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Landscape composition influences pollinators and pollination services in perennial biofuel plantings

Ashley B. Bennett*, Rufus Isaacs

Department of Entomology and Great Lakes Bioenergy Research Center, Michigan State University, 578 Wilson Road, East Lansing, MI 48824, United States

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ABSTRACT

Biofuel cropping systems are considered a potential source of renewable energy and an integral component of a sustainable energy policy. The type of biofuel crop selected for production has the capacity to substantially alter landscape composition, affecting biodiversity conservation and ecosystem services. To understand how increasing production of perennial grasses for biofuels may affect pollinators and pollination services, we identified 20 agricultural fields that varied in their proportion of surrounding grassland cover. Bees and pollination services were measured at each site to determine how bee abundance, diversity, and community composition responded to increasing proportions of grassland, and to quantify how pollination services changed as the proportion of grassland increased in the landscape. Bees were collected from sentinel sunflowers, and pollination services were measured by comparing seed set from open and closed sunflowers at each site. Landscape composition had a significant effect on bee abundance, diversity, and community composition with a greater abundance of bees and a more diverse bee community found visiting flowers at sites with more of the surrounding landscape in perennial grassland. In contrast, the bee community in low grassland sites was dominated by *Apis mellifera*, suggesting that pollination in these landscapes may be more sensitive to declines in this species. Despite these differences, the level of sunflower pollination was similar across sites, even though the bee community responded to changes in landscape composition. Increasing grassland cover through the addition of perennial biofuel plantings would be expected to support a more diverse bee community and a greater abundance of bees, yielding reliable pollination services.

1. Introduction

Biofuel cropping systems are one alternative to non-renewable energy sources and are seen as an integral component of a sustainable energy policy. In the United States, an annual target of 35 billion gallons of ethanol by 2022 has been proposed, including a mandate that 57% of this capacity come from renewable fuels such as bioenergy crops (Tyner, 2008). Annual crops such as corn and perennial crops such as mixed grasslands are being investigated as potential bioenergy crops. Large scale changes in land cover are a potential consequence of future expansion of bioenergy crop production, which may have significant impacts on biodiversity. As a result, biofuel production systems are being compared for their ability to produce biomass while also conserving biodiversity and the provision of multiple ecosystem services (James et al., 2010; Landis and Werling, 2010; Wu et al., 2012; Jarchow and Liebman, 2012).

Incorporating perennial biofuel crops such as native grasslands into agricultural landscapes has the potential for significant effects on biodiversity and the ecosystem services provided to agricultural systems. Empirical studies have consistently found that increasing plant diversity positively impacts arthropod diversity (Siemann et al., 1998; Knops et al., 1999; Koricheva et al., 2000; Scherber et al., 2010), and recent research on biofuel cropping systems also revealed that annual and perennial biofuel crops differentially support beneficial arthropods (Werling et al., 2011). In particular, the abundance and diversity of pollinators were higher in perennial biofuel crops (e.g. prairie and switchgrass) compared to the annual bioenergy crop corn (Gardiner et al., 2010). Developing bioenergy cropping systems that are productive yet support diverse pollinator communities may offer a strategy for energy production that concurrently conserves biodiversity and promotes ecosystem services that are valuable to agricultural and semi-natural landscapes. In agricultural landscapes across the United States, crop pollination is valued at $3 billion per year (Losey and Vaughan, 2006), while

* Corresponding author. Tel.: +1 517 432 9554.
E-mail address: abb@msu.edu (A.B. Bennett).

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globally approximately 87% of flowering plants rely on pollination for fruit and seed set (Ollerton et al., 2011). Although the value of pollination services provided to natural systems has yet to be quantified, it is expected to exceed the value provided to agricultural systems (LeBuhn et al., 2013).

The selection of bioenergy crops for expanded production has the potential to affect pollinators by modifying the diversity and composition of agricultural landscapes. At the local (field) scale, bioenergy crops in the Upper Midwest region of the United States will range from monocultures of annual crops, such as corn, to diverse mixtures of perennial grasses and forbs. The selection of bioenergy crops will substantially affect plant diversity at local scales, influencing the availability of pollen, nectar, and nesting habitat which are primary drivers of pollinator abundance and diversity (Holzschuh et al., 2011; Stanley and Stout, 2013; Nicholls and Altieri, 2013). At larger spatial scales, the addition of bioenergy crops will also change landscape composition. Rising corn prices have recently spurred the conversion of marginal lands into annual bioenergy crops such as corn, which has expanded monoculture plantings and lowered landscape diversity (Wright and Wimberly, 2013). In contrast, adding diverse perennial grassland mixtures could increase landscape diversity and augment the amount of semi-natural habitat needed to support beneficial organisms. Agricultural systems with higher proportions of semi-natural habitat and greater diversity of land use are positively correlated with bee abundance and diversity (Holzschuh et al., 2007; Klein et al., 2012; Kennedy et al., 2013). Furthermore, the proportion of semi-natural habitat in the landscape surrounding pollinator-dependent crops seems integral to maximizing pollination due to the food and nesting resources available to support native bee populations (Winfree et al., 2007; Klein et al., 2012; Holzschuh et al., 2012). These results suggest that diverse perennial bioenergy cropping systems have the potential to facilitate pollinator conservation and increase pollination services across broad spatial scales.

