

## Article

# Assessing Effects of Multi-Scale Landscape Pattern and Habitats Attributes on Taxonomic and Functional Diversity of Urban River Birds

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**Abstract:** Several studies have revealed that urban rivers with relatively complete habitat structures can support a high level of biodiversity in urban areas. However, few studies have analyzed the impact of the plan, design, and management of multi-scale urban riverside green space on bird communities by assessing several aspects of diversity (e.g., taxonomic and functional). In this study, we explored bird community variation (taxonomic and functional) among three rivers (28 sampling sites) with different levels of human disturbance along the urban development gradient in Kunming, Yunnan Province, China, during an annual cycle. This study related bird species richness and functional diversity to environmental variables at three spatial scales: landscape metrics at two different landscape scales (500 and 100 m radius) and vegetation structure at patch scales (20 m radius). Using partial least squares regression (PLSR) and multiple linear regression, we found that bird species richness and functional diversity were strongly related to various landscape- and patch-level variables. Multiple linear regression models revealed that, compared with the richness influenced by explanatory variables on three spatial scales (500, 100, and 20 m), the functional diversity was significantly influenced by explanatory variables on the 100 and 20 m scales. Tree cover at the 20 m scale had significantly positive impacts on bird species richness and functional diversity. Forest land in the 100 m scale had a significantly positive effect on bird species richness and functional diversity, while construction land in the two landscape scales (the 500- and 100 m scales) had a significantly negative effect on species richness. Accordingly, we suggest that urban riverside green space should be planned and managed at multiple scales.

**Keywords:** biodiversity; urban rivers; spatial scales; functional diversity; bird community



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## 1. Introduction

Globally, urban land expansion causes the loss of natural habitat, the fragmentation of remaining natural areas, and the alteration of natural areas' abiotic and biotic characteristics [1–3]. This has had and will continue to have a significant influence on biodiversity, both directly and indirectly [4]. On the one hand, biodiversity is an important part of any healthy ecosystem and is thus essential to the provision of ecosystem services [5]. On the other hand, urban biodiversity is crucial for human well-being because high biodiversity enables residents to enjoy nature in cities.

Several recent studies have focused on the analysis of the relationship between bird diversity and urban landscape patterns at different scales [6–8]. On the landscape scale, patch area, connectivity, and level of urbanization in the surrounding matrix were found to be the most important variables in explaining bird species diversity in urban areas [9–11]. Meanwhile, open features, especially open water, could be an important factor affecting bird diversity in forests in urban areas [12]. Bird distribution patterns in urban areas were

strongly associated with habitat evenness, the largest patch index for woodland at the 400 m scale, and the contagion index at the 400 and 1000 m scales [13].

At the patch scale, attention was paid to management intensity and habitat characteristics, like the vertical heterogeneity of forest patches [10,14,15]. A study of bird communities and habitat vegetation composition in Shanghai's urban park found that vegetation complexity and structure positively affected bird community composition [14]. Bird species richness was related not only to the amount of vegetation structure but also to whether the green space was cultivated or natural, and it was discovered that cultivated greenery leads to homogeneous bird communities in the urban landscape [15].

The appropriate way to quantify and enhance the function of urban green space as a wildlife habitat has been frequently mentioned. Many studies suggest that species diversity estimates based on landscape indicators should be multi-scaled [16–18]; however, there are few case studies, particularly on birds [19–21]. One of the reasons is that the statistical approaches required to manage these challenges are still being researched [17].

In recent years, several studies have focused on bird diversity in specific urban green spaces, such as streets, small parks, and backyards. A study analyzing the taxonomic, functional, and phylogenetic diversity of birds influenced by street design suggested minimizing paved road areas to boost bird diversity in streets [22]. The abundance of bird species in small urban parks may be predicted most accurately by two factors: the area of the park and the proportion of canopy cover [7]. A study explored the contribution of residential backyards to urban bird diversity, finding that backyards with the largest areas, tallest trees and bushes, and proximity to other green places increase species diversity [23].

Studies have revealed that the urbanization process impacted the decrease of bird functional diversity through biotic homogenization [24,25]. Functional diversity (FD) is a measure of the diversity of species traits found in communities that provides a link between species' traits and how they influence ecosystem functions [26]. Taxonomic and functional diversity may respond differently to anthropogenic effects and therefore necessitate different conservation strategies.

Urban rivers are essential for preserving urban biodiversity and promoting the health of urban ecosystems [27,28]. Urban rivers have relatively complete habitat structures and are ecological corridors that support a high level of biodiversity and connect fragmented urban green space, reducing isolation, and thus maintaining urban biodiversity [29,30]. However, human activities change the form and function of urban river landscapes, such as buried, cut, and hardened rivers, and increase the surface coverage of roads and buildings [31,32]. This reduces the naturalness, variety, sustainability, and landscape quality of rivers, ultimately decreasing biodiversity [33]. Due to these challenges, researchers are becoming increasingly interested in urban river corridors and are paying attention to the relationship between river network connectivity and bird community structure [27]; the landscape-scale characteristics of suburban rivers impacting bird diversity [29]; and the impact of urban structure, combination of land use, and infrastructure on avian riparian habitat [34]. However, few studies have analyzed the impact of the plan, design, and management of multi-scale urban riverside green space on bird communities by assessing several facets of diversity, such as taxonomic and functional.

In this study, we explored bird community variation (taxonomic and functional) among the three rivers with different levels of human disturbance along the urban development gradient. This study related bird species richness and FD to environmental variables at three spatial scales: landscape metrics at two different landscape scales (500 and 100 m radius) and vegetation structure at patch scales (20 m radius).

## 2. Materials and Methods

### 2.1. Study Area

The research was conducted in Kunming, the capital of Yunnan Province, China (24°53' N, 102°42' E). Yunnan is well known for the Hengduan Mountains and the Yunnan–Guizhou Plateau, and it has the highest bird species richness in China, accounting for more

than 60% of the country's total [35,36]. Kunming is the largest city in Yunnan, located in the center of the Yunnan–Guizhou Plateau. It covers an area of 21,013 km<sup>2</sup> and has a permanent population of 8.5 million people [37]. Kunming has a variety of vegetation types dominated by subtropical evergreen broad-leaved forest and coniferous-broad mixed forest [37], while the main urban area and its surroundings are primarily covered with artificial woods, secondary forests, and secondary bushes. The main urban area is developing around Dianchi Lake, which is expanding from north to south to encircle the lake. A dozen rivers flow through the city's construction zone into Dianchi Lake, establishing ecological corridors for the city.

