Ground beetle response to prairie strips and their potential ecosystem service delivery in crop fields

by

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A thesis submitted to the graduate faculty

in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Co-majors: Entomology; Sustainable Agriculture

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Iowa State University
Ames, Iowa
2024

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ACKNOWLEDGMENTS

I want to express my deepest gratitude to my co-advisors, Drs. Lisa Schulte Moore and Matthew E. O’Neal, for their unwavering patience, immense support, and continuous encouragement throughout my master's program. Special thanks go to my Plan of Study Committee – Dr. Matthew E. O’Neal, Dr. Lisa Schulte Moore, Dr. Anna Tucker, and Dr. Gregory W. Courtney – for their invaluable assistance and insightful feedback on my project. I would like to thank Grass2Gas (USDA-NIFA) for the source of funding as well as the soybean checkoff program, specifically the North Central Soybean Research Program, that helped support me through research assistant during the growing seasons. I am also deeply thankful to my technicians, Yojana Leon and Lalitaambiga Balakrishnan, for their guidance and for allowing me the opportunity to learn from them. To my lab mates in the O’Neal and Hodgson Labs and all those in the Department of Plant Pathology, Entomology, and Microbiology, as well as the NREM recreation basketball team, thank you for your friendship and advice during my time at Iowa State. I am grateful to the Ronald E. McNair program at Iowa State University for equipping me with the necessary tools to reach where I am today. Gracias a mi familia por apoyarme durante mis estudios y por el amor que me han dado. To my wife, Alejandra, thank you for your love, your encouraging words, and for giving me the drive to keep going strong.

ABSTRACT

Vegetative conservation practices in the U.S. Midwest promote soil health and reduce nutrient runoff by adding perennial vegetation within and around agricultural fields. While most vegetative conservation practices are planted as a monoculture, prairie strips are a relatively new practice composed of a diverse suite of native grasses and forbs that is expected to support a diverse faunal community. In this thesis, I describe two experiments conducted in Iowa, USA, to evaluate the influence of prairie strips on ground beetles (Coleoptera: Carabidae) and the removal of ground-beetle prey within adjacent corn (*Zea mays*) and soybean (*Glycine max*) fields. The first experiment used a paired design to compare beetle communities in fields with and without prairie strips and found that prairie strips supported significantly higher beetle activity-density and greater species richness. The second experiment assessed the effect of grassed waterways and prairie strips on the ground beetle community and their potential predation on prey within adjacent crop fields. I found significantly higher activity-density for ground beetles inside crop fields compared to grassed waterways and prairie strips. I observed the lowest predation in traps that occurred near multiple prairie strips compared to traps inside the crop field and adjacent to grassed waterways. I found larger female body length in the paired prairie strip compared to male beetles in the crop only configuration. I also found pronotum length was larger in beetles in the paired prairie strip compared to other landscape configurations. I also observed differences in body mass after lipid removal. Overall, these studies provide insights into the potential use of prairie strips as both a conservation and an integrated pest management strategy. Insights from these projects can inform future research on the strategic integration of grassland land cover within annual crop fields to synergistically achieve production and conservation outcomes.

CHAPTER 1. GENERAL INTRODUCTION

Agriculture has changed dramatically over the last century in an effort to feed a growing number of people and has become the dominant land use globally (Ellis et al. 2020). In Iowa – a leading agricultural state in the US Midwest – 80% of the landscape was historically dominated by diverse, native grasslands called prairie (Santelmann et al. 2004), but less than 0.1% of those native prairies remain today (Li et al. 2023, Matson et al. 1997, Samson and Knopf 1994). Iowa agriculture is presently dominated by extensive monocultures of two annual crops, corn (*Zea mays*) and soybean (*Glycine max*; Brown and Schulte 2011). While highly productive, associated tillage, fertilizer, and pesticide use is typically associated with negative impacts on soil health, water quality, and biodiversity (Schulte et al. 2017). Many Iowans, including farmers and farmland owners, expect agriculture to provide a broader suite of beneficial outcomes (Schulte et al. 2017) and are willing to invest in methods to provide them (Khanal et al. 2022).

