central region of the lower Yangtze River, is located between 31°14′N to 32°37′N latitude and 118°22′E to 119°14′E longitude. The city experiences a subtropical monsoon climate, characterized by four distinct seasons. It has cold winters and hot summers, with abundant precipitation resulting in an average annual rainfall of 1005.9mm, and a relative humidity average of 76%. The city encounters maximum wind speeds reaching up to 25 m/s, with prevailing winds originating from the southeast and east during the summer months, and from the northeast and east during winter. The annual absolute minimum temperature plunges to −14°C, while the annual absolute maximum temperature reaches 43°C. The yearly average temperature is recorded at 15.7°C, with the coldest month averaging at −1.5°C, and the hottest month averaging at 28.1°C (Wang et al., 2016). In fact, Nanjing holds significant importance as an essential node in the East Asia–Australasia bird migration route. Additionally, Nanjing's geographic location, particularly its proximity to the lower Yangtze River and Xuanwu Lake, makes it an important wintering site for various waterfowl species.

Field work was conducted on the Xinzhuang campus of Nanjing Forestry University (NJFU), which covers an area of 83.8 hectares with a green space ratio of 53.8% and a green coverage of 78% (Wang et al., 2016). The campus is well endowed with natural resources, including a large number of large and long-standing trees and a water system connecting the various landscape spaces, resulting in a high degree of habitat continuity and a rich variety of habitat types. It is surrounded by an urban matrix including commercial development, residential communities, and urban green space (Figure 1). Moreover, the campus has a close relationship with the core areas of Nanjing's main urban area, Zijin Mountain and Xuanwu Lake, and is located between these core habitat sources (Ding et al., 2023). As a result, it is considered one of the larger urban forests in Nanjing. The known flora of the campus forest consists of 603 species (including subspecies and varieties) in 91 families, showing a high species richness. The campus also exhibits a variety of vegetation types, with the natural secondary forest dominated by deciduous broad-leaved and mixed evergreen and deciduous broad-leaved forests, while the planted forest consists of fewer plant species and a simpler hierarchy with a single species of street trees. In terms of species diversity, the herbaceous layer shows the highest diversity, followed by the shrub layer and the tree layer. The campus is particularly rich in herbaceous plants. The available records indicate the presence of 70 bird species from 29 families, including both resident and migratory species. Among them, magpie (*Pica pica*) and grey magpie (*Cyanopica cyana*), belonging to the family Corvidae, and included in the IUCN Red List, are the most widespread species in the study area. They are ideal species to study the relationship between landscape factors and urban nesting preference. The areas of observation activity mainly focus on open sites where birds are in close contact with human activity.

2.2 Field methods

The field survey was conducted during the spring of 2023, spanning from February to July, which coincided with the breeding season. The primary objective of the survey was to investigate the landscape factors that influence nest site selection. The survey covered the entire campus area, and all nests within the sample area were located and recorded. Weekly nest site surveys were repeated to identify new nests, based on the