The bird survey was conducted in three major rivers (namely, the Panlong River, the Maliao River, and the Laoyu River) along the urban development gradient (Figure 1). We chose the typical riverside green spaces along each river that flows through the urban area to set up 28 sampling sites (Figure 1). The three rivers were found to be affected by human activity at different levels (the Panlong River—high-human disturbance rivers; the Maliao River—medium-human disturbance rivers; the Laoyu River—low-human disturbance rivers). The Panlong River running through the old city has a width of 12–20 m, and the green space is around 45–150 m wide (including the river surface). The revetment is concrete, and there are walkways and piazzas nearby the river revetment. The Maliao River is approximately 15–90 m wide, and the green space is around 100–160 m wide. The trees, such as *Cinnamomum camphora* and *Ligustrum lucidum*, are normally not tall, and there are soft revetments and several aquatic plants. The width of the Laoyu River is around 30–100 m, while the width of the green space is approximately 100–330 m. Large trees like *Camptotheca acuminata* and *Taxodium distichum* can be found, as well as a big area of lawn with low management intensity, few trails, and a high canopy density of trees (Figure 1).

## 2.2. Bird Survey

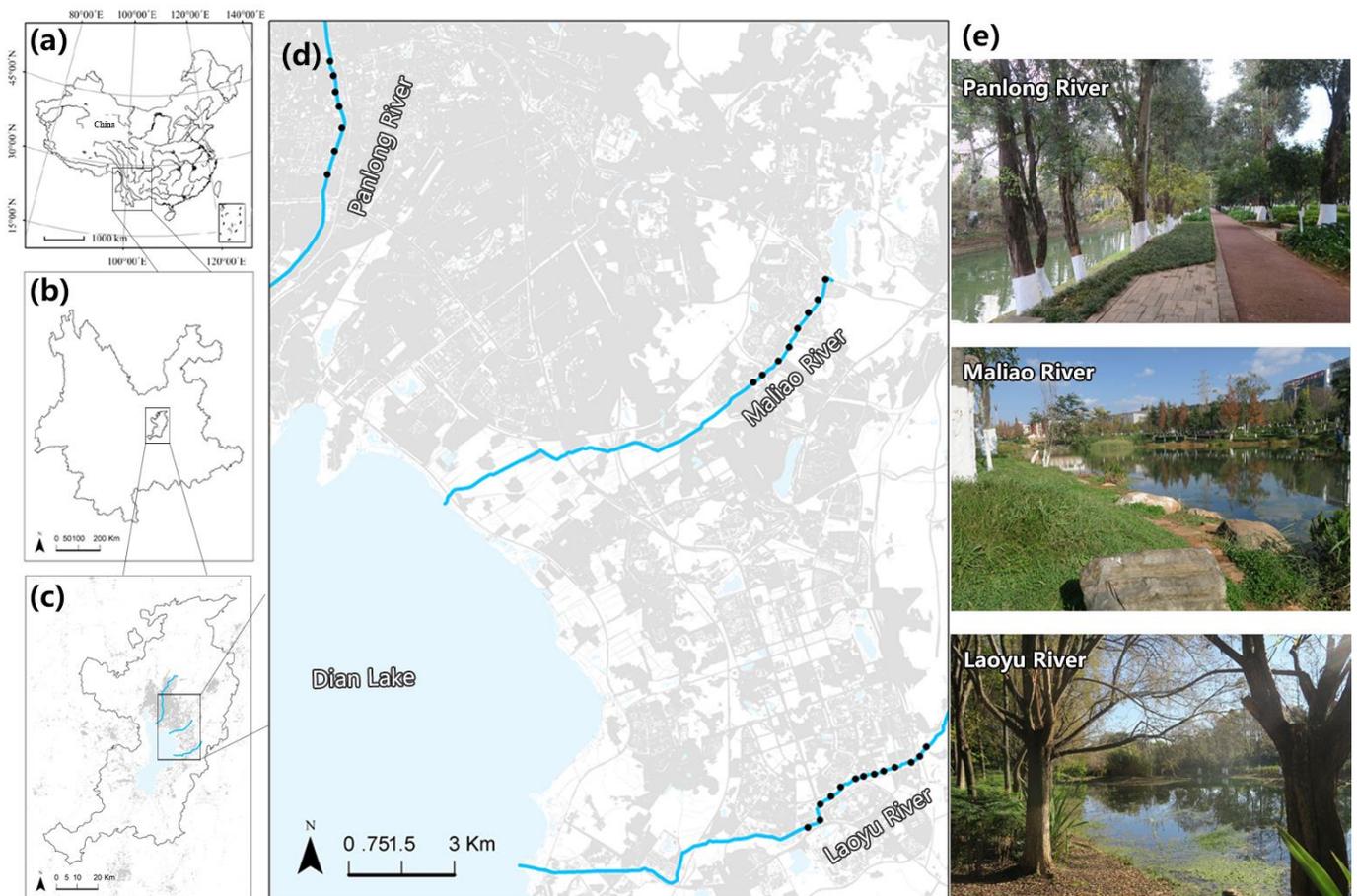
We conducted monthly bird surveys from March 2021 to February 2022 and obtained a total of 12 months of field data, covering both the breeding and non-breeding seasons. We surveyed between 7:00–10:00 and 15:00–18:00 on sunny days. Within a 100 m radius of the sampling sites, we identified and counted birds with the naked eye or binoculars over 10 min [38]. The sampling sites were at least 300–1000 m apart to assure each site's independence. The nomenclature of species follows the BirdLife taxonomic checklist version 3.0 [39].

## 2.3. Functional Traits and Functional Diversity

To evaluate FD, birds' functional traits were obtained using the EltonTraits database [40], which includes feeding habits, vertical foraging strata, and body mass. The EltonTraits database [40] provides the proportions for 10 food categories as well as proportions for 7 foraging strata (see Appendix B). To quantify functional diversity, we calculated the functional dispersion index (FDis) using the R package "FD". The functional dispersion index is the mean distance of individual species to the community centroid of all species in trait space [41]. A higher value of FDis indicates a higher level of niche differentiation.

## 2.4. Landscape-Level Variables

We assessed landscape- and patch-level variables at three different spatial scales for each sampling site: 500 m, 100 m, and 20 m (Table 1). High-resolution satellite pictures were collected using Google Earth Pro, which has been extensively used in other studies [13,42,43], and land use data was extracted within a 500 m radius using ArcGIS 10.0 [44]. We identified six land cover variables: forest, open green space (lawn, weedy patch), aquatic plant, river, constructed land (impervious surface, excluding municipal roads), and road (municipal roads). Using the FRAGSTATS 2.4 program [45], we calculated three landscape indices: PLAND (percentage of coverage area), ED (edge density), and AREA MN (mean patch area) for each land cover type within a circle of radius 500 m and 100 m, respectively (Table 1).



