RETRACTED ARTICLE: The diversity of birds in typical urban lake-wetlands and its response to the landscape heterogeneity in the buffer zone based on GIS and field investigation in Daqing, China

Tianyi Chen, Lu Bao, Liu Bao Zhu, Yu Tian, Qing Xu and Yuandong Hu

*Northeast Forestry University, Harbin, China; †Key Laboratory of Heilongjiang Province Cold Landscape Plant Germplasm Resources Development and Landscape Ecological Restoration, Harbin, China

ABSTRACT
This study selected nine typical urban lake-wetlands in Daqing as the research object, and analyzed the key factors influencing diversity of the lake-wetland bird based on GIS technology and the field investigation. The bird diversity index ($H'$) was significantly positively correlated with the proportion of grassland area within the 500 m buffer zone, and the bird diversity was positively correlated with the proportion of grassland area, and grassland became the main habitat or foraging place for birds. Multiple regression analysis of common species and 10 habitat environmental characteristics parameters showed that there were inter-species differences in habitat parameters affecting distribution of birds, which was related to the differences in bird adaptability to different habitats. Moreover, the diversity of birds decreased with the increase of the proportion of urban construction land and the degree of human disturbance. So maintaining the diversity of habitat types and structures is the key to improving the richness of birds. Measures to protect the natural habitat of city and restore the effective habitat of plants and plants will help to increase the diversity of species in urban lake-wetlands.

Introduction
As a highly sensitive biological group to urbanization, birds are widely concerned (Beissinger & Osborne, 1982; Blair, 1996; Blandón et al., 2016; Emlen, 1974; Gaston, 2000; Lancaster & Rees, 1979; Rottenborn, 1999; Shou, 2015). Birds are also an important part of the biodiversity of urban lake-wetlands, whose diversity level is often used to measure the health status of lake-wetland ecosystems (Gong et al., 2013; Noss et al., 1996). In the process of rapid urbanization, the land-use pattern changes dramatically. The landscape, around the lake-wetland evolves from simple, homogeneous and continuous whole to complex, heterogeneous and discontinuous patch mosaics. Continuous large-scale natural habitats are divided by urban buildings and roads. The fragmentation of birds' natural habitats is becoming more and more serious, which leads to a large reduction of birds' habitat and food resources, and affects the distribution pattern of bird diversity and community composition (Farmer & Parent, 1997; Harding et al., 1998; Hu et al., 2015; Matthews et al., 2002; Robinson et al., 1992; Sih et al., 2000; Wiens, 1995; Wu & Lv, 2008). Can birds adapt to the rapidly changing urban environment? Does urban land-use change have a significant impact on the habitat utilization of wetland birds? All these issues are worthy of our in-depth discussion.

Based on the field investigation of bird species and diversity distribution in typical lake-wetlands in Daqing City, this paper reveals the response relationship between bird diversity in lake-wetland and habitat composition, and tries to explore the main factors affecting bird diversity distribution in urban lake-wetlands in Daqing area.

Daqing City is located in the middle of Songnen Plain and the west of Heilongjiang Province, China, between 45°23′–47°28′N and 123°45′–125°42′E (Figure 1). Daqing City is rich in lake-wetland resources. There are 154 lakes in the urban area alone of Daqing. In recent years, land use and land cover types around lake-wetlands have changed strongly in the process of rapid urbanization. Most of the lake-wetlands have been continuously changed into domestic water sources, sewage absorption areas, rainwater collection areas or agricultural irrigation water sources. The animal and plant habitats of lake-wetland ecosystems are severely fragmented, water environment pollution is intensified, and biodiversity continues to decrease.

Research methods
Lake-wetland selection
By using typical sampling methods, nine representative urban lake-wetlands (Table 1) in the highly urbanized area of Daqing City were selected as the main research objects, including Yueliang Lake (YLP), Dongfeng Lake (DFH), Chengfeng Lake (CFH), Chenjiadayuan Lake (CJDYP), Ming Lake (MH), Dongkaliang Lake (DKLP),...
Lande Lake (LDH), Dongjia Lake (DJP), and Sanyong Lake (SYH). These typical lake-wetlands are evenly distributed on both sides of Shiji Avenue, which runs through the center of Daqing City (Figure 2). The lake-wetlands are relatively closed and isolated, and there is no natural channel connection between lake-wetlands.

