Habitat Suitability Evaluation and Environmental Factor Identification for Spatial Distribution of Urban Birds: A Case Study of Hongshan District, Wuhan City, China

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Abstract. The article takes 11 species of birds in Hongshan District as the research object based on the bird observation data 2020 and then identifies the spatial distribution of their habitats through the MaxEnt model. According to the results, we analyze the distribution characteristics and problems of bird habitats in Hongshan District and finally put forward the optimization suggestions according to the cohort groups. We conclude that water habitats and urban forest parks have higher suitability for bird spatial distribution and that the influence of various environmental factors on different types of birds is somewhat different. Based on the data analysis results, we provide references for the conservation of bird diversity and habitat restoration in Hongshan District: (1) Control the area of construction land and the number of high-rise buildings to make room for bird migration, enhance gene exchange among birds in different patches, and enrich species diversity. (2) Increase the number of bird migration "stations" between long-distance habitat patches to provide resting points for birds during long-distance migration. (3) Increase the number of bird migration "stations" between long-distance habitat patches to provide resting points for birds in the urban forest park. (4) Adopt tree-shrub-grass planting to provide more living space for birds. (5) Reserve a green corridor around urban roads and water systems to reduce the impact of urban roads on the distribution pattern of bird suitability.

Keywords: guild groups; environmental factors; maximum entropy model; bird diversity

1. Introduction

Biodiversity is the product of the continuous evolution of life on Earth, serving as both the natural foundation of the biosphere and the material basis upon which human societies thrive[1]. At the top of the food chain, birds play a crucial role in determining the status of other organisms and the overall health of an ecosystem[2]. The abundance of bird species reflects the diversity of the ecosystem and its overall health, making birds important indicators of urban biodiversity and ecosystem health[3]. Given the intensifying environmental challenges in urban areas, such as the dense population and increased industrial and anthropogenic activities, evaluating environmental factors is essential for safeguarding bird diversity[4]. Analyzing the structure of bird communities through environmental factors can provide insights for developing conservation policies and protecting bird diversity[5]. Therefore, employing environmental factors to understand the structure of bird communities is a critical tool in preserving bird diversity.

Michael et al [6].defined a group of birds that use similar methods to utilize environmental resources as a "sympatric group". This is based on the fact that certain bird species exhibit similar habitat selection and feeding mode preferences. Prior studies examining the relationship between bird diversity and environmental factors typically begin with an investigation of the structure of bird communities, and then expand to explore the impact of habitat and socio-economic factors on bird diversity [5; 7; 8]. However, the selection of habitat factors for simulating species distribution is not standardized and varies depending on the research goals [9]. Habitat identification and evaluation studies are commonly used to inform habitat restoration strategies [10; 11]. The primary goal of such studies is to improve the management of urban nature reserves, restore urban habitats, and protect biodiversity[12; 13]. Additionally, there is a lack of conservation measures targeting birds with specific habitat selection characteristics in regional planning and design efforts related to bird

diversity. Overall, the objectives of such research efforts include restoring urban habitats, protecting biodiversity, establishing a nature reserve system, and providing ecosystem services [14].

Hongshan District in Wuhan City possesses abundant blue-green spaces and natural resources, serving as a crucial area for bird habitats. However, due to habitat loss and fragmentation caused by human activities, there is a declining trend in bird populations in Hongshan District[15]. Most studies on Hongshan District in Wuhan City have focused on the urban spatial structure[16-18]. However, there is still a significant gap in research on the spatial distribution pattern of birds. The use of species distribution modeling can compensate for this lack of research on bird diversity, which is of utmost importance for optimizing the ecological environment in Hongshan District, Wuhan City.

Previous studies on bird diversity have mainly focused on selecting a single bird species as the study object or analyzing the bird richness patterns of all species in the study area, or classifying birds based on their ecological habits and behavioral preferences[9; 19]. However, there is a shortage of studies categorizing birds according to their habitats[10; 11]. In this study, we defined birds with the same feeding mode as a sympatric group and selected 13 environmental factors, including climatic factors, topographic factors, habitat factors, and disturbance factors. This enabled us to more precisely analyze the relationship between environmental factors and bird diversity, and propose conservation measures applicable to specific bird species.

Regarding research methodology, each species has its unique ecological niche, which is usually more stable. This is the basis for the ecological niche model to predict the potential distribution range of the species[20]. The Maximum Entropy Model (Maxent), a species distribution model, is based on the ecological niche model theory and estimates the distribution of species by determining the stable relationship between the species and the environment[20]. Maxent only requires data on species' "occurrence points," avoiding the problem of obtaining data on species' "non-occurrence points," and plays a crucial role in predicting the distribution of bird species.