**Figure 1.** Location of the 28 sampling sites among three rivers with different levels of human disturbance along the urban development gradient in Kunming, Yunnan Province, China (the Panlong River—high-human disturbance rivers; the Maliao River—medium-human disturbance rivers; the Laoyu River—low-human disturbance rivers). (a) The location of Yunnan Province in China. (b) The location of the main urban area (the six administrative districts) of Kunming surrounding Dianchi Lake. (c) The three rivers with different levels of human disturbance along the urban development gradient in Kunming. (d) The location of the 28 sampling sites. The sampling sites we selected were located in the typical green space along each river. (e) Pictures of the typical habitat types in each river.

**Table 1.** List of landscape- and patch-level variables assessed for each sampling site in three urban rivers at the 500, 100, and 20 m scales.

Metrics	Land Cover	Buffer Radius (m)	Description
AREA_MN	Forest, open green space (lawn, weedy patch), aquatic plant, river, constructed land (impervious surface besides municipal roads), road (municipal roads)	500; 100	The mean patch area of a selected land cover type within a 500 or 100 m radius
ED	Forest, open green space (lawn, weedy patch), aquatic plant, river, constructed land (impervious surface besides municipal roads), road (municipal roads)	500; 100	The edge density of a selected land cover type within a 500 or 100 m radius

Table 1. Cont.

Metrics	Land Cover	Buffer Radius (m)	Description
PLAND	Forest, open green space (lawn, weedy patch), aquatic plant, river, constructed land (impervious surface besides municipal roads), road (municipal roads)	500; 100	% of a selected land cover type within a 500 or 100 m radius
PLAND	Mean foliage cover < 0.5 m	20	% of foliage cover at 0–0.5 m height within a 20 m radius
PLAND	Mean foliage cover 0.5–1 m	20	% of foliage cover at 0.5–1 m height within a 20 m radius
PLAND	Mean foliage cover 1–2 m	20	% of foliage cover at 1–2 m height within a 20 m radius
PLAND	Mean foliage cover 2–3 m	20	% of foliage cover at 2–3 m height within a 20 m radius
PLAND	Mean foliage cover 3–4 m	20	% of foliage cover at 3–4 m height within a 20 m radius
PLAND	Mean foliage cover 4–6 m	20	% of foliage cover at 4–6 m height within a 20 m radius
PLAND	Mean foliage cover 6–8 m	20	% of foliage cover at 6–8 m height within a 20 m radius
PLAND	Mean foliage cover 8–10 m	20	% of foliage cover at 8–10 m height within a 20 m radius
PLAND	Mean foliage cover 10–12 m	20	% of foliage cover at 10–12 m height within a 20 m radius
PLAND	Mean foliage cover 12–15 m	20	% of foliage cover at 12–15 m height within a 20 m radius
PLAND	Mean foliage cover >15 m	20	% of foliage cover above 15 m height within a 20 m radius
Foliage vertical diversity	-	20	The Shannon–Wiener index computed by using the number of points with leaves at each height range as individuals
PLAND	Litter layer	20	% of the litter layer cover area within a 20 m radius

### 2.5. Patch-Level Variables

Taking each sampling site as the center, we formed four perpendicular 20 m lines along which observation points were selected at 4 m intervals. The height profiles of foliage were determined using the 20 observation points [10,46]. Using a 4 m measuring stick as a visual reference, we recorded the presence or absence of leaves at heights of 0–0.5, 0.5–1, 1–2, 2–3, 3–4, 4–6, 6–8, 8–10, 10–12, 12–15, and >15 m at each observation point [10,47]. The observer (YD) visually assessed the proportion of litter layer cover within a 20 m radius around each sampling site [48,49].

We calculated the proportion of vegetation cover across each height range by dividing the number of points in each height range that have leaves by the total number of observation points in that height range [10]. We counted the number of points with leaves at each height range and used that number as individuals to compute the Shannon–Wiener index, which is the index of vertical heterogeneity of vegetation (Table 1) [10,50].

### 2.6. Statistical Analysis

We combined each set of 12 surveys into community data for each sampling site [15,51]. We then calculated the bird species richness, abundance, Shannon–Wiener index, and FDis in the annual cycle, breeding season, and non-breeding season, respectively. A one-way analysis of variance (ANOVA) and Tukey’s HSD post hoc test were used to examine differences in bird species richness, Shannon–Wiener index, and FDis among three urban river habitat types. The R packages “fundiversity” and “vegan” were used.

To assess the impact of habitat attributes on taxonomic and functional diversity of birds, we used species richness and FDis as dependent variables. We used the following variables as initial independent variables: 36 landscape-level variables (three landscape indices: PLAND, ED, and AREA MN for each land cover type in 100 and 500 m scales) and 13 patch-level variables in 20 m scales (see Table 1 for details). The number of predictor variables was higher than our observations, thus we needed to select important ones before the multiple regression analysis. When describing the impact of landscape structure on certain characteristics of biotic communities, it is hard to determine a priori which metrics should be selected to depict the various landscape structure components [52]. We used partial least squares regression (PLSR) to select a subset of the important predictors, after which we could apply multiple regression analysis [17,53].

Partial least squares regression is a linear regression approach that maximizes the covariance between the scores and the response, as well as calculates scores and residuals, by decomposing a matrix with predictors and a matrix with responses [54]. This approach is useful when there are more explanatory variables than observations and significant multicollinearity [53]. It has been applied in chemistry and ecology studies [55–59].

