Vegetation structure of farmland ditches and its role in promoting bird diversity

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A B S T R A C T

Agricultural intensification has simplified farmland landscapes, resulting in reduced bird diversity. Ditches, as linear features in farmland, play a crucial role in biodiversity conservation. However, little research has explored how vegetation characteristics of different ditch types affect farmland bird diversity. In this study, we analyzed the effects of ditch vegetation types on bird diversity by quantifying the proportions of trees, reeds, and herbs in ditches across intensively managed cropland in the North China Plain. Our results revealed that the proportion of reeds had a highly significant effect on bird abundance, while the proportion of trees and herbs showed a significant effect. Furthermore, bird community composition varied significantly across habitat types, with wheat habitats exhibiting lower diversity than others, and tree-dominated habitats supporting higher bird diversity. These findings suggest that optimizing ditch vegetation structure, particularly by increasing the proportion of trees and reeds, can enhance farmland bird abundance. We recommend maintaining habitat heterogeneity in farmland management to promote bird community conservation and restore biodiversity.

1. Introduction

The global assessment report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) warns that biodiversity is declining at a rate not seen at any time in human history and that all of nature's contributions to humankind are diminishing, except for the food supply at the expense of other contributions (Watson et al., 2019). The Aspirations for Biodiversity Beyond 2020 states that to cope with the decline in biodiversity, integrated nature-promoting and nature-based solutions for rural areas are needed to conserve biodiversity (Watson et al., 2021). Agricultural landscapes in China are a suitable habitat for 220 bird species, including 39 nationally important bird species and 14 globally threatened bird species assessed by the IUCN. Nearly 25 % of the national-protected species and 20 % of the threatened species use farmland as habitat. Therefore, the conservation of farmland biodiversity can largely make up for the gaps in nature reserves, and farmland cannot be ignored to achieve biodiversity conservation goals (Li et al., 2020).

Agricultural intensification leading to more homogeneous landscapes is the most significant pressure for declining bird diversity. Between 1980 and 2016, the number of birds living in agricultural environments has declined by more than half (57 %) (Mills, 2023; Ram et al., 2020). High yields from agricultural intensification are negatively correlated with bird densities (Guerrero et al., 2012), the frequency of insectivorous and grain-eating birds in olive groves in eastern Algeria, for example, tends to decrease with increasing agricultural intensification (Bouam et al., 2017), and when Hungary generally shifted to less intensive agriculture, the population density of common farmland birds became higher (Báldi and Batáry, 2011). According to data from the North American Breeding Bird Survey, 57 (74 %) of 77 farmland-associated species experienced population declines from 1966 to 2013, and habitat loss or modification was second only to pesticides in terms of negative impacts on farmland birds (Stanton et al., 2018). Implementing agri-environmental programs in the EU is the main conservation tool to protect declining farmland birds in Europe, aiming to halt and reverse the general decline of biodiversity in agricultural

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landscapes (Tarjuelo et al., 2021). In Germany, where flower strips are one of the most common agri-environmental schemes, arable landscapes planted with bands of perennial wildflowers have higher bird species richness and territorial densities (Schmidt et al., 2022). Structurally complex landscapes can increase the local diversity of agroecosystems, thus compensating for localized high-intensity management (Tscharntke et al., 2005). Birds were most abundant in fields with complex marginal habitats, nearly three times the number of birds inhabiting fields with simple marginal habitats (Gailly et al., 2017). Buffer strips are attractive to farmland-breeding birds, and more complex landscapes harbor more biodiversity and landscape complexity is increased by altering composition, configuration, or heterogeneity (Estrada-Carmona et al., 2022), e. g., planting small trees along field margins can increase the abundance of wintering birds (Kross et al., 2016). Even planting Christmas trees in landscapes dominated by grassland with low hedge density can locally increase the richness and abundance of bird species (Gailly et al., 2017). Semi-natural habitats, including open scrubland and agricultural hedgerows, have great potential to promote and conserve bird communities in intensively used agricultural landscapes, as both are suitable habitats for species with different ecological requirements (Šálek et al., 2022), and reeds are important habitats for many bird species (Yang, 2021).

Artificial ditches, which mainly refer to watercourses artificially dug for drainage and irrigation purposes (Xi et al., 2005), are organically combined with green vegetation to form an ecological network system (Xuan et al., 2016). They act as interspersed zones on the edges of farmland ecosystems, provide valuable non-crop habitats and refuges for farmland animals, provide food resources lacking in drought-prone

and intensively managed farmlands (Herzon and Helenius, 2008), and increase the biodiversity of farmland ecosystems. Species richness and abundance of farmland birds are positively correlated with highly vegetated furrows (Marja and Herzon, 2012).

Based on the above-mentioned studies, we hypothesized that ditches with different habitat compositions support different bird communities, and that bird diversity increases with the proportion of trees and reeds in the ditch, as these key habitat features play a crucial role in shaping bird species' richness and abundance. To test this hypothesis, we investigated the proportions of trees, reeds, and herbs in farmland ditches in Qihe County, Shandong Province, and classified the ditches into different types; we conducted bird diversity monitoring experiments to analyze the effects of different types of ditches on bird diversity and the effects of ditch parameters on bird diversity; and we recorded the specific habitats of birds located in the ditches to analyze the relationship between habitat heterogeneity of the ditches and bird diversity.