Method of birds survey

Site-fixed observation
The fixed-point observation method was used in this field survey of birds. The observation tools were mainly binoculars and monocular, and the species and number of birds in each lake-wetland were recorded in detail.

Belt transect method
The investigation time of the sample strip method generally chooses the morning or evening of every day, and tries to choose the weather with fine weather and low wind speed for investigation. During bird survey, 10 sample lines were set in each lake-wetland, and the width of each sample line was 200 m and the length was 1 ~ 2 km (Gong et al., 2013). The 20x60x binoculars and 15 × 45 zoom telescopes were used to move along the line at an average walking speed of 2 km/h, and to record bird species and their population distribution.

The determination of species name, classification, fauna and habitation type of the bird was mainly based on the *Atlas of birds of China* (Qian, 1995), *A complete checklist of species and subspecies of the Chinese birds* (Zheng, 1994), *Zoogeography of China* (Zhang, 2011).

Table 1. The basic situation of the representative urban lake-wetlands in Daqing city.

| Name                      | Total area (km²) | Shoreline length (km) | Current main use                        |
|---------------------------|-----------------|-----------------------|-----------------------------------------|
| Yueliang Lake (YLP)       | 2.98            | 5.93                  | Sewage absorption                       |
| Dongfeng Lake (DFH)       | 2.50            | 5.37                  | Sewage absorption/Landscape/Amusement   |
| Chengfeng Lake (CFH)      | 2.12            | 4.17                  | Sewage absorption/Landscape             |
| Chenjiadayan Lake (CJDYP) | 2.29            | 4.86                  | Rainwater collection/Sewage absorption  |
| Ming Lake (MH)            | 2.14            | 5.38                  | Rainwater collection/Landscape/Amusement |
| Dongkaliang Lake (DKLP)   | 1.57            | 3.58                  | Sewage absorption/Rainwater collection  |
| Lande Lake (LDH)          | 1.00            | 3.58                  | Cultivation/Landscape/Amusement         |
| Dongjia Lake (DJP)        | 2.04            | 4.23                  | Sewage absorption/Landscape             |
| Sanyong Lake (SYH)        | 4.10            | 6.48                  | Cultivation/Landscape/Amusement         |

Bird survey in typical habitats
To further explore the impact of different land-use types on bird diversity, special attention was paid to the observation and recording of bird species composition and number in typical habitats. Typical habitat types in this survey included grassland (G), marshland (R), open water area (W) and farmland&residence area (F). Among them, habitats such as farmland and woodland are close to residential areas, and closely related to human beings. With intense human interference activities, the bird species in these habitats is basically the same. Therefore, farmland and residential areas are
uniformly classified into one habitat type. All surveys of field investigation were conducted in the spring of 2009.

**Selection of environmental variables of bird habitat**
In the process of rapid urbanization, the change of land use often leads to habitat fragmentation (Wu & Lv, 2008). It is often difficult to truly and effectively reflect the impact of land use on birds by using a single variable. So, in order to explore the impact of land-use types on the distribution of bird species and diversity in lake-wetlands, according to the characteristics of the lake-wetland and the surrounding area, this paper select 10 characteristic variables of bird habitat including the area (A), shape index (SI), food richness (FA), food diversity (FD), water quality (WQ), noise disturbance (ND), vegetation index (VI), connectivity Index (CI), urban construction index (UI) and human disturbance (HD) (Bolger et al., 1997; Chen et al., 2000; Liu et al., 1994; MacArthur & Wilson, 1967; Mills et al., 1989; Rottenborn, 1999) into the multiple regression analysis (Table 2). It can better determine the key influenced factors of land-use types on the distribution of bird species and diversity in these lake-wetlands. The connectivity index, urban construction index and vegetation index is mainly based on previous research results and calculation methods (Bolger et al., 1997; Chen et al., 2000; Rottenborn, 1999). The land-use data are obtained from the QuickBird high-resolution satellite image data of Daqing urban area in 2009. Make calibration and digital processing in ArcGis9.2 software and do visual interpretation for the satellite image data, then the land-use information and landscape pattern index (Hu et al., 2015) in the 1000 m, 500 m and 100 m buffer zones near the shore of each lake-wetland can be extracted.