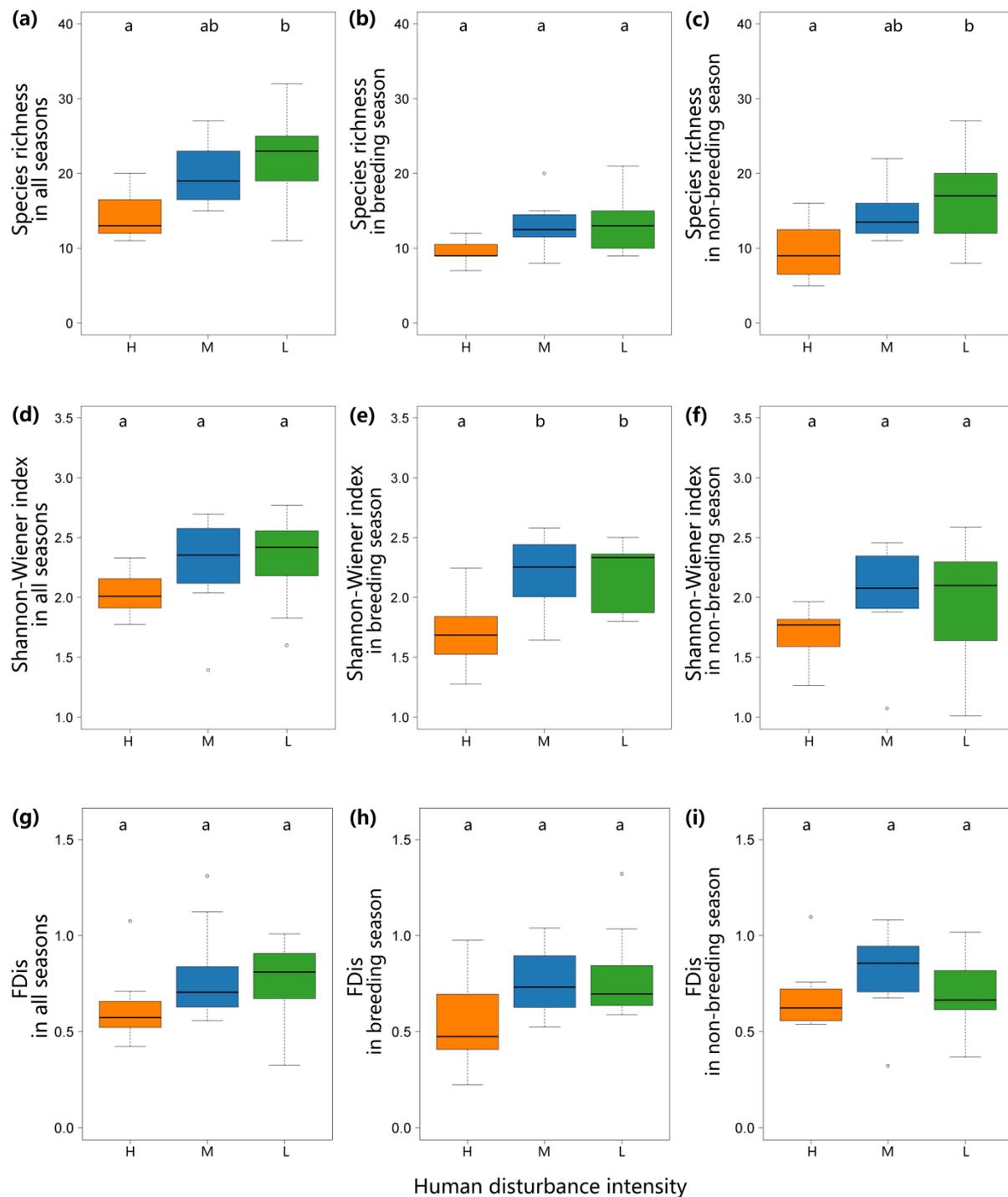
With the landscape- and patch-level variables as predictors and species richness and FDis as responses, we applied the PLSR using R 3.5.3 [60] and the package “mdatools” [61]. We used the function “vipcores” in the package “mdatools” to calculate the variable importance in the projection (VIP), which can be used to choose the most important predictors. See [62] for further information about VIP scores. We kept the predictors with  $VIP \geq 1$  to reduce the number of predictors and the possibility of collinearity so that we could proceed to the next steps for multiple regression analysis [62].

We constructed multiple linear regression using the predictor with VIP scores greater than 1 and no multiple collinearity to assess how landscape- and patch-level variables affected bird species richness and functional diversity. We performed multiple linear regression with no more than three predictors since the number of predictors has to be limited to one-tenth of the sample size to prevent overfitting [15,63]. For model selection, we applied information theoretic methods to calculate Akaike’s Information Criterion corrected (AICc) for small sample size [64]. We then calculated the  $\Delta AICc_i = AICc_i - \min(AICc)$  for the  $i$ th model and selected the models with  $\Delta AICc < 2$ , which were considered to have the best fit [64]. To compute model coefficients, we applied model averaging to the selected models. We used the package “MuMIn” in R [65] for model selection and averaging.

### 3. Result

#### 3.1. Species Diversity and Functional Diversity and Their Variation among Rivers

We recorded 71 species (3387 counts) from 34 families and 12 orders in 12 replicated surveys covering 28 sampling sites during the breeding and non-breeding seasons (see Appendix A). The bird species richness ranged from 11 to 32 (mean  $\pm$  s.e. =  $19.11 \pm 1.05$ ) for the different sites. The Panlong River (a high-human disturbance river) contained 38 species; the Maliao River (a medium-human disturbance river) contained 46 species; and the Laoyu River (a low-human disturbance river) contained 57 species. We recorded a total of 45 bird species in the breeding season and 63 species in the non-breeding season across all sampling sites in the three rivers (Figure 2). The range of species observed at each sampling site in the breeding season was between 7 and 21 (mean  $\pm$  s.e. =  $12.32 \pm 0.67$ ), while in the non-breeding season, the range was between 5 and 27 (mean  $\pm$  s.e. =  $14.00 \pm 0.99$ ). Meanwhile, Moran’s S from the spatial correlation analysis was not significant ( $p = 0.118$ ), indicating that species richness was spatially independent.