In conclusion, this study combines the effects of various environmental factors on the distribution points of birds and proposes conservation measures for birds with specific habitat selection characteristics. This provides guidance and basic information for the conservation of birds in Hongshan District and multi-species systematic conservation planning.
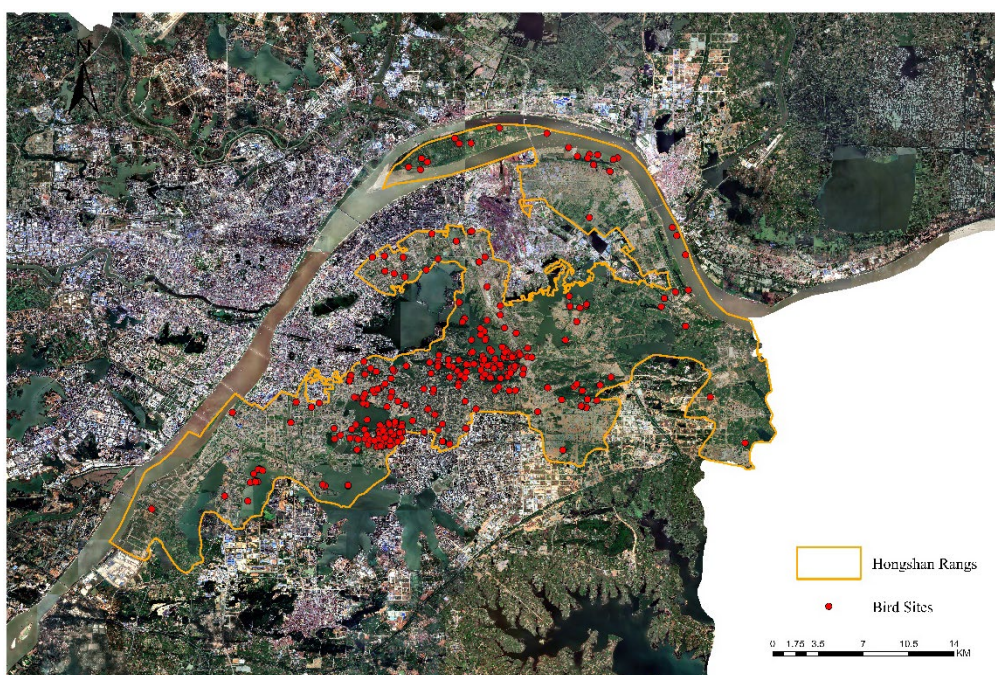
2. Study Area

Fig. 1 Study area and bird distribution records

Hongshan District is located in the southeastern part of Wuhan, with geographical coordinates ranging from east longitude 114°7′ to 114°38′ and north latitude 30°28′ to 30°42′, forming a semicircle that surrounds the Wuchang and Qingshan districts. The district's landforms are characterized by plains, hills, and lakes, which are rich in natural resources. The peaks in the territory are generally distributed in a belt-shaped extension from east to west, with 14 lakes and rivers branching out, creating spectacular natural scenery.

The landscape of Hongshan District is predominantly flat, with mountains and water, broad waterways, and vast land. The northwest is slightly lower in elevation compared to the southeast, with 93% of the land in the district below sea level. The average elevation is 25.3 meters above sea level, with 93% of the land below 40 meters above sea level. The central part of the territory has low hills extending from west to east, while the eastern part is dominated by ridge plains. Numerous ridges and slopes run in an east-west direction, forming a large natural barrier. The waterfront ecological environment and abundant flora and fauna resources provide a solid foundation for birds to feed and nest.

3. Research Methods and Data

3.1 Basic Data and Processing

3.1.1 Bird Distribution Point Data

The study collected data on 199 bird species from the List of Wildlife under State Key Conservation and relevant literature[15; 21]. Bird distribution data was obtained by web crawling from the Wuhan Birdwatching Association and China Birdwatching Records Center's website (http://www.birdreport.cn/). A total of 55,757 observation records with clear geographic coordinates were obtained in 2020 by searching for species names and study areas. The point distribution data were organized after coordinate correction and imported into ArcGIS software to obtain bird distribution data points.

3.1.2 Environmental factor data

The selection of habitat factors for birds has a direct impact on the accuracy of the final predictions made by the model. Currently, there are no uniform regulations for selecting habitat factors in species distribution simulation, and the factors selected may differ depending on the purpose of the study. In a previous study, Chen Daan et al. categorized environmental factors as either environmental or disturbance factors[9], while Li Hui et al. categorized them as climatic, terrain, habitat, and disturbance factors[10].

