The impact of urbanization on avian communities during the breeding season in the Huanghuai Plain of China

Meiting Liu[1], Jiayi Shi[1], Ziruo Zhang[1], Xinyi Zhang[1], Xiaohan Li[1], Ruohui Tang[1], Chunna Zhang[1], Siyu Wu[1], Chenfang Wu[1], Junpo Zhu[1], Zhirong He[1], Yujia Sun[1], Yuehuan Wang[2], Supeng Wang[1], and Na Zhao[1]

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Abstract

The noise pollution, habitat loss, and human disturbance caused by urbanization have led to damage in bird communities. Research on the relationship between urbanization and birds predominantly focuses on highly urbanized areas, with few studies in underdeveloped urbanized areas. Given the greater stability of the bird community during breeding season, it was chosen for this study. Here, we conducted bird surveys along the urban-rural continuum by utilizing 150 line transects within a 51385 km2 area from June to August in 2022 and 2023, aiming to explore the impact of urbanization on bird species diversity and functional traits during the breeding season in the Huanghuai Plain of China. We found that species diversity and functional traits had significant differences among three habitats (i.e., urban, suburban, and rural). Additionally, the urbanization synthetic index had significant negative correlations with species richness and the Shannon-Wiener index, while having no significant correlation with functional traits. We then assessed that the environmental noise, the distance to the county center, and the proportion of building area within a 250-meter radius were critical factors affecting species diversity, as well as environmental noise and the distance to the county center being the best predictors for functional traits. Urban birds preferred to construct nests at crown, and the diets of them tended to be omnivorous. Our study highlights the importance of the environmental noise, the distance to the county center, and the building index for the protection of urban birds in Huanghuai Plain. The research findings filled the gap in the study area regarding the relationship between urbanization and avian communities based on the urban-rural continuum.

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Abstract: The noise pollution, habitat loss and human disturbance caused by urbanization have led to damage in bird communities. Research on the relationship between urbanization and birds predominantly focuses on highly urbanized areas, with few studies in underdeveloped urbanized areas. Given the greater stability of the bird community during breeding season, it was chosen for this study. Here, we conducted bird surveys along the urban-rural continuum by utilizing 150 line transects within a 51385 km^2 area from June to August in 2022 and 2023, aiming to explore the impact of urbanization on bird species diversity and functional traits during the breeding season in the Huanghuai Plain of China. We found that species diversity and functional traits had significant differences among three habitats (i.e., urban, suburban, and rural). Additionally, the urbanization synthetic index had significant negative correlations with species richness and Shannon-Wiener index, while had no significant correlation with functional traits. We then assessed that the environmental noise, the distance to the county center, and the proportion of building area within a 250-meter radius were critical factors affecting species diversity, as well as environmental noise and the distance to the county center were best predictors for functional traits. Urban birds preferred to construct nests at crown, and the diets of them tended to be omnivorous. Our study highlights the importance of the environmental noise, the distance to county center and building index for protection of urban birds in Huanghuai Plain. The research findings filled the gap in the study area regarding the relationship between urbanization and avian communities based on urban-rural continuum.

Keywords: Huanghuai Plain; Urbanization; Breeding season;Bird species diversity; Functional characteristics;

Dear Editors,

We are pleased to submit our manuscript entitled **"The impact of urbanization on avian communities during the breeding season in the Huanghuai Plain of China"** (authors: Meiting Liu, Jiayi Shi, Ziruo Zhang, Xinyi Zhang, Xiaohan Li, Ruohui Tang, Chunna Zhang, Siyu Wu, Chenfang Wu, Junpo Zhu, Zhirong He, Yujia Sun, Yuehuan Wang, Supen Wang, Na Zhao) **for consideration as an article in *Ecology and Evolution* .**

Our paper represents a novel contribution to provide recommendations for the conservation of avian populations under the pressure of urbanization and will be highly cited because, firstly, we investigated the variation of species diversity and functional traits along the urban-rural continuum, including three habitats (i.e., urban, suburban, and rural). Then, we explored the relationship between urbanization synthetic index and species diversity and functional traits. Finally, we identified which urbanization-related factors most associated with the species diversity and functional traits of birds in the Huanghuai Plain of China. And the identification of urbanization-related factors influencing the loss of species diversity and the changes of functional traits is crucial for the effective management of protected birds of the study area.

