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Crop spatiotemporal dominance is a better predictor of pest and predator abundance than traditional partial approaches

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ABSTRACT

Landscape-scale agricultural intensification can concentrate pest resources (high host density) and impede natural enemy populations through a reduction in non-crop resources or disturbance events. Current approaches examine the impacts of crop dominance on pest pressure through a simple lens, either spatially (i.e. landscape complexity), or temporally (i.e. diversity of crop rotation schedules). However, these partial approaches are inadequate because they do not take into account the impact of multiple years of non-rotation, or the impacts of the surrounding landscape, respectively. In this study, we use a unique method that allows land use in both space and time to be quantified simultaneously with a single metric, "spatiotemporal dominance". We examined the impact of spatiotemporal dominance of sweet corn on populations of a key insect pest, *Ostrinia nubilalis*, and its potential predators. Additionally, we evaluated site-specific variables such as crop rotation, percent agriculture in the landscape, cover crop use, and frequency of insecticide applications, to determine their relative importance in predicting pest pressure, alongside our metric of spatiotemporal crop dominance in the landscape. *Ostrinia nubilalis* adult abundance was positively associated with spatiotemporal dominance of sweet corn in the landscape (space and time) and high proportional agricultural land use (space), but was unrelated to the previous year's crop (time). Predatory soldier beetle abundance was negatively associated with sweet corn spatiotemporal dominance (space and time), but not associated with the previous year's crop (time) nor percent agricultural land use (space). Our contrasting results between the new spatiotemporal dominance metric and either crop rotation history or percent agricultural land use or both emphasized that the new method predicts impacts of agricultural intensification on arthropods that were not captured by traditional techniques. In general, pest populations were more abundant in areas with high host dominance, whereas certain predators were less abundant when high disturbance management practices were used (e.g. no cover crop, high insecticide use). Therefore, quantifying spatiotemporal crop dominance refines and strengthens our ability to implicate intense agricultural land use in creating high pest pressure situations through simultaneous bottom-up and top-down effects.

1. Introduction

Agriculture can substantially affect communities of arthropod pests and their natural enemies by altering resource concentrations and creating disturbance events. In simplified agricultural landscapes, where there are few habitat types beyond the homogenous agroecosystem, arthropod pests often benefit from a high concentration of suitable hosts (i.e., the crop) in space and time (Root, 1973). This can result in higher populations of some pests (Meehan et al., 2011; O'Rourke and Jones, 2011; O'Rourke et al., 2011) and lead to increased insecticide use (Meehan et al., 2011; O'Rourke and Jones, 2011) and, consequently, insecticide resistance development (Huseth et al., 2015).

Natural enemy populations are often compromised in intensified agricultural landscapes due to disturbance (e.g. tillage, pesticide use) and the lack of refuge and resource diversity provided by nearby non-crop habitat (Tscharntke et al., 2005; Bianchi et al., 2006; Chaplin-Kramer et al., 2011). Pesticides often have negative non-target impacts on natural enemies, resulting in direct mortality or sub-lethal effects that reduce reproduction or predation efficiency (Croft, 1990a; Desneux et al., 2007; Biondi et al., 2012; Mills et al., 2016). Cover crops and perennial non-crop habitat can provide floral resources and shelter to natural enemies (Landis et al., 2000), which can increase their populations and improve pest management (Orr et al., 1997; Tillman et al., 2004; Prasifka et al., 2006; Pullaro et al., 2006; Schmidt et al., 2007; Jackson and Harrison, 2008; Lundgren and Fergen, 2010). Relaxed top-down pressure from natural enemy populations in simplified

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agricultural landscapes can further exacerbate pest problems. However, impacts of landscape simplification on natural enemies do not always translate into changes in pest abundance or crop yield (Bianchi et al., 2006; Chaplin-Kramer et al., 2011; Perez et al., 2018).

Landscape simplification is often estimated using the amount of agricultural or non-agricultural land within a given radius (Chaplin-Kramer et al., 2011). Less frequently, the amount of a *particular* crop species is used to predict arthropod abundance (O'Rourke et al., 2011; Huseth et al., 2015). Crop dominance can also impact arthropod populations via temporal channels, depending on the diversity of crop rotation schedules (Davis et al., 2012; Rusch et al., 2013; Huseth et al., 2015). While it is clear that agricultural intensity has both temporal and spatial components, few studies simultaneously quantify their impacts on pest and predator populations (Huseth et al., 2015; Schmidt-Jeffris et al., 2016). The new metric used in these studies sums the area planted to the crop of choice within a buffer for a selected number of prior years and divides this amount by the area planted to the crop of choice in any year prior to the study. New metrics that account for both spatial and temporal aspects of crop intensity may improve our ability to predict locations of pest outbreaks, but we still lack adequate field data to reliably apply these tools. We sought to fill this gap by examining the system of processing sweet corn, an important pest, *Ostrinia nubilalis* (Hübner) (Lepidoptera: Pyralidae), and its predators through the lens of a spatiotemporal dominance metric.