2. Materials and methods

2.1. Research area

The study area (Qihe County, Fig. 1) is located in the southernmost part of Dezhou City, Shandong Province, on the bank of the Yellow River Jinan, between latitude 36°24′37″-37°1′44″N and longitude 116°23′28″-116°57′35″E. The climate is warm temperate continental monsoon. The average annual temperature is 12.9℃ and the average annual precipitation in Dezhou City is 548 mm. The city's average annual frost-free period is 208 days, with medium and light loam as dominating high-
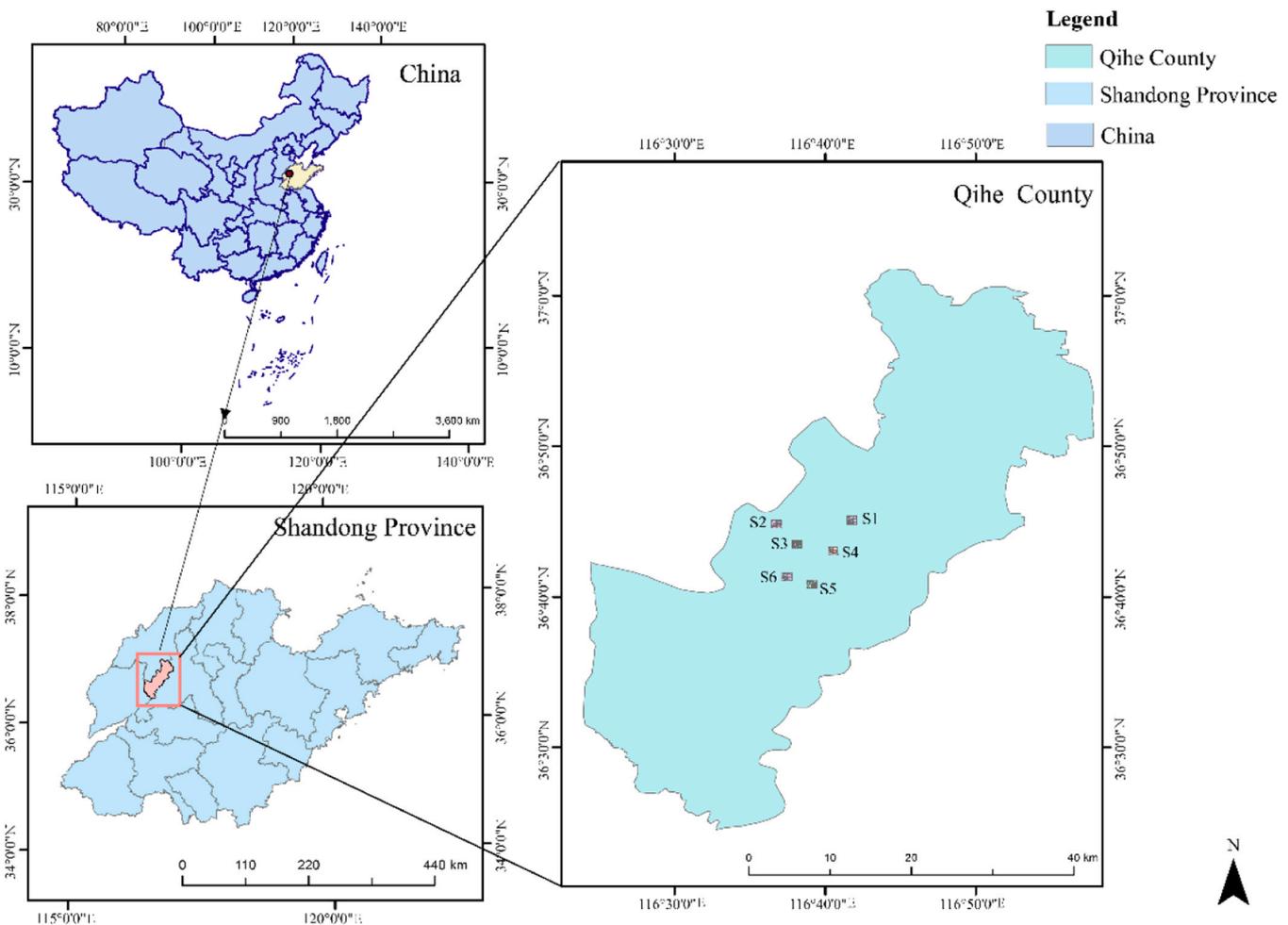

Fig. 1. Qihe County, Shandong Province, China, and the six test sites of 1 × 1 km each.

quality soil types, allowing for an intensive crop rotation of winter wheat followed by maize, which is repeated every year on almost all arable fields.

2.2. Research methods

2.2.1. Selection of landscape locations

We selected 16 test sites (1 km × 1 km in size) following a modified method (Pasher et al., 2013). Briefly, the site selection was based on farmland coverage (60–90 %) and Mean Patch Size to maximize landscape heterogeneity, while ensuring spatial independence (minimum center-to-center distance of 2.5 km). These criteria were applied using a cultivated land cover map derived from high-resolution remote sensing images and Fragstats V4.2 (McGarigal and Cushman, 2023) analysis for landscape metrics. Considering the spatial proximity of the sites and the variation in the mean patch size values, we selected six test sites to ensure a gradient in landscape heterogeneity.