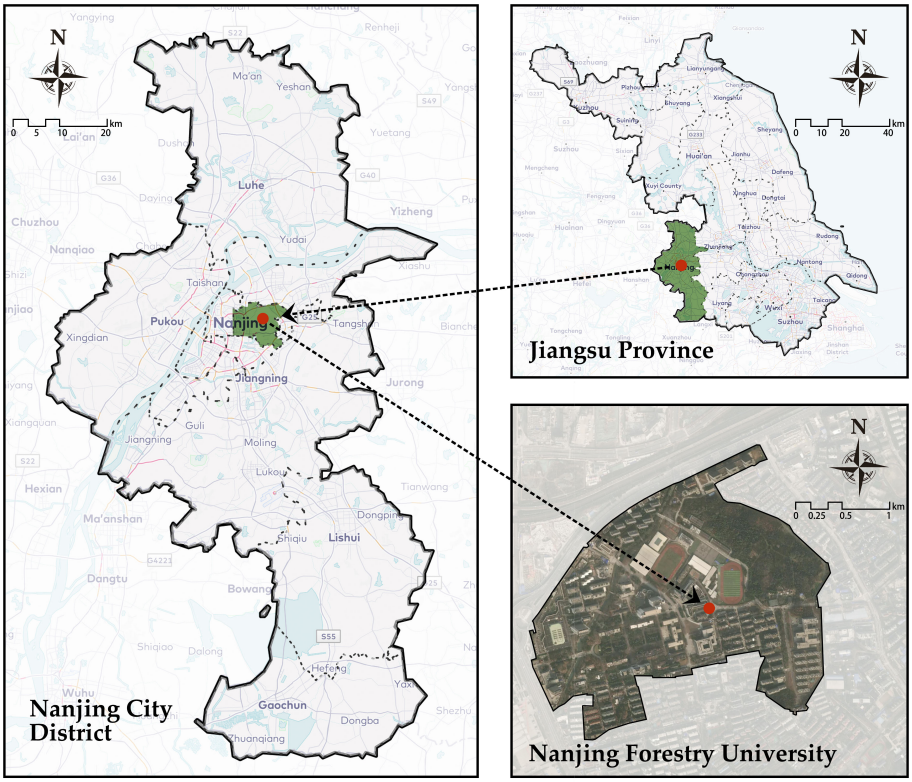

FIGURE 1
Schematic of study area: Nanjing Forestry University.

characteristics of the birds' life history and breeding processes in the study area. The survey was conducted in favorable weather between 09:00 and 16:00, using binoculars, a DJI Mavic air drone, and a digital camera for observation and photography (Gao et al., 2014). Upon the initial discovery of a new nest, the bird species occupying the nest was identified and the latitude, longitude, and altitude of the nest were recorded using a handheld GPS (eTrex30, Garmin, China). After nesting concluded, these sites were revisited to identify the vegetation of nesting substrate. The current usage status of each nest site was ensured through a minimum of 30 minutes of observation in the vicinity of the nest site. The center of the nesting trees was selected, and a 50 m×50 m square sample plot was used as a standard plot to count the area surrounding the sample square. Moreover, various landscape factors within the presence–absence sample square of the nest site was measured and recorded. This study collected a total of eight landscape factors that are related to bird nest site selection (see Table S1).

2.3 Statistical analysis

In order to explore the impact of landscape architecture elements on bird nest site selection in urban habitats, we employed semi-parametric generalized additive models with a logit link function (Hastie and Tibshirani, 1987; Wood, 2004). These models were utilized to analyze the effects of eight landscape variables on 152 presence–absence data points (Y=1 or 0) at each site. The landscape variables considered were tree height (TH), distance from the central lawn (D), tree coverage (TC), shortest distance to the water source, herbaceous coverage, shrub coverage, percentage of buildings, and percentage of hard pavement. Non-significant landscape variables were removed, and candidate GAMs (Table S2) were constructed using the remaining significant landscape variables. The model with the lowest Akaike's Information Criterion (AIC) value was selected as the best model. To assess the nonlinear effects of each landscape variable on the occurrence of bird nest selection, we examined the partial residual plots of these variables within the best model. The 'gam' function in the 'mgcv' package (version 1.8-40; Wood, 2004) was used to carried out the GAM fit.

3 Results

3.1 Bird's nest distribution characteristics

During the 2023 breeding season in Nanjing Forestry University, a comprehensive survey on the campus identified a total of 76 nests attributed to magpie and grey magpie (Figure 2). These nests were exclusively located in trees and were continuously monitored throughout the breeding season for subsequent statistical analysis. Among the 76 nests, the predominant nesting tree species were *Metasequoia glyptostroboides*, *Platanus acerifolia*,