Vegetative Conservation Practices

Vegetative conservation practices are used in many places to protect cropland from erosion and ameliorate the negative effects of agricultural production on the environment (Asbjornsen et al. 2014, Martin et al. 2019). There are many types of vegetative conservation practices listed by the United States Department of Agriculture-Natural Resources Conservation Service (USDA-NRCS), including grassed waterways, vegetated buffers, filter strips, and riparian forest buffers (Dabney et al. 2006, DeLong et al. 2021). Grassed waterways (CP 412) are graded channels with perennial vegetation commonly placed in portions of fields susceptible to erosion and are arranged to shift surface water at a non-erosive velocity. This practice was recognized by the USDA Soil Conservation Service in 1947 and is placed in natural drainageways where water drains from all sides. The grassed waterway's shape and size can be variable and must meet the requirements provided by the USDA-NRCS Engineering Field Handbook (Part 650 Chapter 7). Species in the grassed waterway must reach sufficient density, height, and vigor within a specified time frame to ensure the waterway's stabilization. Prairie strips (CP-43) are a new practice within USDA's Conservation Reserve Program (CRP) and are less commonly used at present. Prairie strips are continuous plantings of native perennial vegetation established within row crop fields that do not exceed 25% of the cropland (USDA 2019). Prairie strips were recently included in the 2018 farm bill, which allows farmers to receive financial benefits for implementing this practice (Agriculture Improvement Act 2018). Prairie strips increase water quality by reducing water runoff, phosphorus and nitrogen load, support wildlife, and increase biodiversity in adjacent crop fields (Liebman et al. 2013, Schulte et al. 2016, 2017, Schuck et al. 2017). Prairie strips increase the community and abundance of beneficial insects (Landis et al. 2005, Cox et al. 2014, Kordbacheh et al. 2020, Kemmerling et al. 2022, Borchardt et al. 2023), which could spill over into the adjacent field.

Insect Communities and the Family Carabidae

Insects are well known to affect crop production. Several insects are pests that can cause severe damage to many types of crops (Scudder 2017, Belluco et al. 2023). Many more species of insects living in agricultural environments can provide benefits, however, including pollination, soil movement, and biological control that promote stability (Landis et al. 2005). Beneficial insects can also provide biocontrol by preying on insect pests and weed seeds. Prairie strips increase the abundance of beneficial insects in the orders Coleoptera, Orthoptera, and Hymenoptera (Kemmerling et al. 2022, Kordbacheh et al. 2020).

Within Coleoptera, ground beetles (Family: Carabidae) are generalist predators found in many areas of the world. Carabidae is an extensive family of insects, with both larval and adult stages of most species being predators (Larochelle and Larivière 2003, Holliday et al. 2014). Carabid adults can range from 2-35 mm and may live up to four years (Lovei and Sunderland 1996). Carabids are known to consume weed seeds, soft-bodied insects, and animal material. Carabids are also found in many habitats, including grasslands, forests, and mountainous regions (Thiele 1977, Larochelle 1990). Many studies have also found that carabids occupy arable cropland and can be abundant in these areas (Kromp 1999). In studies investigating the community in cropland, researchers have found that surrounding vegetation, including grasslands, wildflower strips, and forests, increases the community and abundance of carabids (Carmona and Landis 1999, Bianchi et al. 2006, Kromp 1999).

Purpose of research and thesis organization

The aim of this research is to understand the potential influence of prairie strips on the ground beetle community in crops in Iowa and the associated ecosystem service of biocontrol. Because prairie strips are a new conservation management practice in the Midwest, their effects on the carabid community are unknown. Prairie strips are composed of diverse, native, and perennial plant species that may provide habitat for a larger and broader community of carabids than either the cropland they reside within or vegetative conservation practices with limited plant diversity, such as grassed waterways or filter strips planted to smooth brome. If indeed prairie strips support a more robust carabid community, the associated ecosystem services may spill over to benefit the production of the surrounding crops. Investigating these patterns could aid farmers and landowners in making more ecologically sound management decisions for production and conservation.

My specific research objectives were to (1) characterize the ground beetle community in fields with and without prairie strips, (2) evaluate carabid activity-density based on vegetation cover in crop fields, and (3) evaluate the ecosystem service provided by carabids in the adjacent crop field. In Chapter 2, I report on a study of the ground beetle community in crop fields with and without prairie strips. In Chapter 3, I report on a study of ground beetle predation on insect pests, noting the implications that high resource areas play on predation in crop fields. Chapter 4 concludes this thesis with a summary of findings and suggests future research endeavors.