**Data processing**

**Analysis of bird diversity**
The species diversity index \( H' \) of birds is calculated as follows:

\[
H' = - \sum V_i \ln V_i
\]

**Analysis of multiple regression and correlation**
Multiple stepwise regression, curve estimation, logistic regression and other analysis methods were used to determine the factors influencing birds’ distribution and diversity. The above statistical analysis was completed in SPSS19.0 software.

**Results and analysis**

**Species composition and diversity of bird community**
A total of 71 species of birds, belonging to 10 orders and 27 families, were observed in 9 lake-wetland sample plots, including 3 species of national first-class protected animals and 11 species of second-class protected animals in China; 11 species of passeriformes, accounting for 15.49%; 60 species of non-passeriformes, accounting for 84.51%. Dominant and common species include *Ardea cinerea jouyi*, *Ardea purpurea*, *Anas acuta*, *Anas crecca*, *Anas platyrhynchos*, *Falco vesperus*, *Siberian Crane*, *Fulica atra*, and *Vanellus Vanellus*, *Chlidonias leucoptera*, *Himantopus himantopus*, *Oriental Pratincole*, *Larus ridibundus*, *Sterna hirundo*, *Alauda gulgula*, *Passer montanus*, *Corvus corone*, *Pica Pica*, *Hirundo*.
Diversity and the distribution of bird fauna (Table 5), there are 54 species (9.86%) are resident birds, and 3 species (0.59%) are passing migrant birds, which 42 species (59.15%) are summer migrant species in spring, among different types of birds in lake-wetlands (Table 4), migrant types of birds basically indicates the basic quantitative characteristics of lake-wetland birds in Daqing. According to the investigation results of bird species in lake-wetlands (Table 3) and the species diversity index ($H'$), it can be seen that the bird species in Dongfeng Lake, Yueliang Lake and Sanyong Lake are the most, all of which are more than 30 species, while the bird species in Ming Lake, Dongjia Lake and Chengfeng Lake are less than 20 species. The variation trend of the species diversity index is basically consistent with the bird species.

According to the composition of the residence types of birds in lake-wetlands (Table 4), migrant birds are the majority species in spring, among which 42 species (59.15%) are summer migrant birds, 19 species (27.06%) are passing migrant birds, 7 species (9.86%) are resident birds, and 3 species (4.23%) are winter migrant birds. According to the distribution of bird fauna (Table 5), there are 54 species (77.06%) belonged to palaearctic realm, 17 species (23.94%) are cosmopolitan species. Differences in bird species composition in different habitats

The results of bird species investigation in different habitat patches of nine lake-wetlands are shown in Figure 3. The results showed that there were great differences among different types of birds. Among them, the patch type (R) of marsh habitat has the most abundant bird species, with a total of 46 species, mainly including cranes, gulls, herons and crakers. Bird richness in meadow habitat patch type (G) was second. This type of habitat is mainly distributed in flat and low-lying areas. However, due to the fact that most of the meadows are close to shallow water and have rich plant diversity, insects are abundant in number and species, providing habitat and breeding conditions for birds that feed on insects. However, the degree of human disturbance and destruction of such habitats varies, such as reclamation, grazing and harvesting, and the composition of birds in different lake-wetlands also varies significantly.

