Impact of Landscape Simplification on Pollinator Diversity in Agricultural Landscapes of the Middle and Lower Reaches of the Yellow River: A Case Study of Gongyi City (Postprint)

Authors: Wang Run, Ding Shengyan, Lu Xunling, Song Bo

Date: 2017-04-18T00:00:00+00:00

Abstract

In agricultural landscapes, the survival and reproduction of pollinator insects are associated with the area of semi-natural habitats. Intensive production practices have gradually reduced the proportion of semi-natural habitats while increasing that of cropland. How does pollinator insect community diversity change along a landscape simplification gradient (with increasing cropland proportion)? This study selected Gongyi City, a typical agricultural region in the middle and lower reaches of the Yellow River, as the research area. Pollinator insects in cropland and forest land were sampled using Pan traps, with 21 sampling sites representing a landscape simplification gradient (cropland proportion range: 5%-86%). Based on changes in pollinator insect abundance and richness at each site, we investigated the effects of landscape simplification on pollinator diversity. The results showed that a total of 39,660 pollinator insects were captured in the study area, with dominant taxa including Diptera, Hymenoptera, and Coleoptera. Stepwise regression analysis and linear fitting revealed that landscape simplification degree was significantly negatively correlated with pollinator abundance and richness ($P<0.05$). The impacts of landscape simplification also varied among pollinator taxa, with the strongest effect on Coleoptera abundance ($R^2 = 0.27$), and substantial effects on Hymenoptera and Diptera as well ($R^2 = 0.14$, $R^2 = 0.11$). Landscape simplification was positively correlated with Lepidoptera abundance. As landscape simplification intensified, Hymenoptera abundance in cropland habitats showed a significant decreasing trend ($P<0.05$), whereas changes in forest land were not significant. Future landscape planning should prioritize habitat changes and food resource conditions for Coleoptera groups among pollinator insects. Based on these findings, we recommend protecting existing natural vegetation communities in forest land habitats and planting nectar and pollen plants in artificial forests. In cropland

habitats, linear landscape plants can be established as food sources for pollinator insects, in addition to rational planning of weed communities and semi-natural habitat patches.

Full Text

Effects of Landscape Simplification on Pollinator Diversity in Agricultural Landscapes of the Middle and Lower Reaches of the Yellow River: A Case Study of Gongyi City

WANG Run[1,2], DING Shengyan[1,2,*], LU Xunling[1], SONG Bo[1] [1]Key Laboratory of Geospatial Technology for the Middle and Lower Yellow River Regions, Ministry of Education, College of Environment and Planning, Henan University, Kaifeng 475004, China [2]College of Environment and Planning, Henan University, Kaifeng 475004, China

Abstract: In agricultural landscapes, the survival and reproduction of pollinators depend on the availability of semi-natural habitats. Intensive agricultural production has led to a reduction in semi-natural habitats and a corresponding increase in the proportion of land dedicated to agriculture. This study quantified how pollinator diversity changes along a gradient of landscape simplification, using Gongyi City—a typical agricultural region in the middle-lower Yellow River basin—as our study area. We established 21 sampling sites and used pan traps to collect pollinators from both farmland and woodland habitats. Using the Akaike Information Criterion (AIC), we identified the optimal characteristic scale for pollinator response as 500 m, where landscape simplification was determined by the proportion of farmland. The proportion of farmland (ranging from 5% to 86% across sites) served as the basis for our landscape simplification gradient. We then examined how landscape simplification affected pollinator diversity based on species abundance and richness at each sampling point.

We collected a total of 39,660 individual pollinators. The most abundant orders were Diptera (26,236 individuals), Hymenoptera (13,893 individuals), and Coleoptera (2,033 individuals). Stepwise analysis and linear fitting revealed that landscape simplification was significantly negatively correlated with pollinator richness and abundance ($p < 0.05$). However, the effects varied among pollinator groups. Landscape simplification had the strongest effect on Coleoptera ($R^2 = 0.27$), followed by Hymenoptera ($R^2 = 0.14$) and Diptera ($R^2 = 0.11$). In contrast, Lepidoptera abundance showed a positive correlation with landscape simplification ($R^2 = 0.09$). Hymenoptera abundance declined significantly in farmland habitats as landscape simplification increased, while no significant change was observed in woodland habitats.

Our results demonstrate that the proportion of farmland directly affects pollinator abundance and richness. The balance between farmland and semi-natural habitats in certain areas is inappropriate and requires careful reconsideration by decision-makers and stakeholders. In future landscape planning, particu-

lar emphasis should be placed on protecting habitat and food resources for Coleoptera pollinators. We recommend protecting existing natural vegetation communities in woodland habitats and planting nectar-producing plants in artificial forests. Additionally, linear landscape elements planted along farmland boundaries could serve as food sources for pollinators and help protect resource insects such as Hymenoptera.

