Postprint: Plant Diversity in Agricultural Landscapes of Typical Maize Cultivation Areas in the Northeast China Plain

Authors: Bian, Zhenxing; Li, Xiaolu; Yu, Miao

Date: 2018-01-05T00:00:00+00:00

Abstract

Non-cultivated habitats constitute important components of agricultural landscapes, providing food and shelter for organisms and holding significant significance for biodiversity conservation. This study takes Changtu County, Liaoning Province as a case study, employs GIS technology to partition the entire county into 4572 grids of 1km×1km, and analyzes the types, quantities, and area proportions of non-cultivated habitats within the farmland landscape of each grid. From these, 20 grids with non-cultivated habitat proportions ranging from 0~50% were selected as plant community survey zones, and the typical plot method was utilized to investigate plant communities within five major non-cultivated habitat types in the agricultural landscape of the survey areas—woodland, field roads, grassland, ditches, and orchards—exploring the relationship between plant diversity and landscape heterogeneity across different non-cultivated habitat types and proportions. The results demonstrate that: with increasing proportions of non-cultivated habitats, plant species diversity and evenness initially increase then decrease, peaking at 20%~30%; when non-cultivated habitat proportions range from 0-40%, species richness initially increases then decreases, peaking at 20%~30%; when non-cultivated habitat proportions exceed 40%, both landscape patch complexity and dominance of major landscapes exhibit substantial differences, and species richness increases again with values surpassing those observed at 20%~30%. Across different habitats, plants with the highest importance value all belong to Poaceae, though the species differ; the dominance of dominant species follows the order orchard > ditch > grassland > field road > woodland. Species diversity and evenness indices in orchards, grasslands, and ditches are significantly higher than those in woodlands and field roads; the richness index follows the order grassland > woodland > ditch > orchard > field road, and plant community indices exhibit substantial variability among different survey areas within grasslands, orchards, and field roads. The correlation between landscape heterogeneity and species diversity decreases sequentially in grassland, orchard, ditch, field road, and woodland. The study indicates that in agricultural landscapes of typical maize cultivation areas in the Northeast China Plain, the optimal proportion of non-cultivated habitats is 20%~30%; woodlands and ditches within non-cultivated habitats play positive roles in maintaining species diversity and conserving hygrophytic plant diversity; disturbance types and methods differ among various habitats, as does the degree of correlation between landscape heterogeneity and plant species diversity. Future research on biodiversity conservation in agricultural landscapes within the region should integrate multiple influencing factors such as non-cultivated habitat types and proportions, disturbance types and methods, to examine their impacts on biodiversity, ecosystem services, and agricultural yield.

Full Text

Abstract

Non-cropped habitats are essential components of agricultural landscapes, providing food and shelter for organisms and playing a vital role in biodiversity conservation. This study examined plant diversity and its relationship with landscape heterogeneity across different types and proportions of non-cropped habitats in Changtu County, Liaoning Province, a typical maize planting area in the Northeast China Plain. Using GIS technology, the county was divided into 4,572 1 km × 1 km grids, and the type, quantity, and area proportion of non-cropped habitats within each grid were analyzed. From these, 20 grids with non-cropped habitat proportions ranging from 0% to 50% were selected as plant community survey areas. The Braun-Blanquet method was employed to investigate plant communities in five major non-cropped habitat types: woodland, field roads, grassland, ditches, and orchards.

The results revealed that plant species diversity and evenness initially increased then decreased with rising proportions of non-cropped habitats, peaking at 20%-30% habitat coverage. Species richness followed a similar pattern within the 0%-40% range, also peaking at 20%-30%; however, when habitat proportion exceeded 40%, landscape patch complexity and dominance of major landscape types diverged significantly, causing species richness to increase again and surpass the values observed at 20%-30% coverage. Gramineae species held the highest importance values across all habitats, though the specific species varied among habitat types. Dominance of dominant species followed the order: orchard > ditch > grassland > field road > woodland. Species diversity and evenness indices in orchards, grasslands, and ditches were significantly higher than in woodlands and field roads, while richness indices ranked as grassland > woodland > ditch > orchard > field road. Plant community indices showed considerable variability among different survey areas within grassland, orchard, and field road habitats. The correlation between landscape heterogeneity and species diversity decreased sequentially across grassland, orchard, ditch, field road, and woodland habitats.

