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Farm and landscape factors interact to affect the supply of pollination services

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ABSTRACT

Farms can harbor substantial biodiversity, which in turn sustains the supply of ecosystem services. The effectiveness of farm management to enhance biodiversity, however, may be modified by land cover in the surrounding landscape beyond a farmer's direct control. We examined how landscape pattern and farm management affect the abundance and diversity of native bees visiting highbush blueberry in Vermont, USA. We quantified landscape pattern at multiple scales and created an agricultural intensity index that represents farm management practices such as pesticide use, mowed and grain crop area. We observed native bee visitation to assess the supply of pollination service provided to blueberry growers. Across 15 farms, 84 wild bee species were observed visiting highbush blueberry, almost a third of bee species recorded in Vermont. Visitation rate, abundance and species richness increased with the amount of natural area surrounding farms. Less intensively managed farms had higher levels of bee visitation, abundance and a more diverse bee community. Bee communities and the pollination services they provide are influenced by interactions between local management and landscape pattern. In particular, intensive farm management appears to compound the negative effects of landscape simplification. To support native pollinators on their farms, growers should consider farming approaches in the context of the broader landscape.

1. Introduction

Animal-mediated pollination is an important ecosystem service that regulates crop production and quality (Kennedy et al., 2013; Klatt et al., 2014). Pollinator-dependent crops contribute significantly to the global supply of micronutrients (Chaplin-Kramer et al., 2014; Ellis et al., 2015) and are critical to agricultural economies (Klein et al., 2007). Reliance on pollinators is particularly evident in smallholder agriculture, which are susceptible to yield gaps when pollinator densities are low (Garibaldi et al., 2016).

As the demand for agricultural pollination services surges (Aizen and Harder, 2009; Koh et al., 2016), wild pollinator visitation is expected to safeguard against yield limitations (Garibaldi et al., 2013). Although European honeybees *Apis mellifera* L. are frequently employed as crop pollinators, hive failure is increasingly common and managed populations of this pollinator have declined in recent decades (Lee et al., 2015; Neumann and Carreck, 2010). Native bee communities can complement the activity of honey bees and ensure adequate pollination for many economically important crops (Benjamin et al., 2014; Klein, 2009; Kremen et al., 2002). In many cases, native bees are more efficient pollinators because they visit a greater number of flowers per unit time and transfer more pollen per visit. For example, when compared to honeybees pollinating blueberry, native bees have greater visitation rates and deposit more pollen per flower visit (Javorek et al., 2002). Diverse native bee communities are also active over a range of climate (Rader et al., 2013) and temporal scales (Bartomeus et al., 2011), and therefore provide insurance against single species loss (Winfree et al., 2007).

Agriculture disrupts native bee populations at multiple scales through drivers such as habitat degradation, farm management, pathogens and climate change (Goulson and Hughes, 2015; Potts et al., 2010). At broader scales, altered landscape pattern (i.e. changes in the composition and/or configuration of habitat patches) restricts the temporal and spatial distribution of foraging, nesting and overwintering sites (Kremen et al., 2007). Research into landscape pattern effects on pollinators has focused on the importance of habitat composition (i.e. the number and abundance of habitat patches), and to a lesser extent habitat configuration (i.e. the spatial arrangement of habitat patches) (Kennedy et al., 2013). As central place foragers, the amount and proximity of resource patches affects native bee populations and

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regulates ecosystem service supply, with crop visitation rates declining steeply as farms become more isolated from natural habitats (Ricketts et al., 2008). Changes in landscape pattern can also alter landscape-wide bee species pools, with clear benefits to crop pollination for farms situated in areas with greater extent and proximity of natural habitat (Garibaldi et al., 2011).

At local scales, differences in management can influence the delivery of pollination services to crops. Intensive practices that focus on a few crop species and their specific requirements often leads to input-intensive agriculture (e.g. fertilizer input, pesticide application, habitat simplification and decreased crop diversity) (Tscharntke et al., 2005). Less-intensive management practices, such as organic farming or increasing crop-non-crop heterogeneity, can improve pollinator abundance and richness (Boreux et al., 2013; Kennedy et al., 2013; Kremen and Miles, 2012). Management practices can drive variation in bee communities that translate into differences in pollination services provided to crops. For example, canola seed set was on average 3 to 6 times lower on conventional and herbicide-resistant fields than in organic fields, and this reduced seed set was strongly correlated with reduced abundance of native pollinators (Morandin and Winston, 2005).

Theoretical and empirical work shows that landscape pattern and farm management often interact to influence biodiversity (Batáry et al., 2011; Carvell et al., 2011; Concepción et al., 2012). The intermediate landscape-complexity hypothesis predicts that less-intensive farm management will have the greatest positive effect on farmland biodiversity in simple landscapes, but less so for farms in spatially complex regions, because these farms already have abundant and diverse species pools (Tscharntke et al., 2012, 2005). This pattern holds for many taxa: landscape pattern can determine how strongly farm management affects the diversity of bees (Holzschuh et al., 2007), butterflies (Rundlöf et al., 2008) and spiders (Schmidt et al., 2005). Recent meta-analyses have found that agri-environment practices had the greatest effect on the species richness of multiple taxa (e.g. plants, birds, herbivores, pollinators) in landscapes with low levels of intact natural area (Batáry et al., 2011; Lichtenberg et al., 2017).

