

**Evaluation of CRP contour buffer and filter strips as habitat for native bees and
predatory ground beetles**

by

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ABSTRACT

Suitable habitat for beneficial insects providing ecosystem services has declined greatly in agriculturally dominated landscapes. Iowa's landscape once dominated by tallgrass prairie is now dominated by monoculture agriculture, in particular corn (*Zea mays* L.) and soybeans (*Glycine max* (L.) Merr.). Native bees require resources of pollen and nectar and in return provide the service of pollination. Predatory ground beetles are natural enemies of many agricultural crop pests but require some habitat in undisturbed, non-cropped areas.

Conservation Reserve Program (CRP) contour buffer and filter strips are potential areas of habitat within rowcropped fields. The vegetation mixes commonly planted in these strips range from only grass to more highly diverse mixes of grasses and forbs. We assessed native bee communities and predatory ground beetle assemblages in current CRP contour buffer and filter strips of various forb vegetation mixes using a variety of common sampling methods during the growing seasons in 2014 and 2015 from May to August.

Native bee abundance increased as forb diversity increased whereas species richness and diversity was not significantly different among plant diversity levels. Bee communities at high plant diversity sites were significantly different from communities at medium and low plant diversity sites. Positive trends suggest high plant diversity sites support higher abundances and species richness of all bee guilds except bumble bees.

Predatory ground beetle abundance, tribe richness and tribe diversity were not significantly different among plant diversity levels. The majority of beetles at each site

were of medium or large sizes with few to no small or very small sized beetles. Overall, trends showed forb diversity positively influenced the probability of ground beetle assemblages containing beetles from more size classes.

These results suggest that increased forb diversity within contour buffer and filter strips increase available resources for native bee communities but not necessarily for predatory ground beetle assemblages. Overall, increasing the number of forbs in a contour buffer or filter strip to 15 or more species will support a higher abundance and richness of native bees and as few as 5 forb species could be sufficient to support a more functionally diverse ground beetle assemblage.

CHAPTER 1. GENERAL INTRODUCTION

Background

Over several decades, agriculture in the Midwest has intensified through an increase in acreage of agricultural land and a decrease in natural or semi-natural land (Knight et al. 2009; Le Feon et al. 2010; Tscharntke et al. 2005). This intensification can be examined at both the local and landscape scales. At the local scale, individual farm size and monoculture production have increased reducing overall crop diversity. At the landscape scale, contiguous farmed areas are becoming larger and more homogenized, reducing the amount of natural and semi-natural land left in the landscape (Ernoult et al. 2013; Tscharntke et al. 2005). This landscape simplification has been accompanied by losses in biodiversity as well as ecosystem functioning and services (Knight et al. 2009; Vasseur et al. 2013).

Biodiversity loss includes the reduction of native plant species in natural and semi-natural lands along with animal species that utilize those lands. Some of these wildlife species provide essential services to natural and semi-natural ecosystems as well as agricultural systems (Haaland et al. 2011; Knight et al. 2009; Schulte et al. 2006; Tscharntke et al. 2005). One such vital wildlife group is the native bees, a diverse functional group within many ecosystems providing the service of pollination. Pollination is a mutualism which facilitates plant reproduction while provisioning the pollen vector with nectar and pollen. However, within recent decades many native and non-native bees, have been declining. Both habitat loss and fragmentation have been shown to contribute to bee species declines (Bommarco et al. 2010; Carre et al. 2009; Haaland et al. 2011; Le Feon et al. 2010; Morandin et al. 2007) among other factors such as insecticides, mites,

and pathogens (Potts et al. 2010). Habitat loss, while not the only factor causing these declines, results in the loss of essential resources needed for survival.

Predatory ground beetles in the family Carabidae, are another group of organisms which provide an important ecosystem service of reducing the impacts of agricultural pests (Menalled et al. 1999; Woodcock et al. 2010). Carabid beetles are natural enemies of many agricultural insect pests and occur within corn and soybean fields as well as other agricultural crop systems (Larson et al. 2003; Menalled et al. 1999). Ground beetle body size with correlated to feeding and dispersal rates as well as ability to feed upon different prey species. However, studies are finding few large beetle species and many small beetle species in agricultural fields (Aviron et al. 2005; Kotze and O'Hara 2003). This lack of ground beetle diversity could be due to loss of undisturbed non-cropped areas within agricultural systems (Aviron et al. 2005; Ribera et al. 2001).

In the Midwest, particularly Iowa, the landscape once was dominated by diverse tallgrass prairie that now covers less than 0.1% of the land (Samson and Knopf 1994). The vast majority of Iowa has been converted to agriculture, particularly corn and soybeans, which together cover over 70% of the total landscape (US Department of Agriculture 2014). Corn and soybean plants cannot provide the ecosystem services such as reduced soil, water and nutrient movement that perennial prairie plants provide (Zhou et al. 2010, 2014). Annual species, like corn, have shallow root systems and are unable to slow the movement of large volumes of water that carry sediment and nutrients such as nitrogen and phosphorous out of the fields. Perennial plants on the other hand, have deep root systems that better regulate water flow, reducing soil and nutrient loss (Senaviratne et al. 2012; Zhou et al. 2010, 2014). Thus, the large tracts of native prairie that once

covered Iowa built the deep, fertile soils and held them in place. Agricultural systems today are unable to do either but restoration of areas with perennial prairie plants within the current matrix of corn and soybean can reduce further sediment and nutrient movement out of watersheds (Schulte et al. 2006).

The benefits of native plant vegetation have been documented extensively. In 1985, the United States Department of Agriculture (USDA) Farm Service Agency (FSA) initiated the Conservation Reserve Program (CRP) to take environmentally sensitive agricultural land out of production and replant it with vegetation that would reduce wind and water erosion (Malone 1989; United States Department of Agriculture Natural Resources Conservation Service 2014). Various CRP practices were developed that focused on mitigating different environmental issues. One of these practices is contour buffer strips (NRCS Practice Standard 332) and consists of strips of perennial grass only or a grass and legume mix planted along the contour within rowcropped fields. These strips are intended to reduce soil erosion and nutrient runoff (Liebman et al. 2013; United States Department of Agriculture 2011). A second practice is filter strips (NRCS Practice Standard 21), developed to reduce water runoff and remove pollutants from water exiting the field ultimately reducing these inputs downstream. Filter strips are planted along the contour at the footslope of rowcrop fields with vegetation such as perennial grasses, trees and shrubs (Liebman et al. 2013; United States Department of Agriculture 2003). The primary goals of implementing these practices are to improve soil health and reduce sediment and nutrient loss. However, they also could be used to increase wildlife habitat and provide additional ecosystem services (Schulte et al. 2016). Currently, most vegetation mixes are chosen to improve water quality, with less emphasis on adding

vegetation that may benefit wildlife (United States Department of Agriculture 2007; United States Department of Agriculture Natural Resources Conservation Service 2014). Additional studies though are needed to determine if current CRP practices such as contour buffer and filter strips as well as differing plant mixes provide habitat and resources for wildlife.

Researchers in Europe have been investigating the influence of planting grass and wildflower strips in agricultural fields on the pollinator diversity found in these strips. The European Union initiated the Agri-Environment Schemes (AES) to protect and promote bees and other pollinators (Haaland et al. 2011; Rollin et al. 2013). Among these schemes, there are several plant mixes that can be included within or next to agricultural fields: wildflower mixes, pollen and nectar rich mixes, and grass strips. Grass strips are buffer strips, which are similar to USDA buffer strips, and contain only grasses or grass and a few forbs (Blake et al. 2011). Pollen and nectar rich mixes and wildflower mixes are mostly comprised of forbs, including legumes, intended to provide forage for bees (Haaland et al. 2011). Studies examining AES have found that bumblebee richness and abundance were highest on pollen and nectar rich mixes and higher on forb mixes than on grass only strips (Haaland et al. 2011; Korpela et al. 2013; Pywell et al. 2006). One study found that incorporating only thistle and clover for floral resources in grass strips provided better pollinator habitat than crops alone (Pywell et al. 2006). Other studies have reported similar results with a higher diversity of bees in grassy and uncropped strips compared to crop fields, although few bees were present in the grass-only strips (Kells et al. 2001; Marshall et al. 2006). These findings suggest that uncropped strips provide more resources to bees than crop fields in the absence of nearby flower patches.

A review of the effectiveness of wildflower strips on insect conservation reports that 14 out of 16 studies found higher insect abundances in wildflower strips compared to crop edges or fields whereas 11 out of 13 studies found higher insect diversity in wildflower strips (Haaland et al. 2011). A meta-analysis examining AES effectiveness determined that these schemes were positively affecting species richness of a variety of pollinators and were most effective in simple landscapes. When there were forbs in strips within and surrounding crops, pollinators were more abundant and there was an increase in bee species richness (Scheper et al. 2013). When there were mass-flowering crops nearby, wild bees were still found more frequently in semi-natural land, such as wildflower strips, than in the crop fields. However, there was variation in abundance within those patches depending on which flowering plants were present. Different flowers are attractive to different species of bees and the prevalence of certain plant species or genera could influence the abundance of bees in the area (Rollin et al. 2013).

In 2006 the STRIPS project (Science-based Trials of Rowcrops Integrated with Prairie Strips) through Iowa State University began investigating the effects of incorporation of a diversity of native tallgrass prairie forbs and grasses into contour buffer and filter strips on soil, nutrient and water retention, as current contour buffer and filter strips are intended, as well as biodiversity (STRIPs Research Team 2012). At the Neal Smith National Wildlife Refuge in Jasper Co., Iowa, strips composed entirely of native tallgrass prairie species were incorporated into 2 year corn/soybean rotation rowcropped fields in proportions of 0, 10 and 20% of the row cropped area. Researchers documented benefits that were disproportionate to the minimal area taken out of crop production and converted to prairie vegetation. Compared to 100% rowcropped fields,

fields with only 10% area in prairie strips reduced soil and nutrient loss by more than 90% (Zhou et al. 2010, 2014). From 2009 to 2011, plant species richness increased until the strips contained 5.8 times higher plant diversity than the cropped portions of the fields (Hirsh et al. 2013). Forty-five species of birds were found to utilize the strips (Schulte et al. 2016) along with an increase in insect (aphid) predator abundance, particularly in June and September (Cox 2014). In addition, 107 bee species were found within the strips equaling the number of species found in the nearby reconstructed tallgrass prairie (Harris, unpub. data). Overall, adding areas of perennial vegetation (forbs, legumes, and grasses) to crop fields, significantly increased biodiversity as well as provided the environmental benefits for which contour buffer and filter strips are intended.

Much of the research on the benefits of buffer strips to both water quality and pollinators has been conducted in Europe. The STRIPS project is one of the first in the U.S. to investigate these issues. Environmental programs in the U.S. are beginning to make this connection by adding new types of CRP plant mixtures, but have yet to impact change on a large scale.

In 2013, a total of 593,056 hectares in Iowa were delineated as CRP land, with 5,325 of those hectares in contour grass strips and 81,277 hectares in filter strips combining for a total of only 14.6% of CRP land (United States Department of Agriculture 2013). Furthermore, only 0.16% of total Iowa CRP land (944.5 hectares) was specifically designated for pollinator habitat planted with CP 42 mixes (plant mixtures similar to AES wildflower mixes and pollen and nectar rich mixes). As AES studies suggested, in a simplified landscape such as that dominating Iowa, the addition of diverse vegetation mixes could enhance habitat for pollinators. CRP lands, even though not a

large proportion of the state, could be areas for improvement of pollinator habitat.

However, it is first imperative to determine to what extent existing systems are providing habitat and forage for bees.

Current contour buffer and filter strips within agricultural fields are of different vegetation mixes based on CRP contracts developed by the NRCS and the landowner (United States Department of Agriculture 2003, 2011). Some landowners choose all grass seed mixes, some choose to have 2-3 forb species included and others choose to have mixes with more than 15 native forb species. With this variety in vegetation mixes, there is a need to assess how well each system is providing habitat for bees and ground beetles.

Goals and Objectives

The overall goal of this study was to examine the efficacy of current contour buffer and filter strips planted with a range of plant species to provide habitat for native bees and predatory ground beetles. The specific objectives were as follows:

1. Assess native bee species diversity and richness and available flora resources within CRP contour buffer and filter strips of various vegetation mixes throughout the growing season.
2. Assess predatory ground beetle taxonomic and functional diversity within CRP contour buffer and filter strips of various vegetation mixes.

Thesis Organization

This thesis follows the journal paper format associated with each chapter. Chapter 1 provides a general introduction to the thesis. Chapter 2 discusses the impacts of various CRP contour buffer and filter strip vegetation mixes on native bee communities in Iowa. Chapter 3 explores the influence of current contour buffer and filter strip vegetation on

taxonomic and functional diversity of predatory ground beetle assemblages in Iowa.

Chapter 4 summarizes the general conclusions from the two journal papers that comprise this thesis. Manuscript authors each contributed to the research design, data analyses and writing of these papers.

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CHAPTER 2. IMPACTS OF CURRENT CRP CONTOUR BUFFER AND FILTER STRIPS ON NATIVE BEE (HYMENOPTERA: APOIDEA) COMMUNITIES IN IOWA

Modified from a paper to be published in *Agriculture, Ecosystems and Environment*

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Abstract

Native bee species are losing habitat due to the loss of semi-natural and natural lands as agriculture intensifies. Iowa's landscape once dominated by tallgrass prairie is now dominated by monoculture agriculture, in particular corn and soybeans. Potential areas of habitat include Conservation Reserve Program (CRP) contour buffer and filter strips. We assessed native bee communities in contour buffer and filter strips of various floral vegetation mixes using a variety of common sampling methods. Native bee abundance increased as floral diversity increased whereas species richness and Inverse Simpson's Diversity was not significantly different across plant diversity levels. Bee communities at high plant diversity sites were significantly different from the communities at medium and low plant diversity sites. Positive trends suggest high plant diversity sites support higher abundances and species richness of all bee guilds except bumble bees. Contour buffer and filter strips with higher floral diversities support a higher abundance of native bees in agriculturally dominated landscapes than low diversities.

Introduction

Declines in bee populations are occurring throughout the world (Bartomeus et al. 2013; Biesmeijer et al. 2006; Cameron et al. 2011; Kearns et al. 1998; Potts et al. 2010), as a result of several impacts including pesticide exposure, disease, parasites and a lack of forage diversity (Bommarco et al. 2010; Cameron et al. 2011; Goulson et al. 2015; Haaland et al. 2011; Krupke et al. 2012). High losses of natural and semi-natural lands, such as managed grasslands, orchards and hedgerows have occurred in areas of agricultural intensification (Garcia-Feced et al. 2015) where monoculture predominates resulting in a homogeneous landscape with low plant, and therefore, forage diversity (Knight et al. 2009; Tscharntke et al. 2005). This loss of landscape diversity is resulting in the loss of habitat with resources supporting wildlife including bees which provide the essential service of pollination in both agricultural and natural ecosystems (Haaland et al. 2011; Knight et al. 2009; Schulte et al. 2006; Tscharntke et al. 2005).

Many agricultural crops, particularly fruits and vegetables, are dependent upon bees for pollination while providing nectar and pollen forage for bees (Gallai et al. 2009). Wind-pollinated crops such as corn can provide bee forage, albeit poor, when there are limited local food resources (Hoehnerl et al. 2012; Krupke et al. 2012). Other crops may provide resources for bees although the high levels of disturbance and the short bloom period greatly limit the availability of this forage for the vast number of bees inhabiting an area throughout an entire growing season (Corbet et al. 1991). In contrast, large permanent tracts of land with native vegetation may provide the most suitable habitat for bees and other pollinators (Hines and Hendrix 2005).

Diverse tallgrass prairie vegetation once predominated the landscape of Iowa, USA, however, less than 0.1% of that prairie persists (Samson and Knopf 1994). The landscape now is dominated (70-95%) by row-crop agricultural fields, the majority of which produce only two crops, corn (*Zea mays* L.) and soybeans (*Glycine max* (L.) Merr.) (USDA National Agricultural Statistics Service Cropland Data Layer 2014). The remaining prairie lands which provide high quality bee habitat are scarce and persist as small isolated fragments (Kwaiser and Hendrix 2008).

Iowa's landscape today supports over 200 species of native bees, many of which have been found in tallgrass prairie remnants. Kwaiser and Hendrix (2008) compared tallgrass prairie preserves to ruderal, grass-dominated sites such as buffer and filter strips in Iowa. They found the bee community in ruderal lands to consist primarily of common bees with rare bees almost entirely absent when compared to communities found in the prairie preserves. The prairie preserves provided better habitat to support a higher diversity of bees than the ruderal areas. However, the majority of Iowa's landscape no longer consists of tallgrass prairie.

Although high quality bee habitat provided by prairie is scarce within the agricultural landscape, there are other landscape components that can provide enhanced bee forage. For example, a study in Iowa found no differences in bee diversity between exotic-dominated and native-dominated grasslands regardless of lower forb:grass ratios in exotic grasslands (Martin et al. 2015). In addition to the row-cropped portion of agricultural fields there may be embedded areas with more permanent and diverse vegetation. Such areas include National Conservation Reserve Service (NRCS) Conservation Reserve Program (CRP) contour buffer and filter strips. Contour buffer

strips are planted within the row-cropped field using a variety of seed mixes of grass only or grasses, legumes and forbs (NRCS Practice 332, United States Department of Agriculture 2011). Filter strips are also planted with perennial grasses, trees or shrubs on the contour of the footslope (NRCS Practice 21, United States Department of Agriculture 2003). Vegetation mixture characteristics such as the number of blooming species and percent cover of blooming species may greatly influence the presence of bees. Additional vegetation mixtures with high native forb diversity such as Conservation Practice 42 (Pollinator Habitat) can be used to provide floral resources. These areas of higher plant diversity within the agricultural landscape have the potential to provide enhanced habitat which may support a more diverse bee community.

High quality habitat for bees must contain a diversity of floral resources available over an entire growing season as bee species differentially utilize floral resources (Decourtye et al. 2010; Delaney et al. 2015; Tepedino 1979). Harmon-Threat and Hendrix (2015) in their study of tallgrass prairie remnants found that the majority of bees visited flowers of four species: *Amorpha canescens* Pursh. (Fabaceae), *Dalea purpurea* Vent. (Fabaceae), *Ratibida pinnata* (Vent.) Barnh. (Asteraceae), and *Zizia aurea* (L.) Koch (Apiaceae). All four species are widely distributed in prairie remnants, often abundant and together provide bee forage throughout the growing season. In addition to these four potential keystone species however, bees used many other species for forage throughout the entire season. A study in Great Britain found similar results in that four plant species were providing 50% of the nectar for bees but diverse wild areas enhanced floral resources for bees nationally (Baude et al. 2016).

While food is essential, nesting sites are equally important for the persistence of a bee population (Gathmann and Tschardt 2002; Sardinas and Kremen 2014). Individual bee species can be placed into guilds based on their nesting habit (Neame et al. 2013; Sheffield et al. 2013a; Sheffield et al. 2013b). However, as the land is fragmented all guilds may not be equally supported in every fragment of natural or semi-natural land (Neame et al. 2013). In agricultural landscapes, where crops dominate, there may be few areas in which a high diversity of bees find all essential habitat requirements. Such required nesting resources include undisturbed bare soil, plant stems, wood and pre-existing cavities. In addition, resources such as mud and leaves often are needed to line tunnels and bees are generally restricted to areas with these resources (Roulston and Goodell 2011). In agriculturally dominated landscapes, if appropriate nesting resources are not available within or adjacent to crop fields, bees may be forced to abandon the area driving local extinction (Wratten et al. 2012).

