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Landscape structure alters the abundance and species composition of early-season aphid populations in wheat fields

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ABSTRACT

Agricultural landscape composition is reported to have effects on the occurrence of natural enemies in fields, but the responses of herbivorous pests to landscape features have rarely been studied. Our previous landscape-level study in northern China found that natural enemies had no significant effects on the population growth of wheat aphids at the colonization stage. Hence, we hypothesised that the initial aphid population in wheat fields may largely depend on immigration events from other habitats. In this study, we investigated the effects of landscape pattern on wheat aphid abundance and species composition at the colonization stage by surveying population densities of different aphid species along a landscape gradient. We found that noncrop habitats such as woodlots, fallow lands and vegetation around dwellings or wetlands in the landscape all had positive correlations with aphid abundance in wheat fields because they provided a source for aphid colonization. More specifically, the proportion of woodlots, fallow lands, dwellings, and other crops increased the abundance of *Rhopalosiphum padi* (L.), and the existence of water and dwellings in an agricultural landscape facilitated the occurrence of *Sitobion avenae* (Fabricius). Likewise, the abundance of *Schizaphis graminum* (Rondani) in wheat fields was found to be significantly promoted by the presence of water. The habitats around water and dwellings usually provide the overwintering sites for the aphids. Furthermore, wheat production acreage had a significant negative correlation with the abundance of *R. padi*, *S. avenae* and *S. graminum*. Landscape characteristics had a significant effect on the species composition of wheat aphids. Our study suggests that noncrop habitats in a landscape enhance aphid occurrence at the population colonization stage, and differences in overwintering host plants among aphid species may be responsible for the differing responses of the abundance of different aphids to landscape variables, which greatly altered aphid population composition across different landscapes. These results highlight the need for taking landscape effects on the pest itself into consideration when designing landscape-level pest management strategies.

1. Introduction

The composition of agricultural landscapes is known to have significant effects on the population dynamics and community structure of arthropods in crop fields (Tscharntke et al., 2005; Bianchi et al., 2006; Fraterrigo et al., 2009; Rusch et al., 2010; Chaplin-Kramer et al., 2011). Most arthropods, including both pests and natural enemies, are unable to complete their life cycles in cereal fields alone and require resources from surrounding habitats (Landis et al., 2000; Veres et al., 2013). In agricultural landscapes, natural or seminatural habitats (woodlots, fallow lands, and vegetation around dwellings) facilitate pest and natural enemy populations by providing alternative or supplemental food resources, shelter, or overwintering refuges (Landis et al., 2000; Alignier et al., 2014). As noncrop habitats commonly serve as sources of arthropods colonizing crop fields (Schellhorn et al., 2014), the population of arthropods in fields is mediated by both direct (landscape effects on arthropods themselves) and indirect effects (landscape effects on the interaction between arthropods) of the landscape pattern (Chaplin-Kramer et al., 2011; Maisonhaute et al., 2017).

For insects in an agricultural landscape ecosystem, different habitats in the landscape mosaic serve different functions (Schellhorn et al., 2015; Janković et al., 2017). Habitats with high-quality host plants enhance the populations of herbivorous insects by providing preferred conditions that can facilitate insect population growth. Habitats with

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low-quality host plants usually have the opposite effect, depressing the densities of herbivorous pests (Kennedy and Storer, 2000; Chaplin-Kramer, 2010; Tsafack et al., 2013, 2015). Habitats dominated by nonhost plants may still influence pests indirectly by promoting natural enemies (Gardiner et al., 2009a) or directly via physical pathways (such as windbreaks barring the immigration of aphids into crop fields) (Marrou et al., 1979), or by creating a particular microclimate (Dyer and Landis, 1997). Landscape-level studies provide a method to detect habitat functionality for insects at a particular time in the season, which is critical for the successful use of area-wide pest management through landscape manipulation (Schellhorn et al., 2014, 2015).

A large body of theoretical and empirical evidence suggests that natural enemy abundance in fields is enhanced by natural habitats in agricultural landscapes and that such habitats favorable to natural enemies improve control of some pests (Gardiner et al., 2009a; Chaplin-Kramer et al., 2013; Liu et al., 2016). However, natural habitats (such as grass margins) can constitute a source of pests, increasing pest density and subsequently affecting pest distribution and abundance in the neighboring crop fields (Ramsden et al., 2016). In many studies, larger populations of natural enemies in the field did not lower pest density because the pest immigration offset the biological control effects of those natural enemies (Roschewitz et al., 2005; Thies et al., 2005; Chisholm et al., 2014). Thies et al. (2005) found that while complex landscapes promote higher parasitism rates, this effect can be offset by greater aphid colonization rates, resulting in no difference in aphid densities along a landscape gradient.