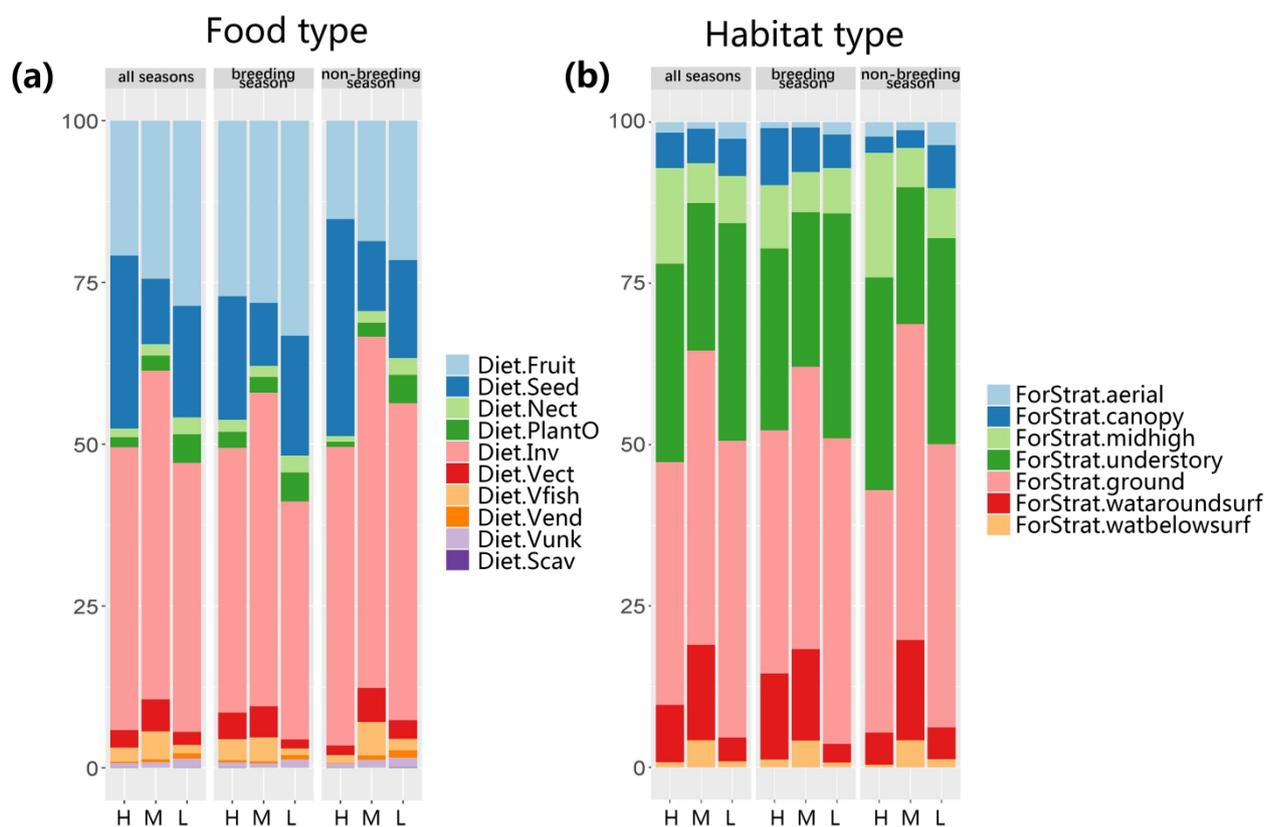
**Figure 2.** The bar plots depict bird richness (a–c), the Shannon–Wiener Index (d–f), and the FDis (g–i) in all seasons, breeding season, and non-breeding season, at high-, medium-, and low-human disturbance rivers (H—high-human disturbance rivers; M—medium-human disturbance rivers; L—low-human disturbance rivers).

During both seasons, the bird species richness along the low-human disturbance river was highest, followed by the medium-human disturbance river and the high-human disturbance river. The degree of human disturbance had a significant effect on bird richness according to the analysis of the one-way ANOVA (Figure 2;  $F_{2,25} = 4.239$ ,  $p = 0.026$ ). Tukey’s HSD post hoc test revealed that the low-human disturbance river had a significantly higher bird richness than the high-human disturbance river ( $p = 0.022$ ; Figure 2). The richness of

the three types of rivers during the breeding season has no significant difference. In the non-breeding season, Tukey's HSD post hoc test revealed that the low-human disturbance river had a significantly higher bird richness than the high-human disturbance river ( $p = 0.030$ ; Figure 2).

Throughout the year and the non-breeding season of birds, the Shannon–Wiener index showed no significant difference. However, in the breeding season, low- and medium-human disturbance rivers had a significantly higher Shannon–Wiener index than the high-human disturbance river ( $p = 0.006$ ,  $p = 0.009$ ). There was no significant difference in FDis among the three types of rivers during the annual cycle, the breeding or non-breeding season.

In the three rivers, the food source of bird species was dominated by invertebrates, followed by fruits, seeds, amphibians, fish, other plants, nectar, birds, and corrosion. With the increase in human disturbance, the relative abundance of fruit-eating and nectar-eating birds decreased while that of seed-eating birds increased (Figure 3). Considering the vertical foraging strata, with the increase in human disturbance, the relative abundance of time spent on the ground stratum by bird species increased (Figure 3; low-human disturbance rivers = 46.01%, medium-human disturbance rivers = 45.62%, high-human disturbance rivers = 37.62%).



**Figure 3.** Relative abundance of different avian groups in the annual cycle, breeding season, and non-breeding season at high-, medium-, and low-human disturbance rivers (H—high-human disturbance rivers; M—medium-human disturbance rivers; L—low-human disturbance rivers). (a) Birds were grouped by their diet (Diet.Fruit—fruit; Diet.Seed—seeds; Diet.Nect—nectar; Diet.PlantO—other plant material; Diet.Inv—invertebrate; Diet.Vect—reptiles, amphibians; Diet.Vfish—fish; Diet.Vend—mammals, birds; Diet.Vunk—vertebrates (general or unknown); Diet.Scav—scavenge, garbage, offal, carcasses, trawlers, carrion). (b) Percentage time spent on the seven categories of the stratum (ForStrat.aerial—canopy stratum; ForStrat.canopy—canopy stratum; ForStrat.midhigh—mid-high stratum; ForStrat.understory—understory stratum; ForStrat.ground—ground stratum; ForStrat.wataroundsurf—around water surface; ForStrat.watbelowsurf—below the water surface).

### 3.2. PLSR Linked Species Diversity and Functional Diversity with Landscape- and Patch-Level Variables

First, we used richness and FDis as the response variables and landscape- and patch-level variables as the explanatory variables to perform PLSR, and the first components explained 38.8% and 16.2% of the variation in the response variable for richness and FDis, respectively. There were 19 and 18 metrics with  $VIP \geq 1$  (i.e., the important explanatory variable; see Tables A3 and A4).

For bird richness, in 19 important explanatory variables, there were 8 landscape indicators on the 100 m scale, 6 landscape indicators on the 500 m scale, respectively, and 5 patch-level variables on the 20 m scale (that is, 42.1%, 31.6%, and 26.3% of the 19 important explanatory variables). For open green space and aquatic plants, the effect in the 100 m radius was more significant than that in the 500 m radius ( $VIP \geq 1$ ). For constructed land, the three landscape indices on both the 500 and 100 m scales were important. The AREA\_MN of the forest was important on both the 500 and 100 m scales. In the 20 m radius, litter layer and ground herbaceous plant coverage, as well as a vertical range of 3–10 m vegetation cover, were important explanatory variables.