Cleptoparasites on the other hand, utilize the nests of their hosts to lay eggs and the host then raises their offspring (Rozen 2001). Some of the hosts are very common while others are not. For many of the cleptoparasites, the exact host is not known (Sheffield et al. 2013b). Thus a genus or genera that many species in the cleptoparasitic genus take advantage of is used as a potential host genus (Werneck et al. 2012). This makes it difficult to say if the specific host is present along with the parasite. However, a parasite would not be present if the host was not present in the area (Bogusch 2005).

Many sympatric bee species are active during different time periods of the growing season and will need forage at times other than crop bloom. As diverse native flowering plants bloom in succession throughout the growing season, they supply a

continuous food resource for bees that crops are not able to provide (Decourtye et al. 2010). Also, the row-cropped ground is frequently disturbed with heavy machinery tilling and planting as well as fertilizer and pesticide applications. Such frequent disturbance precludes nest persistence by ground nesting bees (Delaplane and Mayer 2000; Hopwood 2008). Contour buffer and filter strips on the other hand, are disturbed much less frequently as they are never tilled and only burned or mowed as needed to maintain proper plant density and growth (United States Department of Agriculture 2003; United States Department of Agriculture 2011). Less disturbance and potentially more blooming flowers make contour buffer and filter strips a more ideal location than cropped areas for bees to nest and forage when resources are otherwise scarce.

The extent to which existing contour buffer and filter strips provide habitat for native bees is unknown. This study addresses this question by examining the relationship of various vegetation diversities and associated bee diversities in existing contour buffer and filter strips within rowcropped corn and soybean fields in Iowa. The objectives of this study were to determine: (1) if strips of higher plant diversity sustain a greater diversity of bees than strips of lower plant diversity; (2) if particular strip characteristics are associated with bee diversity; (3) if bee guilds are differentially supported by strips of low and high plant diversity.

Materials and Methods

Study Sites

We conducted all sampling in this study monthly from late May to August in 2014 and 2015 and additionally in early May in 2015 at farm fields with either contour buffer (9 sites) or filter strips (2 sites) of varying plant diversity in central and northeast

Iowa. Prior to the initiation of this study, the strips ranged in age since installment from 2 to greater than 15 years. All sites were separated by a minimum of 3 kilometers to avoid overlap in usage by individual bees (Greenleaf and Kremen 2006; Osborne et al. 2008; Zurbuchen et al. 2010). In 2014, three sites were located in Jasper County, 2 of which were privately owned and 1 at the Neal Smith National Wildlife Refuge. The other sites were located on privately owned farms in each of the following counties: Buchanan, Carroll, Clayton, Dallas, Grundy, Guthrie and Story. In 2015, the Carroll county site was removed from the study by the landowner and in 2015 we sampled a site in the adjacent Greene county (Figure 1). We verified that the vegetation communities at the Carroll and Greene county sites were statistically indistinguishable (Multi-response Permutation Procedure (MRPP)) ($t=-1.118$, $A=0.0217$, $p=0.133$; McCune and Mefford 2006).

Study sites were assigned to 1 of 3 categories based on the diversity of forb species found throughout the growing season. Low diversity sites contained 0-3 forb species (3 sites), medium diversity sites 5-13 forb species (4 sites) and high diversity sites greater than 15 forb species (4 sites). We used CropScape (USDA National Agricultural Statistics Service Cropland Data Layer 2014) 30 meter resolution Cropland Data Layer (CDL) landcover maps to delineate forested area within a 1 km radius of each strip and then calculated the percentage of the forested landscape cover type.

Bee Habitat Evaluation

We assessed floral resource and bare ground availability monthly within each strip. The percent cover of each species in bloom and percent bare ground within a square meter quadrat were estimated every 5 meters along a 60 meter transect for a total of 10

quadrats. We then determined site plant diversity by summing the number of species in bloom among all sample dates (Table 1).

Bee Sampling

We sampled bees on sunny days when ambient temperatures were above 12.8° C and winds below 24 kph. To sample bees we use pan, blue-vane traps and emergence traps as well as non-targeted and targeted sweeping.

Standardized pan trapping utilized 3.5 oz (103.5 mL) white plastic Solo® cups (Droege et al. 2010; Roulston et al. 2007). We deployed a total of 12 cups (4 unpainted, 4 painted either a standardized fluorescent blue or 4 yellow (Guerra Paint®)) in each sampling bout. Traps were placed at vegetation height in random color order every 5 meters along a 60 meter transect. SpringStar® blue vane traps were placed at the end of each transect. Both pan and blue vane traps were partially filled with a weak detergent solution (Dawn®) and remained open for 6 hours. Trapped bees were transferred to 70% ethanol and returned to the lab for identification.

Targeted sweeping consisted of locating and capturing individual bees visiting flowers. Each individual bee caught using targeted sweeping was placed in a separate vial of ethanol and the flower on which the bee was caught was placed in a separate vial of 70% ethanol for subsequent pollen analysis. Non-targeted sweeping, on the other hand, consisted of sweeping vegetation. Targeted and non-targeted sweeping each were conducted separately for 12 minutes adjacent to the trap line (6 minutes per 25 meters). Each type of sweeping was conducted twice via 2 sweepers for a total of 48 minutes of sweeping per transect (Bryant and Euliss unpub.). Bees caught by non-targeted sweeping were combined at each site for identification.

Emergence trap design consisted of a white polyester mosquito net (H. Christiansen Co) pyramid with a 32 oz (946 mL) plastic screw top bottle with inverted funnel bottom. Insects emerging from the soil would climb the net pyramid and inverted funnel and fall into propylene glycol (Prestone® Lowtox Antifreeze). Two 1-meter square emergence traps were affixed to the ground within each contour or filter strip. Emergence traps were located along the 60 meter transects in areas of bare ground among standing vegetation. Prior to placement any standing vegetation that would be contained by the trap was cut and examined for evidence of use by stem nesting bees. In 2014, we installed the traps in late May and in 2015 in early May. Emergence traps remained in place throughout the growing season until late August and we collected their contents twice a month.

Processing and Identification

Field collected bees were prepared for identification following Droege's protocol (Droege 2012). All bees were identified to species (Arduser 2014; Ascher and Pickering 2015; Mitchell 1960; Mitchell 1962).

Data Analysis

Bee Abundance, Richness and Diversity Analyses

Total abundance and species, genera and family richness were analyzed across site and date as well as total abundance for each collection method using repeated measures mixed general linear models. We also analyzed the proportions of species represented by 10 or fewer individuals and proportions of species represented by 1 individual across site using repeated measures mixed general linear models. (Proc Mixed in SAS; Littell et al. 2002).

We used Chao1 estimators to compare estimated species richness at each site and treatment (fossil package; Vavrek 2011; R Development Core Team 2010). Unlike rarefaction, Chao1, a non-parametric method, considers the number of rare species, singletons and doubletons (species represented by one or two individuals), collected to estimate the total number of species that may be present including estimations of undiscovered species (Chao 1984; Colwell and Coddington 1994). Sites were compared using 9 samples each and analyzed using mixed general linear models (Proc Mixed in SAS; Littell et al. 2002). We combined data for the Carroll county (sampled 4 times in 2014) and Green county (sampled 5 times in 2015) sites to attain 9 samples.

To test bee diversity differences among sites we calculated the Inverse Simpson's Diversity Index (vegan package; Oksanen et al. 2016; R Development Core Team 2010) and then analyzed using a repeated measures mixed general linear model (Proc Mixed in SAS; Littell et al. 2002) to test diversity differences. All repeated measures mixed general linear models used year as the repeated measure and site as a random effect with post-hoc Tukey pairwise comparisons to compare differences among plant diversity levels.

Site Characteristic Effects Analyses

We used multiple regressions to assess relationships between site characteristics and bee diversity measures. To test the assumption of independence we ran Spearman-Rank correlations on the following parameters: average percent floral cover, the number of blooming species found within quadrats over a year, the frequency of blooming species, the average percent bare ground and the percent forest cover within a 1km radius. If two variables had a correlation (r value) above 0.7, the variables were

considered correlated and one was chosen to be included in subsequent regression analyses (Proc Corr in SAS; Littell et al. 2002). Separate stepwise multiple regression analyses were run using total bee abundance and total bee species richness as y variables and non-correlated strip characteristics as x variables. The variable entry and exit parameters were set at 0.05 (Proc Reg in SAS; Littell et al. 2002).

Bee Community Analyses

We used repeated measures mixed Poisson models (Proc Glimmix in SAS; Littell et al. 2002) to test effects on bee communities of site plant-diversity level for each sampling date with site as a random effect and post-hoc Tukey pairwise comparisons.

We used Multi-response Permutation Procedures (MRPP) with Bray-Curtis (Sorensen) distance measures (PC-ORD) to test for differences in bee community compositions among plant diversity levels (McCune and Mefford 2006). MRPPs are non-parametric and test for differences in species community compositions between two or more groups (McCune and Grace 2002). We averaged the total abundances of each species for each site among all sampling dates except for the Carroll county and Greene county sites which were only sampled for one year each.

Bee Guild Analyses

Following Sheffield et al. (2013a) individual bee species were placed into 1 of 7 guilds: (1) solitary ground-nesters, (2) social ground-nesters, (3) honey bees, (4) bumble bees, (5) cavity-nesters, including excavators of pithy stems, (6) cleptoparasites and (7) social parasites. To examine guild representation within the bee community at each site we combined all individuals in each guild across each site per year. We compared each guild's abundance among sites using repeated measures mixed general linear models

after data were $\log(y+1)$ transformed (Proc Mixed in SAS; Littell et al. 2002). We used a Pearson's chi-squared test to determine if the number of species in each guild were affected by plant diversity level (MASS package; Venables and Ripley 2002; R Development Core Team 2010).

To test for correlations of the average bare ground percent cover at a site per year with the abundance of ground nesting bees captured in emergence traps we used general linear regression models (stats package; R Development Core Team 2010). We used Pearson's chi-squared test to examine the association of cleptoparasite presence and presence of their respective host(s) (MASS package; Venables and Ripley 2002; R Development Team 2010). Spearman Rank-Correlation tests were run to test for correlations of cavity-nester abundance and species richness with the percent forested area within a 1km radius. Spearman's Rank correlation tests not for a linear relationship but for the relationship that as X increases Y continually increases or decreases (Proc Corr in SAS; Littell et al. 2002).

Bee-Plant Interactions Analysis

To elucidate the use of individual flowering species by bee species and to assess the range of generalization to specialization within the bee community we used the program NeD which tests nestedness (Strona and Fattorini 2014). We assembled a data matrix of interactions between each plant and bee species. We then reorganized the matrix from most general to most specialized species for both plants and bees and then calculated a matrix temperature metric (MT). The matrix creates an isocline and then finds Euclidian distances from each empty or filled cell to the isocline that is different from what would be found in a perfectly nested matrix. The MT is then compared against

the null model of proportional row and column totals to determine probabilities of a cell being occupied (interaction between a particular bee and plant species). In terms of biological significance, the null model finds the probability of there being an interaction between a particular bee and plant species based on the generalization (number of other interactions) with that bee species and that plant species. Comparing against the null model allowed for testing if the MT metric or (bee-plant network structure) is significantly different from only finding the probability of a cell being occupied (Bascompte et al. 2003).

Results

Bee Richness, Abundance and Diversity

During 2014 and 2015 a total of 5,075 individual bees were collected and identified among 151 species. The majority of species were represented by 10 or fewer individuals at each site (between 70 and 87%) and at each level of plant diversity (Table 2). Furthermore, among sites from 31 to 52% of bee species collected were singletons. Bee species collected only as singletons represented 48, 43 and 35% of total species collected at low, medium and high plant diversity sites, respectively. All bee species were not found at each site nor associated with each plant diversity level. However, total species richness did not differ significantly among plant diversity levels ($F_{2,8.11}=2.71$, $p=0.1253$, Figure 2b). Bee species richness was significantly higher at high plant diversity sites from early May through June (Figure 3b). And, medium plant diversity sites supported significantly similar bee species richness to that at low diversity sites in early May and June and higher richness than low diversity sites in late May.

The Chao 1 richness estimates varied by site with no particular level of plant diversity supporting higher estimated bee species richness (Figure 4; Table 2). Chao1 estimates of bee species richness provided overlapping 95% confidence intervals among the different plant diversity levels (Table 2). Chao 1 estimates of bee species richness indicate that 75, 39 and 43% of bee species remained undetected at low, medium and high diversity sites, respectively (Figure 2c).

Total bee abundance was significantly greater at the high than low plant diversity sites ($t_{7,29}=3.65$, $p=0.0201$, Figure 2a, Table 2) throughout the season ($F_{4,73}=53.14$, $p<0.0001$; Figure 3a). However, bee abundance at medium plant diversity sites was significantly lower than that at high diversity sites earliest in the season only and significantly higher than at low diversity sites latest in the season.

All collection methods caught bees and all showed consistent trends of low plant diversity sites collecting fewer bees than medium and high plant diversity sites. There were some significant differences in abundance among plant diversity levels. Specifically, blue vane traps and target sweeping significantly collected high abundances of bees at the high plant diversity sites in comparison to low plant diversity sites. Pan traps, non-target sweeping and soil emergence traps did not significantly collect higher abundances of bees among any plant diversity levels (Table 3).

There were no significant differences among Inverse Simpson's Diversity measures across plant diversity levels ($F_{2,16}=1.04$, $p=0.3764$).

Site Characteristic Effects

Certain site characteristics were correlated with one another whereas others were independent and could be included in multiple regression analyses. The average percent

floral cover, number of blooming species found within quadrats over a season, and frequency of blooming species were all highly correlated (Table 4). The frequency of blooming species and percent bare ground were also correlated and we chose to use the frequency of blooming species in our analysis due to the global necessity of floral resources for all bee species. Percent forest cover was not correlated with any other factor and also was included in the multiple regression analysis (Table 4).

Overall, the best total bee abundance model contained only one predictor variable, frequency of blooming species, which explained 33.43% of the variation and which positively affected total bee abundance ($R^2=0.3343$, $R=0.5782$, $p=0.0076$; Figure 5). Percent forest cover had a positive but statistically insignificant effect on total bee abundance ($R=0.3291$, $p=0.1566$) and was excluded from the model. We found that both the frequency of blooming species and percent forest cover were significant predictor variables of total bee species richness explaining 65.61% and 49.1% of the variation, respectively, and that both variables positively affected total bee species richness (frequency of blooming species: $R^2=0.6561$, $R=0.81$, $p=0.0109$; percent forest: $R^2=0.4910$, $R=0.7007$, $p=0.0006$; Figure 6).

Bee Communities

We found that low and high plant diversity sites supported statistically different bee communities as did medium and high diversity sites ($T=-2.219$, $A=0.077$, $p=0.033$; $T=-1.772$, $A=0.05$, $p=0.046$, respectively). Low and medium diversity sites however, did not support different native bee communities ($T=-0.300$, $A=0.0088$, $p=0.362$).

Bee Guilds

A minimum of 4 guilds were collected at any 1 site. Solitary and social ground nesters as well as bumble bees (*Bombus* spp.) were ubiquitous and 8 of 11 sites supported cleptoparasites (Table 5). Cavity nesters were found at all but one site, however, no stem nesting bees were found in any of the standing vegetation removed prior to emergence trap placement. We found no difference in the number of species representing each guild among plant diversity levels ($\chi^2_{18}=14.5$, $p=0.698$) except within cavity-nesting bees (Table 6).

There was a predominant trend of high, medium and low plant diversity sites supporting the highest, intermediate and lowest within-guild bee abundances, respectively (Figure 7). Abundance of bumble bees (*Bombus* spp.) however, was highest at the medium diversity sites but the single individual social parasite was collected at a high diversity site. There were few significant differences of within guild bee abundance among plant diversity levels. Cavity nesting bees were significantly more abundant at medium and high diversity sites than low diversity sites ($F_{2,8.1}=10.40$, $p=0.0058$; low and medium $t_{8.32}=4.46$, $p=0.0051$; low and high $t_{7.59}=3.27$, $p=0.0271$). Forested areas potentially provide resources for cavity nesting bees, but we did not find the percent forested cover within a 1km radius to be correlated with abundance of bees in this guild ($r=0.291$, $p=0.2129$; Figure 8). Social ground nesting bees were significantly more abundant at high than low plant diversity sites ($F_{2,7.95}=5.71$, $p=0.0290$; $t_{8.31}=3.37$, $p=0.0239$). There were no significant differences in abundance of solitary ground nesting bees, bumble bees (*Bombus* spp.) or cleptoparasites ($F_{2,9.61}=3.12$, $p=0.0719$; $F_{2,16}=1.77$, $p=0.2022$; $F_{2,8.1}=1.28$, $p=0.3279$, respectively).

Emergence traps collected 46 individual bees and 11 species representing both solitary and social ground-nesting guilds (Table 7). There was a significant direct positive relationship in the abundance of bees collected in emergence traps and the amount of bare ground present ($R^2=0.4105$, $F_{18}=14.23$, $p=0.0014$; Figure 9).

Total species richness varied among sites for each bee guild but again there was a trend in which low plant diversity sites supported the fewest and high diversity sites the highest numbers of species within guilds. Again, bumble bees (*Bombus* spp.) species richness was the exception to the trend as the highest numbers were collected at medium plant diversity sites. Despite the predominant trend of greater bee species richness among guilds supported by greater plant diversity, there were few significant differences among levels of plant diversity. There was no significant difference in species richness of solitary ground nesting bees, social ground nesting bees, bumble or cleptoparasitic bees among plant diversity levels ($F_{2,8.19}=3.45$, $p=0.0818$; $F_{2,8.2}=2.17$, $p=0.1753$; $F_{2,16}=1.52$, $p=0.2491$; $F_{2,8.22}=1.32$, $p=0.3178$ respectively) (Figure 10). A total of 22 cleptoparasite and 1 social parasite species were collected among sites and we determined their presence to be highly dependent on host presence ($\chi^2_{22}=38$, $p=0.1832$; Table 8).

Species richness among cavity nesting bees was significantly different among plant diversity levels ($F_{2,8.42}=7.05$, $p=0.0159$). More species were supported at medium and high diversity sites than low diversity sites (low and medium $t_{8.65}=3.61$, $p=0.0156$; low and high $t_{7.88}=2.87$, $p=0.0471$) (Figure 10). The percent forested cover within a 1km radius again was not significantly correlated with cavity nesting species richness ($r=0.313$, $p=0.1797$; Figure 11).

Bee-Plant Interactions

The bee-plant interaction network in this study was determined to be nested with more generalized interactions and fewer specialized interactions. ($Z=-2.965$, $RN=-0.287$, $p<0.01$; Figure 12).

Discussion

Our results show that the flowering vegetation present within a contour buffer or filter strip can influence native bee abundance and community composition but not necessarily richness. Consistent trends however, suggest high diversity sites may support higher abundances and numbers of species than low diversity sites. Similar results have been found in Europe (Kells et al. 2001; Marshall et al. 2006; Pywell et al. 2006). While diversity measures do not differ among plant diversity levels, there are differences in community compositions found at high diversity sites than low and medium diversity sites. Characteristics significantly associated with abundance and richness include the frequency of blooming species and the percent forest cover within a 1km radius of the strip. While abundance and richness varied for each of the different bee guilds, trends suggest that more floral resources support higher abundances and species of bees.