Taking into account the environmental characteristics of Hongshan District and the habitat requirements of birds, Li Hui et al. selected 13 environmental factors, such as elevation, precipitation, air temperature, distance from main roads, and distance from rivers. These factors were chosen from four aspects: climatic, topographic, habitat, and disturbance factors, as they are known to affect the survival and distribution of urban birds. These selected factors were then used to construct the model (as shown in Table 1).

Table 1 Environmental Factors Used for Species Distribution Modeling

Form	Environmental Factor	Abbreviations	Data Sources	Data Processing Methods
Climatic Factors	average annual temperature	AMT	Observations from weather stations at the United States National Climatic Data Center (https://www.ncdc.noaa.gov/)	Kriging interpolation
	Annual precipitation	AP		

Topographic Factors	altitude (e.g. above street level)	ALT	ASTERGDEM (V1) and GDEM (V3) datasets from the Geospatial Data Cloud Platform of the Chinese Academy of Sciences (https://www.gscloud.cn/)	-
	elevation	SLO		DEM data + slope tool
	slope direction	ASP		DEM data + slope direction tool
Habitat Factors	Land cover type	LC	From the Center for Resource and Environmental Science and Data of the Chinese Academy of Sciences (https://www.resdc.cn/), with a spatial resolution of 30 m	-
	Distance from river	DR	Extraction of land cover types for each type of site	ArcGIS Euclidean distance calculation
	Distance to woodland	DW		
	Distance to grass	DG		
	Normalized Vegetation Index (NVI)	NDVI	Geospatial data cloud and geospatial data cloud Landsat-8 images were selected with low cloud cover and spatial resolution of 30 m	$NDVI = \dfrac{NIR - Red}{NIR + Red}$
Interfering Factor	Distance from the main road	DMR	2020 road vector data obtained from the National Geographic Information Resources Catalog Service (https://www.webmap.cn/)	ArcGIS Euclidean distance calculation
	building density	BD	Building floor profile data obtained from the Center for Resource and Environmental Science and Data of the Chinese Academy of Sciences (https://www.resdc.cn/)	Elemental point and nuclear density analysis
	population density	PD	World Population Density Dataset (https://www.worldpop.org/), precision 100m	-

All of the above data were resampled in ArcGIS and then standardized to 30 m×30 m raster size, and standardized to WGS1984 geographic coordinate system.

3.2 Classification of Bird "Sympatric Groups"

In this study, birds with the same feeding mode were classified into guild groups. To ensure consistency with previous research, we adopted Ehrlich et al.'s classification criteria for sympatric groups[22] and cross-referenced the "Distribution List of Birds in China" [23] with the actual

classification of birds in the Hongshan District. As a result, the birds studied were categorized into 11 sympatric groups [24], as shown in Table 2.

Table 2 Classification of Bird Sympatric Groups[10]

Classification of Predation Methods	Description of Predation Methods	Type of Representation
Bird of Diving	Diving and diving to different depths to hunt for food	Little Tern, Pied Kingfisher, etc.
Bird of Wading	Strolls and wades for food in shallow water	Egret, Green Sandpiper, etc.
Bird of Probing	Standing on banks, grassy areas, or cultivated areas at the edge of forests, inserting their mouths into the water or mud to forage for food	Hoopoe, Black-winged Stilt, etc.
Bird of Surface Feeding	Floating on the surface of the water or feeding below the surface	Garganey, Chinese Pond-heron, etc.
Bird of Ground Collection	Collecting food from the ground	Quail, Mynah, etc.
Birds of Reeds and Shrubland Feed on	Mainly active and pecking in reeds or scrub near water	White Wagtail, Brown crake, etc.
Bird of Pouncing	Pouncing on food at high speeds in the air	Northern Harrier, Black Drongo, etc.
Bird of Cutting	Getting food by digging up tree trunks	Speckled piculet, The Great spotted woodpecker, etc.
Bird of Water-skimming	Fly low over the water and reach into the water with their claws to grab food when they find it	sterna albifrons, White-throated kingfisher, etc.
Bird of Predating Intertree	Hiding among the leaves and branches of trees and collecting food from them	Black-winged cuckoo shrike, Hydrangeyed bird, etc.
Bird of Straight Down to Prey on	Dropping from branches to the ground to feed, then flying straight up to higher altitudes	phoenicurus auroreus, Amur stonechat, etc.

3.3 Research Methodology

3.3.1 Species Distribution Modeling Using MaxEnt

The fundamental principle of ecological niche modeling is to establish a connection between geographic and ecological space based on the unique living environment of the species under study. This involves utilizing known distribution data and related environmental variables for the species and applying mathematical and statistical models or machine learning theory to analyze, process, generalize, or simulate the ecological requirements of the species. The resulting models can determine the likelihood of species occurrence in a given habitat and can be used to predict the potential spatial distribution of species based on this probability [25]. In other words, the more suitable the habitat, the higher the probability of species occurrence.

