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Land use in the Northern Great Plains region of the U.S. influences the survival and productivity of honey bee colonies

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ABSTRACT

The Northern Great Plains region of the US annually hosts a large portion of commercially managed U.S. honey bee colonies each summer. Changing land use patterns over the last several decades have contributed to declines in the availability of bee forage across the region, and the future sustainability of the region to support honey bee colonies is unclear. We examined the influence of varying land use on the survivorship and productivity of honey bee colonies located in six apiaries within the Northern Great Plains state of North Dakota, an area of intensive agriculture and high density of beekeeping operations. Land use surrounding the apiaries was quantified over three years, 2010–2012, and survival and productivity of honey bee colonies were determined in response to the amount of bee forage land within a 3.2-km radius of each apiary. The area of uncultivated forage land (including pasture, USDA conservation program fields, fallow land, flowering woody plants, grassland, hay land, and roadside ditches) exerted a positive impact on annual apiary survival and honey production. Taxonomic diversity of bee-collected pollen and pesticide residues contained therein varied seasonally among apiaries, but overall were not correlated to large-scale land use patterns or survival and honey production. The predominant flowering plants utilized by honey bee colonies for pollen were volunteer species present in unmanaged (for honey bees), and often ephemeral, lands; thus placing honey bee colonies in a precarious situation for acquiring forage and nutrients over the entire growing season. We discuss the implications for land management, conservation, and beekeeper site selection in the Northern Great Plains to adequately support honey bee colonies and insure long term security for pollinator-dependent crops across the entire country.

1. Introduction

The phenomenon of sustained and elevated annual losses of honey bee colonies continues to severely impact the US beekeeping industry (Steinhauer et al., 2014; Lee et al., 2015). Such losses have been mainly confined to North America and parts of Europe (NRC, 2007; vanEngelsdorp et al., 2008; Potts et al., 2010), and specifically, annual losses for commercial beekeepers in the US have hovered around 30% since 2006–07, with a low of 22% in 2011–12 and a high of 40% in 2012–13 (vanEngelsdorp et al., 2007, 2008, 2010, 2011, 2012; Spleen et al., 2013; Steinhauer et al., 2014; Lee et al., 2015). Numerous pests, diseases, and pesticides have been implicated in potentiating colony failure, both alone and in combination (Cox-Foster et al., 2007; vanEngelsdorp et al., 2009; vanEngelsdorp et al., 2013).

Because of these continued, and seemingly ubiquitous annual losses, more attention has turned toward how landscapes and land use influence factors related to colony health that may ultimately differentially impact the productivity and survival of honey bee colonies. For example, pollen is primarily required to raise brood and contribute to sustained colony population growth throughout the growing season, but critically, protein nutrition also moderates the impacts of honey bee pathogens, parasites, overall resistance and resilience to stress factors, and foraging behavior (Alaux et al., 2011; Huang, 2012; Scofield and Mattila, 2015). High quality and abundant pollen contributes to increased nutritional stores and an overall decreased (quieter) immune status in individual bees (Alaux et al., 2010; Smart et al., 2016). Further, honey bees

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maintained on a high quality pollen diet exhibit increased longevity when infected with a fungal parasite (Di Pasquale et al., 2013), and honey bees exhibit lower viral levels when maintained on pollen versus sugar syrup or pollen substitute (DeGrandi-Hoffman et al., 2010). The potential impacts of land use via differential nutrition are wide-ranging, including the effects of adequate and sustained floral resource availability and diversity and interactions with environmental pesticide exposure which may influence the nutrition, immune systems, and survival of honey bee colonies (e.g. Naug, 2009; Pettis et al., 2013; Smart et al., 2016).

The Northern Great Plains (NGP) region, including North Dakota, South Dakota, Montana, and Minnesota, has acted as an unofficial "bee refuge" for a large proportion of the managed, commercial honey bee colonies throughout the growing season. Colonies transported to this area of the country for the summer by migratory beekeepers have done well due, in large part, to the presence of an abundance of nectar and pollen-producing flowers. Historically, this region has had less extensive monocultural agriculture compared to regions farther south (e.g. the Midwestern corn belt). This region hosts around 1 million honey bee colonies from May-October every year, representing approximately 40% of the total US managed, commercial pool of honey bee colonies (USDA, 2014). Critical regional blooms include perennial clovers and alfalfa, canola, sunflowers, wildflowers, and, more broadly, contributions from volunteer plant species located in certain land use types such as livestock-grazed pastures and grasslands. Other important types of land use containing forbs are USDA conservation program fields, such as the Conservation Reserve Program (CRP), which is a government program incentivizing landowners to set aside highly-erodible and other sensitive lands into long term conservation covers (Gallant et al., 2014).

In recent years, increasing numbers of colonies have been transported to California to pollinate a single crop, almonds. The approximately 1 million bearing acres of almonds in CA are 100% dependent on the pollination that they receive from honey bees. Currently, approximately 1.5 million of the 2.5 million available colonies nationwide undertake the journey to the central valleys (San Joaquin and Sacramento) of California, many originating from the NGP.