Bee Richness, Abundance and Diversity

Researchers in Europe have been investigating the influence of planting grass and wildflower strips in agricultural fields on the pollinator diversity found in these strips. The European Union initiated the Agri-Environment Schemes (AES) to protect and promote bees and other pollinators (Haaland et al. 2011; Rollin et al. 2013). In simple landscapes, pollinator richness and abundance can be enhanced by increasing other biodiversity components using AES (Batary et al. 2011). Our study found numerous bee

species and individuals among all contour buffer and filter strips regardless of level of plant diversity, but the presence of flowers in the strips supported greater bee abundance than in strips without flowers. Species richness and diversity however, did not differ among plant diversity levels but there was a consistent trend.

Even though bee abundance in this study was greater at high plant diversity sites, there were no significant differences in species richness or diversity among levels of plant diversity. There was a trend of higher numbers of bee species collected at higher plant diversity sites, however, the richness at one of the high diversity sites overlapped that more typical at low plant diversity sites and this level of variation resulted in identification of no statistical significance.

While hedgerows are not contour buffer or filter strips, they are strips of land adjacent to crop fields that have the potential to provide habitat for native bees. Morandin and Kremen (2013) found that native bees had a higher species richness as well as more abundant uncommon species in hedgerows with native perennial plants in comparison to weedy, unmanaged edges, similar to our low diversity sites. In contrast, we found that all contour buffer and filter strips, regardless of plant diversity, supported high proportions of species represented by 10 or fewer individuals indicating high numbers of rare species were found at all sites.

The low diversity sites in our study typically consisted of a monoculture of smooth brome grass (*Bromus inermis* Leyss). As a grass, *B. inermis* is wind pollinated and does not produce pollen collected by bees (McKone 1985). Our low plant diversity sites supported lower bee abundances than sites with better pollen resources. Studies in Europe have found similar results with grass-only strips. Even though there were some

bees present in grass-only strips, the addition of floral resources provide more habitat and forage (Kells et al. 2001; Marshall et al. 2006; Pywell et al. 2006). European Union studies on AES strips consisting of various flowering plant diversity mixes found that the more pollen and nectar available within or next to agricultural fields, particularly landscapes that were mostly simple (similar to Iowa's landscape), greatly increased the abundance and species richness of pollinators in comparison to all crop fields or fields with grass-only strips (Haaland et al. 2011; Korpela et al. 2013; Pywell et al. 2006; Scheper et al. 2013).

Plants only flower at certain times of the year whereas bees may only be present at certain times of the year based on their floral hosts (Olesen et al. 2008). Thus, as the growing season progresses, floral abundance and floral species present change along with the bee abundance and species present (Olesen et al. 2008; Rollin et al. 2015; Wolda 1978; Wolda 1988). Due to changes in floral community composition throughout a growing season and plant community differences among our sites, a temporal change in bee communities across sites can inform which plant communities may be providing better habitat throughout the entire season or at different times of the seasons.

In our study, species richness varied only early in the season. In May and June, species richness was greater in the high diversity sites. But from July through August species richness did not vary. Rollin et al. (2015) found similar results in blooming crop systems in Europe. Thus, the presence of more floral resources at the beginning of the season can influence the bee species present. Throughout the remainder of the season in our study, plant diversity level did not influence differences in species richness. This however, is where bias may come in with sampling techniques. Since there are little to no

floral resources in the low diversity strips, bees flying past may have mistaken the traps for flowers and landed in the strip even though it may not use that strip otherwise (Baum and Wallen 2011; Roulston et al. 2007). This would affect the results of the bee species actually present and utilizing the resources in the strip during different times of the growing season.

We found differences in bee abundances to be more consistent throughout the season than species richness. From early May through August high plant diversity sites consistently supported significantly more bees than the low diversity sites whereas medium diversity sites were similar to either low or high diversity sites depending on the time of season. A study in the UK found similar results with bumble bees being consistently more abundant in ‘grass and wildflower’ field margins than any other field margin treatment, such as tussock grass and cropped margins, whereas species richness was relatively similar across treatment (Meek et al. 2002).

Some methods used in this study to collect bees specifically capture individuals that are utilizing the strips. Both non-targeted and targeted sweeping collected bees that were on the flowers either collecting pollen and nectar or simply resting such as cleptoparasites in close proximity to host nests in the ground. Colored pan traps provide signals of attraction similar to that of flowers and may capture bees in flight (Roulston et al. 2007). Pan trapped bees may not have been using resources in the strip. Pan traps are effective when there are few floral resources, but have been found to undersample bee species richness but not abundance when there are abundant floral resources present (Baum and Wallen 2011; Roulston et al. 2007). In our study, pan traps did not collect significantly different abundances of bees among plant diversity levels. Trends across all

collection methods however, suggest that high diversity sites, with more abundant and available resources, collected higher abundances of bees than the low plant diversity sites. Bees collected with targeted sweeping were more abundant at the high diversity strips compared to the low diversity strips. Non-target sweeping though, showed no significant differences. The consistent trends along with a higher abundance of bees collecting using targeted sweeping, suggest that more bees were present in the high plant diversity sites than the low plant diversity sites.

Site Characteristic Effects

Certain strip characteristics were found to be correlated with abundance and species richness. The frequency of blooming species was found to be correlated with both abundance and richness. Frequency refers to how evenly a blooming species occurred within a strip and as frequency increased, so did bee abundance. These results indicate that not only the abundance of a blooming species is important but that more evenly distributed blooms within a strip are more beneficial than patches of flower. More blooming individual plants can support a higher abundance of bees.

The frequency of blooming species and percent forest cover within a 1km radius was correlated with bee species richness. This indicates that in our study, as the frequency of blooming species increased so did the number of bee species. We found that as the percent forest increased, the bee species present increased as well. Forested area can provide additional floral resources in an area as one study found that forested region near apple orchards had spring flowers that coincided with the bloom of apple flowers those orchards then supported a higher bee abundance and species richness (Watson et al. 2011). Roulston and Goodell (2011) discuss several instances where various bee species

require wood or cavities for nesting that are more frequently found in forested areas. As prairie or grass strips may not provide those resources, nearby forested area could mean bee species that use such areas are travelling from the wooded areas to the strips for floral resources. But, if those nesting resources are not nearby a strip, those species may not be utilizing that strip. In our study, we found that even though forested area increased overall bee species richness it did not significantly influence the abundance and richness of cavity-nesting bees.

One factor that was not examined in this study but could influence abundance and bee species richness is the age of the strip. Young contour buffer or filter strips may have a different plant community than an older strip due to competition, establishment and recruitment of other plant species. A study looking at a chronosequence of restored grasslands that included both grasses and forbs found that forbs decreased significantly over time with near zero percentages of forb cover at sites of 12 years in age (Baer et al. 2002). This could indicate that older strips, while still populated with a few forb species, may be dominated by grasses than a strip of similar plant diversity that was more recently established. This difference in plant community structure could differentially provide food resources as well as nesting resources, such as bare ground, for bees. Our study did find that forb abundance was positively correlated with the percent bare ground in the strip indicating that the differences in plant community can provide varying amounts of nesting resources for ground nesting bees in particular.

Bee Communities

The bee communities found in our study at low plant diversity sites were significantly different than those at high and medium diversity sites. The flowering

vegetation present at any given site was the result of the diversity originally plant under the CRP plan. Thus, not every landowner who had forbs in their strip had the same flowering species. It is thought that the floral community can influence the bee community (Schaffers et al. 2008). Harmon-Threat and Hendrix (2015) found 4 flowering species to be particularly attractive to bees and are abundant across tallgrass prairie remnants. All four of these plants at all high diversity sites and among medium diversity sites however, not every medium site had all four species. These four plant species would attract similar bee species regardless of site within the tallgrass prairie region. However, medium diversity sites contained other plant species potentially attracting different bee species. This would contribute to a potentially different bee community composition than that of high diversity sites. However, this was not the case in our case. Low diversity sites on the other hand, did not have any of the plant species. Without those plant species, many bee species may not be attracted to the strip resulting in a different community composition than that of the medium and high diversity sites.

Bee Guilds

The overall trends among all guilds, except bumble bees (non-parasitic *Bombus* spp.), suggest that high plant diversity levels support a higher abundance and species richness than low diversity sites. High plant diversity sites may be consistently providing more available and abundant floral and nesting resources than low diversity sites for the majority of guilds. As guilds require different nesting resources, high plant diversity sites appear to be more diverse with the resources available for use than low diversity sites. Bumble bees do not follow this trend as the most individuals and species were found in

the medium diversity level. This is possibly due to one medium diversity level site where more bumble bees were found frequenting the strip in comparison to other sites.

The vast majority of the 200+ bee species that persist in Iowa are ground nesters and prefer to nest in bare, undisturbed soil (Roulston and Goodell 2011). In this study, the percentage of bare ground provided an estimate of nesting resources available for both solitary and social ground nesting bees. However, percent bare ground was correlated with the frequency of blooming species which was highly correlated with the number of blooming plant species in strips. It is thought then, that high plant diversity sites and sites with a high frequency of blooming species provided more nesting resources for ground nesting bees than low diversity sites. However, we found that high diversity sites did not significantly support a higher abundance or number of species of solitary ground nesting bees nor a higher species richness of social ground nesting bees. The high diversity sites did significantly support a higher abundance of social ground nesting bees. The positive trends among abundance and richness for both solitary and social ground nesting bees signify that the higher diversity sites supported higher numbers of abundance and richness for both solitary and social ground nesting bees.

Bare ground, though, is not the only factor that contributes to a species' nesting presence. Other factors such as slope, soil compaction and soil type influence whether ground nesting bees nest in the area (Grundel et al. 2010; Potts and Willmer 1997; Sardinas and Kremen 2014). These other factors were not measured in this study but would be important considerations in future research.

Emergence traps are used to monitor bees nesting in the ground. The bees collected using those traps are part of the community from the previous year and thus

may be different from the current year's community reflected in the collections from other traps and sweeping. Sardinas and Kremen (2014) found that the community composition of emerging ground nesting bee was different from the flying bee community composition (bee species collected using pan traps and sweeping) found at the same site. As studies have shown (Williams et al. 2001) that bee community compositions can highly vary from year to year, it follows that the nesting community may be different from the flying community. Our study sampled bees over two years precluding tests of effects of the community of emerging ground nesting bees on the adult bee community composition the following year. In 2015, more bee individuals and species were collected in emergence traps than in 2014. The flying bee community in 2014 was very abundant which may have contributed to the high number of ground nesting species and individuals caught in emergence traps in 2015. However, with ninety-six percent of individuals caught in emergence traps in 2015 found in the flying community at the same site in 2014 and 97% of the individuals caught in emergence traps in 2015 found in the flying community in 2015, the emerging community appears similar to the flying communities of both years.

Forty-five of 46 individuals caught in emergence traps were collected in sites where the vegetation was sparse and conditions appeared ideal for ground nesting bees. The majority of individuals found nesting were in the Halictidae family. Most of the individuals caught were from one site and 8 species were collected. This site had the most bare ground of all sites.

Bees were not necessarily nesting at a site given the presence of bare ground. But, there was a positive correlation between the abundance of ground nesting bees collected

in emergence traps and the amount of bare ground present, indicating that bare ground is an important factor in ground nesting bee habitat use. However, due to financial and time constraints, only 2 emergence traps were set out at each site, covering a total of 2 square meters in each strip indicating that the majority of every contour buffer or filter strip was not being monitored for ground nesting bees. It is possible there were bees nesting in other locations of the strips which were not collected. Sardinas and Kremen (2014) came to similar conclusions regarding the small amount of area occupied by emergence traps even when numerous emergence traps were used at a single location.

Cavity-nesting bees utilize sites in pre-existing holes, rotten logs or twigs (Potts et al. 2005; Roulston and Goodell 2011). These types of resources are not typically found in grass strips unless there are other plant species with stems of sufficiently large diameter. In our study, cavity-nesting were more abundant and specious at medium and high plant diversity sites than low diversity sites. This may indicate that cavity-nesting bees are generally not able to use contour buffer or filter strips of all-grass or low plant diversity due to the lack of appropriate and sufficiently close nesting resources. Bennett et al. (2014) found that bees chose habitat that had available floral resources but also were in close proximity (based on foraging ranges) to nesting substrate. While forested areas potentially provide nesting resources, in the form of rotten logs or twigs, we hypothesized that more forested cover near a strip would increase the abundance and richness of cavity-nesting bees. This however, was not the case. The percent forest cover within a 1 km radius of a strip did not influence bee abundance or richness. Instead, our results indicate that the floral and potentially nesting resources within the strip influence the presence of cavity-nesting bees.

In our study, with few exceptions, whenever a cleptoparasitic species was present, its host was present as well. Previous studies have suggested that the presence of cleptoparasites can be used as a proxy for the status and health of the bee community in regards to the community diversity and stability (Sheffield et al. 2013b). The more diverse the bee community, the more likely it is able to withstand disturbances, with the parasitic species the first to be affected. In healthy ecosystems, parasites play a stabilizing role by reducing the reproductive output of the host by either killing the host egg or larva (Rozen 2001). Some cleptoparasites are generalists and can utilize several hosts whereas others are specialists. Specialist parasites have been shown to increase biodiversity by reducing the ability of the host to become highly abundant and disproportionately use the floral resources in an area reducing exploitative competition. Since many parasites are species specific, they also reflect the overall bee community (Hudson et al. 2006). In our study, the majority of cleptoparasitic species were collected at sites which also supported their respective hosts. There were no significant differences between the abundance of cleptoparasites supported among plant diversity levels. However, there was a trend towards medium and high diversity sites supporting a higher abundance of cleptoparasites than low diversity sites. This may indicate a high level of bee community health and stability in the higher plant diversity levels.

In addition to cleptoparasites, there are social parasitic bees. Only one social parasite was found over the course of the study: *B. citrinus*. This individual was found at a single high plant diversity site in 2014. This is a specialized parasite with only two hosts having been reported (Fisher 1985): *B. vagans* and *B. impatiens*, the latter of which was collected at the same site as well. In addition, a high number of cleptoparasites were

present at that same site and overall site bee richness was high. The positive trends among increasing plant diversity of species richness of social parasites and cleptoparasites are similar to the trends shown in almost all other bee guilds. The overall species richness also follows this trend of higher plant diversity levels supporting higher species richness. Thus, the presence of parasitic bee species may inform the overall diversity of the entire bee community as well as indicating levels of community stability and resilience.

The variety of bee guilds found at a site can show the strip's ability to support a variety of bees (Sheffield et al. 2013a). Overall, it can be said that contour buffer or filter strips with high diversity vegetation mixes tend to support higher levels of abundance and richness across all bee guilds, except perhaps bumble bees.

Bee-Plant Interactions

Floral resource preferences vary among bee species and not all species utilize the same flowering species. Some bee species are generalists, visiting a wide variety of flowers whereas others are specialized and primarily visit flowers of a single plant species or genus (Decourtye et al. 2010; Tepedino 1979). In a bee-plant community, the interactions between individual bee and plant species may range from completely random to being highly nested. To be perfectly nested, all generalist bee species would interact with the more generalist and a larger number of plant species whereas the specialist bee species have fewer bee plant interactions (Bascompte 2003). In our study, the bee-flower species interaction network was not random with the majority of interactions between generalist bees and flowers and few specialists. These suggests that plant mixes

containing generalist forbs could support higher bee abundance and species richness while specialist flowers could be beneficial if specialist bees are present.

High plant diversities in contour buffer and filter strips are able to provide more diverse generalist and specialist floral resources supporting a higher bee abundance and species richness. The high plant diversity strips are providing resources for those bee communities throughout an entire season, from early spring to fall. High plant diversities can also provide more nesting resources for ground nesters than low diversity sites.

Almost all bee guilds, including ground nesters, follow the same trend with higher plant diversities supporting higher abundance and species richness within the bee guilds. The presence of cleptoparasitic bees in particular, are dependent on their host presence, such as various ground nesting bees, and can indicate bee community health and stability. As cleptoparasites tend to be more abundant and specious in higher diversity levels along with other bee guilds, contour buffer and filter strips of higher plant diversity levels may have high bee community stability. Overall, our study confirms the importance of high plant diversity in contour buffer or filter strips, to support higher bee abundance and species richness and the resulting resilience this diverse community provides.

Conclusions

In this study, measures of bee community abundance and richness were found to be highest in contour buffer or filter strips with the highest flowering plant diversity indicating that such sites provided better habitat for bees. And, bee community composition differed significantly between high flowering plant diversity sites and low plant diversity sites and provided insight into which species are more attracted to those sites. The frequency of blooming species was found in greater proportion in strips with

high plant diversity and this likely contributed to the higher bee abundances and species richness among these strips. Overall trends across all bee guilds, except bumble bees, suggest that high plant diversity levels support a higher abundance and species richness than low diversity sites. Higher diversities of flowers can increase available resources early and throughout the season when compared to the lower diversity mixes. Within the matrix of Iowa's simplified landscape of vast tracks of monoculture agriculture, contour buffer and filter strips with as few as 15 species of tallgrass prairie forbs and the increased area of bare ground associated with this level of plant diversity were able to provide key habitat resources supporting a robust community of native bee species.

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TABLES

Table 1. Native forb species blooming in 2014 and 2015 within contour buffer and filter strips of differing plant diversity levels and the month of bloom.

Plant Diversity	Blooming Species	Month Blooming
Low Diversity	<i>Asclepias syriaca</i>	June, July, August
	<i>Echinocystis lobata</i>	August
	<i>Solidago</i> spp.	August
Medium Diversity	<i>Apocynum cannabinum</i>	June, July
	<i>Asclepias syriaca</i>	June, July, August
	<i>Bellis perennis</i>	July, August
	<i>Chamaecrista fasciculata</i>	August
	<i>Dalea purpurea</i>	July, August
	<i>Desmodium canadense</i>	July
	<i>Echinacea pallida</i>	June, July
	<i>Erigeron strigosus</i>	Late May, June, July, August
	<i>Heliopsis helianthoides</i>	August
	<i>Lactuca serriola</i>	August
	<i>Monarda fistulosa</i>	July, August
	<i>Potentilla argentea</i>	June, July
	<i>Potentilla arguta</i>	June
	<i>Solidago altissima</i>	August
	<i>Ratibida pinnata</i>	July, August
	<i>Rudbeckia hirta</i>	June, July, August
	<i>Solidago rigida</i>	August
	<i>Solidago</i> spp.	August
	<i>Symphyotrichum novae-angliae</i>	July, August
	<i>Verbena stricta</i>	July
	<i>Verbena urticifolia</i>	Late May, July, August
	<i>Zizia aurea</i>	Late May
High Diversity	<i>Anemone canadensis</i>	Late May, June
	<i>Apocynum cannabinum</i>	June, July
	<i>Asclepias syriaca</i>	June, July
	<i>Asclepias tuberosa</i>	June, July
	<i>Baptisia alba</i>	June, July
	<i>Chamaecrista fasciculata</i>	July, August
	<i>Coreopsis</i> spp.	June
	<i>Dalea purpurea</i>	June, July, August

Table 1 cont.