The most typical habitat patch in the area of lake-wetland is the open water area (W). A total of 27 species of birds have been observed on there, including the dominant species: Aythya ferina, Anas acuta, Larus ridibundus, Chlidonias hybridus, Chlidonias leucoptera and Anas platyrhynchos. Although the richness of bird species in this habitat is very low, the number of birds is the largest. Common birds in shallow water area include: Ardea cinerea, Egretta alba, Platalea leucorodia, Vanellus Vanellus and so on. The richness of bird species in habitat type of farmland-residence area (F), such as farmland, woodland and residential area, is relatively low, and 25 species of birds were observed in the process of this investigation. This kind of habitat type is close to the residential area, closely related to human beings, and strongly interfered by human activities. In the farmland-\n
### Table 2. Environmental variables of bird habitat in typical lake-wetland.

| Sequence number | Habitat variables                                                                 | Value range                                                                                                                                                                                                 |
|-----------------|----------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1               | Area (A)                                                                         | Combining topographic maps and satellite images to estimate the area of lake-wetland (Table 1). Unit: hm².                                                                                           |
| 2               | Shape Index (SI)                                                                 | Combining topographic maps and satellite images to estimate the ratio of perimeter of lake shoreline and the area of lake.                                                                              |
| 3               | Food Abundance (FA)                                                              | Estimated value. With reference to the calculation method of the predecessors (Liu et al., 1994), and according to the actual interview and investigation, food abundance is divided into 5 levels (1–5). 1 indicates that the food is scarce, and 5 indicates that the food is abundant. |
| 4               | Food Diversity (FD)                                                              | Estimated value. It mainly reflects the diversity of food types. The survey method is the same as above. Food diversity is divided into 5 levels (1–5). 1 indicates that the type of food is simplex, and 5 indicates that the type of food is abundant. |
| 5               | Water Quality (WQ)                                                               | Measured value. It mainly reflects the water quality of lake-wetland. Unit: %                                                                                                                          |
| 6               | Noise Disturbance (ND)                                                           | Measured value. Monitor the disturbance degree of the surrounding noise near the main habitats of dominant species and common birds. The monitoring time is one time in the morning and one time in the evening, and the average monitoring time is 10 min (by decibel meter). Unit: dB. |
| 7               | Vegetation Index (VI)                                                            | It represents the proportion of natural vegetation around the lake-wetland. $H'$ = The area of natural vegetation in 100 m buffer zone + 0.5*(The area of natural vegetation in 1000 m buffer zone) + 0.25*(The area of natural vegetation in 500 m buffer zone) |
| 8               | Connectivity Index (CI)                                                          | It reflects the fragmentation degree and isolation degree around the lake-wetland. $CI = The number of habitat patches in 100 m buffer zone + 0.5*(The number of habitat patches in 500 m buffer zone) + 0.25*(The number of habitat patches in 1000 m buffer zone) |
| 9               | Urban construction Index (UI)                                                     | It represents the proportion of urban construction land around the lake-wetland. $UI = The area of urban construction land in 100 m buffer zone + 0.5*(The area of urban construction land in 500 m buffer zone) + 0.25*(The area of urban construction land in 1000 m buffer zone) |
| 10              | Human Disturbance (HD)                                                           | Measured value. Average number of tourists per hectare.                                                                                                                                                |

### Table 3. Richness and the diversity index of bird species.

| Lake name | Quantity of bird species | Diversity index of bird species ($H'$) | Lake name | Quantity of bird species | Diversity index of bird species ($H'$) |
|-----------|--------------------------|----------------------------------------|-----------|--------------------------|----------------------------------------|
| YLP       | 37                       | 1.012                                  | DJYP      | 27                       | 0.707                                  |
| DFH       | 35                       | 0.973                                  | LDH       | 22                       | 0.576                                  |
| MH        | 17                       | 0.501                                  | DJP       | 17                       | 0.545                                  |
| CFH       | 19                       | 0.598                                  | SYH       | 31                       | 0.841                                  |
| DKLP      | 23                       | 0.632                                  |           |                          |                                         |

Note: YLP – Yueliang Lake; DFH – Dongfeng Lake; MH – Ming Lake; CFH – Chengfeng Lake; DKLP – Dongkaliang Lake; CJYDYP – Chenjiadayuan Lake; LDH – Lande Lake; DJP – Dongjia Lake; SYH – Sanyong Lake.
residence habitat area, the dominant species are *Passer montanus, Pica pica, Hirundo daurica, Hirundo rustica*, etc. Although there is a lot of human activity in this kind of habitat, it is still rich in food. There are also some artificial protective forests and green trees around the farmland and residential areas, which provide a better habitat for arboreal birds.