Surprisingly, implications of land use on resource quality, honey bee health, and survival have been considered in relatively few (and recent) studies (e.g. Naug 2009; Odoux et al., 2012; Clermont et al., 2015; Requier et al., 2015; Smart et al., 2016). Other research has focused on spatial foraging patterns of honey bee colonies, and distances of various crops and land use features relative to colony position (e.g., Beekman and Ratnieks, 2000; Steffan-Dewenter and Kuhn, 2003; Couvillon et al., 2014). Recent studies tracking survival of colonies in US migratory beekeeping operations (e.g. Runckel et al., 2011; vanEngelsdorp et al., 2013) did not quantify the health and survival of colonies in relation to specific landscape patterns or features to which the colonies were exposed.

The overarching objective of this study was to quantify the relationship between land use composition and honey bee productivity and survival in the Northern Great Plains region of the US. We followed colonies positioned in six apiaries over three years and hypothesized that survival and honey production would be higher for apiary sites surrounded by a greater amount of land use in potential bee forage (uncultivated forage land, cultivated forage land, and wetlands, Fig. 1) due to a greater presence of nectar and pollen-producing forbs and woody plants in those areas of the landscape. Row crops did not dominate such areas and thus colonies were predicted to experience a greater abundance and diversity of floral resources and overall reduced exposure to agricultural pesticides. Our specific objectives were to (1) identify land use within the larger agricultural matrix associated with higher colony survival and productivity among apiary sites, (2) build a predictive statistical model relating land use to survival and honey production of apiaries, and (3) identify taxonomic origin of bee-collected pollen, identify pesticide residues within the pollen, and describe and compare overall pollen diversity among study sites against the backdrop of varying land use.

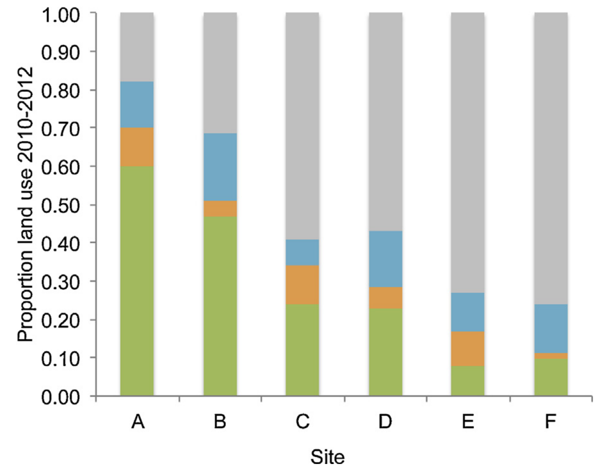

Fig. 1. Proportion of land use area within 3.2-km radius of each apiary, 2010–2012. Categories include (from bottom to top): (1) uncultivated forage land use: CRP, pasture, fallow, grassland, hay land, roadside ditch (green), (2) cultivated forage land use: canola, sunflower, alfalfa (orange), (3) wetlands (blue), and (4) non-forage: corn, soybeans, wheat, and oats (grey). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

2. Materials and methods

2.1. Land use assessments

For each of three years (2010–2012), land use in North Dakota was extensively surveyed on the ground within a 3.2-km (2-mile) radius around each of six sites (apiaries) (Fig. A.1). We chose this scale as a realistic total area (approx. 32 km^2) over which bee colonies at a given site would be expected to forage (Visscher and Seeley, 1982; Beekman and Ratnieks, 2000). We also analyzed more localized foraging radii (500 m, 1000 m, and 2000 m). The average distance between sites was 40 km (9–68 km range). Broad land use categories included: CRP, ditch, fallow land, flowering woody plants and shrubs, grassland, hay land, pasture, alfalfa, canola, sunflower, wetlands, corn, oats, soybeans, and wheat (Table A.1). These broad land categories were subsequently combined into five groups for statistical analyses, including: (1) Uncultivated forage land (CRP, ditch, fallow, flowering woody plants, grassland, hay land, pasture); (2) Cultivated forage land (alfalfa, canola, sunflower); (3) Wetlands; and (4) Non-forage (corn, oats, soybeans, wheat). Sites were lettered (A-F) in descending order of land area in uncultivated and cultivated forage land, i.e. a gradient from high to low expected usefulness to honey bees (Fig. 1).

A surveyor visited each site three times (once each spring in May-June, summer in July-early August, and autumn in late August-September) each year to verify land use in the field and this data, in addition to data from the National Agricultural Statistics Survey (NASS), were entered into ArcGIS v.10 for final quantifications of the area of various types of land use within the 3.2-km radius around each site. Additionally, during each visit the surveyor visually assessed and estimated floral cover of the most commonly occurring flowers within each land category around each site including, sweet clover *Melilotus* spp.; alfalfa *Medicago sativa*; gumweed *Grindelia squarrosa*; native sunflower *Helianthus* spp.;