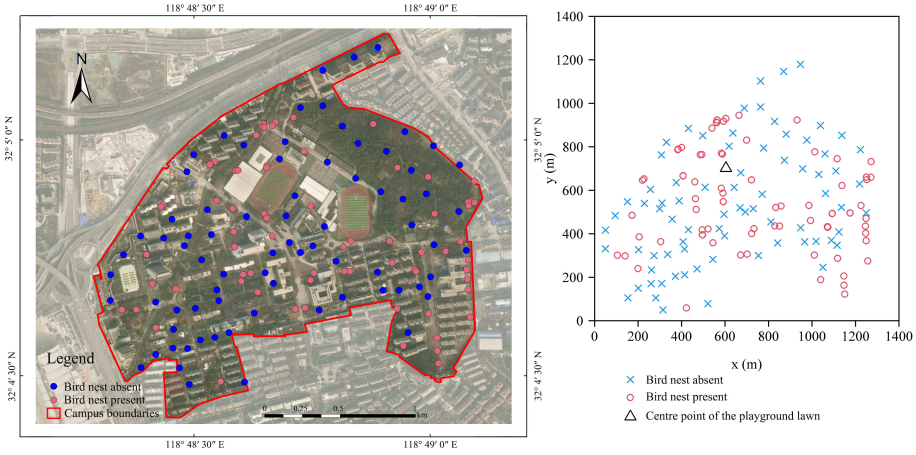

FIGURE 2
Spatial distribution of bird nests (presence–absence) at Nanjing Forestry University.

Pterocarya stenoptera, *Populus euramevicana*, and *Liquidambar formosana*, which collectively accounted for 60.54% of the total nests. Specifically, *Metasequoia glyptostroboides* accounted for 17.11% of the nests, while *Platanus acerifolia* and *Pterocarya stenoptera* accounted for 13.16%, *Populus euramevicana* accounted for 9.21%, and *Liquidambar formosana* accounted for 7.89% (Figure 3). Additionally, nests of magpies and grey magpies were found in various tree species, including representatives from Fagaceae, Magnoliaceae, Sapindaceae, Hamamelidaceae, Ginkgoaceae, Pinaceae, and Lauraceae families. The average height of trees hosting nests was determined to be 19.43 m, ranging from a minimum of 7.7 m to a maximum of 30.00 m. The average nest height was 16.86 m, with the highest nest recorded at 27 m and the lowest at 6.8 m. The minimum distance of nests from water sources was measured to be 171.85 m. Notably, the selection of nest sites for magpies and grey magpies in the sampled locations did not show a significant relationship with the type of nest tree. The majority of the nesting trees belonged to the Taxodiaceae and Salicaceae families, collectively representing 36.85% of all nesting trees, with the Taxodiaceae family accounting for 18.43% and the Salicaceae family accounting for 18.42%.

3.2 Effect of landscape variables on nest site selection

Model 4[y ~ s(TH) + s(d) + s(TC); AIC=183.64] (see Table S2) had the lowest AIC value among the seven candidate GAMs tested, thus it was chosen as the best model. The results of model 4

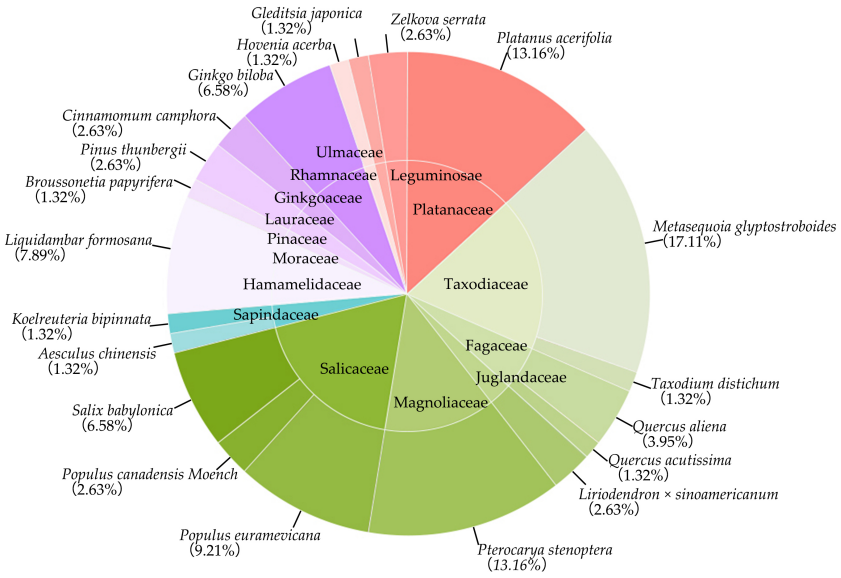

FIGURE 3
Composition and proportion of nesting tree species.

indicated significant effects of TH, D, TC on the occurrence of bird nest selection.