For bird FDis, in the 18 important explanatory variables, there were 8 landscape indicators on the 100 m scale, 7 landscape indicators on the 500 m scale, and 3 landscape indicators on the 20 m scale (that is, 44.4%, 38.9%, and 16.7% of the 18 important explanatory variables, respectively). Similar to bird species richness, the AREA\_MN of the forest was also significant for bird FDis at both the 500- and 1000-m scales, and metrics at the 100-m scale were more significant for open green space. For constructed land, the ED and PLAND in both the 500 m and 100 m scales are important, and the metrics in the 500 m scale are more important than those in the 100 m scale for aquatic plants. On the 20 m scale, the litter layer, foliage cover in 0.5–1 m, and foliage cover in 4–6 m are important.

### 3.3. Multiple Regression Linked Species Diversity and Functional Diversity with Landscape- and Patch-Level Variables

For richness as a response variable, PLSR and VIP approaches were used to derive 19 explanatory variables of interest (i.e.,  $VIP \geq 1$ ). To avoid multicollinearity, we selected indicators with variance inflation factors (VIFs)  $< 10$  ( $n = 15$ ) [66] to create multiple linear regression models. We obtained 7 candidate models (i.e., top models) with independent variable counts less than or equal to 3 and  $\Delta AICc < 2$  (Table 2). Then we applied the model averaging to the top model set, and the independent variables in the average model were mean foliage cover in 4–6 m in the 20 m scale ( $p < 0.05$ ), ED of constructed land in the 100 m scale ( $p < 0.05$ ), AREA\_MN of open green space in the 100 m scale, AREA\_MN of forest in the 100 m scale ( $p < 0.05$ ), ED of aquatic plant in the 100 m scale, ED of forest in the 500 m scale, and AREA\_MN of constructed land in the 500 m scale (Table 3).

**Table 2.** The top model set connected landscape- and patch-level variables and bird species richness, with  $\Delta AICc < 2$  and the number of predictors  $\leq 3$ .

	Acronym	Land Use	Buffer Radius (m)	Model1	Model2	Model3	Model4	Model5	Model6	Model7
(Int)	-	-	-	30.360	25.600	16.250	38.830	10.750	25.230	21.470
	PLAND	Mean foliage cover 4–6 m	20	10.890	10.830				11.510	12.180
	ED	Constructed land	100	−0.021	−0.017		−0.017		−0.015	−0.014
	AREA_MN	Open green space	100	−75.290			−108.600			
	AREA_MN	Forest	100			42.110		48.530		
	ED	Aquatic plant	100			0.016		0.019		0.008
	ED	Forest	500			−0.030	−0.040			
	AREA_MN	Constructed land	500						−0.635	
	AICc			174.500	174.700	175.300	175.600	176.200	176.400	176.400
	$\Delta AICc$			0.000	0.270	0.880	1.110	1.750	1.930	1.970
	weight			0.234	0.205	0.151	0.135	0.098	0.089	0.088

**Table 3.** Results of model averaging for bird species richness for the top models (Table 2). The definitions of predictors are listed in Table 1. *p* values < 0.05 are in bold font.

	Acronym	Land Use	Buffer Radius (m)	Estimate	<i>p</i>
(Int)	-	-	-	25.807	<b>0.004</b>
	PLAND	Mean foliage cover 4–6 m	20	11.188	<b>0.017</b>
	ED	Constructed land	100	−0.018	<b>0.001</b>
	AREA_MN	Open green space	100	−87.460	0.081
	AREA_MN	Forest	100	43.958	<b>0.002</b>
	ED	Aquatic plant	100	0.014	0.073
	ED	Forest	500	−0.035	0.059
	AREA_MN	Constructed land	500	−0.635	0.312

For FDis as the response variable, PLSR and VIP approaches were used to derive 19 explanatory variables of interest (i.e.,  $VIP \geq 1$ ). To avoid multicollinearity, we selected 15 indicators whose VIFs < 10 [66] to create multiple linear regression models. We obtained 4 candidate models (i.e., top models) with independent variable counts less than or equal to 3 and  $\Delta AICc < 2$  (Table 4). Then we applied the model averaging to the top model set, and independent variables in the average model are ED of forest in the 100 m scale, PLAND of forest in the 100 m scale ( $p < 0.05$ ), ED of open green spaces in the 100 m scale ( $p < 0.05$ ), mean foliage cover in 4–6 m in the 20 m scale ( $p < 0.05$ ), and ED of constructed land in the 100 m scale (Table 5).

**Table 4.** The top model set connected landscape- and patch-level variables and bird species FDis, with  $\Delta AICc < 2$  and the number of predictors  $\leq 3$ .

	Acronym	Land Use	Buffer Radius (m)	Model1	Model2	Model3	Model4
(Int)	-	-	-	0.694	0.294	0.555	0.493
	ED	Forest	100	−0.001		$-3.249 \times 10^{-4}$	
	PLAND	Forest	100	0.011			
	ED	Open green space	100	$3.109 \times 10^{-4}$	$3.421 \times 10^{-4}$	$3.717 \times 10^{-4}$	$2.631 \times 10^{-4}$
	PLAND	Mean foliage cover 4–6 m	20		0.562	0.645	0.537
	ED	Constructed land	100				$-2.145 \times 10^{-4}$
AICc				−6.600	−6.300	−6.200	−4.700
$\Delta AICc$				0.000	0.360	0.410	1.980
weight				0.331	0.276	0.270	0.123

**Table 5.** Results of model averaging for bird species FDis for the top models (Table 4). The definitions of predictors are listed in Table 1. *p* values < 0.05 are in bold font.

	Acronym	Land Use	Buffer Radius (m)	Estimate	<i>p</i>
(Int)	-	-	-	0.547	<b>0.034</b>
	ED	Forest	100	−0.001	0.081
	PLAND	Forest	100	0.011	<b>0.003</b>
	ED	Open green space	100	$3.286 \times 10^{-4}$	<b>0.030</b>
	PLAND	Mean foliage cover 4–6 m	20	0.596	<b>0.009</b>
	ED	Constructed land	100	$-2.145 \times 10^{-4}$	0.304

#### 4. Discussion

As the scale dependency of ecological processes and multiple environmental factors at different spatial scales affects bird diversity, multi-scale approaches are better than single-scale models due to the models they produce to assess the effects of multi-scale landscape structure on bird distribution and habitat use [18,67,68]. This study linked environmental

variables both at small- and medium-sized landscape scales and patch scales with river bird species richness and functional diversity (FDIs). We found that the landscape characteristics at 500 and 100 m scales, and patch attributes at 20 m scale had a significant effect on bird species richness, while FD was significantly affected by indexes at 100 and 20 m scales. To improve the urban riverfront landscape management and design strategy, multi-scale habitat attributes should be considered to address how to optimize land uses, which are mainly human driven at multiple scales of space, time, and intricacy of management.

