Spatiotemporal Dynamics of Wild Bee Diversity in Agricultural Landscapes of Changping District, Beijing (Postprint)

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Abstract

In recent years, wild bee diversity has declined sharply due to declining habitat quality and habitat loss, seriously threatening pollination services and the sustainable development of agriculture. To reveal the spatiotemporal distribution patterns of wild bees in agricultural landscape mosaics and the importance of different habitats for wild bee conservation, this study investigated wild bees in four main habitat types (plantation forests, natural shrublands, abandoned grasslands, and peach orchards) within the agricultural landscape of Changping, Beijing from April to September 2016 using sweep netting, and analyzed wild bee diversity and its temporal dynamic characteristics across different habitat types. The results showed that the species richness and individual abundance of total wild bees, large-bodied bees, and solitary bees, as well as the individual abundance of medium-bodied bees, were all highest in natural shrublands; the individual abundance of small-bodied bees was highest in plantation forests; and both the individual abundance and species richness of total wild bees were lowest in peach orchards. Across different months, all functional groups of wild bees exhibited highest abundances in natural or semi-natural habitats, and were lowest in peach orchards in May, possibly due to intensive management of ground-cover weeds in peach orchards. The four dominant species with the highest abundance displayed different temporal dynamic characteristics among habitats. Therefore, while these four habitat types all provided utilizable resources for wild bees, natural and semi-natural habitats played a more significant role; among them, natural shrublands maintained greater numbers of medium-bodied and large-bodied wild bees with higher potential pollination efficiency, thus possessing higher conservation value. Consequently, to promote the diversity of different functional groups of wild bees and pollination services in agricultural landscapes of this region, it is necessary to enhance habitat type diversity while adopting low-intensity habitat management practices during peak wild bee activity seasons.

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Temporal-Spatial Dynamics of Wild Bee Diversity in Agricultural Landscapes of Changping District, Beijing

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Abstract

Pollination represents one of the most critical ecosystem services for both crops and wild plants, with wild bees serving as more reliable pollinators than honey bees due to their ubiquity, adaptability, and species diversity. However, wild bee diversity has declined sharply in recent years because of habitat loss and degradation, threatening pollination services and agricultural sustainability. Wild bee functional group diversity constitutes an important component of overall diversity and may be a better predictor of pollination service than species diversity alone, as species with different functional traits require different resources and respond differently to environmental changes.

To understand the temporal-spatial dynamics of wild bees across different habitats and evaluate the conservation value of various habitats within agricultural landscape mosaics, we surveyed wild bees using net-catching methods in four primary habitat types—planted woodland, natural shrub forest, wasteland, and peach orchard—in the Changping agricultural landscape from April to September 2016. We analyzed wild bee diversity and its temporal dynamics across these habitat types.

Our results showed that natural shrub forest supported the highest species richness and individual abundance of overall wild bees, large-bodied bees, and solitary bees, as well as the greatest abundance of medium-bodied bees. Planted woodland contained the most individuals of small-bodied bees, while peach orchard exhibited the lowest species richness and individual abundance of overall wild bees. All functional groups achieved highest diversity in natural or semi-natural habitats across sampling seasons, but peach orchard showed the lowest wild bee diversity in May, likely due to intensive groundcover management. The four most abundant species—*Nomia thoracica*, *Halictus aerarius*, *Ceratina flavipes*, and *Lasioglossum halictoides*—exhibited distinct temporal dynamics among habitat types.

These findings demonstrate that while all four habitat types provide essential resources for wild bees, natural and semi-natural habitats play a more important role, with natural shrub forest maintaining greater numbers of medium- and large-bodied wild bees that have higher potential pollination efficiency. Therefore, to promote diverse wild bee functional groups and enhance pollination services in this region' s agricultural landscapes, it is crucial to increase habitat type diversity, particularly natural and semi-natural habitats, and implement less intensive management practices during peak wild bee activity seasons.

Keywords: wild bee functional groups; habitat; foraging resources; local management

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Introduction

Pollination is a vital ecosystem service, with 87.5% of angiosperm plants in nature and approximately 75% of global crops depending to varying degrees on pollinators for sexual reproduction to produce seeds and fruits. Consequently, pollinator diversity is essential for maintaining plant genetic diversity, global food security, and human well-being.

