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Secondary crops and non-crop habitats within landscapes enhance the abundance and diversity of generalist predators

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ABSTRACT

An agricultural landscape is usually composed of multiple crops and non-crop habitats, and many studies have examined the effects of main crops and non-crop habitats on arthropod communities. However, secondary crops are also important features in argoecosystems, but how they affect generalist arthropod predators in an agricultural landscape has rarely been considered, especially in landscape dominated by small-scale farming. In this study, we applied a principal component analysis to interpret the landscape composition, and we performed a multiple regression analysis basing on Akaike's information-theoretic selection criterion to assess the effects of secondary crops (other crops besides maize and cotton) as well other landscape component factors (e.g., landscape diversity, non-crop habitats) on the abundance and diversity of generalist predators in Bt cotton fields, across multiple spatial scales in 49 study sites covering at least 600 km^2 in northern China. We found that a high proportion of secondary crops significantly enhanced the abundances of lacewings and vegetation-dwelling spiders within a 0.5 km radius, and an increasing proportion of urban habitats supported a high abundance of these spiders, in contrast to the negative effect that high landscape diversity had on spider abundance. However, we failed to find a significant landscape variable response on the abundances of lady beetles and *Orius* spp. Furthermore, high proportions of both non-crop habitats and urban areas enhanced hoverfly abundance at a 1.5 km radius, while a high proportion of urban areas also supported high diversity but a low dominant species concentration of the predator community at the 2 km scale. Our results suggest that predator abundance and community structure diversity may benefit from secondary crops, non-crop habitats and urban areas in agricultural landscapes, and these habitats and areas will improve the potential ecosystem services of these predators in a pest management program.

1. Introduction

Increasing urbanization and agricultural intensification has modified natural and semi-natural habitats as well as the species composition and distribution of insect communities in these habitats around the world (Wickramasinghe et al., 2004; Gagic et al., 2013; Emmerson et al., 2016; Martin et al., 2016). Urbanization and agricultural intensification are processes that are characterized by major landscape simplification, a process in which many minor crops and non-crop habitats are lost, and chemical insecticides are employed more extensively to suppress crop pests (Meehan et al., 2011; Crowder and Harwood, 2014; Meehan and Gratton, 2015; Rusch et al., 2016), leading to a loss of biodiversity as well as relevant ecosystem services provided by natural enemies or pollinators (Jauker et al., 2013; Gámezvirués et al., 2015; Landis, 2016; Dainese et al., 2017). The mechanism to mitigate the negative effects of modern agriculture on ecosystems has been given extensive attention from ecologists and government agencies.

Natural enemies, especially generalist predators, play a key role in agricultural production. A diversified and stabilized community of predators can provide remarkably valuable ecosystem service by controlling pests (Fox et al., 2005; Costamagna et al., 2007; Safarzoda et al., 2014; Dassou and Tixier, 2016) and decreasing the loss of diverse crops, including fruits and vegetables (Poveda et al., 2010; Liere et al., 2015; Pywell et al., 2015). For example, during the past two decades in China, the widespread adoption of Bt (*Bacillus thuringiensis*) cotton and subsequent decrease in insecticide use has led to both a decrease in the population density of the target pest *Helicoverpa armigera* (Hübner) and an increase in the abundance of generalist arthropod predators that provided biological services for cotton and other crops in the surrounding agricultural landscapes (Lu et al., 2012).

However, species diversity and community characteristics of natural enemies can be affected by landscape composition and spatial scale

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features (Gardiner et al., 2009b; Chaplin-Kramer et al., 2011; Tscharntke et al., 2012; Woltz et al., 2012; Rösch et al., 2013; González et al., 2017). Landscape simplification decreases the diversity of crops and other vegetation that can lead to homogenous habitats suitable to pests, which increases the risk and size of a pest outbreak (Rusch et al., 2016; Tamburini et al., 2016b). More diverse landscapes can provide a variety of habitats with alternative prey resources and overwintering habitats for predators (Gardiner et al., 2013; Burkman and Gardiner, 2014; Smith and Schmitz, 2016; Tamburini et al., 2016a). However, while some natural enemies are oligophagous, others are monophagous and require a specific prey on a specific crop, and a monoculture of that crop may support these species quite well (Batary et al., 2011; Chaplin-Kramer et al., 2011). Nevertheless, generalist predators usually profit from diversified habitats and varied prey species as their food sources (Costamagna et al., 2007; Martin et al., 2016), and a more heterogenous landscape may also support a more diversified and stable predator community.

