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Landscape diversity enhances parasitism of cotton bollworm (*Helicoverpa armigera*) eggs by *Trichogramma chilonis* in cotton

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HIGHLIGHTS

- Influence of land use on parasitism of *Helicoverpa armigera* eggs was investigated.
- *Trichogramma chilonis* was the only parasitoid found in cotton.
- Landscape diversity enhances the parasitism.
- A high proportion of urban habitats and water increases the biocontrol services.

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ABSTRACT

We studied the effects of landscape composition and diversity on parasitism of *Helicoverpa armigera* eggs (Noctuidae: Lepidoptera) by *Trichogramma spp.* (Hymenoptera: Trichogrammatidae) in cotton fields in northern China. Sentinel eggs of *H. armigera* were exposed to parasitoids for a 48 h time periods in experiments conducted in 2012–2013, resulting in parasitism rates ranging from 0 to 38.8%. *Trichogramma chilonis* was the sole species of parasitoid wasp found in parasitized *H. armigera* eggs during the study period. Using open-access satellite imagery from Google earth, we classified the proportion of the landscape surrounding each field at radii of 0.5, 1.0, 1.5 and 2.0 km. Landscape variables were first analyzed using principal component analysis (PCA), and then general linear models containing all combinations of principal components 1–3 (PC1–3) and landscape diversity measured using Simpson's Diversity Index (*D*) were compared using an adjusted Akaike's Information Criterion (AICc). We found that the best fit model to explain detected variation in *H. armigera* egg parasitism varied by spatial scale. Parasitism rates were best predicted at 2.0 km indicating that parasitoids are interacting with the surrounding habitats at a relatively large spatial scale. At this scale the PC2 + PC3 model had the lowest AICc value. Parasitism rates were significantly positively correlated with PC3, indicating that high proportion of urban areas and water within the landscape at a 2.0 km scale leads to higher parasitism rates in cotton fields, whereas landscapes dominated by cotton and maize led to low rates of parasitism within a given cotton field. A non-significant negative correlation with PC2 was found. The landscape diversity (*D*) model had the lowest AICc values at spatial scales of 0.5–1 km and *D* + PC3 was the best fit model at 1.5 km. Cotton fields within diverse landscapes with a high proportion of urban habitats and water resulted greater parasitism of *H. armegera* than those embedded in agriculturally dominated landscapes. This study provides a primary understanding of the relationship between landscape variables and ecosystem services for insect pest management in Chinese small farming systems.

1. Introduction

Agricultural intensification has resulted in major landscape simplification, with a loss of non-crop habitat and a greater reliance on chemical pesticides to manage crop pests (Cardinale et al., 2006; Rundlöf et al., 2009; Crowder et al., 2010; Power et al., 2012; Crowder and Harwood, 2014). These changes have resulted in declines in biodiversity and associated ecosystem services, including those supported by beneficial arthropods. Efforts to mitigate these and other negative effects of modern agricultural production have led to adoption of management schemes which in

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part aim to support these arthropod-mediated ecosystem services (Concepción et al., 2008; Isaacs et al., 2009; Crowder et al., 2010).

Within an agricultural landscape, natural enemies and the biocontrol services derived from their activity are influenced by the abundance of target and alternative prey, supplemental food resources (e.g., pollen and nectar), and access to suitable overwintering habitat (Isaacs et al., 2009). The availability of these resources can be mediated by both localized farm management as well as the composition and configuration of the surrounding landscape (Baggen and Gurr, 1998; Lee and Heimpel, 2005; Isaacs et al., 2009; Pease and Zalom, 2010; Batary et al., 2011; Concepcion et al., 2012; Rodriguez-Saona et al., 2012). A lack of surrounding non-crop habitats such as hedgerows, forest fragments and uncultivated field margins make it difficult for natural enemies to recolonize fields, even if managed in a compatible way to support these organisms (Ostman et al., 2001; Roschewitz et al., 2005; Tscharntke et al., 2007; Gardiner et al., 2009; Grez et al., 2014; Plecas et al., 2014). Several studies have demonstrated that landscape diversity, especially when achieved through the presence of non-crop habitats, can significantly enhance the biocontrol services provided by natural enemies (Thies et al., 2003; Roschewitz et al., 2005; Gardiner et al., 2009). However, fields surrounded by diverse versus simplified landscapes do not always benefit from a greater diversity and abundance of natural enemies or enhanced biocontrol service (Menalled et al., 1999; Caballero-López et al., 2012). This lack of a consistency makes pest and cropping system-specific investigation necessary to advance conservation biological control as part of sustainable pest management.