2.2.2. Ditch vegetation survey

We used high-resolution drone imagery to vectorize the 1 km × 1 km sample sites, delineating features such as farmland, ditches, roads, and trees beyond the ditches. The width of different ditches varied greatly, so we calculated the actual area of each ditch in ArcGIS. Based on the calculation of the ditch area, we further calculated the microhabitat area (i.e. trees, reed, herbaceous plants, bare ground) based on the individual proportions (e.g., proportion of trees, reeds, herbaceous plants, and bare ground) recorded during the survey. First, we standardized the proportion of each microhabitat and then calculated the area of each microhabitat based on the standardized proportions. We categorized the ditches into four types based on the relative proportions of trees and reeds. The first category was "many trees" (MT), with relatively high tree cover; the second category was "few trees and many reeds" (FTMR), with relatively low tree cover and high reed cover; the third category was "few trees and no reeds" (FTNR), with relatively low tree cover and "no reeds"; and the fourth category was no trees (NT), which represented ditches with no tree cover at all. Within the six test sites, one 100 m section of ditch of each type (MT, NT, FTMR and FTNR) was randomly selected, totaling 24 ditches as bird diversity monitoring ditches. Table 1:

2.2.3. Bird surveys

Bird observations were made during peak bird activity, within five hours after sunrise, and the weather at the time of observation being sunny or cloudy; counts were conducted on days with good visibility and low wind. Bird surveys followed the Technical Guidelines for Biodiversity (National Environmental Protection Standard of the People's Republic of China, 2014). Three survey rounds were conducted during the breeding season from late May to early July 2023 (dates: 5.20–5.22, 6.11–6.13, 6.28–6.30). A point count (Technical guidelines for biodiversity monitoring-birds, 2014) method was used, with observers (RH, HY) standing in the center of the ditch sample plot for 10 minutes using binoculars, followed by a 5-minute slow walk along around the survey point for a total of 15 minutes observation time. To ensure that each bird

Table 1
Habitat composition of the selected 24 bird monitoring ditches in Qihe County, Shandong Province. Average values and standard deviation.

	Ditch type	Tree(%)	Reed(%)	Herbs(%)
MT	Many trees	56.67 % ± 12.11 %	8.33 % ± 13.29 %	28.33 % ± 21.37 %
FTMR	Few trees – many reeds	18.6 % ± 7.12 %	21.67 % ± 18.35 %	55 % ± 32.09 %
FTNR	Few trees – no reed	16.67 % ± 8.16 %	0 % ± 0 %	63.33 % ± 28.75 %
NT	No trees	0 % ± 0 %	18.33 % ± 22.29 %	46.67 % ± 26.58 %

was recorded only once during an observation, special care was taken to record the flight path and position of the bird during each observation. If the same bird flew to a different location during the observation, we ensured that only its first occurrence was recorded, thus avoiding double counts. Observations within 100 m of the center of the ditch sample plots were recorded, a distance chosen because most observed foraging flights of most birds occur within 100 m (Morris et al., 2001; Schifferli, 2001). Bird species richness and abundance were summed up over the three observations rounds. During the survey period, wheat grew in the buffer zone within 100 m of the observation centers of the 24 ditches. The number and location of bird species were marked on maps created using ArcGIS pro, along with details of the specific habitats where birds were present at the time of observation (wheat; ditchtree; ditchreed; ditchgrass; ditchground). Fig. 2:

2.3. Data analysis

Our study used several statistical methods to explore the effects of ditch composition (tree, reed, and herb proportions) and different ditch habitats on bird diversity.

Firstly, the Jaccard similarity index was used to calculate the similarity between ditch habitat composition similarity and bird diversity (richness and abundance), and the correlation between them was assessed using the Mantel test (Spearman correlation). Second, to assess the effect of ditch composition (tree_proportion, reed_proportion and herb_proportion) on bird diversity (richness and abundance), bird richness and abundance were modelled and analyzed separately using Poisson Generalized Linear Mixed Models (GLMM) with the equation

bird_richness ~ tree_proportion + reed_proportion + herb_proportion + (1 | site).

bird_abundance ~ tree_proprtion + reed_proportion + herb_proportion + (1 | site).

Fixed effects for the model included the proportions of trees, reeds, and herbs, and random effects considered test sites. We calculated each fixed-effects variable's variance inflation factor (VIF) to test for possible multicollinearity between predictor variables (Zuur et al., 2009). According to the criteria for VIF values, if the VIF value of a variable is between 1 and 5, it indicates that the problem of multicollinearity between the variables is within acceptable limits (no serious covariance).

Based on the detailed habitat monitoring, we standardized the proportion of each microhabitat and then calculated the area of each microhabitat based on the standardized proportions. During the analysis, we standardized species richness and abundance of birds to unit area to facilitate comparison of the effects of different habitat types on bird diversity. After standardizing the data, non-parametric tests (Kruskal-Wallis tests) were used to assess differences in bird richness and abundance per unit area between habitat types. Finally, bird communities were analyzed by Bray-Curtis's distance principal coordinates and combined with PERMANOVA to test for significant differences in bird community composition between ditch types and between ditch microhabitats.

All analyses were performed in R version 4.3.3 (R Core Team, 2020). The following packages were used for data processing and visualization: 'lme4' (Bates et al., 2015), 'ggplot2' (Wickham and Sievert, 2009), 'car' (Fox and Weisberg, 2018), and 'vegan' (Oksanen, 2015)."