Bees (Hymenoptera: Apoidea) are the primary pollinators. Research has shown that wild bee diversity positively correlates with pollination services, likely due to complementary functional niches. Wild bees differ in their foraging conditions and plant preferences, foraging height, lifestyle, body size (which relates to dispersal ability), and other traits, leading to variations in habitat and resource requirements as well as pollination efficiency. Functional groups of wild bees sharing similar traits provide buffering and insurance for ecosystem functions against environmental fluctuations, while different functional groups can utilize complementary resources through niche shifts. Therefore, wild bee functional group diversity may be more closely related to pollination services and serve as a better predictor than species diversity alone, particularly for traits directly linked to pollination.

In recent years, landscape simplification and natural habitat loss, combined with climate change, invasive species, and disease, have caused declines in both wild and managed bees, leading to serious losses of pollination services and threatening agricultural sustainability. While wild bee decline has received considerable attention, most studies have focused on individual economically important species rather than natural/semi-natural habitats and other wild bee species. In intensively managed agricultural landscapes, single-crop habitats cannot meet all resource requirements for wild bees. Vegetation with diverse phenological characteristics across different habitats causes the quantity and diversity of available resources to vary significantly over time. Consequently, diverse habitat types provide continuous resources for wild bees across temporal and spatial scales. This farmland-semi-natural habitat complementarity mechanism enables wild bees to persist in fragmented landscapes and shapes their temporal-spatial distribution patterns in agricultural landscapes.

However, few studies have examined the temporal-spatial dynamics of pollinator insects and their functional groups in farmland-semi-natural landscape mosaics, and there is limited research on the distribution patterns of pollinators across different habitats in agricultural landscapes over time, the mechanisms enabling their persistence, and the factors shaping their diversity characteristics. Moreover, corresponding monitoring networks and specific conservation measures are lacking. Therefore, extensive surveys of wild bee diversity are urgently needed to understand distribution patterns across temporal and spatial scales and inform more scientific conservation strategies. This study investigates the temporal-spatial dynamics of wild bee diversity and functional groups in the agricultural landscape of Changping District, Beijing, to provide a foundation for wild bee conservation in the region.

1.1 Study Area

The study area is located in Changping District, northwestern Beijing (40°2 –40°23 N, 115°50 –116°29 E), at the intersection of the Taihang and Yan Mountains and the North China Plain, with elevations ranging from 30 to 1,000 m. The district has a temperate continental monsoon climate, characterized by dry and windy springs and hot, rainy summers. The average annual sunshine duration is approximately 2,600 hours, mean annual temperature is about 12 °C, and annual precipitation is roughly 550 mm. The northwestern part of Changping is mountainous, dominated by natural shrub forests and mixed shrub-woodland, while the southeastern plain area is a major fruit-producing region with apples, peaches, and strawberries. Since 2012, large-scale plain afforestation projects have been implemented. Based on remote sensing image interpretation and landscape classification from 2015, the main habitat types and their area proportions are: natural forest (47.6%), planted woodland (11.8%), orchard (7.18%), wasteland (2.8%), and non-habitat (29.22%) [Figure 1: see original paper].

1.2 Sampling Design

In 2016, we selected four habitat types in the study area: natural shrub forest (natural habitat in mountainous areas), planted woodland (semi-natural habitat in plain areas), wasteland (semi-natural habitat in plain areas), and peach orchard. Each habitat type included five sampling plots [Figure 1: see original paper] at elevations ranging from 32 to 257 m, with distances between adjacent plots exceeding 2,000 m (except for two plots in natural shrub forest and peach orchard, which were 1,482 m apart). Each plot contained three parallel transects (50 m × 3 m) spaced 10 m apart.

From April to September, during the 23rd–28th of each month, we collected wild bees (excluding cleptoparasites) appearing in the transects using net-catching methods. The survey order of plots each month followed geographic sequence and was completed within 4–5 days. Each plot was sampled once monthly for 30 minutes (specimen processing time excluded). Bees were preserved in alcohol bottles, brought to the laboratory, mounted as pinned specimens, and identified to species by taxonomic experts. Sampling was conducted between 8:30 and

17:30 under sunny or slightly cloudy conditions with temperatures 18 °C and wind speeds <3 m · s ^{1}.

1.3 Data Processing

Wild bee species were classified into functional groups based on body size and lifestyle. Body size categories were: small (L   7.5 mm), medium (7.5 mm < L   11.5 mm), and large (L > 11.5 mm). Lifestyle categories included social (primarily eusocial) and solitary. Cleptoparasitic bees were excluded as they do not build nests or store food and have low pollination efficiency.

In DPS software, we used either one-way ANOVA or non-parametric tests depending on whether the wild bee diversity data followed a normal distribution to analyze differences in species richness and individual abundance across habitats.