The maximum entropy model is used to simulate the distribution of species by calculating the system's state when it has maximum entropy. Its calculation formula is:

$$H(\pi) = -\sum_x \pi(x)\ln(x)$$

The formula for the maximum entropy model involves several variables. The independent variable, represented by x, refers to the environmental variable being analyzed. The probability of occurrence of the independent variable is denoted by $\pi(x)$, while $H(\pi)$ represents the corresponding entropy value. By applying the principle of maximum entropy, the probability distribution that maximizes the entropy value can be obtained[26]:

$$\pi^* = arg \max_{\pi \in \Pi} H(\pi)$$

To make predictions using the MaxEnt model, bird distribution point data and environmental factor data must first be imported into the software. The distribution data is divided into two sets: 60% is selected as the training data, while the remaining 40% is used as the test data. Other parameters are set to the default values provided by the software, and an ASCII raster layer is outputted as the final result [26].

3.3.2 Characterization of the spatial distribution of birds

Geographically weighted summing is a method of overlaying multiple rasters by assigning a weight to each raster and then adding them together. In this study, the suitability zoning map of the 11 guild groups in Hongshan District was used to identify patches with the highest bird abundance. The geographically weighted summation method of the ArcGIS platform was then adopted to overlay these patches, producing a score that reflects the priority of conservation actions for these bird habitats[27]. The higher the score of a given patch, the greater the richness of birds in the area and the more important its habitat is for conservation purposes.

Furthermore, the main environmental factors that influence the spatial distribution of birds were analyzed based on the spatial distribution pattern of bird abundance, and a theoretical framework for urban bird conservation was proposed[9].

4. Results and analysis
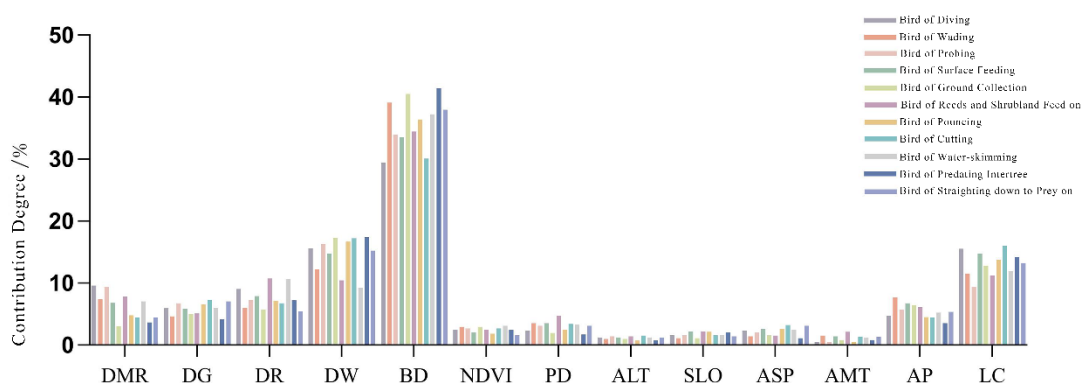
4.1 Environmental factor analysis

Fig. 2 Environmental factor contribution of birds in each guilds group (see Table 1 for abbreviations)

MaxEnt used the area under the Receiver operating characteristic curve (ROC curve) as the AUC value (Area undercurve) to evaluate the prediction accuracy of the model. It is generally believed that the AUC value of 0.5-0.6 indicates that the simulation effect fails; 0.6-0.7 indicates that the effect is poor; 0.7-0.8 indicates that the prediction effect is average; 0.8-0.9 indicates that the prediction effect is good; and greater than 0.9 indicates that the prediction accuracy is optimal[28]. In this study, the ROC curve is used as the basis for the prediction. In this study, the area AUC value under the ROC curve was used to judge the advantages and disadvantages of the model simulation results. The prediction results showed that the average AUC value of birds of 11 ecological taxa was 0.887, the