We conducted bird surveys along the urban-rural continuum by utilizing 150 line transects within 51385 km^2 area from June to August in 2022 and 2023 in Huanghuai Plain of China. Here, 106 species were recorded in field surveys. And we found that the urbanization synthetic index had significant negative correlations with Shannon-Wiener diversity index and species richness, and had no significant correlation functional traits. Urban birds tended to construct nests at crown, and the diets of them tended to be omnivorous. The results of models showed that the environmental noise, the distance to county center and the proportion of building area within 250-meter radius were critical factors affecting species diversity, as well as environmental noise and the distance to county center were best predictors for functional traits. Our study reported the effect of urbanization on the bird communities during the breeding season and underscored the significance of these urbanization-related factors in the protection of birds within the study area. This finding addressed the gap in research that had been previously identified in the Huanghuai Plain. And our paper will provide important insights into ecology and conservation biology.

None of the material in this paper has been published or is under consideration for publication elsewhere, including the internet. All relevant authors and institutions have approved the submission for publication, and all authors have seen and agreed to the submitted version of the manuscript. Our research methods also conform to the legal requirements of China, the country in which the study was carried out, including those relating to conservation and animal welfare, and to the journal's policy on these matters.

Thank you very much for your consideration of our manuscript. We believe that you will find our work to be an important contribution to*Ecology and Evolution* . We hope you enjoy our work and find it relevant for publication in your journal upon review.

Sincerely,

Na Zhao, corresponding author

1 Introduction

Urbanization drastically transforms natural landscape and leads to a decline in biodiversity (Marzluff et al., 2012; McDonald et al., 2020). By 2030, projections suggest that the urban land may be 1.2 million km² (Seto et al., 2012) and approximately 5.2 billion urban populations around the world (United Nations, 2018). Urbanization is concurrent with the reduction in biodiversity (Aronson et al., 2014; Evans et al., 2018; Barbosa et al., 2020). Numerous studies have found that there is a decline in animal diversity with the increase of impermeable surface from rural to urban region (McKinney, 2002; Piano et al., 2020; Hastedt & Tietze, 2023; Vaz et al., 2023). For example, the species-area relationship indicates that the increase of urban land (e. g., artificial grass, paved surfaces, and buildings) result in the loss of plant species richness (Blair & Launer, 1997; Mckinney et al., 2008). And the plant structure in cities often tends to be simplified (Marzluff & Ewing, 2008). These have a negative influence on the diversity of animals, as their diversity concerns the complexity and species richness of vegetation (Savard et al., 2000). Moreover, urbanization is a major driver of biotic homogenization (Mckinney, 2006). Despite being a minority view, certain research findings argue that moderate levels of urbanization can support the highest levels of species diversity, thus supporting the Intermediate Disturbance Hypothesis (IDH) (Lepczyk et al., 2008; Callaghan et al., 2019). As urban areas may have highly spatial habitat heterogeneity (Savard et al., 2000) and the invasion and establishment of exotic species that exceeds the rate of loss (McKinney, 2002, 2006).

Birds are widely distributed in urban ecosystems. Their ecological characteristics (e.g., active behavior and variable vocalizations) make them more easily observable when compared to other biological taxa. Given their sensitivity to environmental changes, the population density and diversity of birds serve as critical indicators of environmental quality and biodiversity in urban ecosystems (Gregory et al., 2003). Consequently, birds are often chosen as focal species in urbanization studies (Neate-Clegg et al., 2023; Duan et al., 2024; Zhong et al., 2024). However, most of studies were focused on developed regions in China, while there is little attention given to other regions (Chen et al., 2000; Chen et al., 2022; Duan et al., 2024).