High Diversity	<i>Echinacea pallida</i>	June, July
	<i>Erigeron strigosus</i>	June, July, August
	<i>Euphorbia corollata</i>	July, August
	<i>Gaura biennis</i>	August
	<i>Gentiana alba</i>	August
	<i>Helianthus grosseserratus</i>	June, July, August
	<i>Helianthus maximiliani</i>	July, August
	<i>Heliopsis helianthoides</i>	July, August
	<i>Lespedeza capitata</i>	August
	<i>Liatris pycnostachya</i>	July
	<i>Monarda fistulosa</i>	July, August
	<i>Oenothera biennis</i>	July, August
	<i>Phlox pilosa</i>	June
	<i>Potentilla argentea</i>	June
	<i>Potentilla arguta</i>	June, July
	<i>Ratibida pinnata</i>	July, August
	<i>Rudbeckia hirta</i>	June, July, August
	<i>Ruellia humilis</i>	July
	<i>Silphium perfoliatum</i>	July, August
	<i>Solidago rigida</i>	August
	<i>Solidago</i> spp.	August
	<i>Symphyotrichum novae-angliae</i>	July, August
	<i>Symphyotrichum pilosum</i>	Late May
	<i>Tradescantia</i> spp.	Late May, June
	<i>Verbena stricta</i>	June, July, August
	<i>Vernonia fasciculata</i>	August
	<i>Zizia aurea</i>	Early May, Late May, June

Table 2. The number of bee individuals and species observed at each site; the number of species and proportion of species with 10 or fewer specimens collected; the number of species and proportion of species with one individual represented; the Chao1 species richness estimate with 95% CI from 9 samplings at each site of either contour buffer and filter strips across 2014 and 2015 (low diversity (LD): 0-3 forb species; medium diversity (MD): 5-13 forb species; high diversity (HD): greater than 15 forb species). Different letters within a column indicate statistically significant differences. (Mixed General Linear Models; Proc Mixed in SAS; Littell et al. 2002).

Site Plant Diversity Level	No. Bee Individuals		No. Bee Species Collected		No. and Proportion Species with ≤10 Individuals		No. and Proportion Singleton Species		Chao 1 Bee Species Richness (95% confidence interval)	
Bo Low	159	830	23	54	19 (0.83)	42 (0.78)	11 (0.48)	26 (0.48)	38 (32-44)	223 (169-278)
Mc Low	352	a	29	a	23 (0.79)	a	13 (0.45)	a	57 (46-67)	a
Sh Low	319		34		27 (0.79)		16 (0.47)		76 (62-91)	
El Medium	613		85		74 (0.87)		43 (0.51)		162 (146-177)	
Ka Medium	566	1959	43	108	35 (0.81)	89 (0.82)	19 (0.44)	47 (0.43)	88 (74-102)	182 (165-199)
Pl Medium	407	ab	36	a	28 (0.78)	a	16 (0.44)	a	68 (57-78)	a
Sl Medium	385		33		26 (0.79)		11 (0.33)		43 (39-47)	
Cr High	552		44		31 (0.70)		14 (0.32)		76 (65-88)	
NS High	978	2153	69	91	50 (0.72)	67 (0.74)	29 (0.42)	35 (0.39)	116 (104-129)	159 (143-175)
Gr High	532	b	45	a	35 (0.78)	a	14 (0.31)	a	100 (86-114)*	a
Pe High	212		29		24 (0.83)		15 (0.52)			

*High diversity site 3 and 4 data were combined for the Chao1 bee species richness estimate.

Table 3. The abundance of bees collected in each collection method for each plant diversity level. Different letters within a column indicate statistically significant differences. (Mixed General Linear Model; Proc Mixed in SAS; Littell et al. 2002).

	Pan Traps	Blue Vane Traps	Non-Target Sweeping	Target Sweeping	Soil Emergence Traps
Low	575 a	205 a	40 a	9 a	1 a
Medium	1056 a	361 ab	387 a	106 a	38 a
High	1146 a	407 b	478 a	233 b	9 a

Table 4. Spearman-Rank Correlation coefficients and p-values for the average percent floral cover in a strip, the number of blooming species found within quadrats over a year, the frequency of blooming species in a strip. And Spearman-Rank Correlation coefficients and p-values for the frequency of blooming species in a strip, the average percent bare ground in a strip and the percent forest cover within a 1km radius of a strip. (Spearman Rank-Correlation; Proc Corr in SAS; Littell et al. 2002).

Spearman Correlation Coefficients, N=20 Prob > r under H0: Rho=0					
	Percent Floral Cover	Number of Blooming Species	Frequency of Blooming Species	Percent Bare Ground	Percent Forest in a 1 km radius
Percent Floral Cover	1.00000	0.86363 p<0.0001	0.93524 p<0.0001	n/a	n/a
Number of Blooming Species	0.86363 p<0.0001	1.00000	0.93157 p<0.0001	n/a	n/a
Frequency of Blooming Species	0.93524 p<0.0001	0.93157 p<0.0001	1.00000	0.72910 p=0.0003	0.55703 p=0.0107
Percent Bare Ground	n/a	n/a	0.72910 p=0.0003	1.00000	0.43321 p=0.0564
Percent Forest in a 1km radius	n/a	n/a	0.55703 p=0.0107	0.43321 p=0.0564	1.00000

Table 5. Bee abundance and number of species in each bee guild at each site across both years. (LD=low diversity; MD=medium diversity; HD=high diversity).

Site	Plant Diversity Level	Bee Guild						
		Solitary Ground Nester	Social Ground Nester	Honey bees	Bumble Bees	Cavity-Nesters	Cleptoparasites	Social Parasites
Bowman	LD	115/13	32/5	7/1	5/4	0/0	0/0	0/0
McClellan	LD	157/15	184/6	0/0	7/4	3/3	1/1	0/0
Sheller	LD	163/19	136/4	0/0	12/5	6/4	2/2	0/0
Elkader	MD	195/39	250/11	83/1	11/6	55/15	19/13	0/0
Kaldenberg	MD	185/22	336/7	2/1	12/4	31/9	0/0	0/0
Plunkett	MD	126/20	188/6	61/1	26/5	4/2	2/2	0/0
Sloan	MD	151/14	180/5	0/0	11/3	30/9	2/2	0/0
Cretsinger	HD	176/22	281/6	3/1	8/4	83/10	1/1	0/0
NealSmith	HD	394/34	486/7	14/1	9/4	58/11	16/11	1/1
Greving	HD	161/23	327/7	0/0	6/3	32/8	6/4	0/0
Peckumn	HD	73/13	114/6	14/1	2/2	7/5	2/2	0/0

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Table 6. The number of species in each bee guild in each plant diversity level across both years. The same letters within a row indicate no statistical significant difference. (Pearson's Chi-Square; MASS package; Venables and Ripley 2002; R Development Core Team 2010).

Plant Diversity Level	Bee Guild no. species (% total species)							
	Solitary ground nesters	Social ground nesters	Honey bees	Bumble bees	Cavity nesters	Clepto-parasites	Social parasites	Total species
Low	27 (.50)a	8 (.15)a	1 (.02)a	8 (.15)a	8 (.15)a	2 (.04)a	0a	54 a
Medium	55 (.51)a	10 (.09)a	1 (.01)a	8 (.07)a	18 (.15)b	16 (.15)a	0a	108 a
High	40 (.44)a	9 (.10)a	1 (.01)a	6 (.07)a	21 (.23)b	13 (.14)a	1 (.01)a	91 a

Table 7. Bee species caught in emergence traps in each strip, each year (1 is 2014 and 2 is 2015), and overall abundance of that species in that year caught in emergence traps at that site. Sites are characterized as low diversity (LD): 0-3 forb species; medium diversity (MD): 5-13 forb species; and high diversity (HD): >15 forb species. Guilds are characterized as GN: ground-nester; SolGN: solitary ground-nester; SocGN: social ground nester.

Plant				
Diversity/Site	Year	Bee Species	Abundance	Guild
LD - Bo	2	Lasioglossum Dialictus	1	SocGN
	1	Augochloropsis fulgida	2	SolGN
	1	Halictus confusus	5	SocGN
	1	Lasioglossum Evylaeus truncatum	7	SocGN
MD - El	1	Lasioglossum spp.	2	GN
	1	Melissodes bimaculata	1	SolGN
	2	Andrena robertsonii	1	SolGN
	2	Andrena spp.	3	SolGN
	2	Halictus confusus	1	SocGN
	2	Lasioglossum Dialictus	12	SocGN
	2	Melissodes bimaculata	1	SolGN
MD - Pl	2	Augochlorella spp.	1	SocGN
HD - Cr	2	Lasioglossum Dialictus	1	SocGN
	2	Melissodes trinodis	1	SolGN
HD - NS	1	Melissodes bimaculata	1	SolGN
	2	Lasioglossum Dialictus	1	SocGN
HD - Pe	2	Agapostemon virescens	4	SolGN
	2	Lasioglossum Dialictus	1	SocGN

Table 8. Cleptoparasite (and one social parasite) present at each site, the cleptoparasite host, and the presence of the host at the site. (GO=grass only; LD=low diversity; MD=medium diversity; HD=high diversity).

No. Spp	No. unique spp	Plant Diversity/Site	Cleptoparasite	Host	Presence of Host
0	0	LD - Bo	None		
1	0	LD - Mc	Stelis spp.	Megachilidae Family	Yes
2	0	LD - Sh	Triepeolus lunatus	Melissodes bimaculata	Yes
			Triepeolus spp.	Melissodes spp.	Yes
7	3	MD - El	Coelioxys rufitarsis	Megachile latimanus	Yes
			Nomada articulata	Agapostemon virescens	Yes
			Nomada australis	Agapostemon spp.	Yes
			Nomada denticulata	Andrena spp.	Yes
			Nomada depressa	Andrena spp.	Yes
			Nomada illinoensis	Andrena spp.	Yes
			Nomada imbricata	possibly Andrena barbara	No
			Nomada integerrima	Andrena spp.	Yes
			Nomada parva	Andrena spp.	Yes
			Nomada spp.	Andrena spp.	Yes
			Sphecodes spp.	Halictus spp. and Lasioglossum spp.	Yes
			Triepeolus lunatus	Melissodes bimaculata	Yes
0	0	MD - Ka	None		
2	0	MD - Pl	Nomada articulata	Agapostemon virescens	Yes
			Sphecodes spp.	Halictus spp. and Lasioglossum spp.	Yes

Table 8 cont.

2	0	MD - SI	Nomada denticulata	Andrena spp.	Yes
			Nomada depressa	Andrena spp.	Yes
1	0	HD - Cr	Nomada spp.	Andrena spp.	Yes
			Bombus citrinus (Social Parasite)	Bombus impatiens	Yes
			Coelioxys octodentata	Megachile brevis	Yes
			Coelioxys sayi	Megachile mendica; Megachile brevis	No; Yes
			Nomada articulata	Agapostemon virescens	Yes
11	7	HD - NS	Nomada spp.	Andrena spp.	Yes
			Nomada superba	Eucera hamata	Yes
			Triepeolus donatus	Melissodes desponsa	Yes
			Triepeolus helianthi	Melissodes agilis; Melissodes trinodis	Yes; Yes
			Triepeolus lunatus	Melissodes bimaculata	Yes
			Triepeolus nigrihirtus	Melissodes spp.	Yes
			Triepeolus simplex	Melissodes communis	Possibly
			Coelioxys sayi	Megachile mendica; Megachile brevis	No; Yes
4	1	HD - Gr	Nomada articulata	Agapostemon virescens	Yes
			Triepeolus concavus	Svastra obliqua	No
			Triepeolus lunatus	Melissodes spp.	Yes
2	0	HD - Pe	Nomada articulata	Agapostemon virescens	Yes
			Nomada depressa	Andrena spp.	Yes

FIGURES

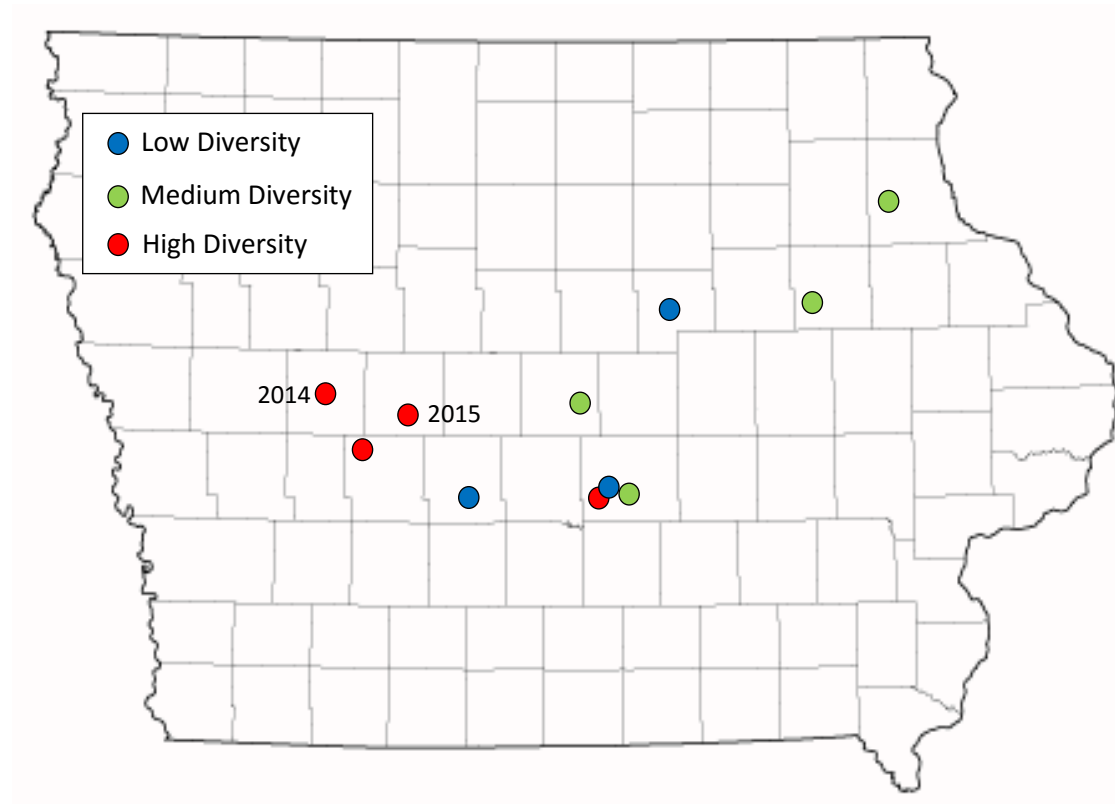


Figure 1. Study site locations and plant diversity type: low diversity (0-3 forb species), medium diversity (5-13 forb species) and high diversity (>15 forb species).

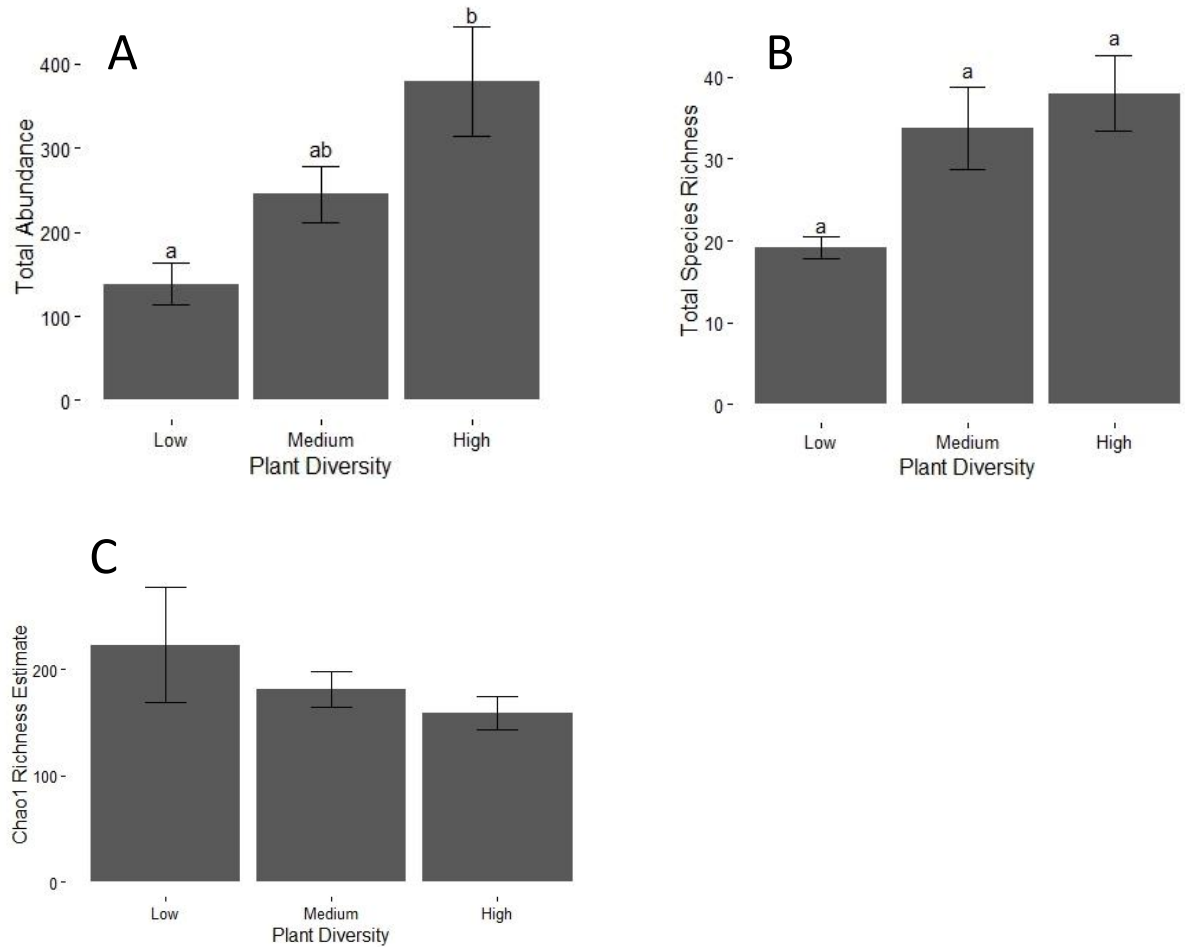


Figure 2. (A) Total bee abundance, (B) total bee species richness and (C) Chao 1 species richness estimate for each plant diversity level across 2014 and 2015 in contour buffer and filter strips with standard error bars. The letters above the error bars indicate significance; sharing the same letter indicates no significant difference. (Mixed General Linear Model; Proc Mixed in SAS; Littell et al. 2002).