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CHAPTER 2. PRAIRIE STRIPS INCREASE THE DIVERSITY OF CARABID BEETLES IN IOWA CROP FIELDS

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Modified from a manuscript to be submitted to *Environmental Entomology*

Abstract

The global decline in insects in recent decades has implications for the delivery of ecosystem services, which is important for agricultural production. Prairie strips, which are composed of small, linear patches established to diverse, native, perennial grassland vegetation within crop fields, are designed to foster biodiversity and improve ecosystem services in agricultural landscapes. We determined the effect of prairie strips on the community of ground beetles (Coleoptera: Carabidae) inhabiting crop fields in Iowa, USA. We predict that prairie strips will increase carabid activity-density and species richness. In 2016 and 2017, we used eight paired corn (*Zea mays*) and soybean (*Glycine max*) fields managed with conventional practices to compare the ground beetle community in fields with (n=4; prairie strips) and without (n=4; control) prairie strips. We placed three pitfall traps in prairie strip fields along a 40 m transect inside the prairie strip, and traps inside the control field were placed along a 40 m transect 400 m into the field. Mean activity-density of carabids was different among site types, with 0.973 ± 0.226 carabids captured per sampling day in prairie strips and 0.258 ± 0.035 in control fields. We further found greater species richness (51 total species and 0.233 ± 0.028 species of carabids per sampling day) in prairie strips than in control fields (28 total species and 0.094 ± 0.010 species per sampling day). While the most abundant species were shared between prairie strip and control fields (*Harpalus pensylvanicus* (DeGeer), *Anisodactylus sanctaecrucis* (Fabricius), *Pterostichus melanarius* (Illiger), and *Poecilus chalcites* (Say)), prairie strips specifically harbor statistically greater numbers of omnivorous and carnivorous beetles than crop fields. Activity-density and richness also varied by block and were greatest during the months of July and August. Overall, our results indicate that conventional corn and soybean fields provide a habitat for a more robust community of ground beetles when they include prairie strips and fields with prairie strips may experience improved biological control of crop pests than those without.

Keywords: Agriculture, Biodiversity, Carabidae, Conservation Biological Control, Insect ecology

Introduction

Insects are declining worldwide (Potts et al. 2010, Wagner et al. 2021), including those that deliver ecosystem services, especially those needed for sustainable crop production, like crop pollination (Kremen et al. 2002) and biological control of pests (Rusch et al. 2016). Declines of biological control agents in crop fields, including carabids, are attributed to habitat loss and degradation as natural landscapes are replaced with agricultural fields (Kromp 1999, Geiger et al. 2010, Crowder and Jabbour 2014, Outhwaite et al. 2022). The loss of native vegetation can affect agriculture, as the insect biodiversity residing within can deliver ecosystem services to adjacent cropland (Isaacs et al. 2009).

Efforts to improve upon the natural control provided by the natural enemies of pests can be achieved through Conservation Biological Control (CBC, hereafter; Landis et al. 2000). CBC is a pest management tactic that aims to improve the carrying capacity of a target pest's natural enemies (Bale et al. 2008). One approach is introducing non-crop vegetation within crop fields to provide shelter and resources for natural enemies (Thies and Tscharntke 1979), such as ground beetles (Coleoptera, Carabidae). Carabidae is a large family with 40,000 species described worldwide. Close to 2,000 of those species occur in North America (Riddick and Capinera 2008), many of which are predators of insect pests and seeds of plants that are often weeds (Larochelle 1990, Larochelle and Larivière 2003). More suitable habitat for carabids is produced by reducing disruptive agricultural management practices such as limiting insecticide use (Lee et al. 2001) and tillage (Aviron et al. 2005, Shearin et al. 2007, Müller et al. 2022), allowing ground beetles free access to insect pests or weed seeds and increasing the complexity of the plant community within a habitat that has lost its biodiversity (Kulkarni et al. 2015). Examples of CBC that have increased the abundance and diversity of carabids include beetle banks and hedgerows (Varchola and Dunn 2001, Prasad and Snyder 2006, Fiedler et al. 2008), both vegetative practices that provide shelter for carabids from disturbances within the adjacent crop (Lee et al. 2001). Beetle banks and hedgerows are strips of perennial grasses and woody plants sown adjacent to the crop field, known to reduce soil erosion and increase ecosystem service delivery (Montgomery et al. 2020).