Keywords: pollinators; diversity; landscape simplification; nectar plants; agricultural landscape

1. Study Area

The study area is located in Gongyi City, Henan Province, which lies in the central-western part of the province and features a warm temperate continental monsoon climate. The region spans 34°31 -34°52 N, 112°49 -113°17 E, covering 1,041 km². The terrain slopes from high in the south to low in the north. The southern Songshan Mountains represent mid-elevation terrain above 1,000 m, while the northern area consists of broad alluvial plains. The region features diverse landforms including river plains, low hills, and mountainous areas, with a long history of cultivation.

Agricultural landscapes dominate the river plain areas, while natural forests, artificial forests, and fallow land are distributed throughout the hilly and mountainous regions. The area has rich plant composition, primarily from the warm temperate North China flora. Common plant species along field margins include grasses such as *Cynodon dactylon*, *Phragmites australis*, *Pharbitis nil*, *Malva sinensis*, *Calystegia hederacea*, and *Sophora japonica*. In addition to these common species and trees like *Populus przewalskii* Maxim., woodlands contain shrubs and herbaceous plants including *Ziziphus jujuba* var. *spinosa*, *Vitex negundo* var. *cannabifolia*, *Heteropappus hispidus*, *Inula japonica* Thunb., *Quercus variabilis*, *Eleusine indica*, and *Cyperus rotundus* [19].

2. Methods

2.1 Landscape Data Sources and Processing

We used Google Earth imagery as our landscape data source and vectorized it using ArcMap 10.0 software to obtain landscape data for the study area. Based on field surveys and actual conditions, we classified the study area into farmland, woodland, and other landscape types that represent the region' s characteristics. Considering the local geomorphological features and degree of human disturbance, we selected typical hilly and mountainous areas in Gongyi City. At each sampling point, we chose two habitat types—farmland and woodland—to represent the landscape simplification gradient, using the proportion of semi-natural habitats to characterize landscape complexity. We ultimately used the proportion of farmland to represent agricultural intensification and landscape simplification. All sample points were then sorted according to farmland proportion from high to low.

2.2 Pollinator Sampling Methods

We used pan traps to collect pollinators. Three plastic bowls (11 cm diameter, 6 cm depth) were painted internally with fluorescent yellow, blue, and white paint and arranged in an equilateral triangle. Each bowl was filled with 200 mL of water and placed in the field for 6 hours before collection [19]. The different colors served as supplementary attractants, mimicking flowers to efficiently capture pollinators. Although sampling occurred only once per site, this method captured numerous pollinator individuals.

Collected insects were preserved in centrifuge tubes with solution and identified to family level using a Leica M125 stereomicroscope, referencing Chinese insect taxonomy literature [20-22]. Simultaneously, we surveyed vegetation characteristics within a 25 m radius of each sampling point.

2.3 Landscape Metric Selection and Data Processing

Studying pollinator diversity requires an appropriate spatial scale [1]. To determine the optimal characteristic scale for pollinators in this region, we created buffers of 250, 500, 750, 1000, 2000, and 3000 m radius around each sampling point [6]. We calculated landscape metrics for each buffer including Patch Density (PD), Contagion Index (CONTAG), Patch Richness (PR), and Shannon' s Diversity Index (SHDI). We then used multi-model inference based on the Akaike Information Criterion (AIC) to relate these landscape metrics to pollinator diversity indices.

We used the R 3.1.0 package for AIC-based model selection to identify the characteristic response scale. Fragstats 4.1 software calculated landscape metrics within each buffer, while PCORD 5.0 calculated pollinator diversity indices. We analyzed relationships between farmland proportion and pollinator diversity using multiple linear regression models, with linear fitting performed using Origin 9.0 software.

2.4 Species Diversity Indices

We selected three diversity indices: 1. **Species richness (S)**: The number of species present in each plot 2. **Shannon-Wiener diversity index (H)**: $H = -\Sigma(P_i \times \ln(P_i))$, where P_i is the proportion of individuals in the ith group 3. **Simpson diversity index**: $D = 1 - \Sigma(P_i^2)$

3. Results

3.1 Pollinator Species Composition

We captured pollinators belonging to 4 orders and 51 families. Diptera was the most abundant (26,236 individuals), followed by Hymenoptera (13,893), Coleoptera (2,033), Thysanoptera (510), and Lepidoptera (498). Dominant families included Syrphidae (29.42%), Anthomyiidae (12.33%), Vespidae (10.09%), Apidae (5.98%), Calliphoridae (3.89%), Mycetophilidae (3.64%), and Bombyliidae (2.81%). Rare groups, while numerous in taxa, accounted for only 9.15% of total abundance.