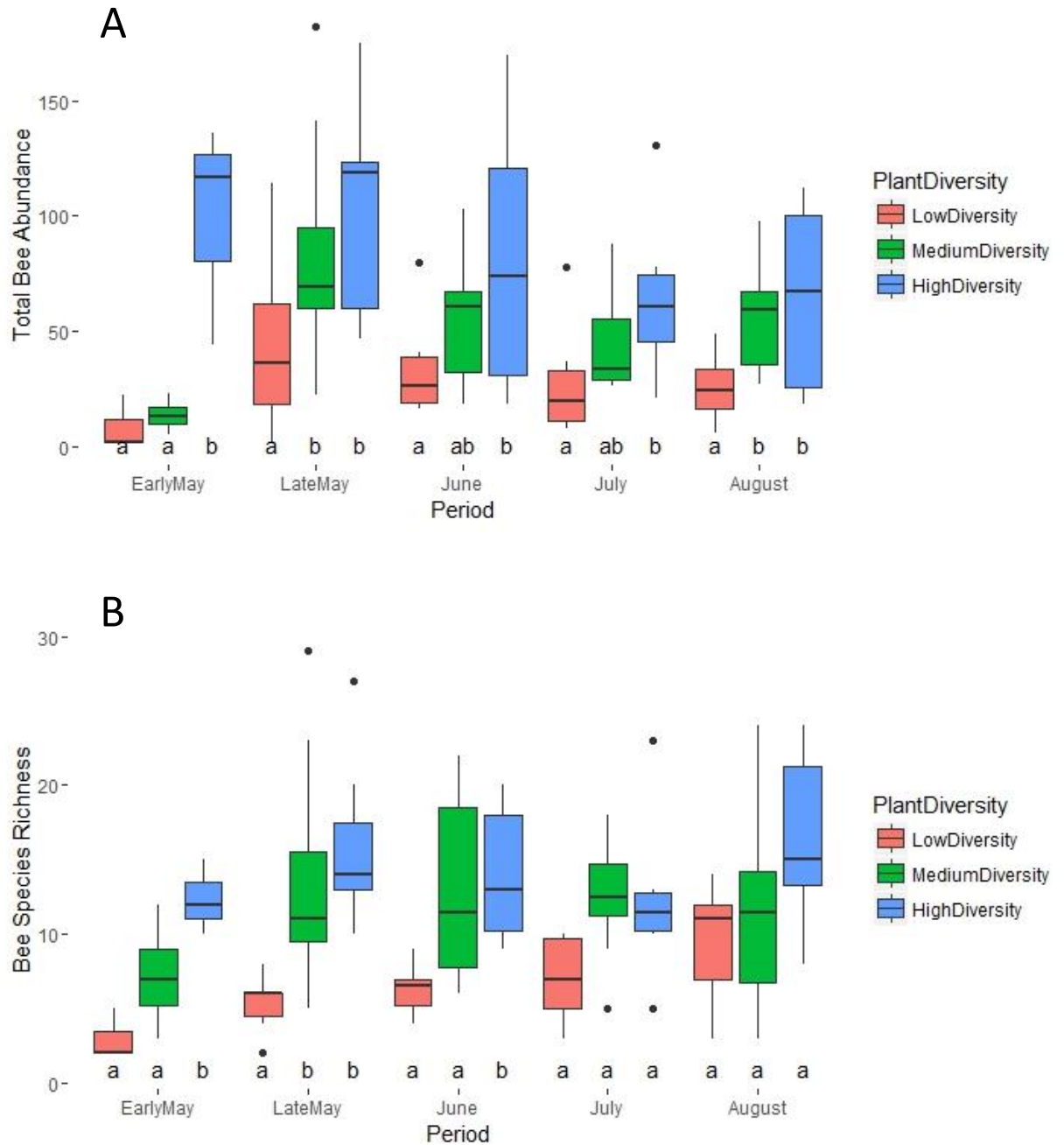


Figure 3. (A) Total bee abundance and (B) total bee species richness supported in each plant diversity level during each sampling period across a growing season in contour buffer and filter strips. The letters below each box indicates significance within that sampling period; sharing the same letter indicates no significant difference. (Mixed General Linear Model; Proc Glimmix in SAS; Littell et al. 2002).

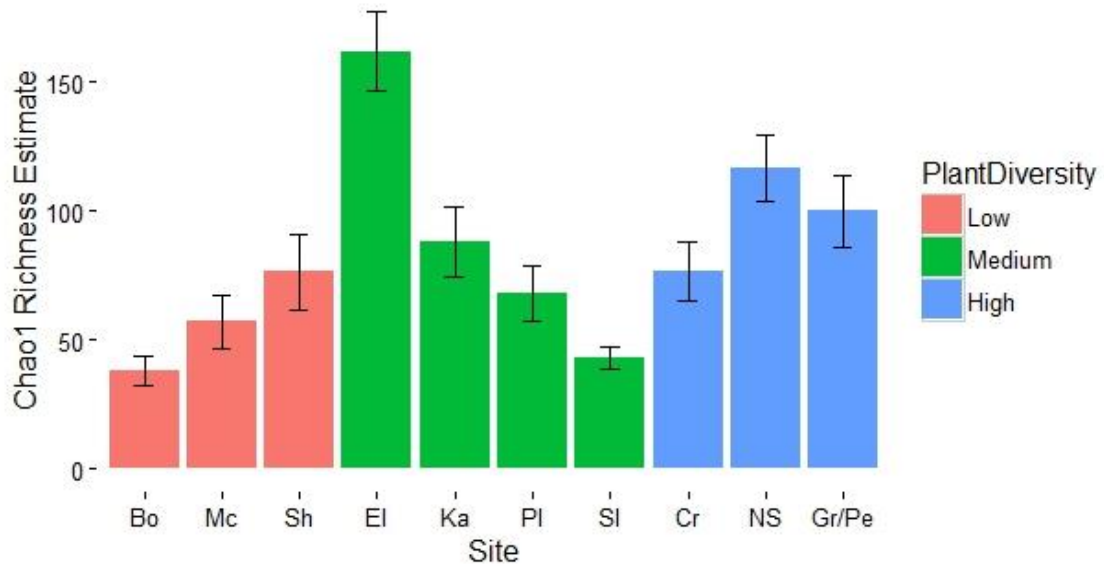


Figure 4. Chao1 species richness estimate for each site calculated after 9 samples from each site with 95% confidence intervals indicated. (Chao1 estimates; Fossil package; Vavrek 2011; R Development Team 2010).

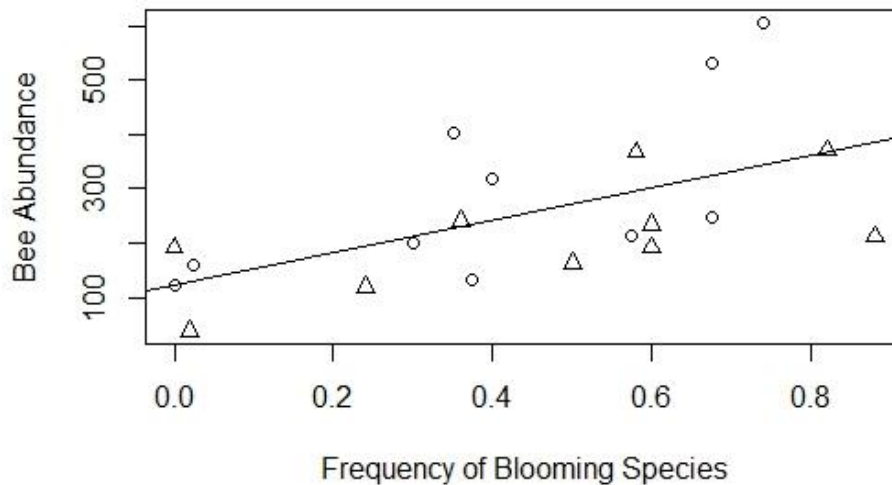


Figure 5. Regression of the total bee abundance versus the frequency of blooming species within contour buffer and filter strips in a year ($R^2=0.3343$, $R=0.5782$, $p=0.0076$). 2014 points are represented as circles while triangles are from 2015. (Multiple Regression; Proc Reg in SAS; Littell et al. 2002).

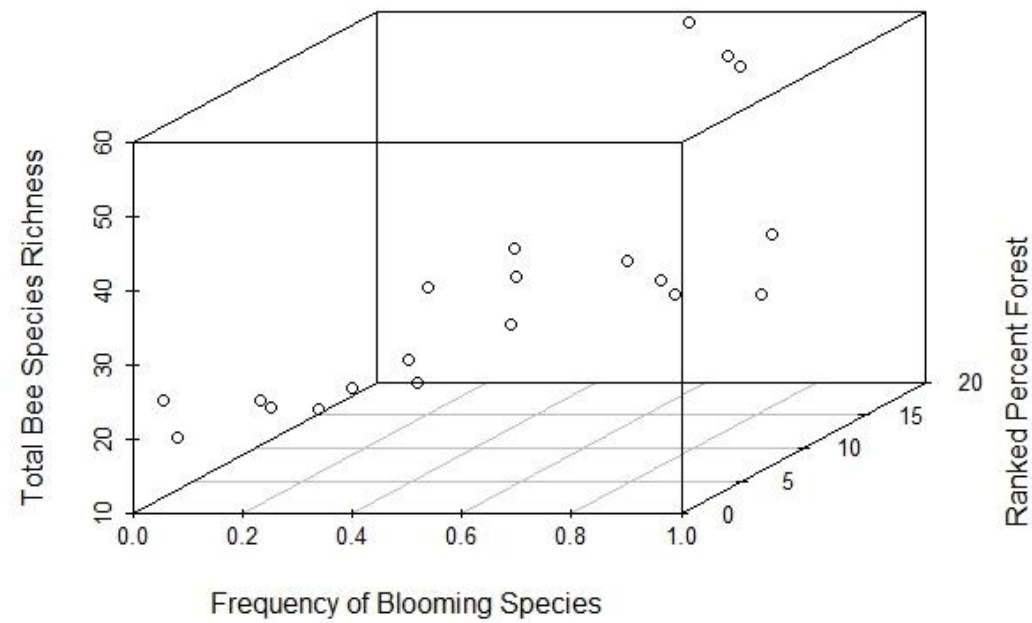


Figure 6. Multiple regression of total bee species richness versus the frequency of blooming species ($R^2 = 0.6561$, $R = 0.81$, $p = 0.0109$) and the ranked percent forest in a 1km radius ($R^2 = 0.4910$, $R = 0.7007$, $p = 0.0006$). (Multiple Regression; Proc Reg in SAS; Littell et al. 2002).

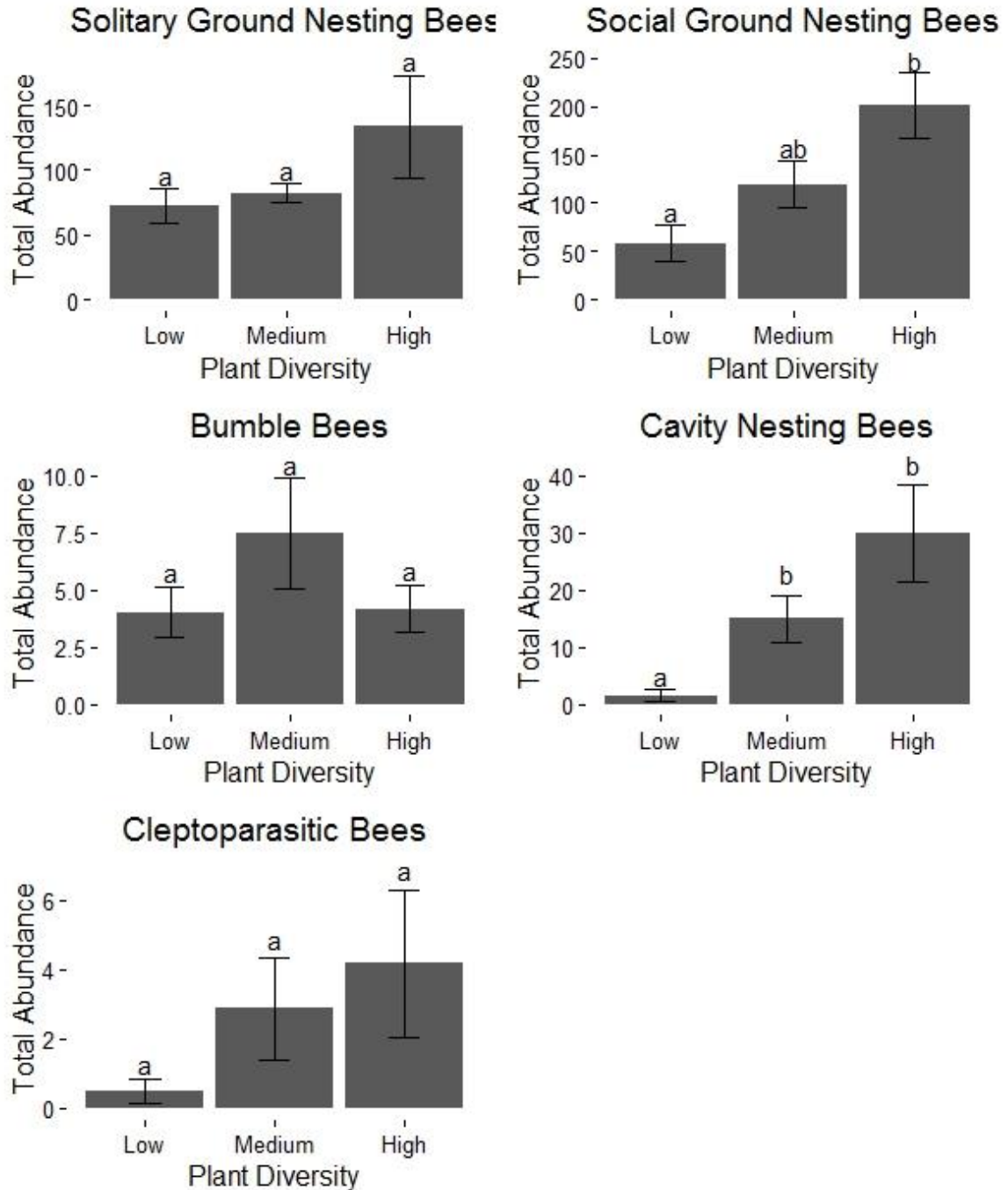


Figure 7. Total bee abundance in each plant diversity level for each guild of bees (solitary ground nesting bees, social ground nesting bees, bumble bees, cavity nesting bees and cleptoparasitic bees) across 2014 and 2015 in contour buffer and filter strips with standard error bars. The letters above the error bars indicate significance; sharing the same letter indicates no significant difference. (Mixed General Linear Model; Proc Mixed in SAS; Littell et al. 2002).

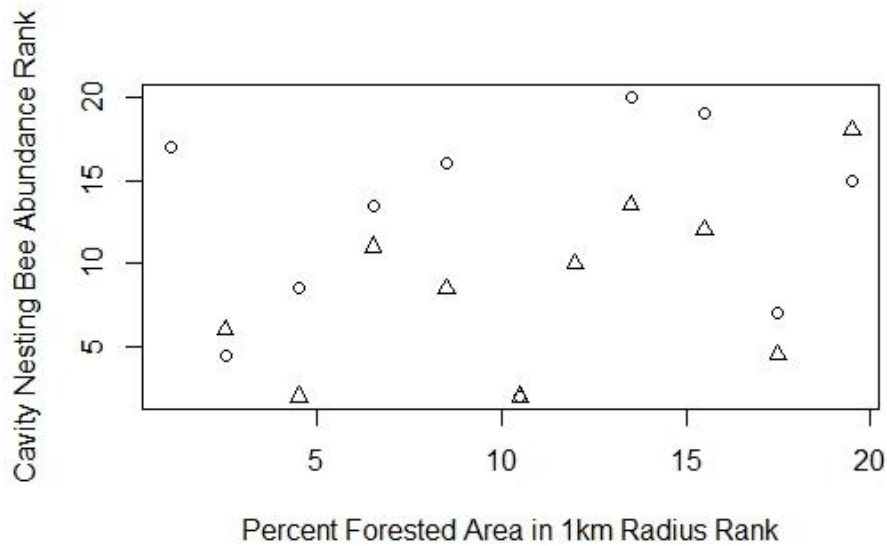


Figure 8. Scatterplot of ranked cavity nesting bee abundance within a year versus ranked percent forested area in a 1km radius of a contour buffer or filter strip using Spearman's Rank correlation ($S=942.67$, $\rho=0.2912255$, $p=0.2129$). 2014 points are represented as circles whereas triangles are from 2015. (Multiple Regression; Proc Corr in SAS; Littell et al. 2002).

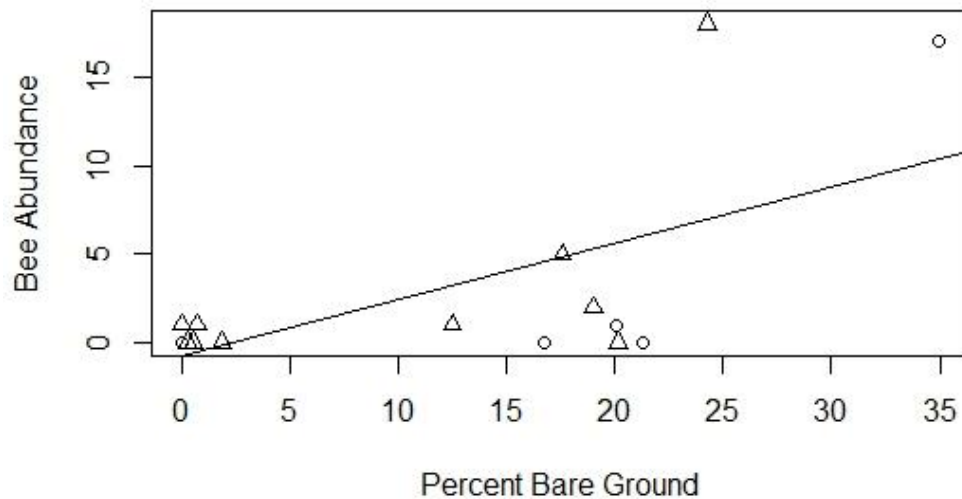


Figure 9. Linear regression of the average amount of bare ground at a site in 2014 (circles) and 2015 (triangles) versus the number of individuals found in emergence traps at that site ($R^2=0.4105$; $F_{18}=14.23$; $p=0.0014$). (Linear Regression; Stats package; R Development Team 2010).

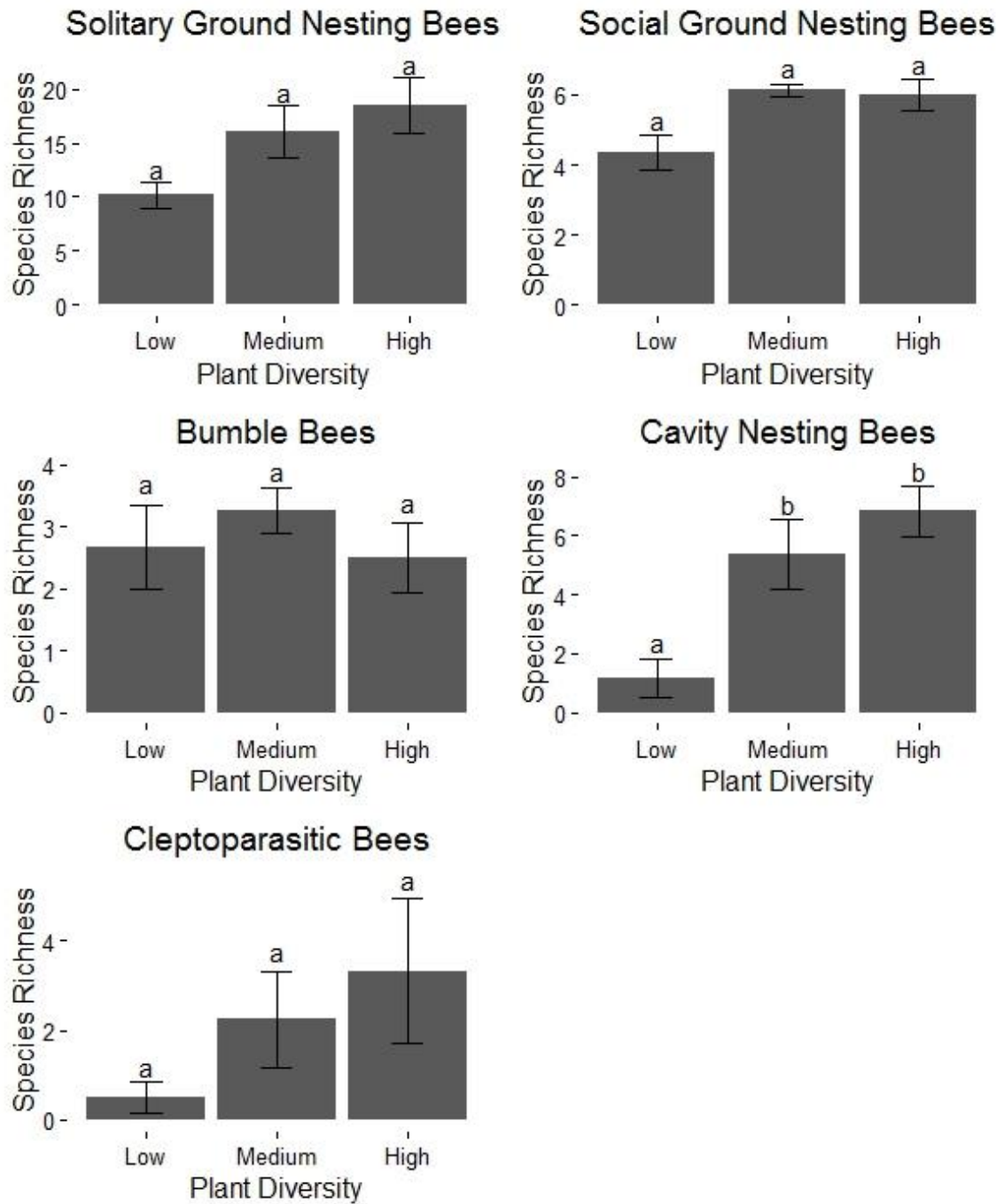


Figure 10. Total bee species richness in each plant diversity level for each guild of bees (solitary ground nesting bees, social ground nesting bees, bumble bees, cavity nesting bees and cleptoparasitic bees) across 2014 and 2015 in contour buffer and filter strips with standard error bars. The letters above the error bars indicate significance; sharing the same letter indicates no significant difference. (Pearson's Chi-Square; MASS package; Venables and Ripley 2002; R Development Core Team 2010).