A similar conservation practice is prairie strips: areas of diverse, native, perennial, herbaceous vegetation (i.e., prairie) established within and at the edge of crop fields to improve their ecological function and conserve native species. Prairie strips are supported in the U.S. by USDA’s Conservation Reserve Program (CRP), also known as CP-43. A key objective of prairie strips is to limit the movement of water, sediment, and nutrients from crop fields. Prairie vegetation is thus established along contours within a field and at the downslope edge. The vegetation within prairie strips includes a mix of native grasses and forbs, increasing the insect community's abundance and diversity, especially pollinators (Schulte et al. 2017, Kordbacheh et al. 2020, Borchardt et al. 2023). To date, only a subset of foliar-based natural enemies (i.e., aphidophagous) have been studied in relation to prairie strips (Cox et al. 2014), with no evidence available on how ground-dwelling insects, such as carabids, may be affected.

Understanding carabid response at a species level is essential for estimating the effectiveness of prairie strips to support biological control (Vandewalle et al. 2010). Most carabids in North America are common, generalist invertebrates. Few carabids in North America are rare and endangered (e.g., *Elaphrus viridis* Horn*, Thalassotrechus barbarae* (Horn); Larochelle and Larivière 2003). The abundance status of ground beetles is related to their functional traits, such as feeding guild, availability of resources, dispersal traits, and geographic restrictions. While the cause of dispersal in common species is debated, species restriction is due to specialization, poor dispersal power, and geographical restriction (Lundgren and McCravy 2011, Kędzior et al. 2020). Semi-natural habitats can enhance the abundance of specialists. However, it has yet to be explored whether incorporating CBC within agricultural fields has the same outcome as for the entire field.

The capacity of carabids to serve as biological control agents is primarily determined by the feeding guilds to which member species belong (Lundgren and McCravy 2011). Carabid species can belong to several feeding guilds, including carnivores, omnivores, and herbivores (Larochelle 1990, Larochelle and Larivière 2003). Based on a subset of 1,054 carabid and cicindelid species (a family often grouped with Carabidae), Larochelle (1990) estimates that the majority are carnivores (59%), a moderate proportion are omnivorous (20%), and few are solely herbivorous (8%). Studies indicated that omnivores prey on both plants and insects. Because of this, omnivores have a high predation and biological control power (Lovei and Sunderland 1996). Dispersal and predation traits are context-dependent, and the extent of their changes with CBC needs to be explored to indicate their effectiveness.

To address these gaps, we evaluated the effects of prairie strips on the carabid community in central Iowa crop fields with and without prairie strips (i.e., two site types). We measured multiple attributes of the carabid community using pitfall traps that account for the activity-density of adults that must move to be captured. Activity-density is dependent on the density and the physical movement of beetles through the landscape (Thomas et al. 1998). In addition to reporting the species richness of the trap contents, we analyzed the feeding guild and breeding period of the adult carabid community. We predict that fields planted with prairie strips would have higher activity-density and species richness and host more rare species than fields without. We expect prairie strips to increase the activity-density and richness of adult carabids due to the diverse vegetation inside these strips (Kordbacheh et al. 2020, Kemmerling et al. 2022, Borchardt et al. 2023). We further predicted that the natural history (e.g., breeding period) of carabids would affect activity-density in crop fields.

Materials and Methods

Study region

This study was conducted in Iowa, USA. Iowa's climate is humid continental with four seasons. The average temperature in 2016 was 16.2 ºC, while the average monthly maximum and minimum temperatures were 30.0 ºC and -11 .1 ºC recorded in July and January, respectively (Iowa Environmental Mesonet 2024). In 2017, the average temperature was 15.8 ºC. The maximum temperature was 30.0 ºC in July, and the lowest was -7.8 ºC in January. The total precipitation was 1213.6 mm in 2016 and 764.8 mm in 2017; 2017 precipitation was 108 mm below the 30-year average. Topography in the state is undulating, with elevation in the study counties ranging 310 – 450 m above sea level. Soil types are predominantly loamy and are highly fertile (USDA NRCS 2022). The primary land use in Iowa and the four specific study counties is cropland for corn (*Zea mays*) and soybean (*Glycine max*) production.