These findings indicate that the optimal proportion of non-cropped habitats in typical maize planting areas of the Northeast China Plain is 20%–30%. Woodlands and ditches within non-cropped habitats positively contribute to species diversity maintenance and hygrophyte conservation. Different disturbance types and intensities across habitats result in varying degrees of correlation between landscape heterogeneity and plant species diversity. Future research on agricultural landscape biodiversity conservation should comprehensively evaluate multiple influencing factors—including non-cropped habitat type and proportion, disturbance type and intensity—on biodiversity, ecosystem services, and agricultural productivity.

Keywords: Typical maize planting areas; Agricultural landscape; Non-cropped habitats; Landscape heterogeneity; Plant species diversity; Northeast China Plain

Introduction

Agricultural landscapes constitute mosaic systems comprising intensively cultivated farmland and non-cropped habitats [1]. Biodiversity forms the material foundation for human survival [2] and determines the stability and complexity of landscape ecosystems [3]. Landscape heterogeneity serves as both a prerequisite for biodiversity and the basis for biological symbiosis within ecosystems [3]. However, continuous agricultural intensification and diversified land use patterns have altered material and energy flows in agricultural landscapes, leading to structural and functional simplification, severe loss of ecosystem functions and services, and consequently, dramatic declines in biological community diversity [4-8]. The consensus that sustainable development of agricultural landscape ecosystems depends on biodiversity has long been established [9-10]. Numerous non-crop organisms coexist with target agricultural species, relying on agricultural landscapes for food and habitat [11-12]. Biodiversity within non-cropped habitats directly affects crop yields through ecosystem services such as biological pest control by natural enemies and crop pollination by pollinators, forming the foundation for sustainable agricultural landscape development and holding significant importance for regional and global sustainability [2]. Therefore, the presence and maintenance of non-cropped habitats and heterogeneity in agricultural landscapes play crucial roles in biodiversity conservation [13-15]. The European Union and the United States have incorporated increasing landscape heterogeneity and constructing non-cropped habitats to enhance biodiversity as key components of agricultural environmental protection [16-17].

Amid the challenge of ensuring food supply for a growing population, balancing agricultural land use and production practices with biodiversity conservation and ecosystem services has become one of humanity' s most pressing challenges [18-21]. Studies have confirmed that win-win scenarios are achievable [22-23]. Numerous Chinese researchers have conducted extensive studies on biodiversity and ecosystem services in agricultural landscapes at landscape, local, and field scales [24-26]; however, these have primarily focused on animal taxa. Due to the negative connotations of the term "weeds" and the emphasis on crop yields, research on plant diversity conservation, distribution patterns, ecological processes, and effects in non-cropped habitats within agricultural ecosystems has received insufficient attention [27]. Yet plants in non-cropped habitats play extremely important ecological roles in ecosystem service provision and sustainable development of agricultural landscapes.

The Northeast China Plain covers 350,000 km², representing China' s largest plain, with approximately 20 million hectares of cultivated land. Maize cultivation occupies about 15 million hectares (76.67% of cultivated area), making the region a major grain production area and important commodity grain base, contributing approximately 30% of national maize output [28]. Agricultural mechanization has enabled large-scale maize cultivation in this region, but this production model leads to landscape homogenization and biodiversity loss. Increased human activity intensity and frequency have significantly impacted landscape structure, severely affecting biodiversity and ecosystem services in agricultural landscapes. Currently, few studies have examined biodiversity within agricultural landscapes in this region [29-30], particularly regarding plant diversity. Critical research gaps remain concerning optimal proportions of non-cropped habitats, stable habitat types, differences in species dominance across habitats, and relationships between biodiversity and landscape heterogeneity—all of which are prerequisites for exploring regional agricultural land use, biodiversity conservation, and ecosystem service maintenance [31]. This study investigates plant diversity in typical maize planting areas of the Northeast China Plain using Changtu County as a case study, examining plant species diversity across different non-cropped habitat proportions and types, and analyzing relationships between plant diversity and landscape heterogeneity across habitat types. The findings provide a theoretical foundation for future animal diversity research and data support for sustainable agricultural landscape construction in the region.

1 Study Area Overview

The study area is located in Changtu County, Tieling City, Liaoning Province, situated between 42°33 -43°29 N and 123°32 -124°26 E. The county covers a total area of 4,317 km², with 2,666.67 km² of cultivated land, of which 1,500 km² is maize cultivation (34.75% of county area and 56.25% of cultivated land). The terrain transitions from low hills in the east to the Liao River Plain in the west. Major soil types include brown earth, black soil, meadow soil, and aeolian sandy soil. The region experiences a mid-temperate sub-humid continental monsoon climate with average annual precipitation of approximately 600 mm and mean annual temperature of 6–7°C.