Results

From April to September 2016, we collected 378 wild bee individuals belonging to 61 species, 21 genera, and 6 families in the Changping agricultural landscape . The genus *Lasioglossum* had the most species (13 species, 71 individuals), accounting for 21.31% of species richness and 18.78% of individual abundance, followed by *Andrena* (8 species, 29 individuals). The genera *Halictus* and *Nomia* had the highest individual abundances (78 individuals each, 20.63% of total).

Dominant species differed among habitats: *Nomia thoracica* dominated natural shrub forest, *Halictus aerarius* dominated both planted woodland and wasteland, while peach orchard had no clear dominant species. Natural shrub forest and wasteland had the most habitat-specific species (11 each), compared to four in peach orchard and two in planted woodland. Natural shrub forest showed the highest species richness (F = 4.124, P = 0.0241) and individual abundance (t = 3.4063, P = 0.0036), while peach orchard had the lowest; planted woodland and wasteland were intermediate and did not differ significantly [Figure 2: see original paper].

Functional group composition varied among habitats [Figure 3: see original paper]. For species richness, large-bodied and solitary bees were highest in natural shrub forest, with no significant differences among habitats for other groups. For individual abundance, medium-bodied and solitary bees were highest in natural shrub forest; small-bodied bee species richness peaked in planted woodland and was lowest in peach orchard; large-bodied bee abundance was highest in natural shrub forest and lowest in planted woodland.

2.2 Temporal Dynamics of Wild Bee Species Richness and Abundance

Except for wasteland, total species richness and individual abundance in other habitats showed similar trends from April to August [Figure 4: see original paper], decreasing from April to May, then increasing and subsequently decreasing from May to August, producing two peaks. In wasteland, species richness and abundance increased initially, peaked in July, then decreased, showing a single-peak pattern.

Temporal variation in functional group diversity differed among habitat types. Small-bodied bee abundance peaked in planted woodland in August and occurred only in this habitat in September; species richness peaked in wasteland in June and July, with both metrics lowest in peach orchard in May. Medium-bodied bee species richness peaked in natural shrub forest in July (lowest in peach orchard in May), while abundance peaked in natural shrub forest in June (lowest in peach orchard in May). Large-bodied bee species richness was highest in natural shrub forest in June, July, and September, in wasteland in April and August, and in peach orchard in July; abundance was highest in wasteland in April and August, and lowest in planted woodland and peach orchard in April, May, and August, and in wasteland in May. Social bee species richness peaked in wasteland in June and planted woodland in July, with abundance highest in planted woodland in July and both metrics lowest in peach orchard in May and September. Solitary bee species richness and abundance peaked in natural shrub forest in July and June, respectively, with both lowest in peach orchard in May.

2.3 Spatial-Temporal Distribution Patterns of Different Species

The four most abundant wild bee species were *Nomia thoracica*, *Halictus aerarius*, *Ceratina flavipes*, and *Lasioglossum halictoides*. These species showed distinct spatial-temporal distribution patterns [Figure 5: see original paper]. *Nomia thoracica* and *Ceratina flavipes* occurred in all habitats except wasteland, with the former active from June to August and the latter active throughout the sampling season. *Halictus aerarius* and *Lasioglossum halictoides* occurred in all four habitats, with the former active from May to September and the latter from April to July.

3.1 Wild Bee Diversity and Temporal Dynamics Across Habitats

Natural shrub forest supported the highest total species richness and individual abundance, significantly greater than peach orchard (which had the lowest). Located in mountainous areas, natural shrub forest features rich shrub and herb species, high-quality nectar plants such as perennial flowering vegetation (*Vitex negundo*), abundant exposed sunny ground, and minimal human disturbance, providing excellent foraging resources and nesting sites for wild bees, particularly for larger-bodied and solitary bees with high energy demands. Compared with small-bodied bees, larger-bodied bees have greater surface area and wings, conferring superior flight capability and pollination efficiency. Therefore, natural shrub forest holds important conservation value for maintaining wild bee diversity and potential pollination services in this region.

Although planted woodland lacks abundant high-quality perennial shrub and herb species, it can meet the needs of small-bodied bees with lower energy requirements. Wasteland also has relatively rich herbaceous plants, but its small total area and patch size in the region make it vulnerable to human disturbance, resulting in lower diversity of small-bodied bees compared with planted woodland. Peach orchards experience year-round disturbance from irrigation, tillage, and pesticides, which damage groundcover vegetation. They provide brief but large-scale foraging resources only during fruit tree flowering. However, if managed appropriately—such as avoiding pesticides during flowering and retaining suitable groundcover vegetation post-flowering—orchards can offer better foraging resources for wild bees.