The odds of nesting by magpies and grey magpies exhibited a notable non-linear relationship with tree height, as illustrated in Figure 4. Initially, there was an upward trend in nesting probability with increasing tree height, reaching its peak at 25 m. However, beyond this point, the odds of nesting started to decline, indicating a diminishing trend. Moreover, as illustrated in Figure 4A, higher tree heights were found to inhibit nesting frequency.

Figure 4B presents the influence of distance (D) from the central lawn of the playground on nest emergence odds. Initially, an increase in distance hindered nest emergence, but as the distance increased further, it began to promote nest emergence. The odds of nesting exhibited an initial decrease with increasing distance from the central lawn, reaching its minimum at D=400. Beyond this threshold, the odds of nesting started to increase with distance. The impact of tree coverage on nesting potential is clearly demonstrated in Figure 4C. It displayed an overall decreasing trend with some fluctuations, eventually leading to a sharp decline. The odds of nesting decreased as tree coverage increased from 0–20%, remained relatively stable between 20–60%, and then experienced a rapid decline for coverage exceeding 60%. Figure 4 demonstrates that the three primary influencing factors (tree height, distance from the central lawn, and tree coverage) exhibited significant non-linear relationships with the odds of nesting, displaying distinct phases of fluctuation.

4 Discussion

Urban environments pose significant challenges to species adapted to natural ecosystems due to high population densities (Kight and Swaddle, 2007), intense artificial light (Dominoni et al., 2013; Gaston et al., 2013), chemical pollution (Hui, 2002), noise levels (Slabbekoorn and Ripmeester, 2008), and fragmented habitats (Grimm et al., 2008; Alberti et al., 2017; Johnson and Munshi-South, 2017). Successful nesting and breeding of bird species in urban habitats depend on the trade-offs they make between inputs and benefits in these environments. In this study conducted on the campus, 76 tree nests belonging to magpies and grey magpies were identified and analyzed. The results revealed no significant preference for specific tree species, but tree height, distance from the central lawn of the playground, and tree coverage emerged as the main factors influencing nest site selection. Nest site selection in urban habitats can be influenced by predator habits. Birds in cities have adapted their nesting strategies to mitigate predation risks, employing various tactics to minimize breeding losses. The findings of this study indicate that optimal nesting sites for magpies and grey magpies on campus were characterized by a tree height of 25 m, proximity to the central lawn of the playground, and tree coverage below 60%. Choosing such locations helps reduce the risk of predation during breeding, leading to successful reproduction. Several factors may contribute to the observed optimal strategy. Nesting at greater heights reduces the detection chances by ground predators such as snakes and rodents, as accessing higher nest locations becomes more challenging for these predators. (Rendell and Robertson, 1989). However, nests situated above 25 m height become vulnerable to aerial predators, which can lead to reproductive failure. Notably, the absence of the crested eagle (Cao et al., 2023), a known aerial predator of magpies and grey magpies, in previous studies conducted at Southern Forest University supports this finding. The nest site selection model of this study further suggests that the odds of nest site selection increases with increasing tree height between 0–25 m and decreases with increasing tree height between 25–30 m, allowing magpies and grey magpies to mitigate the risk of predation from ground and aerial predators.

Foliage surrounding the nest provides shade and reduces the odds of predation on the nesting birds (Martin, 1993). In addition to predator-related factors, magpies and grey magpies in this study showed a preference for nesting near the top of trees in high-density tree species in open green spaces. This finding suggests a trade-off between concealment and light requirements in nest site selection. The birds choose nest sites that offer sufficient concealment while also ensuring adequate light, which is beneficial for the normal development of chick feathers and the maintenance of nest microhabitat temperatures. Dense foliage also provides protection against adverse weather conditions such as wind, rain, and strong