### Relationship between bird richness and lake-wetland area

According to the curve fitting between the richness of bird and the area of each lake-wetland patch recorded in this observation (Figure 4), the relationship between bird richness and lake-wetland area is calculated as follows:

\[ S = 3.863A^{0.342} \]

“\( S \)” represents the richness of birds; “\( A \)” represents the area of lake-wetland.

It can be seen from the regression model and fitting curve that the richness of birds in the lake-wetland is related to the area of the lake-wetland. The richness of birds increases with the increase of the lake-wetland area, which may become a key factor affecting the bird habitat. Therefore, the richness of birds is correlated with the area of lake-wetland, which conforms to the theory of island biogeography.

### Table 4. Bird residence types in urban lake-wetlands of Daqing city in spring.

| Bird residence types       | Non-passeriformes |          | Passeriformes |          | Total |          |
|----------------------------|-------------------|----------|---------------|----------|-------|----------|
|                            | Quantity of bird species | Percentage of total (%) | Quantity of bird species | Percentage of total (%) | Quantity of bird species | Percentage of total (%) |
| Resident birds             | 2                 | 2.82     | 5             | 7.04     | 7     | 9.86     |
| Passing migrant birds      | 17                | 23.94    | 2             | 2.82     | 19    | 27.76    |
| Summer migrant birds       | 40                | 57.34    | 2             | 2.82     | 42    | 59.15    |
| Winter migrant birds       | 1                 | 1.41     | 2             | 2.82     | 3     | 4.23     |
| Total                      | 60                | 84.51    | 11            | 15.49    | 71    | 100      |

### Table 5. Bird fauna composition in lake-wetland in spring.

| Bird residence types       | Non-passeriformes |          | Passeriformes |          | Total |          |
|----------------------------|-------------------|----------|---------------|----------|-------|----------|
|                            | Quantity of bird species | Percentage of total (%) | Quantity of bird species | Percentage of total (%) | Quantity of bird species | Percentage of total (%) |
| Palaearctic realm          | 47                | 67.20    | 7             | 9.86     | 54    | 77.06    |
| Oriental realm             | 0                 | 0        | 0             | 0        | 0     | 0        |
| Cosmopolitan species       | 13                | 18.31    | 4             | 5.63     | 17    | 23.94    |
| Total                      | 60                | 84.51    | 11            | 15.49    | 43    | 100      |

Figure 3. Bird richness in different habitat.
Relationship between bird species distribution and habitat environmental variables

Multiple regression was conducted by using the species richness and quantitative characteristics of birds and 10 selected habitat variables, and the calculated results are shown in Tables 6 and 7.

It can be seen from Table 6 that richness of bird species is correlated with many environmental variables of habitat, indicating that different birds have significant differences in adaptability and selectivity to urban lake-wetlands and their surrounding habitats. Food diversity, connectivity index, vegetation index, urban construction index, and other variables have a significant impact on the lake-wetland habitat of birds. The effect of lake-wetland area on the distribution of most birds is no longer a key factor. In addition, richness of bird species is also affected by shape index of lake-wetland, quality of water and degree of human disturbance and so on.