Investigating the responses of pest populations together with those of natural enemy populations to landscape factors gives a complete and more accurate measure of the ecosystem services provided by a landscape (Chaplin-Kramer, 2010; Chaplin-Kramer et al., 2013; Chisholm et al., 2014). Unfortunately, fewer studies have examined pest responses in a landscape context compared with studies on natural enemies, especially pertaining to the pest population at the initial colonization stage (Bianchi et al., 2006; Chaplin-Kramer et al., 2011). Moreover, these studies provided divergent conclusions (Veres et al., 2013). For example, Alignier et al. (2014) found that seminatural habitats in an agricultural landscape appeared to have no temporal pattern of effects on aphid abundance, as noncrop habitats affected aphids directly and indirectly, both negatively and positively. These results and the scarcity of studies on the subject suggest a need to pay more attention to the effects of different habitats on pests at the landscape scale to promote landscape-level pest control.

Aphids (Hemiptera: Aphididae) are important agricultural pests, causing economic damage to cereal crops. In wheat fields in northern China, the wheat aphid community is composed of four species: *Rhopalosiphum padi* (L.), *Sitobion avenae* (Fabricius), *Schizaphis graminum* (Rondani), and *Metopolophium dirhodum* (Walker). The first three species are the most important cereal pests, reducing yield and quality in the study region (Lu and Gao, 2016). In this study, we investigated the effects of landscape composition at four different spatial scales (0.5, 1.0, 1.5 and 2.0 km), on aphid population density at the early season, crop-colonization stage. Here, we chose early spring as the time to conduct our study because it is the main period for aphid colonization of wheat fields from aphid overwintering habitats. Our previous study showed that a relatively low density of natural enemies at the time of colonization was considered to have no significant effect on aphid populations (Yang et al., 2018), and hence variation in wheat aphid populations among different wheat fields may be due to features of the surrounding landscape. We surveyed aphid complex populations in wheat fields in 2015 and 2016 to test the following hypotheses: (1) The abundance of aphids will be higher in wheat fields within a landscape dominated by noncrop habitats due to immigration from surrounding natural habitats. (2) The abundance of aphids will be lower in wheat fields within a landscape dominated by wheat production due to a dilution effect. (3) Aphid species will respond to landscape features according to their biological property of overwintering. (4) Aphid species assemblages will vary according to landscape features and the biological properties of individual species.

2. Materials and methods

2.1. Study area

The survey was conducted in 48 winter wheat fields (29 fields in 2015 and 19 in 2016) in Hebei Province, Beijing and Tianjin Cites, northern China (Fig. S1), 24 sites (17 sites in 2015 and 7 in 2016) of which had been examined in a previous study (Yang et al., 2018). The study region is one of the major winter wheat producing areas in China, with a temperate semihumid monsoon climate, and a landscape mosaic consisting mainly of crop lands, fallow lands, shelterbelts and dwellings (and associated plants) during the spring-summer season. The study sites were selected along a gradient of landscape composition ranging from simple landscapes with a high proportion of crop fields to complex landscapes dominated by noncrop habitats (Table S1). Within a given year, the minimum distance between any two sites was more than 4 km. The size of sampled wheat fields averaged 11.33 ha (range: 0.51–37.00 ha), and none of the fields were treated with insecticides before the survey.

2.2. Aphid sampling

Aphid densities were sampled twice each year, from April 16 to 29 in 2015 and from April 24 to May 5 in 2016, at approximately 10-day intervals during the wheat elongation stage. At each site, three plots ($20 \times 30\,m^2$ each with an interval of 10 m between two neighboring plots) were randomly selected, and aphid population abundances were surveyed by visual observation at five randomly selected points within each plot; 10 tillers were surveyed for each point. Each selected tiller was at least 10 m from any field edge. The abundance of aphids was calculated as individuals per 100 tillers, and data collected from these two surveys were pooled together.

2.3. Landscape investigation and analysis

Landscape composition was measured outward from the center of each wheat field at four spatial scales (0.5, 1.0, 1.5 and 2.0 km), as landscape features at these scales usually have effects on wheat aphid population abundance (Thies et al., 2005; Alignier et al., 2014; Zhao et al., 2014; Chabert and Sarthou, 2017; Janković et al., 2017). The geographical coordinates of the center of each wheat field were collected using a handheld GIS unit (Model MG758, Beijing UniStrong Science & Technology Co., Ltd., China). We first obtained satellite imagery for the surrounding areas out to a radius of 2.0 km for each site from Google Earth maps using these coordinates. Then, we printed imagery maps and marked the land cover types on the maps by ground verification to eliminate inaccuracies caused by land use changes between the image date and study period (Liu et al., 2016). After that, we digitized the habitat types surrounding each study site and calculated the proportion of habitats in each radius buffer using ArcGIS 10.2 software (ESRI, 2013).

For each spatial scale, we measured the percentage of total area covered by each of six cover types: wheat, fallow, water, other crops (i.e., vegetables, greenhouse, fruit trees, pea, and maize), dwellings (i.e., roads and dwellings), and woodlots (i.e., poplar trees and reforested areas) (Table S1). The landscape surrounding sampled fields varied greatly among the 48 study sites and across all spatial scales, with wheat accounting for 1.62–87.96% and the percentage of woodlots ranging from 1.01 to 54.62% (Table S1). A Spearman correlation test was used to check for correlations among landscape variables (Table S2), and as wheat displayed strong correlations ($> |0.5|$) with the other variables at all spatial scales, we excluded the proportion of wheat in further analysis. The variance inflation factor (VIF) values for