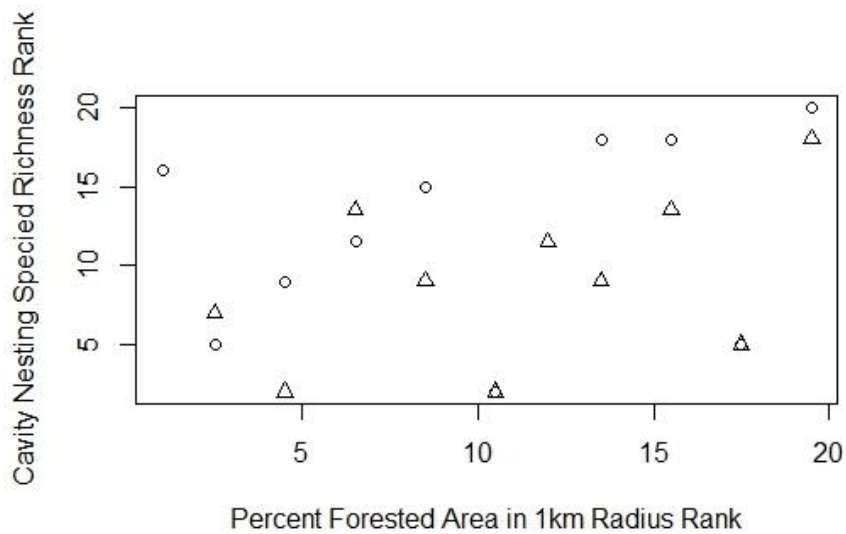


Figure 11. Scatterplot of ranked cavity nesting species richness within a year versus ranked percent forested area in a 1km radius of a contour buffer or filter strip using Spearman's Rank correlation ($S=914.28$, $\rho=0.312573$, $p=0.1797$). 2014 points are represented as circles while triangles are from 2015. (Spearman's Rank correlation; Proc Corr in SAS; Littell et al. 2002).

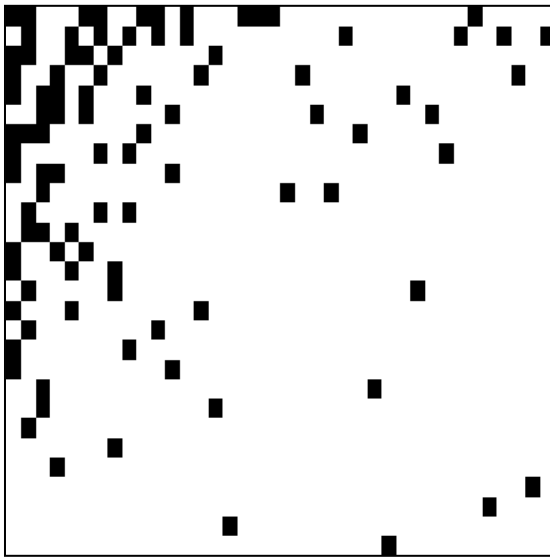


Figure 12. Nestedness matrix of bee-plant interactions. Plant species are the rows and species the columns. The upper left hand corner of the graph refer to the most general (most interactions with this particular bee or plant species) interactions with this particular species. Points beyond this corner represent more specialized interactions between bee species and plant species. Matrix temperature metric analysis was run in NeD and compared against the CE null model (Strona and Fattorini 2014).

**CHAPTER 3. INFLUENCE OF CURRENT CRP CONTOUR BUFFER AND
FILTER STRIP PLANT DIVERSITY ON THE TAXONOMIC AND
FUNCTIONAL DIVERSITY OF PREDATORY GROUND BEETLE
(COLEOPTERA: CARABIDAE) ASSEMBLAGES IN IOWA**

Modified from a paper to be published in *Basic and Applied Ecology*

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Abstract

Predatory ground beetles are generalist predators in corn and soybean fields that likely prey on various agricultural pests. Variation in body size among ground beetle species assemblages can contribute to their functional diversity within an agricultural system thus a more diverse beetle community may provide better crop pest suppression. In Iowa, contour buffer and filter strips are potential areas of habitat to which beetles can retreat from highly disturbed agricultural fields. This study used pitfall and emergence traps to assess assemblages of predatory ground beetles among contour buffer and filter strips of varying plant diversities. Beetles were identified to tribe and pronotum width and body, elytron and hind femur length measurements made. Body length was used as a proxy for body size when examining community composition. Taxonomically, there were no significant differences in abundance, tribe richness, or Inverse Simpson's Diversity among different plant diversities. The majority of beetles at each site were of medium or large sizes with few to no small or very small sized beetles. Overall, trends showed floral diversity positively influenced the probability of ground beetle assemblages containing

beetles from more size classes. While functional diversity is similar regardless of floral diversity, the small body sizes are missing among the Iowa agricultural landscape sites we examined.

Introduction

Ground beetles in the family Carabidae are generalist predators and have been demonstrated to provide the important ecosystem service of reducing agricultural pests (Menalled et al., 1999; Woodcock et al., 2010). Carabid beetles occur in corn and soybean fields as well as other agricultural crop fields and have been demonstrated to serve as an indicator of the overall natural enemy community (Larsen et al., 2003; Menalled et al., 1999; Woodcock et al., 2014). Although Carabids are considered generalists, individual species differentially utilize different sizes and life stages of various insect prey contributing to the functional diversity of the predatory beetle community (Jelaska et al., 2014).

For example, variation in beetle body size has been correlated with feeding rate; the larger the body, the more prey an individual beetle consumes (Kromp, 1999). Also, Carabid beetle body size is a contributing factor as to which prey or prey life stage is predated. For example, small Carabids are more proficient predators of Curculionid eggs whereas larger Carabids primarily will consume pupal and adult Curculionids. Among other types of prey, larger beetles more frequently consume lepidopteran larvae and pest coleopterans (Kromp, 1999). A shift towards the presence of only small or large Carabids could reduce the beetle assemblage impact on the agricultural pest community that may be present.

Although size variation within a beetle community could benefit crop production through enhanced pest suppression, one study has shown that as agricultural and human land use has intensified over the last 50-100 years in Belgium, Denmark and the Netherlands, few large beetle species remain in agricultural systems. This indicates a decrease the functional diversity of the beetle community in those areas (Kotze and O'Hara, 2003). Aviron et al. (2005) reported similar findings of more small bodied beetles in crop fields and larger bodied beetles in more woody areas. As large-bodied Carabid beetle species appear to be less tolerant of disturbance, they would be less likely to be found in agricultural systems where management practices occur at greater frequencies than in the past (Aviron et al., 2005; Ribera et al., 2001).

The landscape of the Midwest region of the US, in particular Iowa, is dominated by an intensively managed agricultural system producing primarily corn (*Zea mays* L.) and soybeans (*Glycine max* (L.) Merr.). Carabid beetles, as natural enemies, utilize a combination of crop and semi-natural habitats and Gardiner et al. (2010) hypothesized that when conditions are favorable, they will be found in crop fields more often than when it is less favorable. In many parts of Iowa, there are few semi-natural areas to which beetles can retreat. Non-production areas within a field are typically grass only waterways or contour buffer and filter strips planted with grasses or a mixture of grasses and forbs (United States Department of Agriculture, 2003; United States Department of Agriculture, 2011). These non-cropped areas within a field may provide beetle habitat in addition to that found in field margins.

The location of suitable beetle habitat can influence how frequently, how many and which prey species may be encountered by predatory beetles (Kromp, 1999;

MacLeod et al., 2004). From field margins beetles are able to reach prey at limited distances into the crop, but patches or strips of habitat within crop fields allow beetles to extend their reach (Collins et al., 2002; MacLeod et al., 2004). The authors referred to these British habitat patches within fields as ‘beetle banks’ which typically consist of various grasses, particularly tussock forming species (Collins et al., 2002). Other studies report that beetles were more likely to be found in areas planted with mixtures of flowering vegetation than in crop fields (Larsen et al., 2003; Varchola & Dunn, 1999; Woodcock et al., 2010). In northeastern Iowa, the highest beetle diversity was found in tallgrass prairie habitat surrounding soybean fields compared to surrounding woodlands or the soybean crop fields (Larsen et al., 2003). In addition, as plant diversity increased, so did the number of beetle species, increasing the functional diversity of these natural enemies (Larsen et al., 2003; Varchola & Dunn, 1999). Conservation Reserve Program (CRP) contour buffer and filter strips (United States Department of Agriculture, 2003; United States Department of Agriculture, 2011) planted with native tallgrass vegetation could provide habitat and refugia for a diversity of predatory beetle species within agricultural fields.

This study examines predatory ground beetle communities found among contour buffer and filter strips under current CRP contract planted with varying diversities of native tallgrass prairie vegetation within row-cropped fields in Iowa. Plant diversity among the strips we studied ranged from low (0-3 forb species) to strips with more than 15 native forb species. We address the following questions: (1) do strips of high plant diversity support a greater abundance, richness and diversity of Carabid beetles than

strips of low plant diversity; (2) do strips of high plant diversity support a greater diversity of Carabid beetle sizes than strips of low plant diversity?

Materials and Methods

Study Sites

We conducted all sampling in this study biweekly from June to August in 2014 and 2015 and additionally in late May in 2015 at farm fields with either contour buffer (9 sites) or filter strips (2 sites) of varying plant diversity in central and northeast Iowa. The strips ranged in age since installment from 2 to greater than 15 years. In 2014, three study sites were located in Jasper County, 2 of which were privately owned and 1 at the Neal Smith National Wildlife Refuge. The other sites were located on privately owned farms in each of the following counties: Buchanan, Carroll, Clayton, Dallas, Grundy, Guthrie and Story. After 2014, the Carroll County site was removed from the study by the landowner and in 2015 we sampled a site with a statistically indistinguishable ($t=-1.118$, $A=0.0217$, $p=0.133$; McCune and Mefford 2006) vegetation community in the adjacent Greene County. (Figure 1).

Contour buffer and filter strip study sites were assigned to 1 of 3 categories based on the diversity of native forb species found throughout the growing season. Our plant diversity categories were as follows: low 0-3 forb species (3 sites), medium 5-13 forb species (4 sites) and high greater than 15 forb species (4 sites). We used CropScape (USDA National Agricultural Statistics Service Cropland Data Layer 2014) 30 meter resolution Cropland Data Layer (CDL) landcover maps to delineate forested area within a 1 km radius of each strip and then calculated the percentage of forested landscape cover type.

Beetle Habitat Evaluation

We assessed floral resource and bare ground availability monthly within each strip. The percent cover of each species in bloom and percent bare ground within a square meter quadrat were estimated every 5 meters along a 60 meter transect for a total of 10 quadrats. We determined site plant diversity by summing the number of species among all sample dates.

Ground Beetle Sampling

Ground beetles were sampled using two techniques: pitfall and emergence traps. Pitfall traps were constructed using 17.8 cm wide plastic funnels with a 3.8 cm neck inserted into a collection bottle. The funnels were placed in the soil with the edge at the soil surface with a rain shield (plastic plate) placed above the trap. Three pitfall traps were spaced approximately every 20 meters along the 60 meter transects in the areas of bare ground amid standing vegetation. Standing vegetation in 1 square meter was removed at each of two emergence trap installations. Emergence traps were constructed of white polyester mosquito netting (H. Christiansen Co.) and 32 oz (946 mL) plastic screw top inverted funnel collection bottles containing propylene glycol (Prestone® Lowtox Antifreeze) as a preservative.

Pitfall and emergence trap contents were removed and placed in 70% ethanol every 2 weeks from June to August in 2014 providing 6 consecutive 2-week sampling collections. Bimonthly trap contents removal was repeated in 2015 beginning in mid-May resulting in 7 consecutive 2-week sampling collections.

Processing and Identification

Emergence and pitfall trap contents were washed and Carabid beetles pinned for identification to tribe using Arnett (1960). Pronotum width and elytron, hind femur and body length (from the front edge of the labrum to the distal end of elytra) of each beetle was measured following (Kotze & O'Hara, 2003).

Data Analysis

Ground Beetle Abundance, Richness and Diversity Analyses

We combined bimonthly beetle collections into 3 monthly collections in 2014 (June-August) and 4 in 2015 (May-August) due to numerous 2 week sample contents without beetles among all sites. We used repeated measures mixed general linear models to analyze total Carabid beetle abundance, tribe richness, proportions of tribes represented by 10 or fewer individuals and proportions of tribes represented by 1 individual among sites and plant diversity level and across dates (Proc Mixed in SAS; Littell et al. 2002).

We used Chao1 estimators to compare estimated tribe richness at each site and treatment (fossil package; Vavrek 2011; R Development Core Team 2010). Unlike rarefaction, Chao1, a non-parametric method, considers the number of rare tribes, singletons and doubletons, (tribes represented by one or two individuals), collected to estimate the total number of tribes that may be present including estimations of undiscovered tribes (Chao 1984; Colwell and Coddington 1994). Sites were compared using 7 samples each and analyzed using mixed general linear models (Proc Mixed in SAS; Littell et al. 2002). We combined data for the Carroll county (sampled 3 times in 2014) and Greene county (sampled 4 times in 2015) sites to attain 7 samples.

To test Carabid beetle diversity differences among sites, we calculated the Inverse Simpson's Diversity Index (vegan package; Oksanen et al. 2016; R Development Core Team 2010) and then analyzed differences with repeated measures mixed general linear models (Proc Mixed in SAS; Littell et al. 2002). All models used year as the repeated measure and site as a random effect with post-hoc Tukey pairwise comparisons to differentiate among plant diversity levels.

Site Characteristic Effects Analyses

We used multiple regressions to assess relationships between site characteristics and ground beetle diversity measures. To test the assumption of independence we ran Spearman-Rank correlations on the following parameters: average percent floral cover, the number of blooming species found within quadrats over a year, the frequency of blooming species, the average percent bare ground and the percent forest cover within a 1km radius. If two variables had a correlation (r value) above 0.7, the variables were considered correlated and one was chosen to be included in subsequent regression analyses (Proc Corr in SAS; Littell et al. 2002). Separate stepwise multiple regression analyses were run using total ground beetle abundance and total tribe richness as y variables and non-correlated strip characteristics as x variables. The variable entry and exit parameters were set at 0.05 (Proc Reg in SAS; Littell et al. 2002).

Carabid Beetle Community Analyses

To test for differences in Carabid beetle community compositions among plant diversity levels we used multi-response permutation procedures (MRPP) with Bray-Curtis (Sorensen) distance measures (PC-ORD) (McCune and Mefford 2006). MRPPs are non-parametric and test for differences in Carabid community compositions between

two or more groups (McCune and Grace 2002). We averaged the total abundances of each tribe for each site among all sampling dates except for the Carroll county and Greene county sites which each were sampled only for one year each.

Body Size

We used repeated measures mixed general linear models for pronotum width and body, elytron and hind femur length to examine average body size supported by a particular plant diversity level (Proc Mixed in SAS; Littell et al. 2002).

Beetle body-size community composition at each site was examined. Following Schweiger et al. (2005), individual beetles were assigned one of four categories based on body size: very small (<5.5 mm), small (5.5-9.0 mm), medium (9.0-14.0 mm) or large (>14.0 mm). The proportion of individuals in each size category was compared within each plant diversity level using repeated measures mixed general linear models in which year was the repeated measure and site a random effect with post-hoc Tukey pairwise comparisons to identify differences among plant diversity levels (Proc Mixed in SAS; Littell et al. 2002).

To examine the number of size categories represented at each plant diversity level we used an ordinal multinomial model with site as a random effect (Proc Glimmix in SAS; Littell et al. 2002). This model provided the cumulative probabilities of having 0, 0 or 1, 0 or 1 or 2, and 0 or 1 or 2 or 3 body size categories represented in each plant diversity level. The representation probability of all 4 size categories was not included in the analysis as only 1 site collection in a single trapping period contained individuals of all 4 body size groups. Each probability was calculated from combined sampling periods and years for each plant diversity category.

Results

Ground Beetle Abundance, Richness and Diversity Analyses

During 2014 and 2015 a total of 977 carabid individuals were collected and identified among 25 tribes. The majority of tribes were represented by 10 or fewer individuals at each site (68 and 100%) and at each level of plant diversity (63 and 74%) (Table 1). Furthermore, between 21 to 55% of ground beetle tribes collected among sites were represented by a single individual. Tribes represented only as singletons represented 13, 25 and 21% of total tribes collected at low, medium and high plant diversity sites, respectively. All tribes were not found at each site or plant diversity level, we did not find tribe richness to differ among plant diversity levels ($F_{2,7.83}=0.32$, $p=0.7376$). Similarly, total carabid abundance did not differ among plant diversity levels ($F_{2,8.31}=0.48$, $p=0.6367$) (Table 1).

The Chao 1 richness estimates varied by site with no particular level of plant diversity supporting higher estimated beetle tribe richness (Figure 2; Table 1). Chao1 estimates of beetle tribe richness did not provide overlapping 95% confidence intervals among the difference plant diversity levels as low diversity sites had the least estimated tribes and medium diversity sites had the highest estimated number of tribes (Figure 3; Table 1).

There were no significant differences among Inverse Simpson's Diversity measures among plant diversity levels ($F_{2,7.95}=0.62$, $p=0.5641$).

Site Characteristic Effects

Only two site characteristics were used as potential predictor variables for total abundance and total tribe richness models. The average percent floral cover and number

of blooming species within quadrats over a season, and frequency of blooming species in a strip were all highly correlated (Table 2) and we chose to include frequency of blooming species in the model. The frequency of blooming species and percent bare ground were also correlated. We chose to include the frequency of blooming species in our model as blooming species add vegetative structure for beetle habitat (Varchola & Dunn 2001). We also included percent forest cover due to its independence of the other parameters in the multiple regression analysis (Table 2). Overall, neither parameter was found to predict the total beetle abundance or tribe richness.