The mechanism in which a variable of an agricultural landscape structure affects natural enemy biodiversity is a function of the variety of habitat types present in an agricultural ecosystem. The various crops and non-crop habitats support herbivores, which directly or indirectly support natural enemies through a trophic food web that enhances natural enemy numbers and diversity within the main crops (Landis et al., 2000; Ostman et al., 2001; Vasseur et al., 2013; Rand et al., 2014). Secondary crops and non-crop habitats usually play important roles in providing alternative hosts for main-crop pests and thus provide alternative prey or nectar sources as well as refuges or overwintering habitats for natural enemies (Thies et al., 2003; Bianchi et al., 2006; Tscharntke et al., 2007; Pluess et al., 2010; Dainese et al., 2016). The loss of secondary crops and non-crop habitats reduces landscape diversity, affecting both pests and the biological control services provided by generalist natural enemies (Landis et al., 2008; Alhmedi et al., 2011; Alignier et al., 2014; Grez et al., 2014; Landis, 2016).

Recently, agricultural production models have been changing with urbanization and agricultural intensification, which has had substantial impacts on the small farmer economy in northern China. Many farmers left their lands and to work in factories, while others have stopped cultivating many minor crops that require high labor costs and high levels of insecticides or have low economic returns, and the farmers have instead turned to growing corn or fruit trees, which require relatively low level of pesticide input and easier field management. The result is that the agricultural landscape is slowly losing its complexity. While there has been some research on the effect of landscape on insect communities, most of the studies have focused on wheat aphids and their parasitoids (Zhao et al., 2013; Zhao et al., 2014; Zhao et al., 2015; Ouyang et al., 2016). Our previous study found that a high landscape diversity and high proportion of non-crop habitats adjacent to cotton and maize fields could enhance the parasitism by *Trichogramma* sp. wasps on cotton bollworm eggs (Liu et al., 2016a, 2016b). Unfortunately, only a few studies have focused on the landscape effects on generalist predators in the cotton fields of this agricultural ecosystem in northern China (Zhou et al., 2014).

We conducted a large-scale study on agricultural landscape composition across four cities by using GIS technology combined with the prevailing ecological and statistical models, and we aimed to evaluate the effects of landscape factors on the diversity and community structure of generalist predators in a cotton field ecosystem in northern China. Specifically, we sought to determine (1) how landscape composition surrounding the focal cotton field affected the abundance and diversity of the community structure feature of generalist predators; (2) what role secondary crops (such as various vegetables, fruit trees) as well as non-crop habitats play in supporting various generalist predators in terms of predator diversity and community structure; and (3) how these effects varied at different spatial scales.

2. Materials and methods

2.1. Study sites and distribution

Generalist predator abundance and community structure were determined for 49 agricultural sites across four geographical regions (Langfang City of Hebei Province, and Wuqing, Jinghai and Ninghe Cities in Tianjin Province) from 2013 to 2016. The study sites covered more than 600 km^2 in the main cotton producing regions of northern China (116°29′–117°37′E, 38°46′–39°36′N), and each study site was centered around a Bt cotton field. Sites were separated by at least 4 km to minimize the disturbance from adjacent sites (Fig. S1).

2.2. Monitoring predator abundance

Study sites were selected to cover a wide range of landscape complexity and to have various land cover ratios of crop and non-crop habitats within a 2 km radius around each focal field (each focal field had a minimum area of 3000 m^2). The study was conducted from the middle of July to late August during the flowering and boll periods of cotton when generalist predators in the Bt cotton ecosystem predate on cotton pests (Ali et al., 2016). In each focal field, three plots, each 300 m^2 area (10 m × 30 m), were randomly selected for monitoring predator abundance and determining predator community structure, which was conducted three times at seven-day intervals for each sampling period. The plots were at least 10 m from the field boundary to reduce any interaction with adjacent plots and edge effects. The abundance (population density) of each vegetation-dwelling predator taxa (including larvae and adults of lady beetles, lacewings, hoverflies, *Orius* spp. and spiders) on 50 cotton plants was determined in each plot employing a “Z” sampling pattern, and each potential morphospecies was sampled and placed in a 2-ml centrifuge tube with 75% ethanol and carried to the laboratory. Species were identified to at least of the family level. All focal fields were Bt cotton fields that had similar agronomic management, and participating farmers were compensated for any yield losses they experienced from not spraying insecticides during the study period.

2.3. Community structure feature of predators

We calculated three common ecological community indexes to indicate the community structure of the predators: the species diversity index (Shannon-Wiener index, *H′*), species evenness index (Pielou's index, *J*), and dominant species concentration index (Simpson, *C*). These indexes are commonly used to define the community structure of arthropods in ecosystems. Equations for these community indexes are as follows:

Species diversity index (*H′*) was computed using the Shannon-Wiener information function (Shannon et al., 1949):

$$H^{'} = |\Sigma\ P_i \times \ln P_i$$

The species evenness index was computed using Pielou's evenness index (*J*) based on Pielou (1966):

$$J = \frac{H^{'}}{In\ S}$$

The dominant species concentration index (*C*) was computed following by Simpson (1949):

$$C = \Sigma\ P_i^2$$

P_i is the proportion of the *i*th species in all predator population, $P_i = N_i/N$, N_i is the number individuals of a predator species *i*, *N* is the number of individuals for all predator species, *ln* is the natural logarithm, and *S* is the richness of all predator species.