The landscape is dominated by dryland agriculture, with farmland as the primary landscape type. Settlements are scattered throughout the region in various sizes. Woodland patches are distributed around farmland and settlements, predominantly consisting of artificially planted poplar forests [Figure 2: see original paper].

2.1 Sample Plot Setup and Data Collection

Based on satellite imagery and 2011 land use maps, the study area was divided into 1 km × 1 km grids using GIS technology. Twenty grids with non-cropped habitat proportions ranging from 0% to 50% were selected as plant diversity survey areas [Figure 1: see original paper]. The Braun-Blanquet method was employed to investigate plant communities in major non-cropped habitats (grassland, ditches, orchards, woodland, and field roads) within each survey area, recording species names, abundance-dominance scores, sociability, and geographic coordinates for each quadrat.

Field surveys were conducted in 2017 across 20 selected areas [Figure 1: see original paper]. Two major non-cropped habitat types were surveyed in each area, with three quadrats established per habitat type, totaling 120 quadrats (15 in grassland, 12 in ditches, 9 in orchards, 51 in woodland, and 33 in field roads). Investigations revealed that natural forests consisted exclusively of Mongolian pine (*Pinus sylvestris* var. *mongolica* Litv.) stands, while artificial forests were predominantly white poplar (*Populus tomentosa* Carr.) stands. Shrub layers were virtually absent across all 20 survey areas and habitat types. Consequently, this study focused exclusively on herbaceous layers for data collection and analysis [Figure 2: see original paper].

2.2.1 Plant Species Identification and Community Indices

Plant specimens were identified using manual identification methods [32] by consulting plant flora, botanical texts, and plant atlases [33-37], utilizing taxonomic keys and computer-based plant identification databases, combined with photographs of major organs (roots, stems, leaves, flowers, and fruits) taken in the field. Identification was conducted at the family, genus, and species levels. The family, genus, species, and abundance of herbaceous plants in all 120 quadrats were determined, and importance values and plant diversity characteristic indices were calculated for each of the five habitat types.

1) Species Diversity Index
The Shannon-Wiener index was selected for analysis [38], calculated as:

$$H' = -\sum_{i=1}^{S} P_i \ln P_i$$

where H' is the Shannon-Wiener index, S is the number of species in the quadrat, and P_i is the importance of species i in the community (the ratio of species i' s abundance-dominance score to the total abundance-dominance score).

2) Species Richness Index
The Margalef richness index was selected for analysis, calculated as:

$$R = \frac{S-1}{\ln N}$$

where R is the Margalef richness index, S is the number of species in the quadrat, and N is the total number of individuals of all species.

3) Species Evenness Index
The Pielou evenness index was selected for analysis, calculated as:

$$E = \frac{H'}{\ln S}$$

where E is the Pielou evenness index, H' is the Shannon-Wiener index, and S is the number of species in the quadrat.

4) Beta Diversity Index
The Whittaker beta diversity index was selected to reflect the magnitude and degree of community composition variation across habitats [39], calculated as:

$$\beta = \frac{\gamma}{\alpha} - 1$$

where β is the Whittaker beta diversity index, γ is the total number of species in a sampled habitat, and α is the average number of species across all sampling points in a habitat type.

2.2.2 Landscape Heterogeneity Indices

Based on research by Wu Jianguo et al. [40-42], three landscape-level heterogeneity indices were selected: Contagion Index (CONTAG), Shannon' s Diversity Index (SHDI), and Shannon' s Evenness Index (SHEI).

1) Contagion Index (CONTAG)

$$\text{CONTAG} = \left[1 + \frac{\sum_{i=1}^{m}\sum_{k=1}^{m} p_i \ln(p_i)}{\ln(m)}\right] \times 100$$

where p_i is the proportion of total area occupied by landscape patch type i, m is the total number of landscape types, and g_{ik} is the probability that two adjacent grid cells belong to types i and k.

2) Shannon' s Diversity Index (SHDI)

$$\text{SHDI} = -\sum_{i=1}^{m} p_i \ln(p_i)$$

where p_i is the proportion of total area occupied by landscape type i, and m is the total number of landscape types.