Despite substantial differences in habitat suitability and resource availability among habitats, all four habitats supported habitat-specific species due to their distinct flowering plant communities, with natural shrub forest and wasteland harboring the most. Therefore, maintaining both habitat type diversity and within-habitat vegetation diversity contributes to conserving habitat-specific species and overall wild bee diversity.

In natural shrub forest, planted woodland, and peach orchard, total species richness and abundance showed two distinct peaks in April and June/July. This pattern likely reflects: (1) the study area' s location in Changping' s fruit cultivation region, where fruit trees bloom primarily in April, providing abundant foraging resources that elevate wild bee diversity above May levels; and (2) the life cycles of northern Chinese wild bees, which include primarily univoltine spring species, summer-early autumn species, and multivoltine species, aligning with Beijing' s seasons (spring: April–May; summer-early autumn: June–September).

The single-peak pattern in wasteland may relate to the active period of its dominant species *Halictus aerarius* peaking in June–July. Although temporal dynamics varied among functional groups, diversity was generally highest in natural/semi-natural habitats, demonstrating that these habitats provide superior resources across temporal and spatial scales. In peach orchards, however, intensive management after peach flowering reduced foraging resource availability, causing lowest species richness and abundance across all functional groups in May. Natural/semi-natural habitats surrounding orchards can provide alternative resources, enabling wild bee persistence in agricultural landscapes. Therefore, to enhance wild bee diversity and potential pollination services in May, we recommend retaining groundcover vegetation in orchard and field margins, eliminating pesticides and herbicides harmful to wild bees, and protecting surrounding natural/semi-natural habitats to provide continuous resources across spatiotemporal scales.

3.2 Spatial-Temporal Distribution Patterns of Different Species

The four dominant wild bee species exhibited different spatial-temporal distribution characteristics. *Nomia thoracica* and *Ceratina flavipes* shared similar habitat distributions but different activity periods, likely reflecting different life cycles. Studies indicate *Nomia* species are typically univoltine with peak activity in summer-early autumn, while temperate *Ceratina* species have longer activity periods, potentially active year-round. *Halictus aerarius* and *Lasioglossum halictoides* occurred in all four habitats but also showed different activity periods, probably due to the complex and diverse life histories within Halictidae, which vary among species and geographic populations and include univoltine, bivoltine, and multivoltine strategies. We hypothesize that *H. aerarius* is likely univoltine in this region with peak activity in June–July, while *L. halictoides* exhibits a spring-summer activity period.

Wild bees move among multiple habitats during the same or different life stages, primarily because flowering vegetation diversity and phenological characteristics differ among habitats, causing foraging resource quantity and diversity to vary significantly over time. This habitat complementarity mechanism enables wild bee persistence in fragmented landscapes and shapes their spatial-temporal distribution patterns in agricultural landscapes.

The habitat distribution patterns of the three dominant species in this study largely align with previous records of their visited plants. Literature documents *Ceratina flavipes* visiting *Vitex negundo*, *Ixeris polycephala*, *Artemisia*, and *Celosia cristata*; *Halictus aerarius* visiting *V. negundo*, *Rosa chinensis*, *Trifolium*, *Alcea rosea*, *Orchidaceae*, *Ixeris*, and *Rosa xanthina*; and *Nomia thoracica* visiting *V. negundo*, *Rosa*, *Hibiscus*, *Chrysanthemum*, and maize. *Lasioglossum halictoides* has been recorded visiting peach, but this study found it in planted woodland, wasteland, and natural shrub forest in addition to peach orchard. As a ground-nesting species, whether these three natural/semi-natural habitats provide nesting sites or foraging resources from other plants requires further investigation.

4 Conclusion

In Changping District, Beijing, different wild bee functional groups occur in both orchards and natural/semi-natural habitats, but their distribution patterns vary among habitats and months. Both orchard and natural/semi-natural habitats play important roles in maintaining wild bee diversity. However, due to differences in species functional traits, vegetation structure, nesting resource suitability, and local management, natural/semi-natural habitats—especially natural shrub forest—contribute more substantially to wild bee diversity conservation. Therefore, to maintain wild bee diversity and pollination services in this region’s agricultural landscapes, it is essential to protect and enhance habitat diversity while reducing management intensity.

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