lowest was 0.863, and the highest was 0.922, which was larger than the random prediction AUC value (0.5), indicating that the model prediction results were more accurate. In terms of the different guilds, among them, wading predators, scouting birds, and reed and scrub predators had more similar environmental requirements, with the difference that reed and scrub predators were more affected by the distance factor from the main road and less affected by the distance factor from the woodland. Ground-collecting and direct-fall predatory birds had more similar environmental needs, with the difference that ground-collecting birds were less affected by the distance from grassland factor and more affected by the distance from woodland and building density factors. The environmental needs of intertree predators and excavators were more similar, except that excavators were more influenced by distance from grassland, and intertree predators were more influenced by building density. Diving, surface-predator, and fly-surfing species also had more similar environmental requirements, with the difference that surface-predator species were more limited by building density, population density, and annual precipitation, while fly-surfing species were less affected by distance from forested land and land cover type. In terms of environmental factors, ground-collecting species were less affected by distance from main roads compared to other bird species, while diving and probing species were more affected by distance from main roads; between-tree predators were less affected by distance from grassland compared to other bird species; wading predators, ground-collecting species, and direct-falling predators were less affected by distance from rivers compared to other bird species, while reed- and scrub-predators and fly-surfing predators were more affected by distance from rivers; and water predators, ground-collecting and direct-falling predators were less affected by distance from rivers compared to other bird species. distance from rivers; distance from woodland is less influenced by fly-by-water species than other birds, while ground collecting, excavating, and inter-tree feeding species are more influenced; building density is less influenced by excavating and diving species than other birds, while inter-tree feeding, ground collecting, and wading species are more influenced; population density is more influenced by reed and scrub feeding species than other birds; and inter-tree feeding species are more influenced by population density than other birds; and the number of people in a given area is more influenced by the number of people in a given area. Reed and scrub predators were more affected by population density than other birds; inter-tree predators were less affected by mean annual precipitation than other birds; and scouting birds were less affected by land cover type than other birds. In terms of all bird species, the environmental factor analyzed with the highest contribution to the model prediction of all bird species was building density (0.36), followed by distance from the forest (0.15) and land cover type (0.13). The degree of influence of various environmental factors on different types of birds showed some variability, which is shown in Fig. 2.

Table 3 Average Contribution of Environmental Factors (%)

DMR	DG	DR	DW	BD	NDVI	PD	ALT	SLO	ASP	AMT	AP	LC
6.2	5.8	7.6	14.7	35.8	2.5	3.0	1.1	1.7	2.2	1.1	5.5	13.1

4.2 Spatial Distribution Pattern of Birds

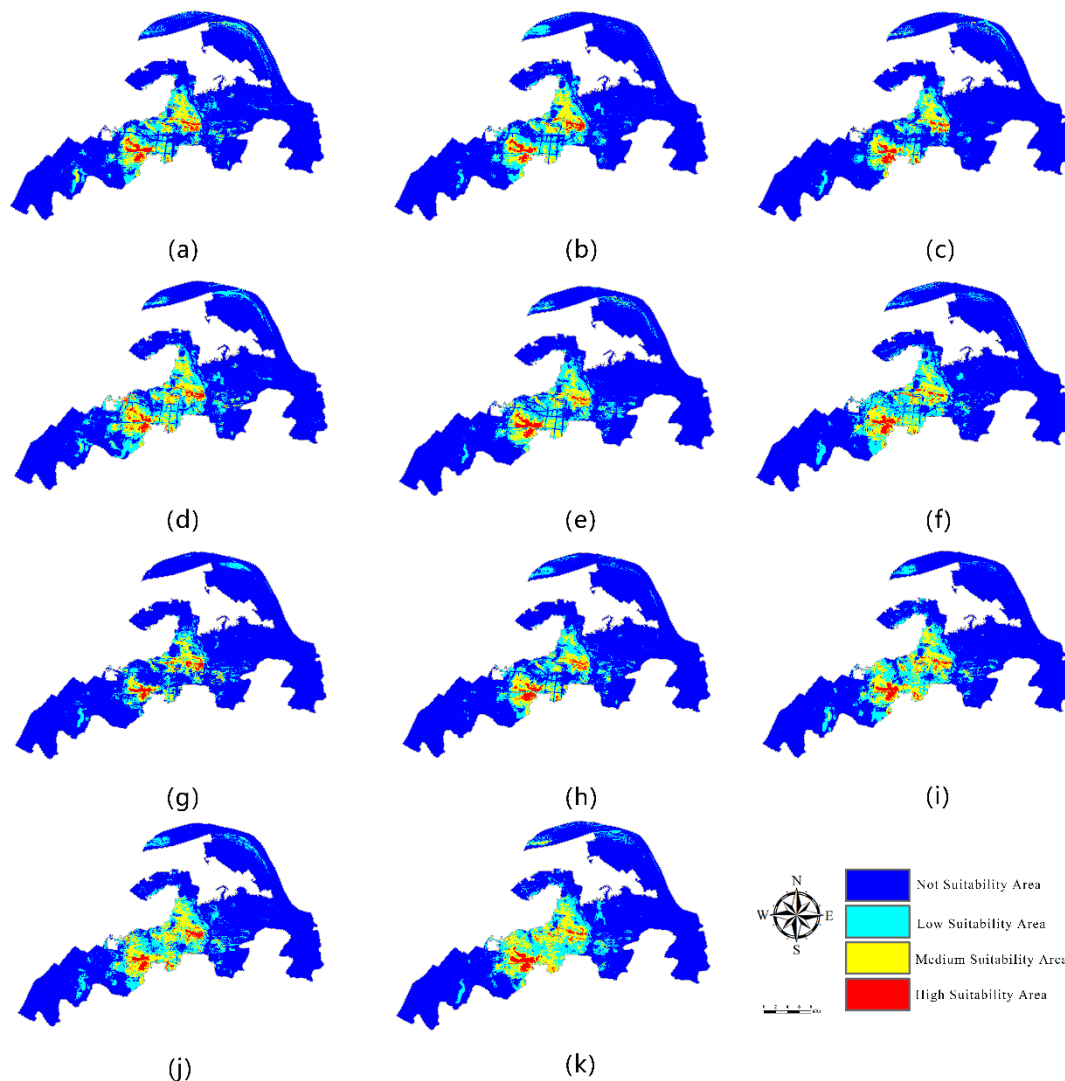### 4.2.1 Distribution Pattern of Bird Suitability for Different Guilds