3) Shannon' s Evenness Index (SHEI)

$$\text{SHEI} = \frac{-\sum_{i=1}^{m} p_i \ln(p_i)}{\ln(m)}$$

where p_i is the proportion of total area occupied by landscape type i, and m is the total number of landscape types present.

2.2.3 Statistical Analysis Methods

Fragstats 4.2 was used to extract three landscape heterogeneity indices for the 20 1 km × 1 km grids containing plant diversity survey areas. Microsoft Office 2007 was used to process all field survey data. One-way ANOVA and correlation analysis were performed using SPSS 16.0. All result figures were generated using Excel and Origin 8.0. When analyzing by non-cropped habitat proportion, plant community indices from different habitat types within the same proportion interval were treated as a single sample. When analyzing by habitat type, indices from the same habitat type across different proportion intervals were treated as a single sample.

3.1 Landscape Heterogeneity Analysis Across Different Non-cropped Habitat Proportions

Landscape heterogeneity showed significant correlations with the proportion of non-cropped habitats within plant community survey areas . As the proportion of non-cropped habitats increased, Shannon' s diversity and evenness indices increased, while landscape patch shape complexity gradually increased and contagion showed the opposite trend . These patterns indicate that lower proportions of non-cropped habitats correspond to greater disparities in area proportions among landscape types, increasing the likelihood of dominance by a few landscape types. Survey areas with 0%–10% and 40%–50% non-cropped habitat proportions showed substantial differences in landscape patch complexity and dominance of major landscape types, with significant differences from other proportion intervals .

3.2 Dominant Species Dominance Across Different Non-cropped Habitat Types

Statistical analysis of herbaceous layer data from different non-cropped habitat types revealed 129 plant species belonging to 35 families and 92 genera. Asteraceae comprised 33 species (25.58% of total) across 21 genera (22.83% of total). Gramineae included 17 species (13.18%) across 15 genera (16.30%). Polygonaceae contained 9 species (6.98%) across 2 genera (2.17%). Leguminosae had

8 species (6.20%) across 7 genera (7.61%). The remaining 62 species belonged to 47 genera .

Dominant species significantly influence community structure, and species importance values reflect dominance across the entire region. Constructing species-cumulative importance value curves reveals the intensity of dominant species dominance [31]. Analysis of dominant species importance values showed that Gramineae species held the highest values across all habitats, though specific species differed: *Lolium multiflorum* dominated woodlands, field roads, and grasslands; *Poa pseudo-palustris* dominated orchards; and *Beckmannia syzigachne* dominated ditches. *Polygonum maackianum*, *Artemisia lancea*, and *Rubus lineatus* showed similar importance values, forming dominant communities in ditches within different survey areas. These results indicate high similarity in dominant species composition across habitats but varying dominance intensities , particularly pronounced in orchards and ditches [Figure 3: see original paper].

Species-cumulative importance value curves revealed the strongest dominant species dominance in orchards, followed by ditches, grasslands, field roads, and woodlands. Dominance in orchards and ditches was significantly higher than in grasslands, field roads, and woodlands [Figure 3: see original paper]. This pattern suggests that increased human disturbance in agricultural landscapes reduces species numbers while strengthening the prominence of dominant species and their control over plant communities [31, 38].

3.3.1 Species Diversity Characteristics Across Different Non-cropped Habitat Proportions

Analysis of plant diversity characteristics across different non-cropped habitat proportions showed significant differences among proportion intervals [Figure 4: see original paper]. Shannon diversity and evenness indices initially increased then decreased with rising habitat proportions, peaking at 20%-30% coverage. Species richness index also increased then decreased within the 0%-40% range, peaking at 20%-30%; however, richness surged at 40%-50% coverage, significantly exceeding other intervals. This anomaly likely occurred because survey areas in the 40%-50% range were located near forest farms where woodland landscape proportions approached those of farmland, highlighting woodland dominance and causing the richness spike.

Standard deviations of diversity indices revealed considerable variability among survey areas in the 30%-40% and 40%-50% intervals [Figure 4: see original paper], suggesting that plant diversity characteristics are closely related to habitat types, internal ecological factor heterogeneity, and external human disturbance intensity and frequency. Comprehensive analysis indicates that the 20%-30% non-cropped habitat proportion yields relatively high and stable Shannon diversity, evenness, and richness indices, representing the optimal proportion for plant community diversity in agricultural landscapes.