Previous findings that urbanization has negative effect on birds, such as birds are particularly vulnerable to traffic noise, with a notable decline in population density in areas with high traffic volumes (Cai, 2012); Light and noise pollution generated by energy infrastructure construction directly affect foraging, breeding, and migration behaviors of bird (Kunz et al., 2007; Tryjanowski et al., 2013), and indirectly influence their choice of habitats and nest sites (National Research Council et al., 2007). However, urban areas also provide green spaces that birds treat it as "refuge habitats", such as urban parks, artificial lakes (Sandström et al., 2005; Callaghan et al., 2019). Moreover, the urban habitats filter out ecologically specialized species, retaining those with specific traits or combinations of traits that are adapted to the urban environment (Zhong et al., 2024). Generally, urban-adapted birds are identified as ecological generalists, characterized by smaller body mass (Cooper et al., 2022), larger clutch size (Callaghan et al., 2019), enhanced migration abilities (Møller, 2009; Zhong et al., 2024), broad ecological niche and diverse diets (Bonier et al., 2007; Callaghan et al., 2019; Palacio, 2020). In addition, urban birds tended to be arboreal, avoiding the ground nest (Conole & Kirkpatrick, 2011; Dale et al., 2015). Despite extensive evidences on the ecological and life history characteristics of birds related to urbanization, the results are often contradictory. For example, urban tolerant birds are medium-sized in a large city in south-eastern Australia (Conole & Kirkpatrick, 2011). It is essential to investigate which functional traits most closely related to the urban adapted birds in urban, which helps us understand the relationship between urban birds and urbanization.

The Huanghuai Plain, the most populous plain in China, features flat terrain, numerous rivers, temperate climate. It has grown into a significant political, economic, cultural, and transportation hub as urbanization. However, prior research on the effects of urbanization on birds has primarily focused on developed areas (e.g., Shanghai, Beijing, and Hangzhou), with a notable lack of studies in underdeveloped areas in China. Therefore, this experiment will fill a gap in the effect of urbanization on birds in the Huanghuai Plain. This study will provide insights into the differences in adaptive traits of birds across various levels of urbanization, offering recommendations for biodiversity conservation.

Here, this study explored the relationship between birds and urbanization by examining species diversity and functional traits in breeding season within Huanghuai Plain of China. We hypothesized that the urbanization has profound impact on birds. Specifically, we considered three alternative hypotheses: (1) species diversity will exhibit a significant difference among three habitats (i.e., urban, suburban, and rural), with the lowest in urban habitat. (2) urban birds will be smaller body mass, larger clutch size, wider distribution breadth than other habitats. And they tend to be arboreal and diverse diets. (3) species diversity and functional traits will have significant negative correlations with the urbanization synthetic index, including the building index, the environmental noise, and the disturbance index, while have significant positive correlations with the distance to the county center.

2 Methods

2.1 Study area

We conducted this study in the southern of Huanghuai Plain in China (33°16'~34deg14N, 116deg23'~117deg02'E), situating in the northern of the Anhui province and certain regions within Henan province. The terrain of the study area is predominantly characterized by plains, and scattered low-lying hills and mountains, with altitudes generally below 200 m. The climate belongs to the warm temperate semi-moist monsoon climate, which the climate is mild and rainy, with an average annual temperature ranging from 14degC to 16degC and an annual precipitation of between 800 and 1000 mm. The vegetation type is warm temperate deciduous broadleaf forests, complemented by coniferous forests and shrublands, offering a relatively diverse habitat composition (Figure 1).