There were significant differences in richness among three different intensities of human disturbance of rivers, either throughout the year or during the non-breeding season, respectively. The species richness of the low-human disturbance river (the Laoyu River) was significantly higher than that of the high-human disturbance river (the Panlong River). During the non-breeding season, some migratory birds, such as shorebirds, prefer to stay in the low-human disturbance river. Low-human disturbance rivers in urban areas are a refuge for birds [48], especially during the non-breeding season [69].

There was no significant difference for FDis among the three rivers, whether for the whole year or in the different seasons. As urbanization increases the functional similarity of the bird community [3,20], the differences in FDis among the sampling sites were not significant. Unlike bird species richness, the FDis was significantly influenced by explanatory variables on 100 and 20-m scales but not on the 500-m scale (Table 5). Functional diversity has a complex relationship with habitat variables because it depends on the habitat and landscape structural needs of species in each functional category at the survey site [70]. For example, frugivore and nectarivore birds can be influenced by vegetation structure and specific plant species [70,71].

Recent studies have explored the functional and taxonomic diversity of birds in urban green spaces [72,73], showing different situations. The canopy heterogeneity affected FD [73] and the presence of large trees enhanced taxonomic diversity and functional diversity [74]. A study conducted in Austria revealed that sealed areas (e.g., roads and buildings) had a considerable negative impact on bird species richness and functional diversity [73]. However, another study showed that tree coverage and site size had a positive correlation with richness, while none of the measured land use characteristics were associated with FD, which means functional diversity was unrelated to measured landscape structure variables [72]. We found that the average patch area of forest had significantly positive impacts on bird richness, the average patch area of constructed land had negative impacts on bird richness, and the area proportion of forest had significantly positive impacts on functional diversity.

Edge density (ED) is a tool to quantify how many marginal habitats are next to other types of land cover. The ED at the class level is the entire length of the patch's edge per unit area for a certain class [75]. The characteristic of a patch edge for a class or an entire landscape is crucial to multiple ecological processes, especially for wildlife. We found that the ED of construction land and forest had negative impacts on bird richness and functional diversity. The ED of construction land reflects the characteristics of its shape, and an increase in ED shows the increasing negative effects on those species sensitive to human disturbance. A higher ED for forestland with the same percentage of forestland area suggests more habitat exposure to human disturbance, which will be detrimental to sensitive species [76–78].

Previous studies have demonstrated the significance of forest leaf litter for insectivorous birds because it provides greater habitat for litter-dependent invertebrates [79–81]. Many birds like to forage among the ground's dead leaves, such as *Turdus merula* and *Turdus dissimilis*. Protection of woodland insectivorous birds is essential since they are in global decline [82,83] and depend on specific forest structures, including large trees, dense undergrowth, and thick leaf litter [80]. Studies indicate that the degree of park management may play a significant role in influencing the bird community structure in urban green space [84,85], and successful management should avoid excessive understory cleanup. In this study, although the litter layer did not appear in the average models, we

obtained the VIP scores of the litter layer by PLSR for bird richness and FD greater than 1 (Tables A3 and A4), which means the litter layer area was an important habitat attribute. In addition, our study focused on a general analysis of anthropogenic impact, but further research could expand on these findings by incorporating additional variables such as human population density and building type.

We suggest that urban riverside green space should be planned and managed at multiple scales, including landscape-scale management (landscape composition and configuration) and patch-scale management (vegetation structure and litter layer). Multi-scale management may be beneficial for the conservation of bird species richness and FD in urban riverside green space. It is critical to increase the total and mean area of the forest while decreasing the mean area and ED of constructed land [13,86,87] at the landscape scale, as well as maintain high vegetation structure [51,88], vertical vegetation heterogeneity [47], and low-intensity management that preserves the litter layer at the patch scale.

## 5. Conclusions

This study linked environmental variables both at small and medium landscape scales and at patch scales with urban river bird species richness and FD. Bird species richness and FD were strongly related to various landscape- and patch-level variables. Tree cover at the 20 m scale had significantly positive impacts on bird species richness and functional diversity. Forest land in the 100 m scale had a significantly positive effect on bird species richness and FD, while construction land in the two landscape scales (the 500 and 100 m scales) had a significantly negative effect on species richness. To improve the urban riverfront landscape management and design strategy, multi-scale habitat attributes should be considered to address how to optimize land uses, which are mainly human driven at multiple scales of space, time, and intricacy of management.

**Author Contributions:** Q.M. and Z.W. were responsible for the research design. Q.M. drafted the main text and prepared the figures. Q.M. and H.B. did the bird survey. Q.M., J.S. and Y.D. surveyed vegetation structure. Q.M., J.S. and Y.D. finished the land cover classification. Q.M., J.S. and Y.D. processed the data. Q.M. developed the modeling framework. Q.M. analyzed the results. All authors were involved in discussions and editing. All authors have read and agreed to the published version of the manuscript.

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## Appendix A

**Table A1.** List of bird species observed in three rivers in Kunming, Yunnan Province, China, during an annual cycle (spring and winter census).