It can be seen from Table 7 that six species of common birds have significant regression relationship with most of the habitat variables, including Anas platyrhynchos, Tringa ochropus, Passer montanus, Vanellus vanellus, Glareola maldivarum, Corvus corone and Alauda arvensis, etc. It indicates that during the process of rapid urbanization, the adaptability and selectivity of different lake-wetland birds to their habitats are also different. These birds are all dominant species, but their distribution has no significant correlation with the area of lake-wetland, and they are not sensitive to noise. It indicates that they do not have high requirements for the area of lake-wetland, and show strong adaptability to habitat fragmentation and urban noise interference caused by the change of land use during urbanization. The Anas platyrhynchos is obviously affected by the food diversity and urban construction index of surrounding area. The influence of water quality, human disturbance and shape index on the number of Tringa ochropus is obvious. With the increase of the ratio of perimeter of lake shoreline and the area of lake, the increase of shape index and the improvement of water quality, the number of Tringa ochropus increases. Both Vanellus vanellus and Alauda arvensis were significantly affected by the proportion of natural vegetation area and food diversity of the buffer zone, which may be related to the fact that Vanellus vanellus and Alauda arvensis mainly roosted and foraged in patches of grass and meadow. Glareola maldivarum and Corvus corone are significantly affected by food diversity, indicating that these birds generally choose habitats with rich food diversity to inhabit and forage as far as possible. The Corvus corone are also affected by connectivity index. With the increase of fragmentation and isolation of the surrounding habitats, the number of Corvus corone will decrease.

Table 6. Regression models for multiple regression of richness of some birds versus habitat variables.

| Multiple Regression Model | $R^2$ |
|---------------------------|-------|
| Richness of birds         | 0.127 |
| 1286.329 + 2.422 (A) −35.572 (SI) +982.786 (FD) |       |
| +45.447 (WQ) +645.087 (VI) −657.203 (CI)      |       |
| −142.092 (UI) −3.867 (HD)                      |       |

Figure 4. The fitting curve of richness of birds and area of lake-wetland.

$S=3.863A^{0.342}$

$R^2=0.210$
It indicates that food diversity has become an important factor in the distribution and diversity of birds in lake-wetlands during the urbanization process, and providing more food sources and foraging channels may be more conducive to improving the richness and diversity of bird communities.

Among the 10 habitat environmental variables selected in this study, such environmental variables as human disturbance, urban construction index and vegetation Index are directly related to urbanization and land use. It is generally believed that the species and diversity of bird communities decrease with the increase of urbanization (Beissinger & Osborne, 1982; Emlen, 1974; Fang et al., 2007; Wilson & Watts, 2008; Yeh & Huang, 2009). It can be seen from the impact of habitat environmental variables on the diversity distribution of birds in lake-wetlands that, by strengthening the protection and restoration of natural vegetation around the lake-wetland, maintaining the natural state and reducing the artificial straightening of the shoreline, providing more food sources, strictly controlling the proportion of land area of urban construction, minimizing human disturbance, especially moderately controlling the number of tourists entering the lake-wetland will help to maintain and improve bird diversity in urban lake-wetlands. Some other researchers believe that moderate urbanization level or human disturbance is conducive to improving the species diversity of bird community (Blair, 1996; Lancaster & Rees, 1979), that is, the diversity of birds increases with the improvement of urbanization level. The results of this study showed that: (1) The diversity of birds in lake-wetlands decreased with the increase of the proportion of urban construction land and human disturbance activities. (2) There are no bird species fully adapted to urbanization in lake-wetlands. Although some birds still maintain a high quantity at a certain urbanization level at present, the number of these birds will gradually decline with the continuous improvement of urbanization level and the significant change of land-use mode, especially the continuous expansion of urban construction land in the buffer zone and the continuous reduction of natural vegetation area. (3) The intermediate disturbance hypothesis proposed by Connell (Connell, 1978) et al. is not completely applicable to the bird communities in urban lake-wetlands. It shows that these wetland birds are a kind of special community in urban animal community, which are easily affected by urbanization process and land-use change.