3. Results

3.1. Diversity of birds in ditches

A total of 26 species of birds belonging to 8 orders, 21 families and 24 genera were recorded in the study. The birds observed belonged to the following orders *Passeriformes, Anseriformes, Pelecaniformes, Bucerotiformes, Cuculiformes, Columbiformes, Galliformes*, of which birds of the order Passeriformes were dominant, with 15 species from 14 families and 15 genera (Fig. 3). Among the different types of ditches, 16 species

Fig. 2. Six test sites, one each of MT, FTMR, FTNR, and NT type ditches were selected from each site, and the circles represent bird monitoring ditches. MT: Many trees; FTMR: Few trees – much reed; FTNR: Few trees – no reed; NT: No trees.

of birds were recorded in MT type ditches, 20 species in FTMR type ditches, 19 species in FTNR type and 18 species in NT type. Different types of ditches had different levels of attraction to birds with FTMR type ditches attracting the highest number of bird species and MT type ditches attracting the lowest number of bird species. Fig. 3 shows that *Spodiopsar cineraceus* only appeared in MT type ditches; while *Emberiza tristrami, Acrocephalus bistrigicep, Chloris sinica* and *Remiz consobrinus* only appeared in FTMR type ditches; and *Egretta garzetta* and *Cuculus micropterus* only appeared in FTNR type ditches. *Passer montanus, Pica serica, Phasianus colchicus* and *Pycnonotus sinensis* were dominant in all ditch types. Mantel's test based on Jaccard's distance showed significant correlations between habitat composition and bird richness and bird abundance (Table 2). These findings suggest that habitat composition plays a key role in shaping bird community structure and that ditches with similar habitat characteristics tend to support similar levels of bird species richness and abundance.

3.2. Effects of ditch parameters on bird diversity

As shown in Table 3, Poisson GLMM results showed that the variance and standard deviation of the random effects for both models (bird richness and bird abundance) were 0, indicating that random effects were negligible at each bird diversity monitoring ditch. Specifically, in

the bird richness model, none of the fixed effects (proportion of trees, reeds, and herbs) reached statistical significance ($p > 0.05$). However, in the bird abundance model, the proportion of trees and the proportion of herbs ($p < 0.05$), and trees ($p < 0.01$) had a significant positive effect on bird abundance. In addition, there was a moderate degree of multi-collinearity between the fixed effects, with variance inflation factor (VIF) values ranging from 1.27 to 1.63, indicating an acceptable degree of multicollinearity. These results were further validated by visualization of the model coefficients (Fig. 4). Regarding bird richness, all estimates were close to zero with a confidence interval of zero, indicating no significant effect.

3.3. Comparison of bird diversity per unit area in different habitats in ditches

The analysis of bird diversity per unit area across different micro-habitats in ditches revealed significant differences in both, species richness and abundance (Fig. 4(a) & (b)). Overall, bird richness and abundance were consistently lower in wheat habitats than in other microhabitats across all ditch types. The differences in bird diversity among the four ditch types of habitats are shown in Fig. 4(c) & (d):

MT ditches (Many Trees): Bird species richness was significantly lower in wheat habitats compared to ditchtree and ditchground habitats
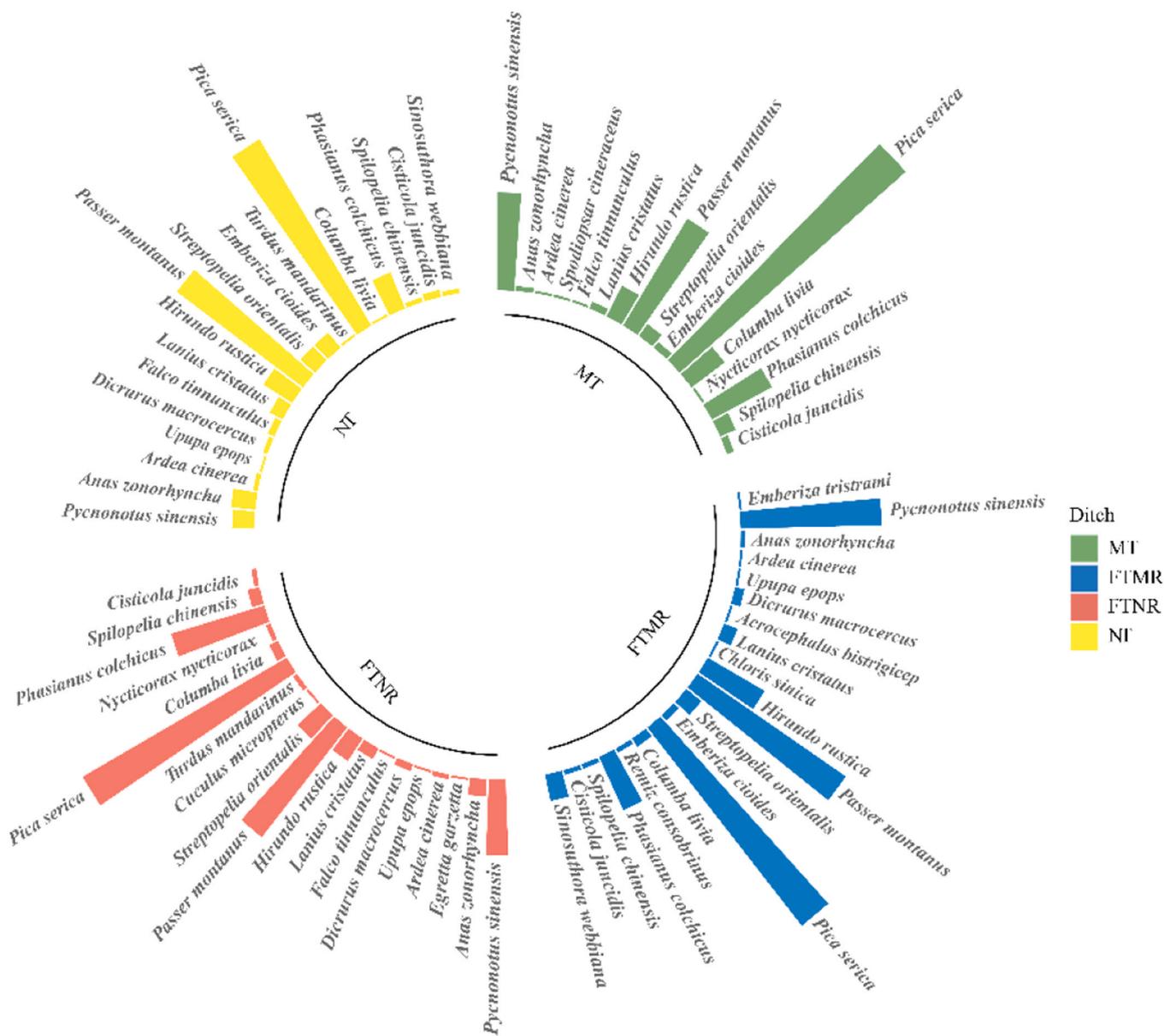
Fig. 3. Bird diversity in different types of ditch, MT: Many trees; FTMR: Few trees – much reed; FTNR: Few trees – no reed; NT: No trees. The length of the bars represents the abundance of the species summed over the three survey rounds (min: 1 observation; max: 124 observations).