2.2 Line transects and habitats classification

We defined three habitats (i.e., urban, suburban and rural), based on the classification system which researchers have previously established about global rural-urban continuum in 2020 (1-kilometer resolution) (Li et al., 2023). Specifically, the vector layer representing the boundary of the study area was used to clip it in ARCGIS 10.8, getting the vector layer of the rural-urban continuum classification system for the study area at first. The vector layer includes nine classifications (i.e., urban, town, village, cropland, grassland, woodland, wild, water, and ice/snow) (Li et al., 2023). Then, we excluded the vector layer of water and classified the remaining eight vector layers, Finally, the urban layer was categorized as urban habitat, the layers of town and village belonging to suburban habitat, and the remaining layers belong to rural habitat. Urbanization varies across different regions, resulting in a gradient of urbanization rang from urban to suburban and rural, with the urbanization decreasing as the distance from the urban increases in the study area. According to the mapping of rural-urban continuum of study area, we have pre-established 150 fixed 1-km line transects. For the transects distributed in water layer, they are reclassified into the above three habitats based on the neighborhood grid attributes of the grid where the transects are located, with 50 line transects allocated to each habitat.

2.3 Field surveys

Bird surveys were conducted by two experienced researchers during 4 h from dawn and 3 h before sunset in good weather (e.g., no wind and rain) in summer during June to August 2022. The observers walked along each line transect at a constant speed of approximately 1.0km/h – 2.0km/h and used binoculars for direct observation to identify birds, and additionally, observers also utilized camera to document bird that were unidentifiable within a 50-m radius, while not included those flying over the head. During June to August

2023, we carried out repeat bird surveys by using same methods. The composition of land use types of each line transects did not change during our surveys.

2.4 Data collection

2.4.1 Avian species identification and classification

The identification and classification of birds based on *A checklist on the Classification and Distribution of Birds of China* (Zheng, 2023) and *A Field Guide to the Birds of China* (Mackinnon et al., 2000). The levels of endangerment and conservation status are based on *The List of National Key Protected Wildlife* , *The IUCN Red List of Threatened Species* (IUCN; https://www.iucnredlist.org/) and *The Red List of Biodiversity in China: Vertebrates.*

2.4.2 Functional characteristics collection

We selected 5 ecological and life history characteristics (i.e., body mass, diet, clutch size, nest site, and distributed provinces) for our study (Wang et al., 2021). Body mass is one of the most critical functional traits, serving not only as a representative of morphological traits of birds but also reflecting the nutritional metabolism and demand of resources. It forms the foundation of physiological, ecological, and evolutionary processes. Diet reflects the requirement of different food, as well as methods of obtaining food, which determines the trophic level within ecosystems and communities (Wenny et al., 2011). Clutch size and nest site can reflect the reproductive strategies and capacity (Larsen et al., 2005). The distributed provinces serve as a proxy indicator for the breadth of bird distribution. Distribution breadth is one of the indices that measures the extent to which a species exploits food and habitats, as well as adaptive capacity to environmental changes (Flynn et al., 2009; Luck et al., 2013).

2.4.3 Urbanization characteristics variables

Compared to earlier studies on urbanization, researchers used a single variable or indicator to substitute the level of urbanization (Marzluff et al., 2001). It appears to be insufficient in fully representing the true level of urbanization within the study area. Some studies have employed an urbanization synthetic index to conduct related research to mitigate negative effects (Chen et al., 2022; Wang & Zhou, 2022). Therefore, we also selected an urbanization synthetic index that includes four main factors (i.e., the building index, the environment noise, the disturbance index and the distance to the city center) (Chen et al., 2000; Wang et al., 2008).

We imported all line transects into ArcGIS 10.8, and established four buffer zones around each line transect, with a radius of 250m, 500m, 1000m, and 2000m, respectively, to estimate the proportion of buildings surrounding the lines (Bolger et al., 1997). Wang et al. (2009) used the method of summing the weighted building proportions to calculate the building index: The Building Index (BI) = 250 m of building area%1 + 500 m of building area%0.5 + 1000 m of building area% 0.25 + 2000 m of building area% 0.125.