3.3.2 Plant Diversity Characteristics Across Different Non-cropped Habitat Types

Analysis of plant species diversity across habitat types showed that orchards had the highest Shannon diversity index, followed by grasslands, ditches, woodlands, and field roads, with no significant differences among orchards, grasslands, and ditches. Species richness was significantly highest in grasslands, ranking as grassland > woodland > ditch > orchard > field road. Species evenness decreased sequentially across orchards, ditches, grasslands, woodlands, and field roads, with orchards and ditches showing significantly higher evenness than grasslands, woodlands, and field roads. Standard deviations indicated substantial variability in Shannon diversity, richness, and evenness indices among survey areas within grassland and orchard habitats [Figure 5: see original paper], reflecting strong influences from external human disturbance frequency and intensity.

Beta diversity indices reflected variation and differentiation in community composition across survey areas within habitats [Figure 5: see original paper]. Woodlands showed significantly greater species composition differences among survey areas than other habitats, followed by field roads, with ditches, grasslands, and orchards showing sequentially lower but non-significant differences. This pattern indicates that plant community structure in non-cropped habitats is strongly affected by human activity intensity and disturbance frequency (notably higher in field roads than in ditches, grasslands, and orchards) and by internal ecological factor heterogeneity (lower in orchards and ditches). In woodlands, herbaceous layers are additionally influenced by interspecific competition and gap dynamics among tree and shrub layers. Standard deviations revealed high variability in beta diversity indices among survey areas for grasslands and field roads, but low variability for woodlands, ditches, and orchards [Figure 5: see original paper].

3.4 Relationships Between Species Diversity and Landscape Heterogeneity Across Habitat Types

Correlation analysis between landscape heterogeneity and plant species diversity across habitat types revealed significant correlations between Shannon diversity, richness indices and landscape heterogeneity in grasslands, but no significant correlations for evenness. In orchards, ditches, woodlands, and field roads, no significant correlations were found. In grasslands, plant species diversity indices were inversely correlated with contagion and positively correlated with Shannon' s diversity and evenness indices, with correlation coefficients of -0.949, 0.973, and 0.771, respectively. Other habitats showed inconsistent correlation patterns .

In grasslands, the correlation strength ranked as richness index > Shannon diversity index > evenness index. In ditches, differences were small between contagion and evenness correlations but large with Shannon' s diversity, ranking as Shannon diversity > evenness > richness. In orchards, Shannon diversity showed the strongest correlation with landscape heterogeneity. In woodlands, differences were minor, with richness showing strongest correlations with contagion and Shannon' s diversity, while Shannon diversity correlated most strongly with evenness. In field roads, richness correlated most strongly with Shannon' s diversity and evenness, followed by evenness with contagion.

The correlation between contagion and diversity indices ranked as grassland and orchard > woodland > ditch > field road. Correlations with Shannon' s diversity ranked as grassland > ditch > orchard, field road, and woodland. Correlations with evenness ranked as orchard and grassland > ditch > field road and woodland. Overall, correlations between landscape heterogeneity and species diversity decreased sequentially across grassland, orchard, ditch, field road, and woodland habitats, indicating that different disturbance types, methods, and intensities produce varying correlations between landscape heterogeneity and plant species diversity.

4 Discussion and Conclusions

In the study area' s agricultural landscape, non-cropped habitat proportion was inversely correlated with contagion and positively correlated with Shannon' s diversity and evenness. As non-cropped habitat proportion increased, landscape patch complexity increased while disparities in area proportions among landscape types decreased, reducing the likelihood of dominance by a few landscape types. Plant species Shannon diversity and evenness indices initially increased then decreased with rising habitat proportions, peaking at 20%-30% coverage. Species richness increased then decreased within the 0%-40% range, peaking at 20%-30%; above 40% coverage, richness increased again, with 40%-50% proportions yielding higher richness than the 20%-30% optimum. Concurrently, landscape patch complexity and landscape type dominance showed substantial differences above 40% habitat proportion, triggering significant changes in species richness. These results indicate that the optimal non-cropped habitat proportion is 20%-30%.

Woodland herbaceous communities exhibited the highest species richness, but tree and shrub layers influenced community composition, which was dominated by Gramineae, Asteraceae, and Cyperaceae. Orchards, grasslands, and field roads, subject to intense human disturbance, were dominated by disturbance-tolerant Gramineae species such as *Poa pseudo-palustris* and *Lolium multiflorum*. *Polygonum maackianum*, a hygrophyte species unique to ditch habitats and one of their dominant species, showed relatively small dominance differences with other species, indicating that ditches positively contribute to hygrophyte diversity conservation. Importance value analysis revealed similar dominant species composition across habitats but differing dominance intensities and ecological functions. Species-cumulative importance value analysis showed dominant species dominance ranking as orchard > ditch > grassland > field road > woodland, with orchards, ditches, and grasslands showing significantly higher dominance than field roads and woodlands. In agricultural landscapes, intense human disturbance in orchards, grasslands, and field roads favors clustering of herbicide-resistant, trampling-tolerant dominant species through natural selection, strengthening their control over plant communities.