Table 2
Mantel test for the relationship between habitat composition and bird richness/abundance.

Comparison	Mantel Statistic(r)	p-value
Habitat composition vs. Bird Richness	0.2133	0.002
Habitat composition vs. Bird Abundance	0.2133	0.004

($p = 0.015$, $p = 0.039$). Bird abundance was also significantly lower in wheat habitats than in ditchtree habitats ($p = 0.029$).

FTMR ditches (Few Trees, More Reeds): Bird species richness was significantly lower in wheat habitats than in ditchtree habitats ($p = 0.001$). Bird abundance was also significantly lower in wheat than in ditchtree ($p = 0.002$). Additional significant differences in bird abundance were observed between ditchtree and ditchgrass ($p = 0.022$) and between wheat and ditchreed ($p = 0.02$).

FTNR ditches (Few Trees, No Reeds): This ditch type exhibited the most pronounced differences in bird species richness. Highly significant

Table 3
Summary of fixed effects in bird richness and abundance models.

Model	Variable	Estimate	Std. Error	p-value	VIF
Bird Richness Model	Tree Proportion	0.0007	0.0038	0.850	1.35
	Reed Proportion	0.0023	0.0047	0.632	1.27
	Herbs Proportion	0.0004	0.0030	0.190	1.50
Bird Abundance Model	Tree Proportion	0.0049	0.0016	0.002 * *	1.46
	Reed Proportion	0.0085	0.0019	0.000 * **	1.35
	Herbs Proportion	0.0036	0.0013	0.006 * *	1.63