While conducting field surveys along each line transect, we measured the environmental noise using a decibel meter. Measurements were conducted once during each of the three time periods: morning, midday, and evening, with each measurement lasting for 10 minutes. The average of the noise values obtained from each line transect was then taken as the environmental noise (Wang & Zhou, 2022). Meanwhile, we also carried out the collection of the disturbance index. The observation at each line transect, human traffic was recorded, with each observation lasting for 10 minutes. The average value was then adopted. The study divided human disturbance into five levels, with level 1 indicating the absence of human; Level 2 indicating human traffic of 1-2 people per minute; Level 3 indicating human traffic of 3-7 people per minute; Level 4 indicating human traffic of 8-17 people per minute; and Level 5 indicating human traffic of 18 people per minute or more (Chen et al., 2000).

Our study divided the study area into county-level units, with the government hall at each county serving as the central point. The distance to the county center (DCC) was measured as the straight-line from line transects to the government hall of each county (km) with Google map.

Following other studies, an urbanization synthetic index (USI) for our study as follows: USI= BI100 / 2 + EN + DI20 + 100 / DCC (Chen et al., 2000; Wang et al., 2008; Wang & Zhou, 2022). We adjusted parameters value to the range of 0-100, with higher numbers representing a higher level of urbanization (Chen et al., 2000; Wang et al., 2008). In detail, the BI value ranged from 0 to 2, we standardized it by multiplying by 100 and then dividing by 2; The EN value ranged from 0 to 100, so it remained unchanged; The DI value ranged from 1-5, so it was multiplied by 20; the DCC value from 0 to 60, so it was taken the reciprocal and multiplied 100.

2.5 Data analyses

We conducted a preliminary analysis by drawing species accumulation curves to evaluate the sampling effort. The result indicated that our field survey was sufficiently comprehensive, allowing for subsequent analyses (Figure 2).

For each line transect, we calculated the species richness, abundance of every species, the Shannon-Wiener diversity index (Shannon-Wiener & Weaver, 1998), the Pielou evenness index (Pielou, 1966) and the Simpson diversity index (Simpson, 1949). Prior to analyses, the Pielou evenness index and species richness were transformed by taking the square-root to achieve normality, while the USI was log-transformed for the same purpose. And then a one-way analysis of variance (ANOVA) was employed to test for differences among three habitats, followed by Tukey's Honest Significant Difference (HSD) test for pairwise comparisons. The Pielou evenness index did not exhibit a significant difference among the three habitats, the rest of diversity indices showed significant differences (Appendix Table S1). Therefore, we then conducted linear mixed models (LMMs) to explore the relationship between urbanization synthetic index and bird species diversity, with the USI as the fixed effect and the research sites as random factor. In addition, we carried out the Pearson correlation analysis to avoid interference in the results due to multicollinearity among the various urbanization factors and species diversity. Although the correlation between the building index and environmental noise was greater than 0.7 ($r=0.745$), giving the significant relationships between both above indices and diversity index and retaining them for subsequent analyses (Appendix Table S3). This experiment also employed linear mixed models to determine which factors in the USI (i.e., BI, EN, DI, DCC) influenced species diversity and their relative importance, with the study sites served as the random factor. We employed the Akaike Information Criterion (AIC) to determine which of the building index proportions within four different radiuses had the greatest impact, and we integrated the lowest AIC value into linear mixed models for further analyses (Appendix Table S2). The analysis yielded a series of models. We then selected and ranked models basing on the cumulative difference values of the Akaike Information Criterion (ΔAICc [?] 2), the candidate models selected were equivalent (Burnham & Anderson, 2002). Subsequently, model averaging was conducted to obtain the relative importance of each parameter within a 95% confidence interval, along with the model estimates and standard errors, in order to mitigate uncertainty in model selection. We employed the same procedures and methods to investigate the relationship urbanization and functional traits (i.e., body mass, clutch size and distribution breadth) of birds. Diet and nest site are categorical data, we analyzed the differences in species richness by calculating the number of species present in each habitat. All analyses were performed in R 4.3.3 (R Core Team, 2024), the significance level was set at $\alpha=0.05$.