Fig. 3 Distribution pattern of bird suitability((a) Bird of Diving; (b) Bird of Wading; (c) Bird of Water-skimming; (d) Bird of Reeds and Shrubland Feed on; (e) Bird of Surface Feeding; (f) Bird of Pouncing; (g) Bird of Cutting; (h) Bird of Probing; (i) Bird of Predating intertree; (j) Bird of Straight down to Prey on; (k) Bird of Ground Collection)

Based on ArcGIS grading results, this study draws the following conclusions:

(1) High suitability areas for birds are concentrated in the south shore of South Lake and Lake Yezhi, the nursery base of Huazhong Agricultural University, and the Blowing Flute Scenic Area of East Lake Scenic Area, Lion Mountain, Nangwang Mountain, Yujia Mountain, Shimenfeng Memorial Park, and Jiufeng Mountain Forest Park, gradually spreading to surrounding rivers, mountains, and woodlands.

(2) The suitability areas of excavation birds have the smallest range of habitats, while ground collectors have the largest range of habitats according to the division of bird co-location groups.

(3) Certain bird species, such as fly-swept birds, reed and scrub predators, swoopers, divers, wading predators, surface predators, and probing birds, show a certain occlusal relationship with the water surface and are distributed along the shore of the South Lake, the experimental field of Huazhong Agricultural University at the north shore of Lake Yezhi, Lion's Hill, the lake along the Blowpipe Scenic Spot of the Donghu Lake, as well as the woodland of

Nanwangshan and Nanwangshan, the test field of Huazhong Agricultural University, and the woodland of Blowing Flute Scenic Spot of Donghu Lake Scenic Spot. These bird species are rarely distributed in residential areas. Ground-collecting birds, tree-to-tree predators, and direct-falling predators have a wider range of habitats, spreading to the area between South Lake and East Lake, as well as to construction sites such as the Optics Valley Software Park.

(4) Flying-surfing birds have a smaller range of habitats in water than reed- and scrub predators and wading predators. Diving birds are more common in the high areas of Yan Xihu and Huangjia lakes, and the range of high suitability areas is closer to the center of the water and larger in scope. Probing birds are mostly concentrated in South Lake, Shimenfeng Memorial Park, and Jiufeng National Forest Park.

(5) The East Lake Scenic Area, Shimenfeng Memorial Park, Jiufeng Mountain Forest Park, and urban parks such as South Lake and Naozhihu Lake serve as the most important habitats for birds. However, the distance between these core habitats is relatively far, and they are divided by a large area of high-rise buildings and hard surfaces centered on Guanggu Square, resulting in less bird communication.

Overall, these findings provide important insights for urban bird conservation by identifying key habitats and areas of importance for different bird species. The study highlights the importance of considering the unique ecological needs of each species when designing conservation strategies and emphasizes the need for maintaining and creating green spaces to support diverse bird populations.