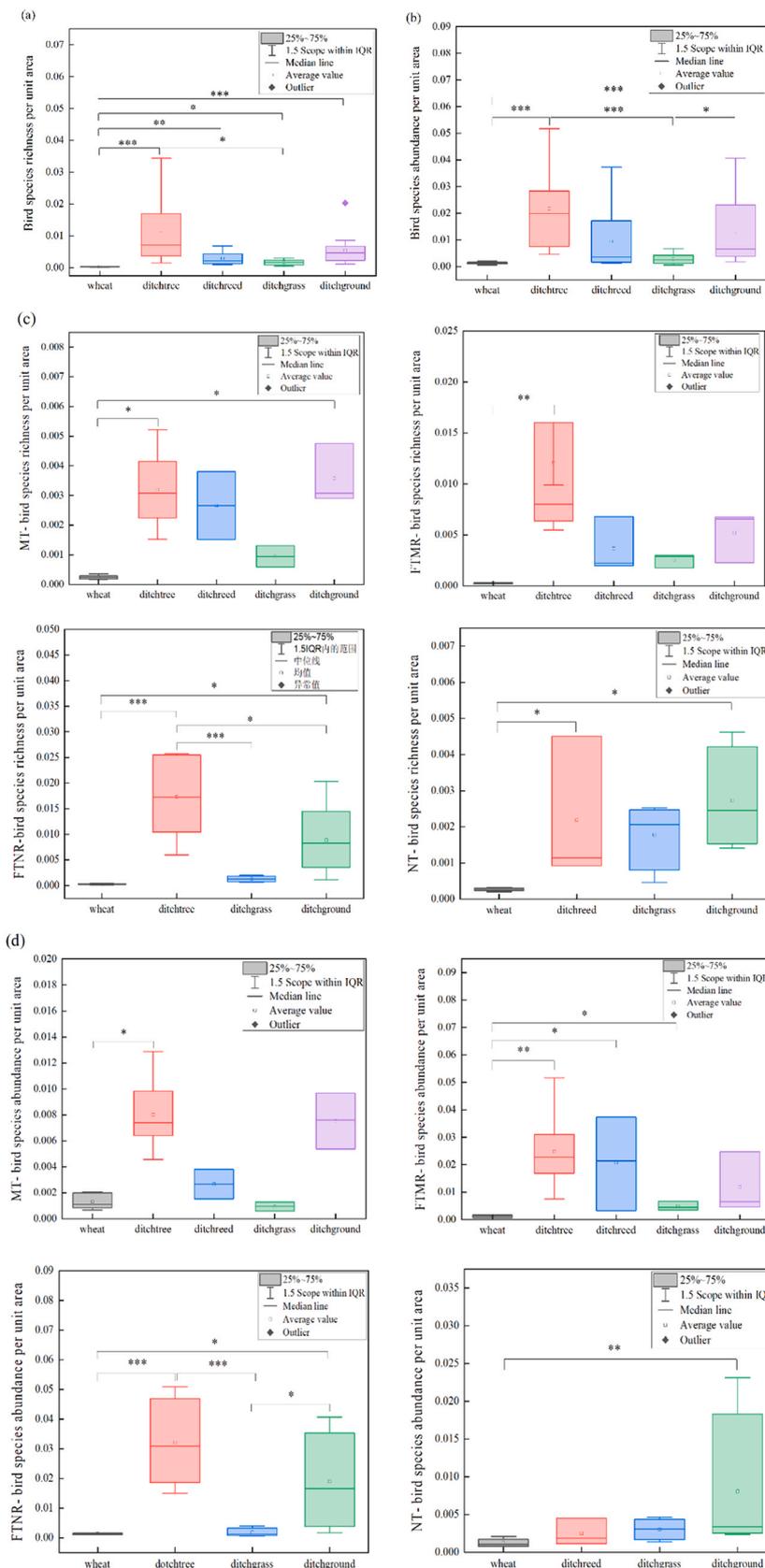| Model	AIC	BIC
Bird Richness Model	108.7	114.6
Bird Abundance Model	220.2	226.1

Fig. 4. (a) & (b) Comparative analysis of bird diversity per unit area across different microhabitats in farmland ditches in Qihe County, North China Plain. Microhabitats include wheat fields (wheat), tree-dominated habitats (ditchtree), reed-dominated habitats (ditchreed), herbaceous vegetation (ditchgrass), and bare soil (ditchground). (c) & (d) Bird species richness and abundance per unit area across microhabitats in four ditch types (MT, FTMR, FTNR, NT).

differences were found between wheat and ditchtree ($p < 0.001$), wheat and ditchground ($p = 0.018$), ditchtree and ditchgrass ($p < 0.001$), and ditchtree and ditchground ($p = 0.02$). Bird abundance showed similarly significant patterns, with highly significant differences between wheat and ditchtree ($p < 0.001$), wheat and ditchground ($p = 0.018$), and ditchtree and ditchgrass ($p = 0.02$).

NT ditches (No Trees): Bird species richness in wheat habitats was significantly lower than in ditchreed ($p = 0.032$) and ditchground ($p = 0.005$). Bird abundance in wheat habitats was also significantly lower than in ditchground ($p = 0.037$).

Across all ditch types, bird species richness and abundance were consistently lower in wheat habitats than in other microhabitats. The most pronounced inter-habitat differences were observed in FTNR ditches. Additionally, ditchtree habitats consistently supported higher bird richness and abundance, emphasizing the ecological importance of tree vegetation as key roosting and foraging sites for farmland birds.

3.4. Distribution of bird diversity in ditch types and microhabitats

Principal Coordinate Analysis (PCoA) based on Bray-Curtis's distance revealed significant differences in bird species composition across different microhabitats, whereas differences among ditch types were not statistically significant.

At the ditch type scale (Fig. 5(a), PCoA1 and PCoA2 explained 24.74 % and 16.82 % of the variation, respectively. However, PERMA-NOVA results ($p > 0.05$, $R^2 = 0.133$) suggested that ditch type had limited explanatory power (13.3 %) for variation in species composition. Among the four ditch types, NT ditches had the highest variation in community composition.

At the microhabitat scale (Fig. 5(b), PCoA1 and PCoA2 explained 29.26 % and 19.89 % of the variation in species composition, respectively. PERMANOVA results ($p = 0.001$, $R^2 = 0.51$) indicated that microhabitat type explained 51.1 % of the variation in bird community composition. Notably, tree-dominated habitats (ditchtree), reed-dominated habitats (ditchreed), and wheat fields were significantly separated from other microhabitats, suggesting distinct bird assemblages and highlighting the strong influence of vegetation structure on community composition.

4. Discussion

Our original hypothesis was that ditches with different habitat compositions support different bird communities and that bird diversity increases with the proportion of trees and reeds in the ditch, as these key habitat features play a crucial role in shaping bird species richness and abundance. Here we first discuss the composition of the bird community. Then we discuss the different ditch types and the microhabitats within the ditches.