3 Results

3.1 Bird community composition

This survey recorded a total of 106 bird species during two breed seasons, which belong to 14 orders and 45 families and including 60 passerine species and 46 non-passerine species. There were 53 species in urban habitats, 77 species in suburban habitats, and 91 species in rural habitats. Among the recorded species, there were 5 listed as Near Threatened (NT) on the *The Red List of Biodiversity in China: Vertebrates* (i.e., *Charadrius placidus* , *Circus cyaneus* ,*Accipiter trivirgatus* , *Falco peregrinus* , *Terpsiphone incei*) and 6 were classified as Class II Key Protected Wildlife in China (i.e., *Platalea leucorodia* , *Accipiter virgatus, Circus cyaneus, Accipiter nisus, Accipiter trivirgatus, Falco peregrinus*) (Appendix Table S7).

3.2 Variation in species diversity with urbanization

The results of linear mixed models showed that the urbanization synthetic index exhibited significant negative correlations with the Shannon-Wiener diversity index (P =0.0342) and the species richness(P =0.0316), while it showed no significant relationship with the Simpson diversity index (P =0.6270) and the Pielou evenness index (P =0.7060) (Figure 3; Table 1).

3.3 The models assessing the impacts of urbanization on avian species diversity

The model average results from the linear mixed model analyses indicated key factors influencing the Shannon-Wiener diversity index of birds include the proportion of building area within a 250-meter radius (w_i = 1.0000, Estimate = -0.4827 ± 0.1568SE, Z = 3.7550, P = 0.0002), the environmental noise (w_i = 0.8000, Estimate = -0.0061 ± 0.0030SE, Z=2.0190, P = 0.0435), and the distance to the county center (w_i = 1.0000, Estimate = 0.0074 ± 0.0027SE, Z = 2.7100, P = 0.0067). Key factor influencing the species richness is environmental noise (w_i = 1.0000, Estimate = -0.0145 ± 0.0060SE, P = 0.0150). The Simpson index and the Pielou evenness index showed no significant relationships with the urbanization factors (Table 2).

3.4 The models assessing the impacts of urbanization on functional traits

The body mass, clutch size and distribution breadth have showed no significant correlations with urbanization synthetic index (Figure 4; Appendix Table S8). However, according to the results of the model average, there was a significant negative correlation between clutch size and the proportion of building area within 2000-meter radius (w_i = 0.8700, Estimate = -0.3118 ± 0.1538SE,P = 0.0444). And the distribution breadth showed a significant negative correlation with the distance to the county center (w_i = 0.8500, Estimate = -0.0249 ± 0.0108SE,P = 0.0223). In terms of body mass, there was not significant correlation with urbanization factors (Appendix Table S9). From the perspective of the dietary groups to which bird species belong, the composition of diet was similar across the urban, suburban, and rural: the order of bird species by diet, from most to least abundant, is: omnivorous, insectivorous, carnivorous and insectivorous, and carnivorous. The number of bird species with each nest site was as follows: crown, ground, shrubbery, water, and rock-wall (Figure 5).