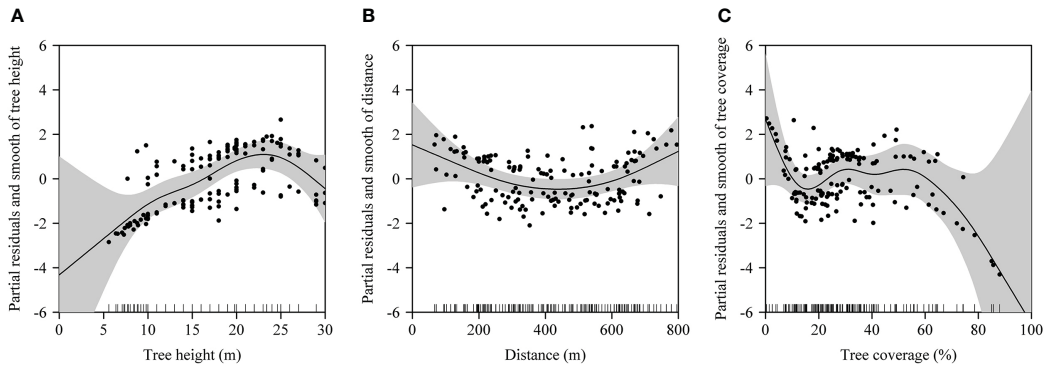

FIGURE 4
For the presence–absence data, plots of the relationship between each feature and the response in the fitted model. Each plot displays the fitted function and pointwise standard errors. Three functions are all cubic splines in **(A)** tree height (TH), **(B)** distance (D) and **(C)** tree coverage (TC).

light (Deng et al., 2001). The study's results indicate that the odds of nest site selection by magpies and grey magpies displayed an overall decreasing trend with some fluctuations, eventually leading to a sharp decline. The odds of nesting decreased as tree coverage increased from 0–20%, remained relatively stable between 20–60%, and then experienced a rapid decline for coverage exceeding 60%.

Furthermore, the study has shown that the choice of nest site for magpies and grey magpies decreases with increasing distance from the center of the playground in the 0–400 m range, with the odds reaching a minimum at a distance of 400 m. At distances greater than 400 m, the odds of nesting begins to increase with distance. The main school playground, with its real grass turf and central location on the campus, has been observed as a favorable foraging site for birds, providing grazing opportunities and access to insects. The anomalous decrease in nesting probability beyond 400 m may be attributed to the omnivorous nature of magpies and grey magpies (Kaplan, 2019), as they may find better foraging sites within and around the school grounds. Magpies exhibit a complex relationship with humans in urban environments, depending on and maintaining a certain distance from human activities, enabling them to access abundant food resources (Hao et al., 1992). They are considered active urban adapters.

Distance from water sources and human activity intensity were not identified as primary factors influencing nest site selection by magpies and grey magpies in this study. This finding can be attributed to the adaptability and flying abilities of these bird species, their larger activity range (Claramunt et al., 2022), the proximity of Xuanwu Lake (which offers better and easily accessible water supply) to the campus, and their overall strong resource access capabilities and adaptability to urban habitats.

Birds in urban environments face challenges that require them to carefully evaluate costs and benefits of their habitat choices. To thrive in cities, birds must weigh that the advantages of the urban ecosystem against its disadvantages. An ideal nesting site provides improved protection, stable materials for nest construction, and proximity to food-rich foraging habitats that support breeding breeding (Hafner and Fasola, 1992). However, urban environments also pose negative impacts on birds, necessitating additional energy expenditure and resource competition compared to their natural habitats. The increasing urban population and urbanization have led to higher levels of artificial light (Hölker et al., 2010; Falchi et al., 2016) and human noise (Job et al., 2016), demanding avian adaptation during crucial breeding periods that require additional resources. In response to urbanization, birds actively seek suitable nesting sites and develop optimal breeding strategies for their survival and prosperity in cities (Sepp et al., 2018).

Magpies and grey magpies are representative of bird species that can coexist with humans in urban ecosystems, displaying the ability to adapt to human activities to a certain extent. However, they also possess specific requirements that may conflict with human activities. For example, the preferred nesting environment provided by poplar trees presents challenges due to the adverse effects of these trees and their globular double-hanging fruit on the human environment. Some researchers and authorities suggest using lower evergreen trees like *Magnolia grandiflora* as alternatives (Liu et al., 2019). However, this poses a challenge to the survival of magpies and grey magpies, as they prefer nesting in deciduous trees at greater heights. Additionally, the impact of tree planting types, tree characteristics, institutional building patterns, and green space distribution on magpie and grey magpie nesting in green spaces warrants further investigation (Ding and Feeley, 2010).