4.1. Diversity of ditch birds

Birds of the *Passeriformes* prefer to inhabit tall and wide bushes, and are diverse, abundant and widely distributed (Schmitt and Edwards, 2022). In our survey of bird diversity in farmland ditches in Qihe County, Shandong Province, we found that 57.7 % of the birds belonged to *Passeriformes*. These included many typical farmland birds (e.g. *Passer montanus*, *Spilopelia chinensis*) and a small number of forest birds (e.g. *Turdus mandarinus*, *Sinosuthora webbiana*). This suggests that ditch habitats not only provide foraging and roosting sites for farmland birds but are also attractive to some forest birds.

In farmland ecosystems, farmland birds are usually adapted to open environments and rely on ditch hedgerows or low vegetation for foraging and nesting. For example, *Sturnus vulgaris* is a typical farmland bird that often forages in hedgerows, between fields (Vickery et al., 2002). Moreover, organic farming or farmland environments in heterogeneous landscapes greatly improve foraging conditions and habitat for finch birds (Smith et al., 2010). Consistent with our study, an agro-ecosystem study conducted in the Kavli River delta in southern India also found that *Passeriformes* dominated the local bird community (Menon and Mohanraj, 2022). Compared to farmland birds, the distribution of forest birds tends to depend on complex vegetation structures such as trees and dense shrubs. Studies have shown that forest birds such as *Turdus mandarinus* prefer to inhabit areas with dense hedgerows or high tree cover (Schmitt and Edwards, 2022). In European farmland, hedge management plays a key role in the abundance of certain finch birds such as *Sylvia communis* and *Emberiza citrinella* (Stoate and Szczur, 2001).
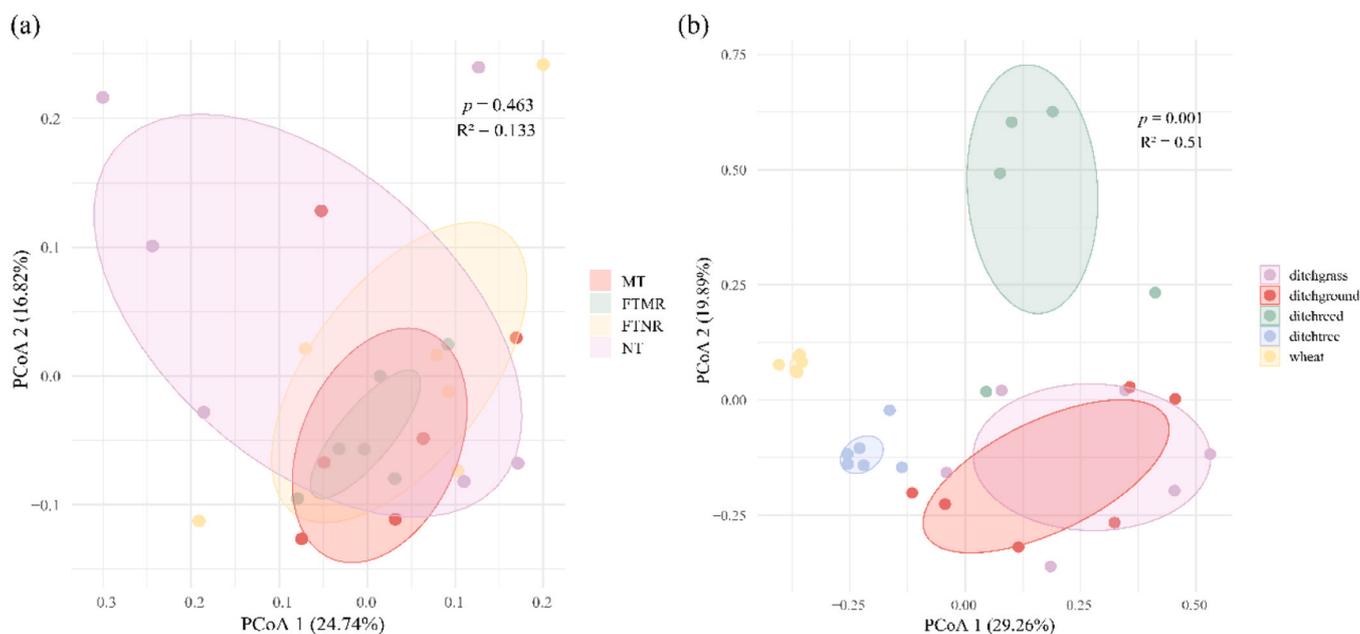

Fig. 5. PcoA analysis of bird diversity for ditch types (a) MT: Many trees; FTMR: Few trees – much reed; FTNR: Few trees – no reed; NT: No trees. And for ditch microhabitats (b): wheat; tree habitats (ditchtree); reed habitats (ditchreed); herbaceous vegetation (ditchgrass); bare soil (ditchground) in the farmland ditches in Qihe county, North-Western China plain.

The role of habitat composition in shaping bird community structure was further confirmed by the results of the Mantel test, which revealed a significant correlation between habitat similarity and bird richness and abundance. This suggests that ditches with similar vegetation composition tend to harbor similar bird communities. Overall, our results suggest that the heterogeneity of ditch vegetation structure plays a key role in maintaining the diversity of farmland birds and forest birds. Farmland birds mainly utilized open fields and hedgerows for foraging, whereas forest birds preferred trees or dense vegetation. Therefore, in farmland management, the diversity of ditch vegetation should be maintained as much as possible to simultaneously meet the needs of different ecological bird groups.