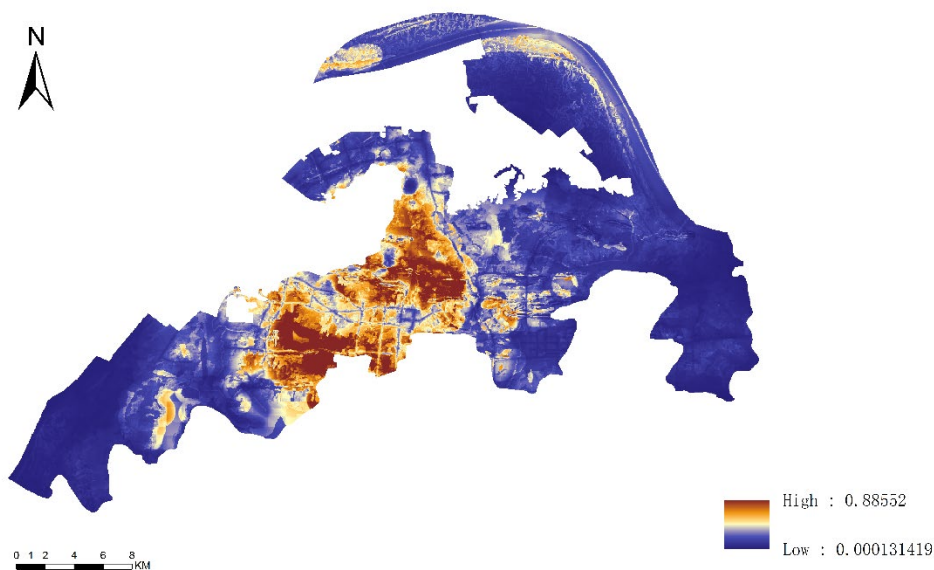### 4.2.2 Distribution pattern of suitability for all bird species
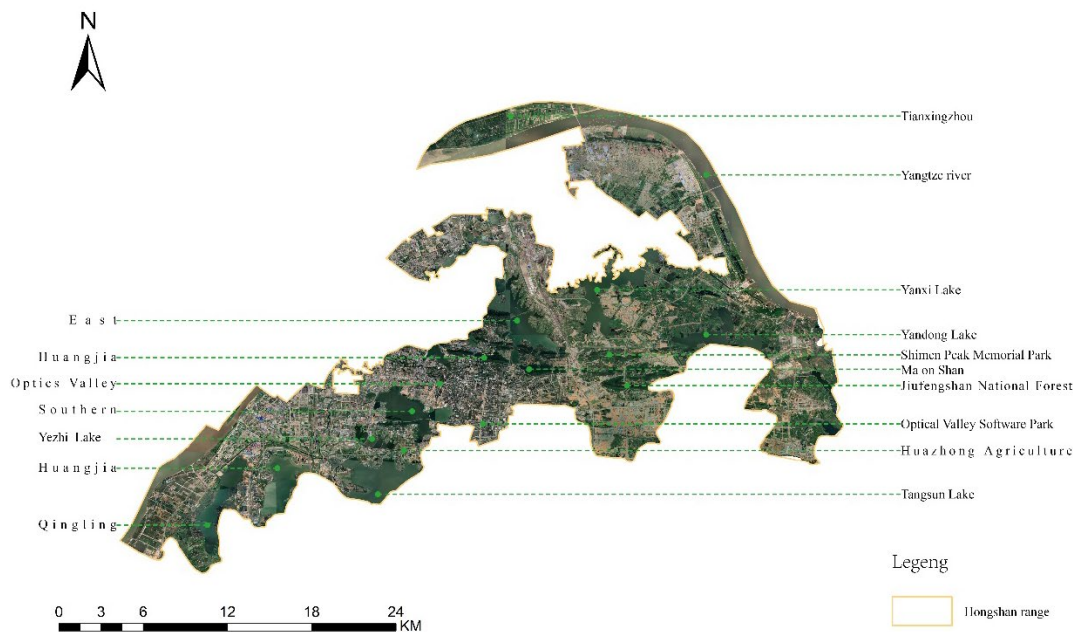

Fig. 4 Pattern of bird richness

Fig. 5 The main distribution places of birds

By superimposing the spatial distribution of the 11 guilds of birds onto the bird suitability distribution pattern, it can be observed that habitats such as the Huangjia Lake coast, the southwest coast of Lake Townsend, Lake Naozhi, the coast of South Lake, East Lake, the coast of Yan Dong Lake, the coast of Yan Xihu, Tianxingzhou, and other lakes have high suitability for bird distribution. Urban green spaces such as the Wuchang College of Engineering internal green space and the Optics Valley Software Park, as well as natural areas such as Huazhong University of Science and Technology, Huazhong Agricultural University, the peaks of the memorial park along Shimen Park, Jufeng Mountain Forest Park, Erfeishan, Fathers and Sons Mountain, Nanwang Mountain, Lotus Leaf Mountain, Fengdu Mountain, Yujiashan, Yujiashan North Road, the woodland between Tuanshan Road and Lumo Road, Donghu Lake Falling Geese Scenic Spot, and Donghu Lake Blowing Descending Flute Scenic Spot also have high suitability for bird distribution.