Experimental design

Our study used a paired design in which the pairs of conventional crop fields—one with a prairie strip and one without—were considered a block. Each pair was located in one of four Iowa counties (Guthrie, Linn, Marshall, and Pottwattamie; Table 2-1 and Figure 2-1). Fields receiving a prairie strip treatment had 6-11% of the field area sown with a diverse mix of native prairie species, and the remainder of the field sown to row crops. This experiment was conducted from one to three years post-seeding, with the vegetation in each prairie strip varying by field. These data were collected as part of a larger experiment measuring the response of insects to prairie strips. A summary of prairie strip establishment and plant community composition within the prairie strips can be found in Kordbacheh et al. (2020). Control fields were entirely sown to row crops and were selected based on hosting the same crop, crop management and proximity to treated fields (1000-3000 m distant). There were fewer than 15 known fields with prairie strips in Iowa at the time of study site selection because prairie strips were a new practice. Fields selected for this study were chosen based on permission to access from the landowners and proximity to Ames, Iowa, where the field data collection crew was based.

Carabid collection

To account for phenological variation in the carabid community, data were collected at distinct stages of the growing season to measure activity-density and the amount of vegetation in crop fields. In 2016, samples were taken during five time periods between June and August, and in 2017, five-time periods occurred between May and September. Combining the time periods from both years, the overall sampling spanned over 18 weeks, with sampling days ranging from

14 to 39 days after pitfall traps were deployed. To standardize the sampling days between the two years, we grouped the sampling days into six three-week periods based on pitfall trap collections. However, for weeks 18-22, we grouped the days into a single four-week period due to the extended deployment of pitfall traps in 2017 compared to 2016.

Carabids were collected using pitfall traps constructed with 17.8 cm wide plastic funnels with 3.8 cm necks inserted into collection cups (1,000 mL) and filled with 500 mL of propylene glycol antifreeze (Prestone® Lowtox Antifreeze) to preserve carabids during sampling. In 2016 and 2017, three pitfall traps were placed inside prairie strips at 20 m intervals along one transect, and, in the control field, three pitfall traps were set at 20m intervals 400 m from the edge of the field.

Carabids were stored in a 70% ethanol solution until identified. Carabids were identified by species using the (Lindroth 1969) and Noonan (1991) keys, and names were standardized using Bousquet and Larochelle (1993). Beetles were classified by feeding guild based on Larochelle (1990) and Larochelle and Larivière (2003). For the purposes of this study, we placed carabids that feed on animal material and other insects into a ‘carnivorous’ category, carabids that feed only on plants into a ‘herbivorous’ category, and carabids that feed on a mix of plant and vertebrate/invertebrate material into ‘omnivorous’ category. Species for which we had no evidence of feeding guild membership were classified as ‘unknown.’ We further classified beetles as ‘spring breeding’ (summer larva), ‘fall breeding’ (winter larva), or ‘all season’ (reproduction extends from spring into the fall) based on the adult reproductive period. Adults for which no breeding data was available were classified as ‘unknown.’

Statistical methods

We analyzed carabid activity-density (i.e., total number of carabids collected), species richness, feeding guild membership, and adult breeding type on fields with and without prairie strips. Sampling dates were binned into six three-week periods to account for variations in sampling days that occurred in 2016 and 2017. We used a generalized mixed model with a negative binomial distribution to evaluate the data, employing the package "glmmTMB." Preliminary analysis indicated that a negative binomial distribution best fit the data (i.e. residual plots and contingency tables), which we used to measure activity-density and species richness. To control for known sources of variation, we treated year, block, site type, and sampling days as fixed effects in our model. Julian date and replication nested within site type and block were random effects in our models. The nested structure was used to account for the randomness associated with each pitfall trap in each transect by site type and block. All statistical analyses were performed in R (R Core Team 2022). Each pitfall trap was treated as an observation, and means are reported on a per-trap, per-day basis to account for the period each pitfall trap was deployed.

A one-way analysis (ANOVA) was conducted to compare the effects of site, sampling week, and site type on the activity-density and richness of feeding guilds and adult breeding. For all responses that showed significance, we performed a simple main effect contrast from the package "emmeans." A paired t-test with a Bonferroni correction was used to measure differences between means among block and field type using the pairwise function in R.