### Table 7. Regression models for multiple regression of distribution of some birds versus habitat variables.

| Species                  | Multiple Regression Model                                                                 | R²   |
|--------------------------|------------------------------------------------------------------------------------------|------|
| *Anas platyrhynchos*     | $6.733 + 1.028 \times (FD) -0.433 \times (UI)$                                          | 0.208|
| *Tringa ochropus*        | $328.672 + 27.971 \times (SI) +51.778 \times (WQ) -23.775 \times (HD)$                | 0.143|
| *Vanellus vanellus*      | $21.204 + 1.221 \times (FD) +1.867 \times (VI)$                                        | 0.247|
| *Glaerola maldvvarum*    | $197.676 + 4.769 \times (FD)$                                                           | 0.584|
| *Corvus corone*          | $68.221 + 1.890 \times (FD) -0.184 \times (CI)$                                       | 0.529|
| *Alauda arvensis*        | $654.189 + 2.012 \times (FD) +2.744 \times (VI)$                                      | 0.454|

### Discussion

#### Relationship between habitat environment and bird diversity

In the process of rapid urbanization, land-use change leads to the fragmentation of natural habitats, the area of wildlife habitat also changes and be formed an “island” habitat. Urban lake-wetland habitat is equivalent to a typical “island” formed by the isolation of urban construction land. The theory of island biogeography believes that there is a positive correlation between the area of island and the number of species (Mills et al., 1989; Wu, 1989). That is to say, compared with small islands, the habitat diversity of large islands is relatively high, and large islands have some specific habitat types and structures that small islands do not have, which can accommodate more groups of birds (Luo et al., 2012; Riffell et al., 1996). The results of this field survey show that the number of bird species is positively correlated with the area of lake-wetland, which is in line with the theory of island biogeography.

The impact of habitat fragmentation on forest bird communities was very obvious (Bellamy & Newton, 1996; Hansson et al., 2010; Sisk et al., 1997; Small & Hunter, 1988; Xu et al., 2018). Many researchers believe that landscape factors are important influencing factors of bird community ecology in heterogeneous state, but this is easily ignored in the study of bird communities in urban lake-wetlands (Farmer & Parent, 1997). Generally speaking, in natural lake-wetlands, food resources affect the preference of different groups of birds for habitat utilization, and food richness is a key factor affecting bird distribution (Hansson et al., 2010; Liu et al., 1994). However, this conclusion is not completely applicable to fragmented habitat areas. The migration of birds and their dependence on the lake-wetland ecological environment determine the sensitivity of these birds to the landscape (Farmer & Parent, 1997). In general, food richness is an important factor affecting the diversity of forest birds (Liu et al., 1994), but the results of this study suggest that: richness of food has no significant effect on the bird community in lake-wetlands. Instead, they were more influenced by food diversity. It indicates that food diversity has become an important factor in the distribution and diversity of birds in lake-wetlands during the urbanization process, and providing more food sources and foraging channels may be more conducive to improving the richness and diversity of bird communities.

The regression model of habitat diversity and bird distribution is shown in Table 7. The regression model of the study suggests that: richness of food has no significant effect on the bird community in lake-wetlands. Instead, they were more influenced by food diversity. It indicates that food diversity has become an important factor in the distribution and diversity of birds in lake-wetlands during the urbanization process, and providing more food sources and foraging channels may be more conducive to improving the richness and diversity of bird communities.
Strategies for protecting bird diversity in urban lake-wetlands

From the survey results of the number of bird species in different habitat patches, it can be seen that maintaining the diversity of habitat types and structures is an important factor in improving species richness. In addition, most researchers believe that understanding the factors that affect the diversity of birds in lake-wetlands and the preference of birds in different groups for habitat utilization, and taking measures such as protecting the natural heritage, restoring and increasing the effective habitat area of wildlife will be conducive to improving the diversity of birds in urban lake-wetlands and effectively managing lake-wetland resources (MacGregor-Fors, 2008; Vale & Vale, 1976).