Shannon diversity and evenness indices in orchards, grasslands, and ditches were significantly higher than in woodlands and field roads, though orchards and grasslands showed considerable variability among survey areas. Species richness ranked as grassland > woodland > ditch > orchard > field road, with high variability among survey areas in grasslands, orchards, and field roads. Thus, plant community structure in grasslands, orchards, and field roads is vulnerable to human disturbance frequency, intensity, and internal ecological heterogeneity, making them less favorable for species diversity conservation. In contrast, ditches and woodlands maintained high and stable Shannon diversity, richness, and evenness, positively contributing to plant species diversity conservation.

The correlation strength between landscape heterogeneity and species diversity ranked as grassland > orchard > ditch > field road > woodland, with only grasslands showing significant correlations between Shannon diversity, richness and landscape heterogeneity. Combined with dominant species distribution patterns and diversity index distributions, these results demonstrate that different disturbance types, methods, and intensities produce varying correlations between landscape heterogeneity and diversity indices. Grassland communities are herbaceous-dominated with each species' importance value <1, relatively simple structure, unstable individual numbers, and susceptible total species numbers and coverage, resulting in correlation strength ranking as richness > Shannon diversity > evenness. In orchards, human interference for fruit quality and yield favors dominance of herbicide-resistant, shade-tolerant species, reducing species numbers and making Shannon diversity highly responsive to landscape heterogeneity. Ditches comprise natural and artificial hardened types; hardening causes direct species loss, reduced coverage, and lower evenness, producing small differences in correlations with contagion and evenness but large differences with Shannon' s diversity, ranking as Shannon diversity > evenness > richness. Field roads experience varying trampling intensities and herbicide effects across seasons, causing significant changes in individual numbers and highlighting dominant species ecological advantages, resulting in strong correlations between richness, evenness and landscape heterogeneity. Woodlands contain trees, shrubs, and herbs, where interspecific competition and gap dynamics create large differences in herbaceous species numbers and individuals, producing strong correlations between richness, Shannon diversity and landscape heterogeneity.

Grassland landscapes have simple structures; orchards and field roads experience the most severe human disturbance, exhibiting strong landscape homogeneity, low plant species diversity, and prominent dominant species ecological advantages that are unfavorable for conservation. Ditches are unique: despite hardening disturbance, they maintain moderate, stable plant diversity with low variation and differentiation, serving as reproduction and habitat sites for hygrophyte specialists like *Polygonum maackianum*. Woodlands, as primary habitats and refuges for flora and fauna, exhibit the highest and most stable plant diversity, crucial for farmland species diversity conservation and enhancement. Liu et al. [41] found that species richness and diversity indices correlated most strongly with landscape heterogeneity at the 1,000 m scale, confirming close linkages between landscape heterogeneity and farmland plant diversity in plain regions.

Changtu County, a renowned agricultural county and key commodity grain base, represents a typical northern wavy plain dryland agricultural region where agricultural landscapes comprise mosaic systems of intensive farmland and non-cropped habitats [1]. Non-crop organisms depend on these landscapes for food and habitat [11-12]. Natural and semi-natural habitats (field roads, woodlands, orchards, grasslands, ditches) provide rich sources for non-cropped organisms, serving as habitats, breeding sites, food sources, and refuges that critically influence biodiversity maintenance [43]. Deepening understanding of how agricultural landscape heterogeneity affects biodiversity and balancing ecosystem services with agricultural production represent urgent scientific challenges in agricultural landscape management [44]. Global change and intensified human disturbance have drastically reduced agricultural landscape biodiversity [45], while linear corridors like roads decrease connectivity and reduce habitat species [46]; this study similarly found that field roads had lower Shannon diversity, richness, and evenness than other habitats. Balancing agricultural production, biodiversity conservation, and sustainable ecosystem services requires optimizing landscape structure and managing non-cropped habitat layout to maximize ecological service effects—a major challenge facing current agricultural production and landscape management. This study analyzed only herbaceous diversity, neglecting tree and shrub layers whose composition and structure significantly influence ecosystem function and understory herbaceous diversity [47]. Different non-cropped habitat types and proportions in the study area produced varying species dominance and diversity patterns. Future agricultural structure design and biodiversity conservation should consider habitat type effects and optimize non-cropped habitat proportions while protecting and constructing habitats that positively contribute to diversity conservation. Further research on biodiversity conservation and healthy, sustainable agricultural ecosystem development should comprehensively evaluate multiple factors—including topography, non-cropped habitat proportion and type, and external disturbance intensity and frequency—and their effects on biodiversity, ecosystem services, and agricultural productivity.