However, the suitability for the spatial distribution of birds in the southwestern, southeastern, northeastern, and northern villages of Hongshan District was not high. This suggests that water habitats and urban forest parks are important for supporting high spatial distribution suitability for birds. Overall, these findings provide important insights into the conservation of urban bird populations by identifying key habitats and areas of importance for different bird species. The study highlights the need for maintaining and creating green spaces in urban areas to support diverse bird populations and promote their spatial distribution suitability.

5. Conclusion

This study utilized the Maxent model to analyze the distribution pattern of bird suitability zones in Hongshan District based on the distribution points of 11 co-located bird species and 13 environmental factors. The analysis aimed to determine the influence of environmental factors on bird distribution patterns and to provide recommendations for wildlife conservation and planning departments.

The study revealed, for the first time, the distribution pattern of bird suitability for 11 different co-located groups of birds, including ground collectors and divers. The results showed that habitats with higher suitability for birds feeding in or near waters are lakes, rivers, and other water habitats, as well as woodland habitats. The areas with higher suitability for birds feeding among trees or on the ground are primarily the green areas of forest parks and lakes, followed by grasslands and cultivated land. In

contrast, construction land with more human activities had lower suitability for birds. Therefore, lakes and forest parks in Hongshan District are the main living conditions and core areas for birds.

The study found that environmental factors have different impacts on the birds of different cohorts. For example, building density contributes to the distribution of birds in the Hongshan District, which is consistent with the characteristics of the bird habitats in the typical inland area. The populations of inland birds inhabiting the area are relatively rich, and other birds living in or around water areas are also more restrictive to building density. Meanwhile, the effects of distance from woodland and land cover type on bird distribution reflect that urban birds are influenced by urban construction land and vegetation types. However, elevation has less influence on bird migration due to the flatter terrain in the Hongshan District.

This academic paper proposes several recommendations for bird conservation strategies based on the analysis of the distribution pattern of bird suitability zones in Hongshan District. These strategies aim to enhance the richness of bird populations, strengthen the connection between birds in different habitat patches, and reduce the impact of human activities on the distribution pattern of bird suitability.

Firstly, controlling the area of construction land and the number of high-rise buildings is crucial in enhancing the richness of birds. The disturbance factor, especially building density, has the greatest influence on bird suitability zoning. Therefore, limiting the height of neighboring buildings, especially those on bird migration routes, is recommended to strengthen the connection between birds in different habitat patches.

Secondly, increasing the number of bird migration "stations" between long-distance habitat patches can provide resting spots for birds migrating long distances. Adding appropriate migration "stations" between distant habitat patches can create conditions for birds to migrate over long distances.

Thirdly, adopting tree-shrub-grass planting can provide birds with more survival space in vertical space. Increasing the level of plant configuration in vertical space in areas with greater human interference, such as green space in the construction land of urban centers, can enhance the richness of bird populations.

Lastly, reserving a green corridor around urban roads, water systems, etc. can reduce the impact of urban roads on the distribution pattern of bird suitability. Building wetland parks on urban roads and increasing banded green space can form a protective barrier for birds and serve as a transition from man-made to natural habitats.

In this paper, the spatial distribution pattern of birds and different bird species is obtained by inputting the data of bird point distribution and environmental factors into MaxEnt maximum entropy model, and based on this, the influence of environmental factors on the spatial distribution is analyzed. Finally, suggestions for the protection of bird diversity were given for different bird species. The study found that: 1) the environmental factor with the highest contribution to the model prediction of all bird species was building density (0.36), followed by distance from woodland (0.15) and land cover type (0.13). The degree of influence of various environmental factors on different types of birds showed some variability.2) Bird habitats in the area centered on East Lake and South Lake were separated by large residential and commercial land, and the genetic exchange of birds was hindered.3) Watershed habitats and urban forest parks supported higher suitability for the spatial distribution of birds. Therefore, Hongshan District should emphasize the control of construction land in the inland area of the city and the protection and restoration of parks and lakes, and wetlands, to prevent the insufficiency and degradation of urban green space, to increase the number of tall trees, and to improve the ecological carrying capacity of different cohort groups of birds by "inserting greenery into the seams" in the urban construction land. The connectivity between bird habitats in Hongshan District is weak, especially in the urban center development area, and the connectivity between bird habitats should be increased at the urban scale. As land is tight in the city and it is difficult to increase urban green space in large areas, how to optimize the habitat quality and pattern of these habitats has become a key issue to be studied[9].

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