To date the majority of studies quantifying landscape-scale influences on beneficial arthropods and ecosystem services have been conducted in the United States and European countries (Marino et al., 2006; Landis et al., 2008; Thies et al., 2011). Yet within recent decades improving access to GIS technology for landscape pattern analysis (Bender et al., 2005; Steiniger and Hay, 2009; Chisholm et al., 2014) has allowed for rapid growth in the quantification of landscape properties and assessment of their impacts on arthropod-mediated ecosystem services worldwide (Grez et al., 2014; Midega et al., 2014; Xie and An, 2014). In China, growers typically manage very small farms averaging less than 0.6 hectares (CNSB 2005). These farms encompass many small fields with a diverse complex of crops (including cereals, vegetables, fruits and oils) produced within a single farm (Zhou et al., 2014). However, the agricultural landscape in China is rapidly changing. Northern China is one of the largest cropping regions in the country, supplying about 25%, 60% and 30% of the country's cotton, wheat and maize, respectively (CNSB 2014). During the last several years, maize production has drastically grown and the cultivated areas of cotton, sorghum, millet and beans have been greatly reduced (http://www.zzys.moa.gov.cn/). Currently, many agricultural landscapes in northern China are dominated by maize production. Urbanization and agricultural intensification have resulted in landscape simplification and the loss of non-crop habitat within this region. To date, few studies have examined the effects of the landscape diversity and its change on the population of natural enemies and the effectiveness of their biological control within the dynamic landscapes of northern China (Zhou et al., 2014).

Cotton bollworm, *H. armigera* (Hübner) (Noctuidae: Lepidoptera), is an important insect pest of cotton, maize, peanut, soybean and vegetable crops in northern China, and *Trichogramma spp.* (Hymenoptera: Trichogrammatidae), mainly *T. chilonis*, comprise the primary group of wasps that parasitize its eggs (Guo, 1998). Chemical control became the dominate means to control the cotton bollworm in China, with application rates exceeding 20 sprays per year in many fields by the 1990s resulting in significant resistance being detected within *H. armigera* and other cotton pests (Wu and Guo, 2005). A dramatic rise in the use of cotton genetically modified to contain the *Bacillus thuringiensis* (Bt) toxin Cry1Ac in China has dramatically suppressed *H. armigera* population and decreased conventional broad-spectrum insecticide use (Wu et al., 2008; Lu et al., 2010, 2012); however, this technology is not a panacea. The increasing frequency of Cry1Ac resistance genes has been found in *H. armigera* field populations in China (Li et al., 2007; Zhang et al., 2012; Jin et al., 2015), again illustrates the need for an integrated control strategy for this pest within both transgenic and conventional cotton that includes conservation biological control.

Given the dramatic change in both the composition and management of agricultural landscapes in northern China, our study aimed to understand whether landscape structure and diversity altered the biological control of *H. armigera* within cotton fields. We focused on measuring parasitism rates of the egg stage by *Trichogramma spp.* and predicted that *H. armigera* egg parasitism within cotton fields would (1) increase with increasing landscape diversity; (2) increase with the percentage of non-crop habitat and (3) decrease with the percentage of dominate host crops (cotton and maize) present.

2. Methods and materials

2.1. Rearing of egg masses

To establish a laboratory colony, adult *H. armigera* were collected at night using artificial lights at the Langfang Experimental Station (Institute of Plant Protection of the Chinese Academy of Agricultural Sciences, Hebei province, China). The moths were maintained at 25 ± 1 °C, 60 ± 10% RH and 16:8 h (L:D). Larvae were reared on an artificial diet, the main components of which were wheat germ, casein and sucrose, and the adult moths were given a 20% honey solution after emergence (Liang et al., 1999).

In the laboratory, female adults of *H. armigera* prefer to lay eggs on gauze, providing an easy method of egg collection (Liang et al., 1999). When moths were ready to begin oviposition, a new piece of gauze was placed over an oviposition cage containing female adults at 18:00 h. The next morning (6:00 h) we collected the gauze with *H. armigera* eggs attached. The "egg gauze" was cut into small pieces (approximately 3 cm wide and 5 cm long), and any flat eggs (i.e., unfertilized eggs) were removed using an insect pin under a stereomicroscope ("XTZ-A" type, Shanghai Optical Instrument Factory, Shanghai, China). After removal each piece of egg gauze contained 50–100 eggs; these eggs were used in field studies within 4 h of collection (8:00–12:00 h).

2.2. Field sites

All field sites were distributed around the city of Langfang in Hebei province, and the cities of Wuqing and Jinghai in the Tianjin province of northern China, where all cotton crops were Bt cotton. We chose 23 sites (12 sites in 2012, and 11 sites in 2013) along a gradient of landscape diversity. Within each year, a minimum distance of 5 km separated each field site (Fig. 1). Experiments were conducted from middle July–August, when the 3rd and 4th generations of *H. armigera* occurred and usually had high population level.

2.3. Experimental design

In the center of each commercial cotton field, a plot that ranged from 3000 to 10,000 m^2 was established. We selected this area in order to reduce the disturbance of boundary habitats adjoining the study field. Within this plot a total of 10 cotton plants were