4.2. Effects of ditch parameters on bird diversity

Studies have shown that higher landscape heterogeneity is associated with higher bird diversity (Barbaro et al., 2021). This was confirmed by our results, where the Poisson GLMM model showed that the proportion of reeds in the vegetation composition of the ditch had a highly significant positive effect on bird abundance ($p < 0.01$), while the proportion of trees and the proportion of herbaceous plants also had a significant positive effect on bird abundance ($p < 0.05$). This finding is consistent with the other study that reeds, as an important habitat element, contributed to the increase in bird abundance by providing a rich food source for birds and reducing predation pressure through its dense vegetation structure (Yang et al., 2021).

In addition, the proportion of trees to herbaceous plants also had a significant positive effect on bird abundance, consistent with the findings in Nepal (Thorn et al., 2020), which showed that mature scattered trees in agricultural landscapes significantly enhance bird diversity and their ecosystem services. This may be because such vegetation provides ideal roosting and nesting environments for birds and reduces the risk of predation through concealment (Menon and Mohanraj, 2022). Higher proportions of trees and herbaceous plants not only increase the complexity of habitat structure, but also provide multiple food sources for birds, thus contributing to the richness and diversity of bird communities (Li, 2021). Together, these results suggest that the introduction of vegetation types with higher structural complexity may further contribute to bird richness and abundance in intensive farmland environments with low landscape heterogeneity.

However, it is important to note that our study only recorded the cover of trees, reeds, herbs and open spaces, and did not measure structural parameters such as height and canopy width of trees. This means that our analyses focused on habitat quantity (i.e., percent cover of different vegetation types) rather than habitat quality (e.g., structural complexity of habitats characterized by metrics such as tree height). This limitation may have compromised our deeper understanding of the mechanisms by which vegetation affects bird communities. For example, taller trees may provide better nesting conditions and richer vertical habitat hierarchies (Marja and Herzon, 2012; Dvořáková et al. 2023), a factor that could not be quantified in this study. Therefore, future studies could incorporate metrics such as tree height and vegetation level to more fully assess the effects of vegetation structure on bird communities.

4.3. Effects of different microhabitat types in ditches on bird community composition

Our study demonstrates that microhabitat type within ditches is an important factor driving changes in bird diversity and community composition. Results from PCoA and PERMANOVA analyses based on the Bray-Curtis distance showed significant differences in bird species composition between microhabitats ($p = 0.001$, $R^2 = 0.51$), but not between ditch types ($p > 0.05$, $R^2 = 0.133$). This result emphasizes the decisive role of vegetation structure on bird communities at the microhabitat scale, while the overall effect of ditch type was relatively small.

Specifically, wheat habitat had the lowest bird richness and abundance of all ditch types, while ditchtree and ditchground habitats had the highest bird diversity (Fig. 4). This is consistent with Lindenmayer (2019) findings that heterogeneous landscapes can contribute to bird diversity by increasing resource available to birds (e.g., food, nesting sites) and providing diverse ecological niches. Ditchtree habitats had significantly different bird community composition from other microhabitats (Fig. 5b), suggesting that the presence of trees plays an important role in shaping bird communities. A similar study found that trees and scrub in agricultural landscapes can effectively support the habitat needs of forest and scrub birds (Morelli and Tryjanowski, 2017).

In addition, bird communities in ditchreed habitat also differed significantly from other habitats, suggesting that this habitat may support specific wetland bird communities (Liu et al., 2013). This is consistent with our results that reed proportion had a significant positive effect on bird abundance (3.2). In contrast, the wheat habitat consistently showed the lowest bird diversity, possibly due to the more homogenous structure of this habitat, which lacks crypticity and abundant food resources (Chen et al., 2022).

Overall, these results suggest that bird diversity can be significantly enhanced by optimizing ditch vegetation structure (e.g., by adding trees and reed habitats) in intensive agricultural landscapes. This further emphasizes the importance of agricultural ditches as ecological corridors, and future farmland management practices should place greater emphasis on ditch microhabitat diversity to promote biodiversity conservation in agricultural landscapes.

5. Conclusions and recommendations

Our study found that the proportion of reeds in the ditch had a highly significant effect on bird abundance, and the proportion of trees and herbs likewise had a significant effect on bird abundance. In addition, different microhabitat types within the ditch had significant effects on bird richness and abundance per unit area, with wheat habitat having a significantly lower effect on birds than other habitat types. Differences between ditchtree and ditchground habitats in bird communities were particularly significant, with ditchtree habitats having significantly higher bird richness and abundance than ditch grass habitats, suggesting that ditchtree habitats play a key role in promoting bird diversity. Based on these results, in order to effectively promote the conservation of bird diversity and optimize the ecological functions of farmland ditches, it is recommended that in farmland management: the existing ditchtree should be maintained, the proportion of tree and shrub belts along the ditch edges should be increased, and the coverage of reed habitats inside the ditches should be upgraded, so as to enhance the heterogeneity of the landscape along the edges of the farmland, and to provide a more stable habitat and food source for birds.

CRediT authorship contribution statement

Hu Runan: Writing – original draft, Visualization, Investigation, Formal analysis, Conceptualization. **Herzog Felix:** Project administration. **Klein Noëlle:** Formal analysis, Conceptualization. **Zheng Hongyan:** Investigation, Formal analysis. **Jan Bogaert:** Software, Conceptualization. **Wang Lili:** Writing – original draft, Resources, Funding acquisition, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence

the work reported in this paper.

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Data availability

The data that has been used is confidential.

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