The population distribution around the lake-wetlands in Daqing City is relatively dense because of the beautiful environmental environment. In recent years, with the acceleration of the rapid urbanization process, the interference of human activities has been increasing, resulting in the change of the natural morphology of the original shoreline, the replacement of natural revetments by a large number of artificial revetments, and the gradual simplification of habitat types. At the same time, activities such as fishing and breeding lead to excessive consumption of aquatic biological resources, deterioration of water environment, and significant degradation of lake-wetlands. Therefore, lake-wetland management and ecological restoration need to be strengthened urgently. Among them, returning farmland to lake-wetland, returning farmland to wetland, and effectively managing lake-wetland resources in multifaceted scope. According to the research conclusion of this paper, we also suggest that urban planners should scientifically plan the layout of land use within 500 m buffer zone of lake-wetland. In addition, in the process of urban construction, the destruction of natural vegetation should be avoided or reduced, the diversity of surrounding urban green landscape should be increased, and the heterogeneity of bird habitat should be improved. These measures will not only help increase the diversity of green space habitats and bird habitat, but also improve the ecological environment and effectively prevent further degradation of lake-wetlands and maintain the stability of lake-wetland ecosystem structure and function, so as to provide birds with more abundant food sources and suitable habitat, which is also conducive to better maintaining the health of urban lake-wetland ecosystem and sustainable urban development.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by the Fundamental Research Funds for the Central Universities, Northeast Forestry University [Grant Number:2572017CA12 & 2572018CP006].

References

Beissinger, S.R., & Osborne, D.R. (1982). Effects of urbanization on avian community organization. The Condor, 84(1), 75–83. https://doi.org/10.2307/1367825
Bellamy, P.E., & Newton, H.L. (1996). Factors influencing bird species numbers in small woods in Southeast England. Journal of Applied Ecology, 33(2), 249–262. https://doi.org/10.2307/2404747
Blair, R.B. (1996). Land use and avian species diversity along an urban gradient. Ecological Applications, 6(2), 506–519. https://doi.org/10.1890/1051-0761(1996)006[0506:LUASDA]2.0.CO;2
Blandón, A.C., Perelman, S., Ramirez, M., López, A., Javier, O., & Robbins, C.S. (2016). Temporal bird community dynamics are strongly affected by landscape fragmentation in a Central American tropical forest region. Biodiversity and Conservation, 25(2), 311–330. https://doi.org/10.1007/s10531-016-1049-2
Bolger, D.T., Scott, T.A., & Rotenberry, J.T. (1997). Breeding bird richness in an urbanizing landscape in coastal southern California. Conservation Biology, 11(2), 406–421. https://doi.org/10.1046/j.1523-1739.1997.96307.x
Chen, S.H., Ding, P., Zheng, G.M., & Zhu, Y. (2000). Impacts of urbanization on the wetland waterbird communities in Hangzhou. Zoological Research, 21(4), 279–285. https://kns.cnki.net.cn/kcms/detail/detail.aspx?FileName=DWXY200004004&DbName=CJFQ
Connell, J.H. (1978). Diversity in tropical rain forests and coral reefs. Science, 199(4335), 1302–1310. https://doi.org/10.1126/science.199.4335.1302
Emlen, J.T. (1974). An urban bird community in Tucson, Arizona: Derivation, structure, regulation. The Condor, 76(2), 184–197. https://doi.org/10.2307/1366729
Fang, W.Z., Chen, Z.H., Chen, X.L., & Lin, Q.X. (2007). Avian community diversity during winter in Xiamen wetlands. Marine Sciences, 31(1), 10–16+27. https://kns.cnki.net.cn/kcms/detail/detail.aspx?FileName=HYKX200701002&DbName=CJFQ
Farmer, A.H., & Parent, A.H. (1997). E
Hansson, L.A., Nicolle, A., Brönmark, C., Hargeby, A., Lindström, Å., & Andersson, G. (2010). Waterfowl, macrophytes, and the clear water state of shallow lakes. Hydrobiologia, 646(1), 101–109. https://doi.org/10.1007/s10750-010-0169-x
Harding, J.S., Benfield, E.F., Bolstad, P.V., Helfman, G.S., & Jones, E.B.D. (1998). Stream biodiversity: The ghost of land use past. Proceedings of the National Academy of