We captured 26,236 pollinators in farmland habitats and 13,624 in woodland habitats. Farmland showed higher species abundance than woodland. Different habitat conditions and plant compositions led to differences in pollinator community composition between habitats. For example, Anthomyiidae was dominant in both habitats but showed only slightly higher abundance in farmland. Some groups, such as Calliphoridae and Frankliniella intonsa, were more abundant in woodland (Table 1).

Community composition of pollinators in different habitat types

3.2 Substrate Test Results

Our sampling points were distributed across hilly and mountainous areas. To verify whether substrate differences affected our results, we conducted one-way ANOVA on pollinator richness between the two geomorphological types. No significant differences were found ($p > 0.05$), indicating that substrate effects could be ignored when examining landscape impacts on pollinators.

3.3 Optimal Characteristic Scale Analysis

Because pollinator groups are strongly influenced by habitat conditions and food resources, and different groups have different foraging distances, they are affected by landscape structure at different scales [21]. To select the optimal characteristic scale, we related pollinator diversity indices to landscape metrics (PD, CONTAG, PR, SHDI) across different scales using multi-model inference. The 500 m scale showed the highest Akaike weight ($wi = 0.68$), indicating it was the most significant scale for pollinator diversity, while the 3000 m scale had a weight of only 0.15. Therefore, we selected 500 m as the characteristic scale for this study.

At the 500 m scale, farmland proportion across sampling points ranged from 5% to 86%, while semi-natural habitat proportion ranged from 3.06% to 89.52%. The two habitat proportions were negatively correlated (Fig. 4). We used farmland proportion as our indicator of landscape simplification, creating a gradient with 21 sample points.

[Figure 4: see original paper] Proportion of farmland and semi-natural habitats in the 500 m characteristic scale

3.4 Effects of Landscape Simplification on Pollinator Richness and Abundance

Previous research has shown that complex landscapes support more species than simplified landscapes, as habitat patches in complex landscapes receive higher potential colonization from regional species pools [22]. To examine how pollinator diversity changed along our landscape simplification gradient, we used linear regression with farmland proportion as the independent variable and pollinator abundance and richness as dependent variables.

Farmland proportion was significantly negatively correlated with species richness ($p < 0.05$). As landscape simplification increased, pollinator richness decreased (Fig. 5). Because pollinators such as butterflies are highly sensitive to changes in plant composition and habitat structure, and pollinator diversity differs significantly between habitats [24-26], we examined farmland and woodland habitats separately. While species abundance in farmland showed a decreasing trend with landscape simplification, it remained higher than in woodland habitats. However, the effect of landscape simplification was more pronounced in woodland habitats ($R^2 = 0.24$) compared to farmland ($R^2 = 0.18$), indicating that woodland pollinator abundance was more sensitive to landscape simplification (Fig. 6).

[Figure 5: see original paper] Fitting curve of farmland area proportion and species richness

[Figure 6: see original paper] Fitting curve of farmland area proportion and species abundance in different habitats

3.5 Effects of Landscape Simplification on Different Pollinator Groups

Katja Poveda' s research indicates that landscape simplification benefits Lepidoptera such as moths [23]. Our results support this, showing Lepidoptera abundance increased slowly with farmland proportion ($R^2 = 0.09$). We examined the four major pollinator orders—Coleoptera, Diptera, Hymenoptera, and Lepidoptera—as response variables to assess differential responses to landscape simplification.

Farmland proportion was significantly negatively correlated with Coleoptera, Diptera, and Hymenoptera abundance, but the strength of effects differed. Landscape simplification had the strongest effect on Coleoptera ($R^2 = 0.27$), followed by Hymenoptera ($R^2 = 0.14$) and Diptera ($R^2 = 0.11$). Lepidoptera abundance increased slowly with landscape simplification (Fig. 7).

[Figure 7: see original paper] Fitting curve of farmland area proportion and abundance of different groups

4. Discussion

Natural habitats and nectar resources in agricultural landscapes serve as critical mediators linking landscape structure to pollinator communities. Land use changes and human activities have gradually reduced these landscape mediators [24-25], consequently affecting pollinator abundance and richness [26]. Landscape simplification elicits different responses among pollinator groups, as different vegetation compositions [27] affect interspecific relationships and community composition [29-30].

Our results show that landscape simplification most significantly affected Coleoptera. Coleoptera is the largest insect order, comprising 40% of total insect species and playing important ecosystem functions in agriculture [32]. The significant decline in Coleoptera abundance may be related to landscape configuration heterogeneity in our study area. While increasing farmland reduced semi-natural habitat area, this gradient change did not necessarily represent landscape heterogeneity. Research indicates that Coleoptera are more strongly influenced by landscape configuration than composition [33], and increasing configurational heterogeneity can significantly enhance Coleoptera abundance. In agricultural landscapes with >60% farmland, Coleoptera abundance dropped to extremely low levels. Extrapolating our fitted curve suggests that Coleoptera abundance would decline sharply when farmland exceeds 80%. Therefore, future landscape planning should consider landscape configuration, semi-natural habitat shape, and the food and habitat requirements of Coleoptera.