4 Discussion

Our findings revealed that a total of 106 bird species were recorded during the breeding season. The species richness, abundance and Shannon-Wiener diversity index were the highest in rural habitat, followed by suburban habitat, and the lowest in urban habitat, showing the decrease along the urbanization gradient. This pattern is not only same as our first hypothesis, but also consistent with other outcomes of previous studies (McKinney, 2002; Piano et al., 2020; Hastedt & Tietze, 2023; Vaz et al., 2023). And this aligns with the results of the linear mixed model analyses, which the species richness and the Shannon-Wiener had a significant negative relationship between urban synthetic index. In contrast to other two habitats, suburban habitats were classified as moderate disturbance. Nevertheless, species richness in suburban habitats was lower than in rural areas, which counters the intermediate disturbance hypothesis. This discrepancy contrasts with the findings of previous research (Wang et al., 2022; Duan et al., 2024). The level of disturbance in urban habitat is the highest, resulting in the lowest number of bird species. This difference may be attributed to the combined effects of various factors such as the regional biodiversity, the extent of urbanization, and management policies, which may lead to diverse outcomes (Wang et al., 2012).

Li et al. (2020) simulated the distribution habitats of 1111 bird species across China, revealing that 220 species tended to select rural as their habitats. It is consistent with our findings that the average value of species richness, as well as the Shannon-Wiener and the Simpson diversity index were highest in three habitats. This is closely related to the higher openness and abundant food resources in rural habitat, especially during the period of crop maturity and harvest (Crampton et al., 2011; Rosin et al., 2016). The insects, weed seeds, and leftover grains in the grasslands within the agricultural fields provided rich food for birds. Consequently, rural habitat is characterized by a prevalence of omnivorous and insectivorous bird species

(Figure 5). Additionally, the rural landscapes had many paddy field, rivers, and artificial irrigation channels within the study area, which have attracted many birds primarily feeding on carnivorous diets, within a lot of aquatic birds. This finding is consistent with previous research on the effects of artificial landscapes on breeding bird communities (Wang et al., 2021). However, the Pielou evenness index of the three habitats was low, due to the dominance of human-associated species (e.g., *Hirundo rustica* , *Cecropis daurica* , *Passer montanus* , *Spilopelia chinensis*) within the avian communities, which account for majority of the total bird individuals (i.e., urban (67.35%), suburban (42.48%), and rural (54.36%)).

Life history refers to the sequence of stages that an organism goes through from birth to death, including all the events and processes that occur during its lifetime, which can effectively reflect the adaptive plasticity of species (Martin, 2004). To date, although there are numerous studies about the impact of urbanization on functional traits in China (Chen et al., 2006; Chen et al., 2022, 2023), few studies have compared them of urban to other build-up (towns) or non-build-up (e.g., open fields, forest-field ecotones, and forests) environments of the urban-rural landscape gradient. Therefore, this study constructed an urban-rural continuum of Huanghuai Plain and classified three habitats (i.e., urban, suburban, and rural). There was a significant difference in the average body mass of birds among the three habitats, with urban birds having the smallest (Appendix Table S1). The most common raptors (Accipitridae) in urban centers are smaller (Cooper et al., 2022). The clutch size in urban was at an intermediate level, and a higher number of clutches can enhance the population growth potential. Species with high reproductive capabilities could rebuild their populations more rapidly following disturbance (Larsen, 2005). Among the 53 bird species recorded in urban habitats, the omnivorous birds are the most numerous (Figure 5). It could be evergreen plants, fruiting trees in urban parks, and residential waste generated by the community serving as food sources for omnivorous birds (Marzluff & Ewing, 2001). The artificial lakes within the park, along with the planting of aquatic vegetation, provide habitats for large waterfowl and various waders, offering them spaces for survival and reproduction (Zhang et al., 2020). Moreover, the selection of nesting sites is crucial for the reproduction and survival of birds. Urban birds predominantly consist of arboreal species, whereas ground-nesting birds, particularly those that construct nests on the ground or in shrubbery, tend to favor locations distant from urban environments (Dale et al., 2015). In this study, nearly half of the urban birds utilized crown sites, consistent with previous research findings. Complex plant communities enhance the safety of nesting sites for urban birds and ensure an abundant food supply, which are key factors determining whether birds can inhabit urban areas. Therefore, exploring the relationship between the life story of birds and urbanization helps us have useful implications for the protections for birds in urban ecosystems (Martin & Roper, 1988). In summary, the results were consistent with our second hypothesis.