References

[1] Bennett A F, Radford J Q, Haslem A. Properties of land mosaics: Implications for nature conservation in agricultural environments[J]. Biological Conservation, 2006, 133(2): 250-264
[2] Fu B J. Landscape diversity analysis and mapping[J]. Acta Ecologica Sinica. 1995, 15(4): 345-350
[3] Qin X H. An approach to relation between biological diversity and landscape

heterogeneity[J]. Natural sciences journal of Harbin normal university, 1997, 13(04): 98-102
[4] Robinson R A, Sutherland W J. Post-war changes in arable farming and biodiversity in Great Britain. Journal of Applied Ecology, 2002, 39(1): 157-176
[5] Foley J A, DeFries R, Asner G P, et al. Global consequences of land use.Science, 2005, 309(5734): 570-574
[6] Meehan T D, Werling B P, Landis D A, et al. Agricultural landscape simplification and insecticide use in the Midwestern United States. Proceedings of the National Academy of Sciences of the United States of America, 2011, 108(28): 11500-11505
[7] Forrnan R T T, GodronM. Landscape Ecology[M]. Xiao D N, Translation, Beijing: Science Press, 1990
[8] Forrnan R T T. Land Mosaics: the Ecology of Landscape and Regions [M]. London: Cambridge University Press, 1995
[9] Altieri M A. The ecological role of biodiversity in agroecosystems. Agriculture, Ecosystems and Environment, 1999, 74(1/3):
[10] Marshall E J P, Brown V K, Boatman N D, et al. The role of weeds in supporting biological diversity within crop fields. Weed Research, 2003, 43(2): 77-89
[11] Midgley G F. Biodiversity and ecosystem function[J]. Science, 2012, 335(6065): 174-175
[12] Tscharntke T, Klein A M, Kruess A, et al. Landscape perspectives on agricultural intensification and biodiversity-ecosystem service management. Ecology Letters, 2005, 8(8): 857-874
[13] Ernoult A, Alard D. Species richness of hedgerow habitats in changing agricultural landscapes: are and diversity shaped by the same factors? Landscape Ecology, 2011, 26(5): 683-696
[14] Groot J C J, Jellema A, Rossing W A H. Designing a hedgerow network in a multifunctional agricultural landscape: balancing trade-offs among ecological quality, landscape character and implementation costs. European Journal of Agronomy, 2010, 32(1): 112-119
[15] Marshall E J P, Moonen A C. Field margins in northern Europe: their functions and interactions with agriculture. Agriculture, Ecosystems and Environment, 2002, 89(1/2): 5-21
[16] Jackson L, van Noordwijk M, Bengtsson J, et al. Biodiversity and agricultural sustainagility: from assessment to adaptive management. Current Opinion in Environmental Sustainability, 2010, 2(1/2): 80-87
[17] Whittingham M J. The future of agri-environment schemes: biodiversity gains and ecosystem service delivery? Journal of Applied Ecology, 2011, 48(3): 509-513
[18] Godfray H C J, Beddington J R, Crute I R, et al. Food security: the challenge of feeding 9 billion people. Science, 2010, 327(5967): 812-818
[19] Phalan B, Onial M, Balmford A, et al. Reconciling food production and biodiversity conservation: land sharing and land sparing compared.Science, 2011, 333(6407): 1289-1291
[20] Tscharntke T, Clough Y, Wanger T C, et al. Global food security, bio-