Lepidoptera abundance increased slowly with landscape simplification. The Lepidoptera in our study were primarily Geometridae, Pyralidae (agricultural pests feeding on fruit trees), and some pollen-feeding Papilionidae. Geometridae and Pyralidae accounted for 85% of total Lepidoptera abundance. The resource concentration hypothesis and natural enemy hypothesis [34] suggest that simplified landscapes with high farmland proportions support more herbivores, while complex landscapes support more diverse species including pests and their natural enemies [35]. Landscape simplification reduces habitat and food resources for natural enemies, benefiting pest populations, which explains our results.

Hymenoptera abundance decreased significantly with increasing farmland proportion in farmland habitats but showed no significant change in woodland habitats ($p > 0.05$). This difference can be explained by vegetation distribution, farming intensity, and semi-natural habitat shape. Our sampling points were in hilly and mountainous areas with relatively undisturbed natural forests. Plant surveys revealed complex community structures in woodlands with abundant herb and shrub layers providing continuous nectar resources [22], which can maintain Hymenoptera populations. In contrast, farmland habitats primarily grow wheat, corn, and peanuts, with semi-natural habitats continuously decreasing as landscape simplification intensifies. Research shows that shrub patches and linear landscape features directly affect wild bee pollination services [37], but farmland habitats in our region contained few shrubs. Only sparse weeds such as *Dicranostigma leptopodum* and *Ixeridium chinense* were present. Therefore, Hymenoptera showed different responses between habitats.

During field surveys, we observed that farmland habitats contained weed communities, though intensification has greatly altered these communities. Species-rich weed communities, as components of agroecosystems, provide essential pollen and nectar resources for pollinators [38]. Future agricultural landscape planning should protect existing natural habitats like weed communities and plant appropriate linear landscape elements along farmland boundaries, which would have significant ecological benefits for conserving resource insects like Hymenoptera.

The more significant effect of landscape simplification on woodland habitat species abundance suggests that while farmland pollinators may find refugia, woodland pollinators face severe declines. Two factors may explain this: (1) Non-crop plants and semi-natural habitat patches in farmland provide important ecological functions, maintaining species abundance through food resources and shelter; (2) Woodland habitats may not fully realize their ecological functions. In our sampled woodlands, poplar plantations had simple herbaceous communities with few nectar plants or exposed ground, while natural forests with rich understory vegetation could not maintain species abundance under the broader influence of landscape simplification. Species abundance is influenced by multiple factors including resource spatiotemporal distribution and interspecific relationships [39]. Existing research shows that semi-natural habitat boundaries in agricultural landscapes help maintain high abundance levels [40], and spillover effects facilitate species exchange between farmland and adjacent semi-natural habitats [41]. In late May during crop growth, farmland habitats experience less disturbance, and crops like buckwheat and vegetables provide food resources, enabling pollinators to reproduce in fragmented farmland microhabitats and resulting in higher abundance than in woodland habitats.

5. Conclusions and Recommendations

Our results support our initial hypotheses: (1) Landscape simplification significantly affects pollinator diversity, with abundance and richness decreasing as simplification increases; (2) Different pollinator groups respond differently to landscape simplification; (3) Coleoptera and Hymenoptera show stronger relationships with landscape simplification.

Key conclusions and recommendations:

1. **Coleoptera conservation**: Landscape simplification most strongly affected Coleoptera. Future agricultural landscape planning must prioritize protecting food resources and habitats for this group.
2. **Hymenoptera management**: Hymenoptera abundance declined with landscape simplification. Protecting existing natural vegetation in wood-

lands, ditches, and other semi-natural habitats is essential, and planting nectar-producing plants is equally important.

3. **Habitat configuration**: In the gradient of landscape simplification, farmland habitats showed higher pollinator abundance than woodlands, but this trend would reverse with continued intensification. Protecting appropriately sized semi-natural linear landscape elements in farmland habitats will directly affect pollinator abundance and richness.

4. **Optimal landscape proportions**: Our results suggest that a farmland proportion of 5-86% spans the gradient, but the specific optimal ratio of farmland to semi-natural habitat for maintaining high pollinator diversity requires further consideration of the trade-offs between agricultural production and ecological conservation [5]. Decision-makers and stakeholders must carefully reconsider the current balance between farmland and semi-natural habitats in certain areas [42].

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Note: Figure translations are in progress. See original paper for figures.