The effects of management decisions on biodiversity are clearly context-dependent, but few studies have investigated the resulting effects on ecosystem services (ES). As the biophysical and social conditions by which people obtain benefits from ecosystems, these services can be quantified in terms of supply and benefit. Evaluating ES supply typically involves measuring the presence of species, ecosystems, or ecological processes that contribute to human livelihoods, whereas evaluating ES benefit also involves demand for services, as determined by social and economic factors (Mitchell et al., 2015; Villamagna et al., 2013). For example, crop pollination can be measured as bee visits to crop flowers (supply) or as changes in the value of crop production (benefit) (Ricketts et al., 2016). Ecosystem service supply and benefit are often related; for pollination, increased visitation is known to be associated with improved production across crops and growing regions (Garibaldi et al., 2013).

Here we use crop pollination to examine how landscape pattern interacts with farm management to affect biodiversity and the supply of an ecosystem service. We focus on wild, native bees visiting highbush blueberry (*Vaccinium corymbosum* L.), because pollination is critical to fruit production for this crop (Dogterom et al., 2000; Isaacs and Kirk 2010). We predict that native bee biodiversity and ecosystem service supply would be affected by both farm management and habitat composition and configuration, and that these factors interact, such that less-intensive management practices would have the greatest effect in simple landscapes. Rather than classify farms into simple binary categories (e.g. organic vs. conventional), we use an agricultural intensity index to better capture realistic gradients of management strategies. We use this index, combined with landscape data and observations of native bee pollination, to explore the following questions: (i) Do native bee communities respond to differences in landscape composition and configuration, and does this alter the supply of pollination services? (ii) Does farm management influence native bee communities and associated pollination services? (iii) Is the effect of farm management on bee communities and derived pollination services dependent on landscape pattern?

2. Methods

2.1. Study system

The Champlain Valley, Vermont, USA (44.45° N, 73.09° W) is an important agricultural region due to rich alluvial soils and a growing period extended by a nearby lake. Land cover in the region is spatially heterogeneous; residential exurban areas and small-scale agriculture are interspersed with second-growth forests dominated by maple (*Acer* spp.), birch (*Betula* spp.) and beech (*Fagus grandifolia*). Agriculture in the region is a mix of pastureland and grain production, along with smaller fruit and vegetable farms. Our study system consists of 15 highbush blueberry farms. None of these farms import honeybee hives for pollination, although a few (N = 3) have hives for honey production. Blueberry acreage on these farms ranges from < 0.5 ha to 3.6 ha with a median field size of 1.1 ha.

2.2. Agricultural intensity index

We quantified differences in farm management by creating an agricultural intensity index that included measures of pesticide use, mowed area and grain crop area. To quantify pesticide use across farms, we adapted the environmental impact quotient (Kovach et al., 1992) to develop a pesticide use index based on known impacts to bees. Pesticide use indices have been used with multiple arthropod taxa (Dormann et al., 2007) and this approach is well documented for native bees (Park et al., 2015). We obtained pesticide identity and use information directly from farmers for each managed crop, and if precise application rates were unknown we used the regionally suggested rates for each reported crop (New England Small Fruit Management Guide 2015–2016). We follow Park et al. (2015) by summing across all pesticides (fungicides, herbicides and insecticides) the product of the pesticide's (i) bee impact quotient (BIQ = pesticide toxicity ratings times the half-life on plant surfaces) (Kovach et al., 1992; Morse, 1989), (ii) percentage active ingredient in material sprayed and (iii) maximum application rate (quantity per acre of a given crop) (see Table A.2 for a list of pesticides recorded in this study). This provides a farm level index that is derived from a crop-specific, per-area calculation of the effects of a farm's pesticide application on bees, and thereby accounts for differences in crop area between farms. We provide measures in terms of acres, because it is the unit relevant to participating land managers. We further captured differences in agricultural intensity by quantifying the extent of grain crops (corn and soy) and mowed areas on and adjacent to study farms. These forms of land use are frequently disturbed, thereby limiting nesting sites, and offer little in terms of floral resources. Moreover, landscape-scale assessments report declines in native bee abundance associated with the conversion of natural habitats to row crops (Koh et al., 2016). We calculated the areal coverage of these two land uses within 300 m of each farm's blueberry crop because this scale encompasses the crop area of observed farms.

Rather than arbitrarily weight management variables based on perceived impact to bee populations, we scaled each variable from 0 to 1 and reduced these continuous variables through principle componen ts analysis (PCA). We use the first principle component score (45% of the overall variation), scaled from 0 to 1, as our agricultural intensity index (AII) (Fig A.1). While PCAs are useful for emphasizing variation and eliminating collinearity between dimensions, the resulting scores are unit-less and their biological relevance becomes abstract. We therefore compared AIIs between farms that self-reported as organic or conventional to ground truth our index. We found that our intensity index is associated with, albeit marginally, whether a farm is organic