Ostrinia nubilalis, European corn borer, is a generalist pest that preferentially attacks corn (Hudon et al., 1989; O'Rourke et al., 2010). The caterpillar stage is highly susceptible to genetically modified corn varieties containing *Bacillus thuringiensis* (*Bt*) proteins (Hutchison et al., 2010). Increased adoption of *Bt* corn has been attributed to the dramatic decline of *O. nubilalis* damage in field corn and vegetable crops (Hutchison et al., 2010; Bohnenblust et al., 2014; Schmidt-Jeffris et al., 2016; Dively et al., 2018). Sweet corn grown for the processing industry does not contain the *Bt* trait, enabling it to be sold to international markets that have low consumer acceptance of genetically modified crops. Because this sweet corn is *Bt*-free, *O. nubilalis* and other caterpillar pests are managed with foliar insecticides, primarily broad-spectrum pyrethroids. While pyrethroid use generally has been effective in managing *O. nubilalis*, there are logistical challenges of making well-timed insecticide applications against caterpillars in corn (Buntin, 2008), and situations exist where economically damaging infestations still occur. Therefore, *O. nubilalis* infestations may be locally concentrated in areas where processing sweet corn has high spatiotemporal dominance in the landscape, especially because of its short dispersal distance (Merrill et al., 2013) and propensity to overwinter in or near corn fields (Hudon et al., 1989). Moreover, because crops with *Bt* traits are less disruptive to natural enemies than broad-spectrum insecticide applications (Musser and Shelton, 2003; Naranjo, 2005), areas where processing sweet corn is spatiotemporally dominant also may have lower abundances of predators.

Pest pressure might be expected to increase where processing sweet corn is dominant via bottom up processes (high host density in space and time) and top-down processes (compromised predator populations due to increased insecticide use and low resource diversity). Altogether, patchy spatiotemporal matrices of susceptible and *Bt* crops will interact with local management tactics (pesticide use, refuge availability) to shape pest pressure and natural suppression. Increased understanding of these interactions will allow for prediction of pest outbreaks and improved protection of natural pest control services, which could be applied to other systems.

The objective of this study was to compare the results attained with our spatiotemporal dominance metric with results attained by using more traditional, one-dimensional methods to estimate agricultural intensity. We predicted that the spatiotemporal dominance metric would better describe arthropod abundance compared with either spatial or temporal metrics alone. This was done by determining the impact of processing sweet corn's spatiotemporal dominance on the abundance of *O. nubilalis* and its potential predators in processing sweet corn fields. We also hypothesized that areas with high processing sweet corn spatiotemporal dominance would have higher *O. nubilalis* abundance and lower abundance of predators, due to a concentration of bottom-up resources (i.e., host abundance in space and time) and relaxed top-down control caused by insecticide applications, respectively. Additionally, we identified certain production practices that might disturb or conserve the predator community.

2. Methods

2.1. Field sites and landscape analysis

The single sweet corn processing company in New York provided detailed information about the location and cropping history of all their contracted sweet corn fields since 2010. Locations of all fields were given as polygon shape files and GPS coordinates. This information was used to classify annual landscape use within New York as either processing sweet corn or not. Using QGIS (QGIS, 2015), a 1000 m radius buffer was created around the point representing each processing sweet corn field. The processing sweet corn dominance metric (PSCDM) was calculated for the area within each buffer. This is a metric adopted from previous studies that quantified spatiotemporal crop planting intensities (Huseth et al., 2015; Schmidt-Jeffris et al., 2016). Briefly, the metric is defined as:

$$PSCDM = \frac{\sum_{i=1}^{j} T_i}{Processing\ sweet\ corn\ area_i}$$

where i is a year prior to the study and j is every consecutive year prior to i. T_i is the total area of processing sweet corn within the buffer for each of the years prior to insect sampling. Therefore, this area is summed through all years prior to the study (starting with 2010, the first year the data were available). *Processing sweet corn area*$_i$ is the total area planted to processing sweet corn in any year prior to the study. Higher PSCDM scores indicate higher dominance of processing sweet corn in time and space for that particular area. In cases where a location had never had part of its area planted to processing sweet corn, *Processing sweet corn area*$_i$ would equal zero, causing a divide by zero error. For these buffers, the PSCDM was manually entered as "0".

From all possible processing sweet corn fields to monitor in a given year, only those within the top and bottom 25% of PSCDM scores were selected to be sampled for arthropods. These sites were classified as "high" and "low" for the dominance metric, respectively. From this pool of "high" and "low" PSCDM fields, 17 high and 17 low sites were sampled in 2015 and 15 high and 11 low sites were sampled in 2016 (Fig. 1). Site locations were chosen to minimize overlap between buffers. However, most locations with a high PSCDM score were clustered in one general region (Fig. 1). This area is repeatedly planted to processing sweet corn, presumably because of its proximity to the processing facility. Fewer sites were used in 2016 because insect damage and drought caused many fields to be abandoned early in the season, resulting in a discontinuation of typical production and management practices. Sites where the crop was not harvested were then excluded from the analysis.

Processing sweet corn fields monitored in this study were planted from 1 May to 7 July 2015 and 12 May to 30 June 2016, which is within the typical timeframe for plantings in New York. The processor also provided additional information about field management and production, including whether or not a cover crop preceded the sweet corn crop, type of cover crop, and the number of insecticide applications applied to the sweet corn crop. Previous crop (processing sweet corn or not) is captured by the PSCDM, but the metric extends beyond just the previous year and also accounts for spatial dominance.