Carabid Beetle Communities

We found that there was no difference in carabid community composition among plant diversity levels ($T=0.706$, $A=-0.036$, $p=0.739$).

Body Size

There were no significant differences in body length or elytron length among plant diversity categories ($F_{2,8.87}=0.76$, $p=0.4948$; $F_{2,8.95}=0.40$, $p=0.6835$ respectively). Similarly, there were no significant difference in hind femur length or pronotum width among plant diversities ($F_{2,8.44}=0.33$, $p=0.7250$; $F_{2,8.27}=0.93$, $p=0.4340$ respectively) (Figure 4).

Neither body length nor the variation found within body length differed among plant diversity levels (Figure 5). There was no difference in the number of body size categories represented among levels of plant diversity ($F_{2,9.684}=0.07$, $p=0.9303$). The majority of the ground beetles collected in low and medium plant diversity levels were large, greater than 14 mm, followed by medium sized beetles, 9.0-14.0 mm. The majority of ground beetles collected at high diversity sites however, were medium sized beetles

followed by large sized beetles. All plant diversity levels significantly differed in the proportion of beetles in each body size group (low diversity: $F_{3,17}=15.15$, $p<0.0001$; medium diversity: $F_{3,24}=19.00$, $p<0.0001$; high diversity: $F_{3,16}=18.27$, $p<0.0001$). All plant diversity levels supported similar proportions of medium and large beetles and similar proportions of small and very small beetles. However, all plant diversity levels had significantly smaller proportions of very small and small beetles than medium and large beetles (Figures 6 and 7).

The probabilities of sites having beetles in any number of body size groups were similar among plant diversity levels. The cumulative probabilities were approximately the same for all plant diversity levels. The cumulative probability of each number of beetle size groups being represented was lowest for high plant diversity sites (Figure 8). Non-cumulative probabilities of each number of beetle size groups being represented were similar among all plant diversity levels. The medium diversity sites had the highest probability of having 0 body size groups represented or only 1 body size represented among all plant diversity levels. The probability of having 2 body size groups was highest at approximately 48% for all plant diversity levels. The high diversity sites had the highest probability (27%) of having 3 beetle size groups represented whereas medium diversity sites had the lowest probability (21%). There was nearly a 0% chance of any plant diversity level site having 4 body size categories represented (Figure 9).

Discussion

Our results show that the flowering vegetation present within a contour buffer or filter strip does not influence taxonomic or functional diversity of predatory ground beetles. Total abundance, tribe richness and community composition were not

significantly different among the plant diversity levels. Furthermore, no plant diversity level supported significantly larger or smaller ground beetles. More medium and large sized beetles were supported than small or very small sized beetles among all plant diversity levels. There also were similar probabilities among plant diversity levels of supporting a particular number of beetle size groups although high diversity sites did have a slightly higher probability of supporting as many as 3 beetle size groups than low or medium diversity sites.

Ground beetles utilize non-cropped land as overwintering habitat and refugia (Gardiner et al., 2010). Typically beetle supportive habitat consists of grasses, including tussock grasses (Collins et al., 2002), but beetles are also more likely to be found in areas which include forbs (Woodcock et al., 2010). However, we found no difference in ground beetle abundance across a range of forb diversities. The low diversity sites, at which vegetation predominantly consisted of a single grass species, had similar abundances of ground beetles as the sites with a high diversity of grass and forb species. O'Rourke et al. (2008) however, found that crop fields of perennial forbs such as alfalfa and triticale-alfalfa had higher abundances of ground beetles than crop fields of corn and soybean.

Woodcock et al. (2005) found that the types of grass species, tussock versus fine grasses, influenced ground beetle abundance in field margins. In their study, the forb diversity present was lower (11 species) in the tussock grass and higher (19 species) in the fine grass field margins. Their study only reports differences based on the grass types as the forb species in the different mixes were similar. In our study only species of forbs were identified and measured although each site also had grass species present. The types of grasses present at our study sites could have influenced beetle abundance.

Plant diversity also was not found to influence carabid tribe richness or diversity in our study. However, the low plant diversity sites most often supported the lowest beetle abundance and the fewest tribes in comparison to sites of greater plant diversity. Other studies report that some flowering plant mixtures support more diverse ground beetles (Larsen et al., 2003) and higher carabid species richness (Varchola & Dunn, 1999). Varchola & Dunn (1999) studied field borders in Iowa and found that the more vegetatively diverse field borders had similar ground beetle community compositions as simple grass borders, results similar to those of our study.

Previous studies tested richness at the taxonomic level of species (Collins et al., 2002; O'Rourke et al., 2008; Varchola & Dunn, 1999; Varchola & Dunn, 2001). Identifying the carabid species among the tribes collected in our study may allow detection of more subtle differences in beetle communities at that finer taxonomic scale. However, our investigation of carabid size classes reveals that contour buffer and filter strips with some forb diversity had a greater probability of supporting a greater number of size classes than sites of lower forb diversity indication that such plant diverse strips can provide ground beetle habitat within rowcropped fields.

Carabid community composition was similar among sites in this study in concert with forb diversity level having no significant effect on either beetle abundance or tribe richness. These results contrast with those of previous studies in which local plant species composition was a good predictor of the ground beetle assemblage (Schaffers et al., 2008). However, in our study the largest number of beetle individuals collected in each plant diversity level were of a single tribe, Opisthiini; members of this tribe accounted for between 30 and 40% of all individuals collected among all plant diversity levels. The

tribe Opisthiini is comprised of a total of 5 species contained within 2 genera, only one of which occurs in North America, *Opisthius richardsoni* (Bousquet & Smetana, 1991).

Hence, a large portion of the beetle community among all sites and plant diversity levels was of a single species and such a community will have very low functional diversity and be less likely to contribute significantly to crop-pest suppression. Similarly, other studies have found that the majority of beetles captured in or near agricultural fields in the Midwest have been of 5 or fewer species (Clark et al., 1997; Luff, 2002; O'Rourke et al., 2008).

In addition to Opisthiini, other tribes were present in our study and provided some diversity in contour buffer and filter strips, but diversity was similar among sites regardless of plant diversity. The majority (68-100%) of beetle tribes identified at each site were represented by fewer than 10 individuals with 21-55% of the tribes consisting of only one individual. Given such disproportionate distributions of beetle individuals among tribes it is not surprising that we found no significant differences in beetle diversity among study sites or levels of plant diversity. Other studies, such as Woodcock et al. (2005) and Varchola & Dunn (1999) report similar results with ground beetle diversity across various vegetation mixes in field margins.

Ground beetle size has been correlated with their dispersal and feeding abilities and may effect which prey or prey life stage is consumed (Kromp, 1999; Woodcock et al., 2014). Previous studies have found a lack of large ground beetles within agricultural fields (Aviron et al., 2005; Kotze & O'Hara, 2003; Ribera et al., 2001). Aviron et al. (2005) used body size to classify large beetles as those with total body length >15mm and small <5mm. They, found more small bodied and fewer large bodied ground beetles in

intensively managed agricultural fields and the larger beetles were found more frequently where there were woody elements in the landscape. Kotze & O'Hara (2003) report steep declines of large bodied beetles in three European countries with increasing proportions of small bodied beetles. In Britain, the most abundant beetles in agricultural contexts were small, <5mm in total body length (Woodcock et al., 2005).

In our study the majority of beetles were of medium and large sizes. Examining average body lengths revealed no differences among sites regardless of plant diversity level. But, the average body length was 13mm, which is not considered small. We did not collect ground beetles in the rowcropped portions of the fields and therefore cannot address possible differences from the beetle community in the strips. However, given consistent results from other studies in which the beetle community within crops was generally lacking larger beetles, it is possible that the contour buffer and filter strips examined in our study provide a more suitable habitat for larger beetles.

Large beetle species tend to be flightless and their ability to escape areas of disturbance is thus reduced resulting in greater numbers of small beetles with functional wings found in areas of frequent and intense disturbance such as crop fields (Aviron et al., 2005; Kotze & O'Hara, 2003). Coombes & Sotherton (1986) found that more of the beetles found in field margins tend to disperse by crawling or walking rather than by flying. Since most of the ground beetles found in the contour buffer and filter strips, regardless of plant diversity, were larger bodied, these strips may be providing good overwintering habitat and access into the cropped portion of the fields.

Several studies indicate that the presence of some flowering species in addition to grasses supports a higher abundance and diversity of ground beetles (Larsen et al., 2003;

Varchola & Dunn, 1999; Woodcock et al., 2010). In our study, there was a similar trend among the plant diversity levels in the varying probabilities of beetle size groups represented at a site. The probability of having 2 body size groups represented was highest for all plant diversity sites at approximately 47% and the majority of beetles collected at each level were of medium and large size. The probability of having 3 body size groups represented was highest for the high diversity sites with low and medium sites having similar, slightly lower probabilities. However, no very small beetles were found at any high diversity site. The medium diversity sites also consistently had the highest cumulative probabilities of having higher numbers of body size groups represented. These results indicate that the higher levels of plant diversity were providing better habitat for beetles. Nevertheless, low diversity sites had the best representation of all body sizes and consistently had representation probabilities between medium and high diversity probabilities making the relationship of plant diversity and beetle diversity unclear. Together these results indicate that increasing the diversity of forbs among grass in contour buffer or filter strips from 0 to as few as 5 species may sufficiently enhance habitat to support a more functionally diverse community of ground beetles.

Conclusions

The functional diversity of the ground beetle community supported among contour buffer and filter strips censused in this study was not necessarily high. The high numbers of individuals of a single beetle tribe found among all sites contributes to lowering functional diversity. In addition, primarily larger beetles were collected. Large beetles are often flightless and therefore have limited dispersal abilities that could result in lower crop-pest suppression than would be provided by smaller flying beetles. No

particular forb plant diversity level among contour buffer and filter strips was found to support significantly greater taxonomic diversities of predatory ground beetles. However, higher plant diversity was directly related to higher probabilities of the presence of beetles from more size classes which could contribute to greater functional diversity. These results suggest that by increasing the number of forbs among grasses in contour buffer and filter strips, from 0 to as few as 5 species, habitat may be sufficiently enhanced to support a more functionally diverse community of ground beetles.

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TABLES

Table 1. The number of beetle individuals and tribes observed at each site; the number of tribes and proportion of tribes with 10 or fewer specimens collected; the number of tribes and proportion of tribes with one individual represented; the Chao1 estimate with 95% CI from 9 samplings at each site of either contour buffer and filter strips across 2014 and 2015 (low diversity (LD): 0-3 forb species; medium diversity (MD): 5-13 forb species; high diversity (HD): greater than 15 forb species). Different letters within a column indicate statistically significant differences. (Proc Mixed; Littell et al. 2002).

Site Plant Diversity Level	No. Beetle Individuals		No. Beetle Tribes Collected		No. and Proportion Tribes with ≤10 Individuals		No. and Proportion Singleton Tribes		Chao 1 Tribe Richness (95% confidence interval)	
Bo Low	46	218	10	15	9 (0.90)	10 (0.67)	3 (0.30)	2 (0.13)	13 (13-13)	15.7
Mc Low	35	a	11	a	10 (0.91)	a	6 (0.55)	a	20 (15-25)	(14.9-16.4)
Sh Low	137		13		110 (0.77)		5 (0.38)		26 (18-33)	a
El Medium	97		17		14 (0.82)		6 (0.35)		23 (20-26)	
Ka Medium	78	534	14	24	11 (0.79)	15 (0.63)	4 (0.29)	6 (0.25)	18 (15-21)	36.4
Pl Medium	19	a	6	a	6 (1.0)	a	2 (0.33)	a	7 (6-8)	(29.4-44.4)
Sl Medium	340		19		13 (0.68)		4 (0.21)		22 (20-24)	a
Cr High	150		16		12 (0.75)		6 (0.38)		34 (24-44)	
NS High	25	225	12	19	12 (1.0)	14 (0.74)	5 (0.42)	4 (0.21)	15 (13-17)	21.7
Gr High	10	a	5	a	5 (1.0)	a	2 (0.40)	a	11 (11-11)*	(19.8-23.5)
Pe High	40		8		7 (0.88)		3 (0.38)			a

*High diversity site 3 and 4 data were combined for the Chao1 tribe richness estimate.

Table 2. Spearman-Rank Correlation coefficients and p-values for the average percent floral cover in a strip, number of blooming species found within quadrats over a year, frequency of blooming species, the average percent bare ground in a strip and the percent forest cover within a 1km radius strip. (Spearman's Rank Correlation; Proc Corr in SAS; Littell et al. 2002).

Spearman Correlation Coefficients, N=20 Prob > r under H0: Rho=0					
	Percent Floral Cover	Number of Blooming Species	Frequency of Blooming Species	Percent Bare Ground	Percent Forest in a 1km radius
Percent Floral Cover	1.00000	0.86363 p<0.0001	0.93524 p<0.0001	n/a	n/a
Number of Blooming Species	0.86363 p<0.0001	1.00000	0.93157 p<0.0001	n/a	n/a
Frequency of Blooming Species	0.93524 p<0.0001	0.93157 p<0.0001	1.00000	0.72910 p=0.0003	0.55703 p=0.0107
Percent Bare Ground	n/a	n/a	0.72910 p=0.0003	1.00000	0.43321 p=0.0564
Percent Forest in a 1km radius	n/a	n/a	0.55703 p=0.0107	0.43321 p=0.0564	1.00000

FIGURES

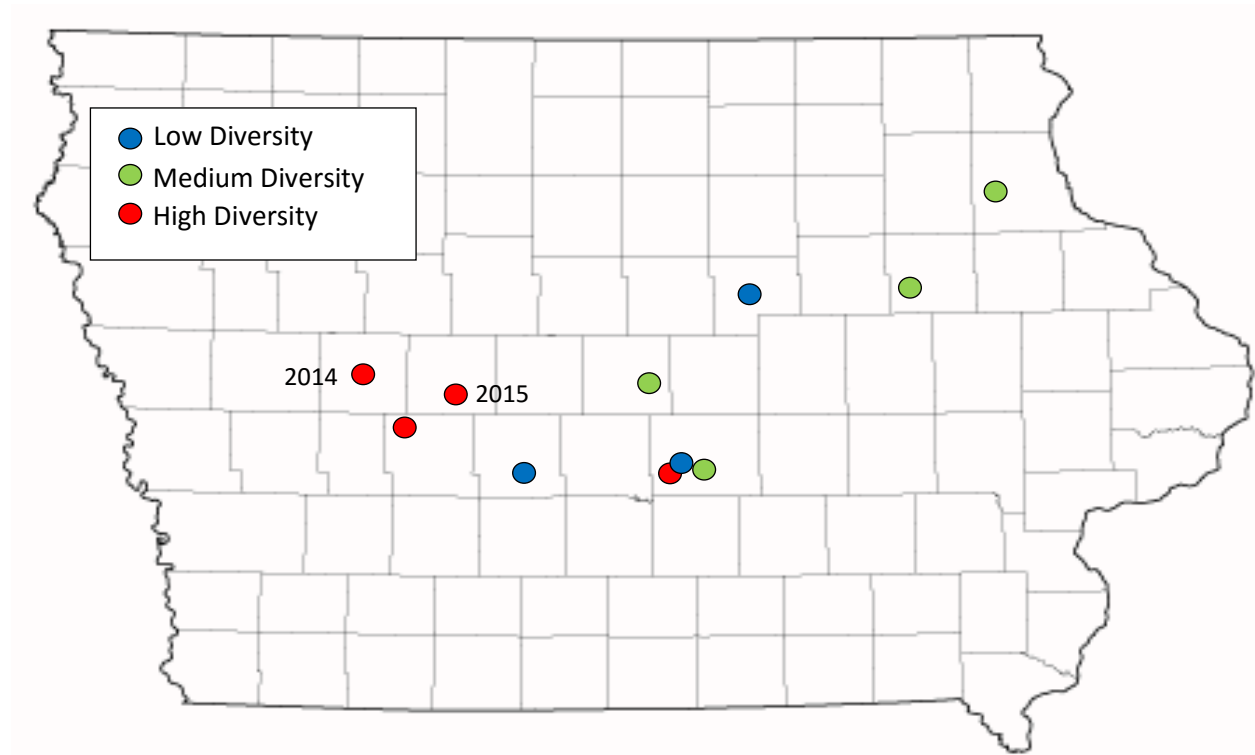


Figure 1. Study site locations and plant diversity type: low diversity (0-3 forb species), medium diversity (5-13 forb species) and high diversity (>15 forb species).

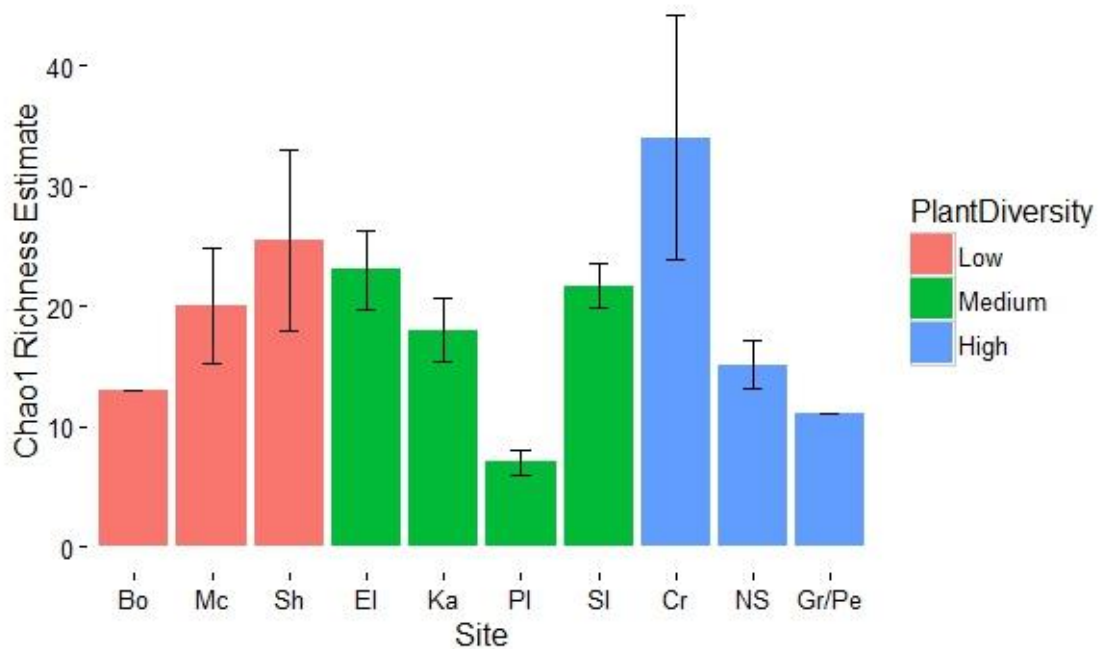


Figure 2. Chao1 tribe richness estimate for each site calculated after 7 samples from each site with 95% confidence intervals. (Chao1 estimate; fossil package; Vavrek 2011; R Development Core Team 2010).