Understanding how the expansion of different biofuel cropping systems will shape landscape composition and subsequently affect biodiversity and ecosystem services will be critical to developing a sustainable bioenergy policy. Our aim in this research was to determine whether pollinators and pollination services vary in response to the amount of perennial grasslands in the surrounding landscape. We selected 20 agricultural fields along a gradient of low to high amounts of perennial grassland in the surrounding landscape to sample bees and measure pollination services. We predicted that (1) bee abundance and diversity would be positively correlated with the amount of perennial grassland, (2) bee community composition would change across the gradient of low to high grassland cover, and (3) pollination services would increase as the proportion of grassland increased in the landscape surrounding fields.

2. Methods

2.1. Study sites

To measure the effect of landscape composition on bees and pollination services, we identified 20 soybean fields in Michigan, USA that varied in their proportions of surrounding perennial grassland and were at least 3 km apart (Fig. 1). Soybean fields were used as study sites because they occur in various landscape contexts, and the soybean crop, a monoculture intensively managed for weeds, limits variability (e.g. plant diversity, management practices) at the field scale. In addition, the soybean plant has self-pollinating flowers, meaning it does not require insect pollination but visitation by bees can improve yield (Free, 1993; Milfont et al., 2013). A preliminary analysis of landscape variables was performed at 500 m, 1000 m, 1500 m, and 2000 m, and the strongest response

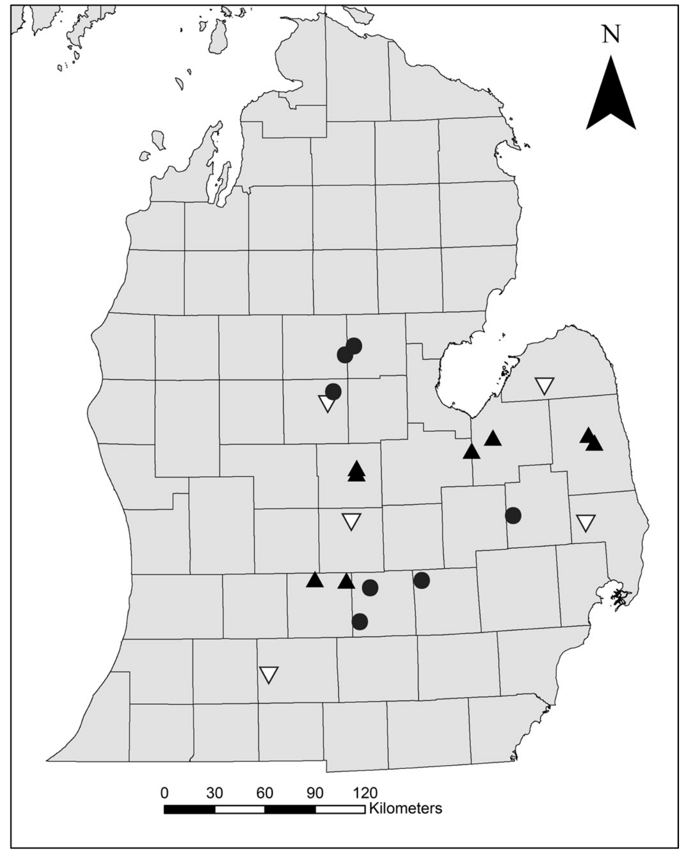

Fig. 1. Location of the 20 Michigan soybean fields used to sample bees and measure pollination services. Symbols represent the proportion of grassland measured in the 1500 m surround study sites (circles—high grassland cover; hollow triangles—intermediate grassland cover; solid triangles—low grassland cover).

to landscape variables was found for the 1500 m scale. The 2012 cropland data layer (CDL, 30 m resolution) was used to characterize the area of annual and perennial habitats within a 1500 m radius of each site (USDA, 2013). Research examining the effect of landscape composition on bees often combines semi-natural area into one variable (Kennedy et al., 2013, but see Woodcock et al., 2013; Le Feon et al., 2010, 2013). Because we were interested in the effect of increasing perennial grassland biofuel crops on bees, natural area was classified separately as either grassland or forest, allowing the relative importance of these variables to be determined. The CDL was reclassified prior to analysis to include the original cropland classes in addition to classes for grassland (combined areas of clover, pasture, hayfields, shrubland, and perennial grasslands), forest (deciduous, coniferous, and mixed forest combined) and urban (open, low, moderate, and high intensity urban combined). The classes included in the grassland category were not under biofuel production but served as a surrogate for what would be expected if perennial biofuel production was expanded across Michigan. The classes included in the grassland variable were combined because each represents a perennial habitat that contains floral resources and experiences few agricultural disturbances, making the nesting and food resources similar across classes. After reclassification, we used ArcGIS 10.0 to create 1500 m buffers around the center of each site. The "Calculate Area" tool was then used to determine the proportion of grassland, forest, urban, and crops within each buffer. In addition to calculating land cover percentages, we also quantified landscape diversity represented by Simpson's diversity for the 1500 m surrounding sites using the reclassified layer (McGarigal et al., 2012).