Common Name	Scientific Name
Little Grebe	<i>Tachybaptus ruficollis</i>
Oriental Turtle Dove	<i>Streptopelia orientalis</i>
Spotted Dove	<i>Spilopelia chinensis</i>
House Swift	<i>Apus nipalensis</i>
White-breasted Waterhen	<i>Amaurornis phoenicurus</i>
Common Moorhen	<i>Gallinula chloropus</i>
Cinnamon Bittern	<i>Ixobrychus cinnamomeus</i>
Black-crowned Night-heron	<i>Nycticorax nycticorax</i>
Striated Heron	<i>Butorides striata</i>
Chinese Pond-heron	<i>Ardeola bacchus</i>
Cattle Egret	<i>Bubulcus ibis</i>
Grey Heron	<i>Ardea cinerea</i>
Intermediate Egret	<i>Ardea intermedia</i>
Little Egret	<i>Egretta garzetta</i>
Grey-headed Lapwing	<i>Vanellus cinereus</i>
Common Sandpiper	<i>Actitis hypoleucos</i>
Green Sandpiper	<i>Tringa ochropus</i>
Black-winged Kite	<i>Elanus caeruleus</i>
Eurasian Buzzard	<i>Buteo buteo</i>
Eurasian Hoopoe	<i>Upupa epops</i>
Common Kingfisher	<i>Alcedo atthis</i>
White-throated Kingfisher	<i>Halcyon smyrnensis</i>
Eurasian Wryneck	<i>Jynx torquilla</i>
Common Kestrel	<i>Falco tinnunculus</i>
White-throated Fantail	<i>Rhipidura albicollis</i>
Black Drongo	<i>Dicrurus macrocercus</i>
Ashy Drongo	<i>Dicrurus leucophaeus</i>
Long-tailed Shrike	<i>Lanius schach</i>
Common Magpie	<i>Pica pica</i>
Grey-headed Canary-flycatcher	<i>Culicicapa ceylonensis</i>
Yellow-bellied Tit	<i>Pardaliparus venustulus</i>
Green-backed Tit	<i>Parus monticolus</i>
Great Tit	<i>Parus major</i>
Plain Prinia	<i>Prinia inornata</i>
Clamorous Reed-warbler	<i>Acrocephalus stentoreus</i>
Barn Swallow	<i>Hirundo rustica</i>
Mountain Bulbul	<i>Ixos mcclllandii</i>
Brown-breasted Bulbul	<i>Pycnonotus xanthorrhous</i>
Sooty-headed Bulbul	<i>Pycnonotus aurigaster</i>
Yellow-browed Warbler	<i>Phylloscopus inornatus</i>
Pallas's Leaf-warbler	<i>Phylloscopus proregulus</i>
Dusky Warbler	<i>Phylloscopus fuscatus</i>
Black-throated Tit	<i>Aegithalos concinnus</i>
Oriental White-eye	<i>Zosterops palpebrosus</i>
Black-streaked Scimitar-babbler	<i>Erythrogonys gravivox</i>
White-browed Laughingthrush	<i>Garrulax sannio</i>
Blue-winged Minla	<i>Siva cyanouroptera</i>
Chestnut-tailed Starling	<i>Sturnia malabarica</i>
Red-billed Starling	<i>Spodiopsar sericeus</i>
Common Blackbird	<i>Turdus merula</i>
Black-breasted Thrush	<i>Turdus dissimilis</i>
Oriental Magpie-robin	<i>Copsychus saularis</i>

Table A1. Cont.

Common Name	Scientific Name
Blue Whistling Thrush	<i>Myophonus caeruleus</i>
Red-throated Flycatcher	<i>Ficedula albicilla</i>
White-capped Water-redstart	<i>Phoenicurus leucocephalus</i>
Plumbeous Water Redstart	<i>Phoenicurus fuliginosus</i>
Daurian Redstart	<i>Phoenicurus auroreus</i>
Common Stonechat	<i>Saxicola torquatus</i>
White-rumped Munia	<i>Lonchura striata</i>
Scaly-breasted Munia	<i>Lonchura punctulata</i>
Russet Sparrow	<i>Passer cinnamomeus</i>
Eurasian Tree Sparrow	<i>Passer montanus</i>
Olive-backed Pipit	<i>Anthus hodgsoni</i>
Rosy Pipit	<i>Anthus roseatus</i>
Gray Wagtail	<i>Motacilla cinerea</i>
Citrine Wagtail	<i>Motacilla citreola</i>
White Wagtail	<i>Motacilla alba</i>
Brambling	<i>Fringilla montifringilla</i>
Chinese Grosbeak	<i>Eophona migratoria</i>
Common Rosefinch	<i>Carpodacus erythrinus</i>
Black-headed Greenfinch	<i>Chloris ambigu</i>

## Appendix B

Table A2. List of functional traits for birds with descriptions.

Functional Trait	Definition
Diet.Fruit	Percentage of fruit in the diet
Diet.Seed	Percentage of seeds in the diet
Diet.Nect	Percentage of nectar in the diet
Diet.PlantO	Percentage of other plant material in the diet
Diet.Inv	Percentage of invertebrates in the diet
Diet.Vect	Percentage of reptiles and amphibians in the diet
Diet.Vfish	Percentage of fish in the diet
Diet.Vend	Percentage of mammals and birds in the diet
Diet.Vunk	Percentage of vertebrates (general or unknown) in the diet
Diet.Scav	Percentage of scavenge, garbage, offal, carcasses, trawlers, and carrion in the diet
ForStrat.aerial	Percentage time spent in the canopy stratum
ForStrat.canopy	Percentage time spent in the canopy stratum
ForStrat.midhigh	Percentage time spent in the mid-high stratum
ForStrat.understory	Percentage time spent in the understory stratum
ForStrat.ground	Percentage time spent on the ground stratum
ForStrat.wataroundsurf	Percentage time spent around the water surface
ForStrat.watbelowsurf	Percentage time spent below the water surface
Body mass	Body mass in grams

## Appendix C

**Table A3.** The PLSR analysis utilizes richness as the response variable and landscape- and patch-level variables as the explanatory variables. The explanatory variables with  $VIP \geq 1$  were selected (sorted by VIP score value).

Acronym	LAND USE	Buffer Radius (m)	VIP
AREA_MN	Open green space	100	1.722
PLAND	Open green space	100	1.490
ED	Aquatic plant	100	1.482
ED	Constructed land	100	1.464
PLAND	Mean foliage cover 3–4 m	20	1.377
PLAND	Mean foliage cover < 0.5 m	20	1.306
AREA_MN	Forest	100	1.263
ED	Forest	500	1.235
AREA_MN	Constructed land	500	1.206
ED	Constructed land	500	1.175
PLAND	Constructed land	500	1.163
PLAND	Mean foliage cover 4–6 m	20	1.160
PLAND	Litter layer	20	1.156
PLAND	Mean foliage cover 8–10 m	20	1.128
PLAND	Constructed land	100	1.070
AREA_MN	Forest	500	1.061
AREA_MN	Constructed land	100	1.055
ED	River	500	1.033
ED	Open green space	100	1.032

**Table A4.** The PLSR analysis utilizes bird FDis as the response variable and landscape- and patch-level variables as the explanatory variables. The explanatory variables with  $VIP \geq 1$  were selected (sorted by VIP score value).

Acronym	Land Use	Buffer Radius (m)	VIP
AREA_MN	Forest	500	1.990
ED	Constructed land	100	1.759
PLAND	Constructed land	500	1.633
PLAND	Mean foliage cover 0.5–1 m	20	1.594
ED	Constructed land	500	1.517
PLAND	Constructed land	100	1.514
PLAND	Mean foliage cover 4–6 m	20	1.505
PLAND	Litter layer	20	1.494
AREA_MN	Open green space	100	1.381
AREA_MN	Forest	100	1.378
ED	Open green space	100	1.287
PLAND	Open green space	100	1.183
ED	River	500	1.171
ED	Aquatic plant	500	1.145
PLAND	Forest	100	1.068
ED	Forest	100	1.051
PLAND	Forest	500	1.047
AREA_MN	Open green space	500	1.034

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