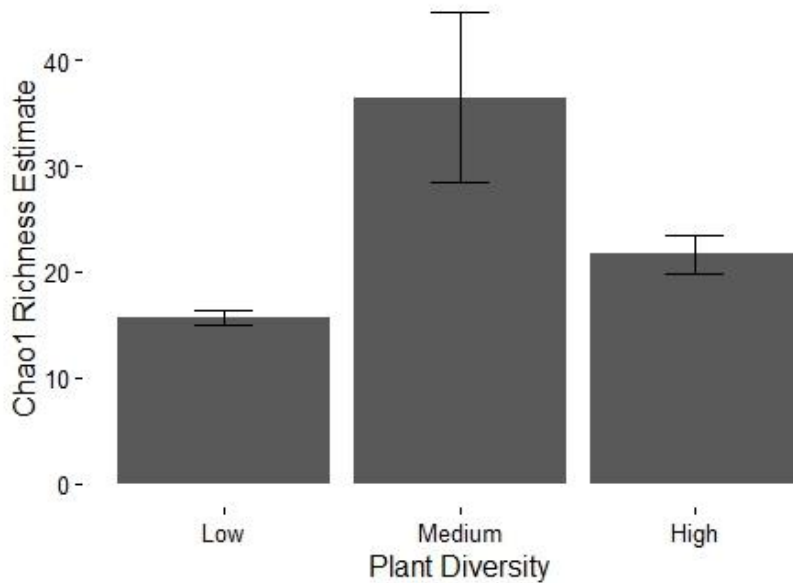


Figure 3. Chao1 tribe richness estimate for each plant diversity level after 21 samples with 95% confidence intervals. (Chao1 estimate; fossil package; Vavrek 2011; R Development Core Team 2010).

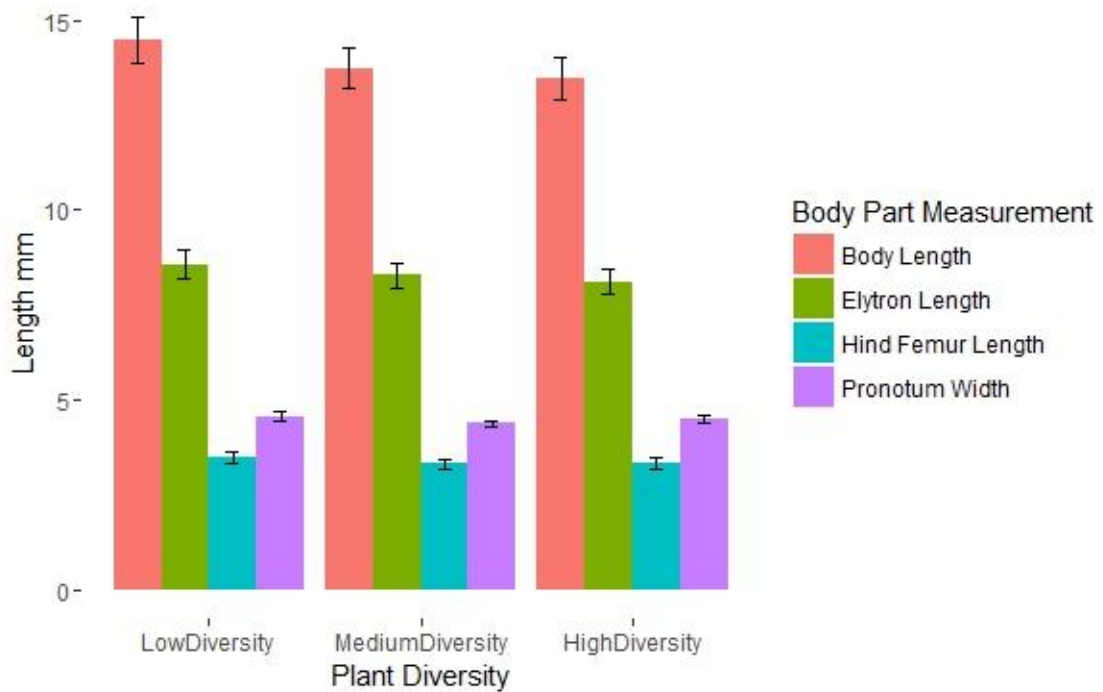


Figure 4. Mean pronotum width and body, elytron, and hind femur length of carabid beetles for each plant diversity level. Low diversity (0-3 forbs), medium diversity (5-13 forbs) and high diversity (>15 forbs). (Proc Mixed; Littell et al. 2002).

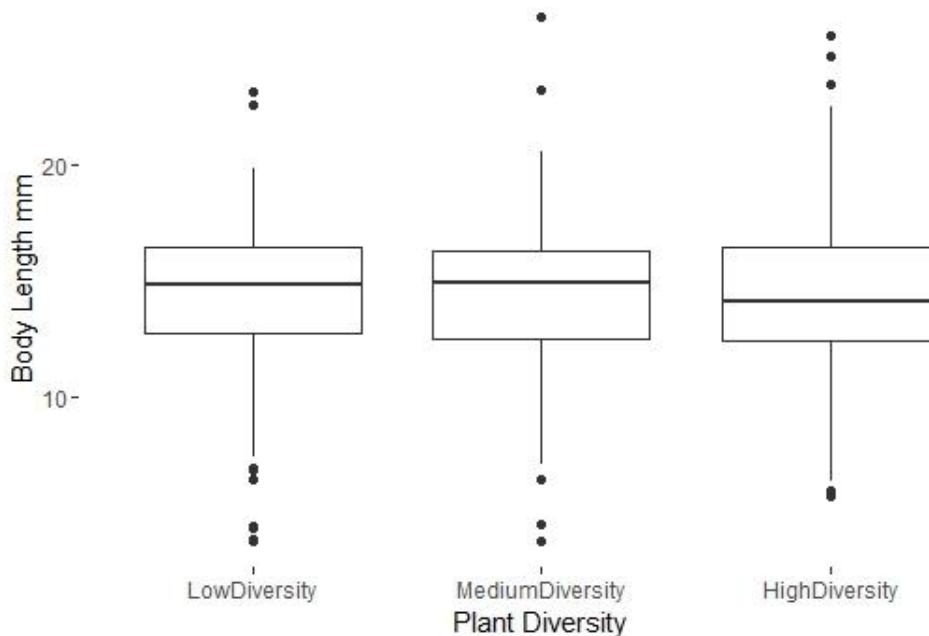


Figure 5. Box plot of body lengths of ground beetles collected at sites of different plant diversity levels: low diversity (0-3 forbs), medium diversity (5-13 forbs) and high diversity (>15 forbs). (Proc Mixed; Littell et al. 2002).

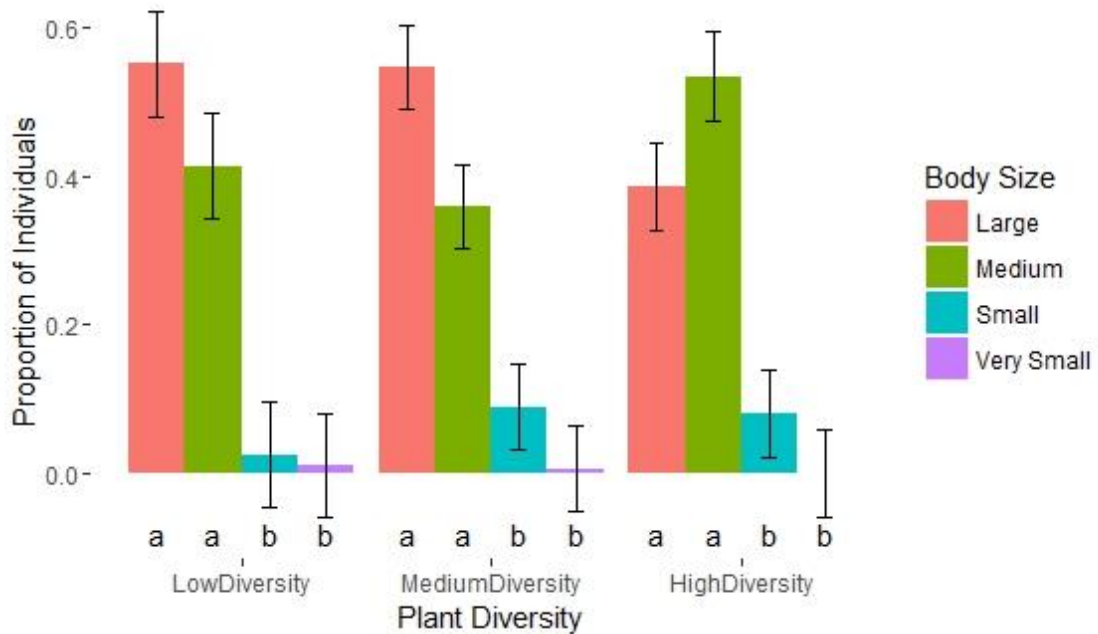


Figure 6. The proportion of ground beetle individuals in each plant diversity level for each body size group. Low diversity (0-3 forbs), medium diversity (5-13 forbs) and high diversity (>15 forbs). (Proc Mixed; Littell et al. 2002).

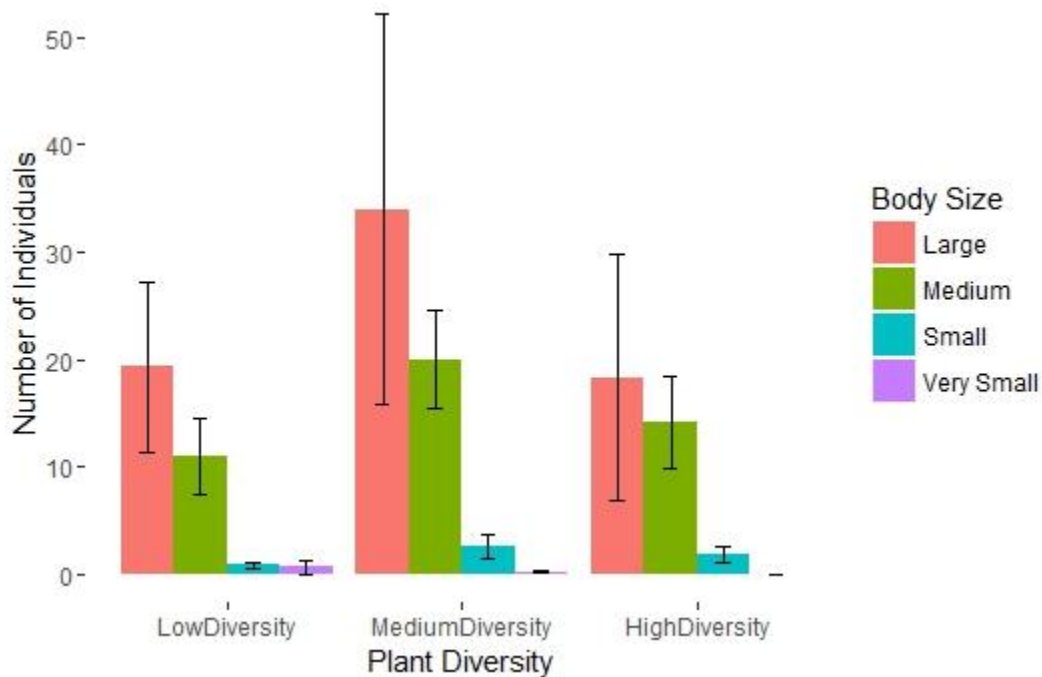


Figure 7. Number of ground beetle individuals found in each body size category in each plant diversity level. Low diversity (0-3 forbs), medium diversity (5-13 forbs) and high diversity (>15 forbs).

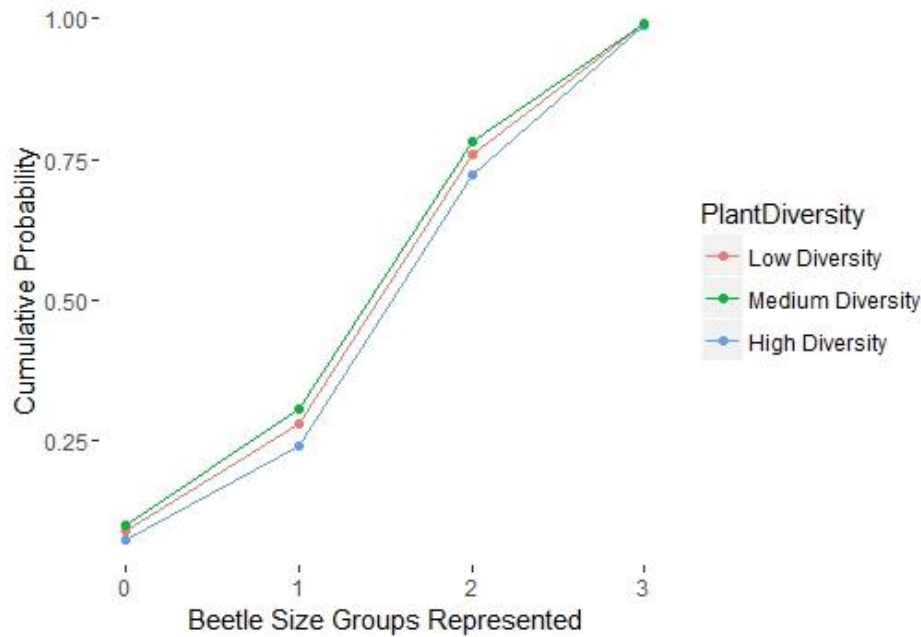


Figure 8. Cumulative probabilities of each plant diversity level having a different number of ground beetle size categories represented. Low diversity (0-3 forbs), medium diversity (5-13 forbs) and high diversity (>15 forbs). Probabilities were generated using an ordinal multinomial regression in SAS (Proc Glimmix; Littell et al. 2002).

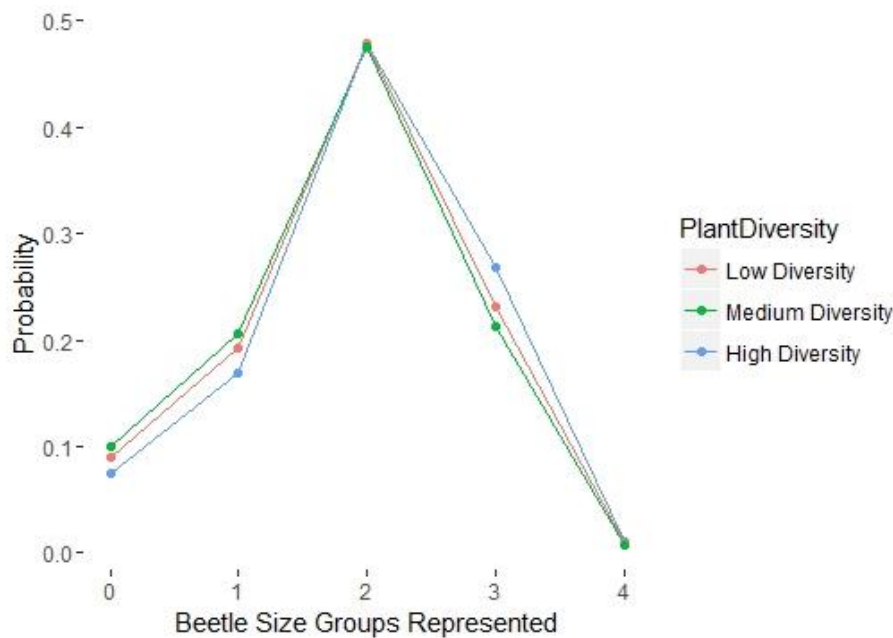


Figure 9. Individual probabilities of a plant diversity level supporting different numbers of ground beetle size groups. Low diversity (0-3 forbs), medium diversity (5-13 forbs) and high diversity (>15 forbs). The probabilities and plot were generated in R (R Development Core Team, 2010).

CHAPTER 4. GENERAL CONCLUSIONS

Summary

With Iowa's landscape dominated by agricultural land, there is little semi-natural or natural habitat in the landscape for beneficial insects to utilize. Various farming practices include small tracts of land potentially available to provide wildlife habitat within the agricultural matrix. Such potential habitat includes contour buffer and filter strips located within the rowcropped field. However, the plant communities within these strips vary greatly from all-grass to grasses with high forb diversities. This study investigated contour buffer and filter strips of several levels of plant diversity as potential habitat for native bee communities and predatory ground beetle assemblages.

This study demonstrates that better habitat for native bee communities was provided as the diversity of floral resources increased. The number of bee species and individuals increased as plant diversity increased within contour buffer and filter strips. These results are similar to studies in Europe examining different Agri-Environment Schemes (AES) as habitat for pollinators. As the floral resources increased in AES habitat, bee abundance and richness increased (Haaland et al. 2011; Kells et al. 2001; Korpela et al. 2013; Pywell et al. 2006; Scheper et al. 2013). However, this study found no difference in bee diversity among plant diversity levels in contrast to the results of other studies such as Morandin and Kremen (2013) which examined native bee diversity in hedgerows.

Bee guilds reflect the differing nesting habits among bee species. Overall trends among all guilds, except bumble bees, suggested that strips of higher plant diversity supported higher bee abundance and species richness than low diversity sites. However,

numerous bee species are ground nesters and require areas of bare ground. Floral diversity in this study was correlated with the amount of bare ground in a strip. As floral diversity increased the amount of bare ground increased as well. In higher plant diversity sites we found a higher ground nesting bee abundance in emergence traps. Future studies could examine ground nesting communities in high plant diversity contour buffer and filter strips and compare the findings to communities in large areas of high diversity semi-natural habitat. This comparison could elucidate how successfully ground nesting bees utilize small areas of available habitat within an agriculturally dominated landscape.

Native bees also need floral resources and in this study as the growing season progressed, floral species present varied along with the bee abundance and species present. From early May through August, high plant diversity sites consistently had significantly higher abundances of bees present than low plant diversity sites. Bee species richness, on the other hand, was only significantly higher in high plant diversity sites in May and June. Even though floral species present changed over time all of the high diversity sites had the four floral species Harmon-Threat and Hendrix (2015) found to be particularly attractive to bees. The bee communities that are supported across Iowa interact with various plant species such as those identified by Harmon-Threat and Hendrix and those interactions are not random. The majority of interactions take place between generalist bees and generalist plants with fewer interactions between specialist bees and plants suggesting that plant mixes with generalist floral species could be beneficial to a higher abundance and number of bee species.

Contour buffer and filter strips regardless of vegetation diversity supported taxonomically similar predatory ground beetle tribe assemblages in Iowa. A large portion

of beetles collected in each plant diversity level was represented by a single tribe, likely contributing to lowered functional diversity. The size of ground beetles correlates with feeding and dispersal rates. Larger beetles are often flightless and are limited in their ability to disperse potentially limiting the ability to suppress crop pests consumed by smaller flying beetles. This study found the majority of beetles among all sites to be of medium and large size with an average body length of approximately 13mm. These results contrast with those of European studies in which few large ground beetles were found in agricultural fields (Aviron et al. 2005; Kotze and O'Hara 2003; Ribera et al. 2001). However, a higher plant diversity was related to higher probabilities of the presence of beetles in more size categories. Based on our results, increasing forb diversity from 0 to 5 or more species in a contour buffer or filter strip could enhance a strip's likelihood to support a more functionally diverse community of ground beetles.

Overall, this study has contributed to the growing knowledge base of potential habitat sources for bee pollinators and predatory ground beetles within agriculturally dominated landscapes. With the loss of semi-natural habitat, contour buffer and filter strips with high diversity vegetation mixes better support native bees than strips of grass-only vegetation. Contour buffer and filter strips in general are providing habitat for similar predatory ground beetle assemblages regardless of plant diversity but the addition of a few forbs could provide support a more functionally diverse assemblage. Understanding how current CRP contour buffer and filter strip vegetation mixes influence beneficial insect communities can improve future strip designs for increasing suitable habitat within the landscape.

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