Urban birds face various survival pressures, and the relationship between urbanization and birds is currently of great concern to researchers (Isaksson, 2018; Møller et al., 2015; Leveau et al., 2021; Chen et al., 2023). Our study employed an urbanization synthetic index and constructed linear mixed models aiming to investigate which specific urbanization factors affect bird diversity. the results were consistent with our third hypothesis. They exhibited a significant negative correlation between environmental noise and the Shannon-Wiener index and species richness. Some research have demonstrated that environmental noise has adverse effects on bird fitness, survival and reproduction (Habib et al., 2007; Gross et al., 2010; Schroeder et al., 2012). Anthropogenic noise reduces bird species richness and diversity decrease in urban parks (Perillo et al., 2017). In addition, a negative relationship between maximum point-count noise and avian species richness was found in research that untangled the role of anthropogenic noise on bird species richness in a Neotropical city (Carral-Murrieta et al., 2020). These are consistent with our findings. The distance to county center is often used as one of the indicators to measure the level of urbanization, with longer distance suggesting lower urbanization (Chen et al., 2000; Wang et al., 2004). As the distance to county center increases, there is a decline in urbanization and human disturbance, concurrently leading to a higher proportion of natural habitats, which contributes to an enhancement of bird diversity within the distant area (Chen et al., 2000; Wang et al., 2004). Our findings also yielded similar outcomes that distance to the county center exhibited a significant positive correlation with species richness and diversity. In addition, As the distance to the county center decreased and the distribution breadth became broader. It indicated that birds in urban habitats exhibited a wider distribution range and were better adapted to habitat heterogeneity. Because urban habitat may also provide the resources and space they require. Previous finding shown that the increase in the proportion of buildings within the small-scale wetlands has resulted in the loss of natural habitats, thereby posing a challenge to the survival of certain bird species (Wang & Zhou, 2022). In this study, the Shannon-Wiener index and clutch size had a significant negative correlation with the proportion of building area within a 250-meter radius, yet it also indicated that an increase in building proportion may have harmful effects on bird.

5 Conclusions

Through field surveys of birds, this study has preliminarily compiled a checklist of breeding bird species in the Huanghuai Plain. Species diversity (i.e., Shannon-wiener index, and species richness) have negative relationship with USI by using LMMs. And the results also showed that the environmental noise, the distance to the county center and the proportion of building area within a 250-meter radius were key factors affecting bird species diversity. The environmental noise and the distance to the county center were critical factors affecting functional traits. Urban birds tended to have smaller body mass, larger clutch size, diverse diets, and arboreal nesting sites in our study. Therefore, we understood that these functional traits associated with the urban-adapt birds, as well as highlights the importance of the environmental noise, the distance to the county center and the building index for protection of urban birds in Huanghuai Plain. The research findings filled the gap in the study area regarding the relationship between urbanization and avian community. However, there is a slight deficiency in fully understanding the distribution pattern of bird diversity in the Huanghuai Plain, and efforts should be strengthened in the future to investigate the bird resources.

Author contributions

Supen Wang and Na Zhao conceived the study. Meiting Liu collected data, performed data analyses and wrote the first draft. Jiayi Shi gave advice during writing and revising.

Ziruo Zhang, Xinyi Zhang, Xiaohan Li, Ruohui Tang, Chunna Zhang, Siyu Wu, Chenfang Wu, Junpo Zhu, Zhirong He, Yujia Sun and Yuehuan Wang collected data. Supen Wang and Na Zhao reviewed and revised the first draft. All authors read and approved the final manuscript.

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Conflict of Interest Statement

The authors declare that they have no conflicts of interest.

Data Availability Statement

All data and R code used in the study are available in Dryad. https://doi.org/10.5061/dryad.0p2ngf2b6.

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