This study aims to enhance the protection and cultivation of tall trees in highly urbanized areas and urban habitats such as schools, with the goal of safeguarding wildlife such as magpies and grey magpies. Achieving this requires increasing the number of tall iconic landscape structures while considering their compatibility with green space design. Urban planning and green space landscape design should prioritize retaining a mix of "high-medium-low" levels of tree species in new institutions or the renovation and upgrading of existing ones. Furthermore, various plant configuration patterns should be considered in the design process to ensure a proportionate balance of open grassland and open forest in the green space landscape. These measures will reduce damage to the native ecological base, promote ecological continuity within green spaces, mitigate habitat fragmentation, and contribute to the development of better and sustainable urban ecosystems where humans and nature coexist harmoniously.

5 Conclusion

In this study, we conducted field surveys, collecting 152 presence–absence data of bird nests, which were subjected to rigorous analysis using generalized additive models. The primary objective was to investigate the impact of landscape factors on bird nest site selection in urban green spaces and uncovering the adaptive strategies employed by birds in urban environments. Our findings have led to several significant conclusions:

Firstly, the distribution of bird nests in the campus habitat was strongly influenced by three key factors: nest tree height (TH), distance from the central lawn (D), and tree cover (TC). Notably, the proximity to water sources, herb coverage, shrub coverage, percentage of buildings, and percentage of hard pavement did not show a significant effect on nest site selection.

Secondly, for magpies and grey magpies, the odds of nesting initially increased with rising tree height, reaching a maximum at ca. TH=25 meters, after which it gradually declined with further increases in tree height.

Thirdly, the odds of magpies and grey magpies nesting displayed an initial decrease with increasing distance from the central lawn, reaching its lowest point at D=400 meters, and subsequently started to rise with greater distances.

Lastly, the odds of nesting decreased as tree cover increased within the range of 0–20% TC, exhibited relatively consistent fluctuations between 20–60% TC, and experienced a rapid decline beyond 60% TC.

To deepen our understanding of the landscape and environmental factors influencing breeding success in urban areas, future research should focus on quantifying nesting site preferences and success at finer scales. Specifically, it is crucial to consider environmental factors such as the size, shape, and proximity to human traffic of plant patches, as well as the contributions of parental breeding inputs. These further

investigations will contribute to a more comprehensive understanding of avian nesting dynamics in urban habitats.

Further research should quantify both nest-site preference and success at finer scales, such as plant patch size, shape, isolation and distance to human traffic to better understand the landscape factors impacting nest-site selection strategies in urban areas. The examination of "urban adapter", exemplified by magpie and gray magpie, offers a unique opportunity to explore the nesting strategies adopted by birds thriving in urban environment. Concurrently, there exist other avian species known as "urban avoider", which have also ventured into urban areas. Investigating the nesting preferences and adaptive mechanisms of these "urban avoider" is a compelling line of research. Understanding the factors that influence these birds to thrive in urban environments can provide valuable insights into the broader dynamics of urban ecology and bird conservation. By delving into the very different strategies and adaptations of "urban pioneers" and "urban escapees", we can gain a fuller understanding of bird responses to urbanization and contribute to the sustainable coexistence of wildlife and human communities in urban landscapes.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material. Further inquiries can be directed to the corresponding authors.

Author contributions

ZD: Conceptualization, Data curation, Formal Analysis, Investigation, Software, Validation, Visualization, Writing – original draft. AG: Formal Analysis, Investigation, Methodology, Resources, Validation, Writing – original draft. ML: Data curation, Formal Analysis, Resources, Validation, Visualization, Writing – original draft. YW: Conceptualization, Investigation, Visualization, Writing – original draft. WY: Conceptualization, Investigation, Resources, Writing – original draft. HJ: Investigation, Resources, Validation, Writing – original draft. XZ: Investigation, Resources, Validation, Writing – original draft. CQ: Investigation, Resources, Validation, Writing – original draft. JL: Conceptualization, Formal Analysis, Methodology, Resources, Writing – review & editing. JC: Conceptualization, Funding acquisition, Methodology, Resources, Validation, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

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