diversity conservation and the future of agricultural intensification.Biological Conservation, 2012, 151(1): 53-59
[21] Gomiero T, Pimentel D, Paoletti M G. Is there a need for a more sustainable agriculture? Critical Reviews in Plant Sciences, 2011, 30(1/2): 6-23
[22] Clough Y, Barkmann J, Juhrbandt J, et al. Combining high biodiversity with high yields in tropical agroforests. Proceedings of the National Academy of Sciences of the United States of America, 2011, 108(20): 8311-8316
[23] Seufert V, Ramankutty N, Foley J A.Comparing the yields of organic and conventional agriculture. Nature, 2012, 485(7397):
[24] Liu Y H, Yu Z R, Wang C L, et al.The diversity of ground-dwelling beetles at cultivated land and restored habitats on the Bashang plateau[J].Acta Ecologica Sinica.2011, 31(2): 465-473
[25] Yu Z R, Gu W B, Hu D X. On landscape pattern and biodiversity in rural areas of Jianghan plain-Taking two villages as a case study[J].Resources science.2000, 22(2): 19-23
[26] Chang H, Zhang X Z, Duan M C, et al.Spatial distribution pattern of carabid assemblage in agricultural landscape of Miyun County, Beijing[J].Chinese Journal Applied Ecology, Jun.2012, 23(6): 1545-1550
[27] Rundl f M, Edlund M, Smith H G. Organic farming at local and landscape scales benefits plant diversity[J]. Ecography, 2010, 33(3): 514-522
[28] Yang B, Chen Y Q, Sui P, et al.Comprehensive assessment on ecological health in intensive-cropland under different Fertilization measures[J].Crops.2010(04)
[29] Gu Y F, Hu N, Ding S Y, et al.Community structure and dynamics of agricultural weeds under different land utilization regimes in Kaifeng area[J].Acta Ecologica Sinica..2007, 27(4): 1359-1367
[30] Wang Y, Wang G, Du Y Q, et al.Influence of edge effects on arthropods communities in agroforestry ecological systems[J].Acta Ecologica Sinica..2011, 31(20): 6186-6193
[31] Lu X L, Tang Q, Liang G F, et al.Plant species diversity of non-agricultural habitats in the lower reaches of the Yellow River plain[J].Acta Ecologica Sinica..2015, 35(5): 1527-1536
[32] Chen Y F, Liu H, Chen Q.Status and Prospect for the Study of Plants Identification Methods[J].World Forestry Research. 2014, 27(4)
[33] Chinese Academy of Sciences Chinese Flora Editorial Board.Chinese Flora[M].Beijing: Science Press, 2004
[34] Li S X.Liaoning Flora[M].Liaoning: Liaoning Science and Technology Press, 1988, 11
[35] Fu P Y.Northeast herbaceous plant[M].Beijing: Science Press, 1998, 11
[36] Ma W L.Botany[M].Beijing: Higher Education Press, 2009
[37] Institute of Botany, Chinese Academy of Sciences.China Higher Plant Illustration[M].Beijing: Science Press, 1972
[38] Ma K P, Liu Y M.Measuren of biotic community diversity I-Method of diversity meacure[J].Chinese Biodiversity.1994, 2(4): 231-239
[39] Chen S B, Ou Y Z Y, Xu W H, et al.A review of beta diversity studies[J].Chinese Biodiversity.2010, 18(4): 323-335

[40] Wu J G.Landscape Ecology[M].Higher Education Press.2007
[41] Liu D, Ding S Y.Research on ono-crop community characteristics and the relationship of landscape heterogeneity of agricultural landscape in the lower region of the Yellow River plain[D].Henan University.2013
[42] Dong C F, Liang G F, Ding S Y.The multi-scale effects of landscape heterogeneity on plant species diversity: a case study of Gongyi City[D].Henan University.2014
[43] Fahrig L, Baudry J, Brotons L, et al. Functional landscape heterogeneity and animal biodiversity in agricultural landscapes[J]. Ecology Letters, 2011, 14(2): 101-112
[44] Song B, Ding S Y, Zhang Z H, et al.Effects of agricultural landscape heterogeneity on biodiversity and ecosystem services[J].Chinese Journal of Eco-Agriculture, Apr. 2016, 24(4): 443−450
[45] Butchart S H M, Walpole M, Collen B, et al. Global biodiversity: Indicators of recent declines[J]. Science, 2010, 328(5982):
[46] Dong C F, Liang G F, Ding S Y, et al.Multi-scale effects for landscape metrics and species diversity under the different disturbance: a case study of Gongyi City[J].Acta Ecologica Sinica.2014, (12): 3444-3451
[47] Lu X L, Ding S Y, You L, et al.Effects of forest canopy structure on understory vegetation characteristics of Funiu Mountain Nature Reserve [J].Acta Ecologica Sinica.2013, 33(15): 4715-4723

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