Results

Carabid activity-density

Over two years, we captured 2,299 adult carabids across all locations and sampling dates. Overall, activity-density of adult carabids varied significantly between field types (Table 2-3), with 3.78 times more carabids captured in the prairie strips as compared to the cropland of the control fields per day (Estimate = 0.70516, SE = 0.19526, $P = 0.0003$; Figure 2-2a). Our model revealed significant variation by block (Estimate = 0.5290, SE = 0.12100, $P \leq 0.0001$), with one block showing higher activity-density (RHO, Estimate = 1.4938, SE=0.33672) in the prairie strip (Mean = 1.78 ± 0.447 SEM) compared to the control (0.359 ± 0.121 SEM; Figure 2-3a). The year-to-year variation in activity-density was not significant (Estimate = -0.25497, SE=0.22644, P=0.2602); however, on average, 0.790 ± 0.189 beetles were captured per day in 2016 compared to 0.400 ± 0.109 in 2017

Carabid activity-density varied significantly by sampling weeks (Figure 2-4a). The most significant differences in activity-density between prairie strip (Mean = 2.01 ± 1.08 SEM) and control fields (0.216 ± 0.068, $P < 0.05$) per sampling day were observed in August (weeks 32-34). This largest difference observed was compared to mid-June (weeks 23-25, prairie strip 0.201 ± 0.041 and control 0.195 ± 0.051). This difference spans from 10.0 to 1.24 times more beetles captured per sampling day. Regardless of field type, the least activity-density was observed from May through early July (weeks 18-25).

Carabid richness

A total of 56 species were found across all locations and years of this study (Table 2-5). The mixed model revealed a significant difference in the number of species collected between field types, with species also varying significantly between years (Table 2-3, Figure 2-2b). Statistical differences in species richness among blocks were found per sampling day (Estimate = 0.4150, SE = 0.0688, $P \leq 0.0001$). A paired t-test revealed significant differences between site type and block, with RHO (Mean = 0.263 ± 0.039 SEM) and WHI (0.403 ± 0.086) prairie strip sites having the highest mean species richness compared to all other sites and site type (Figure 2-3b).

Overall, more species were found across sampling dates in the prairie strip sites compared to the control sites (Figure 2-4b). The year-to-year variation in species richness was significant, with an estimated difference of 0.4850 (SE = 0.1720, P = 0.0047). On average, there were 2.75 times more species captured per day in 2016 (mean = 0.228 ± 0.025) compared to 2017 (0.083 ± 0.010). Additionally, a paired t-test revealed species richness varied by sampling week (Figure 2-4b). Significant differences in species richness between site types occurred in August (weeks 32-34) compared to all other sampling periods ($P \leq 0.01$). The largest difference was observed between August and June (weeks 23-25), with prairie strips having, on average, 0.126 ± 0.023 species compared to control fields with 0.072 ± 0.014 species, translating to 3.33 to 1.90 more species per sampling day.

Overall, there were 2.48 times more carabid species captured per day inside the prairie strip than in the control field (Estimate = 0.6720, SE = 0.1010, $P \leq 0.0001$), with a total of 46 species found in the prairie strips and 35 species found in the crop portion of the control fields. Regardless of field type, 67% of the carabid community comprised the following four species: *Pterostichus melanarius* (Illiger), *Harpalus pensylvanicus* (DeGeer), *Anisodactylus Sanctaecrusis* (Fabricius), and *Poecilius chalcites* (Say). The most common species collected in control fields were *P. melanarius* (10% of total individuals) and *H. pensylvanicus* (7%). The most common species in prairie strips were *H. pensylvanicus* (29% of total individuals) and *A. sanctaecrusis* (12%). *Poecilius chalcites* were abundant in both prairie strip (8% of total individuals) and control (3% of total individuals) fields.

Guild Analysis

When summarizing the activity-density of feeding guilds, the majority of carabids collected in this study were omnivorous species, followed by carnivorous and herbivorous. For activity-density, 79.2% of active beetles were omnivorous, and 14.7% were carnivorous (Figure 2-5A). One-way analyses revealed differences in the activity-density for all feeding guilds by field type (Table 2-4; $P \leq 0.01$). On average, omnivorous beetles (Estimate= 0.5280, SE = 0.1890, $P = 0.0056$) were 3.61 times more active inside the strip (Mean = 0.731 ± 0.191 SEM) compared to the control (0.202 ± 0.033; Figure 2-6C). Active carnivorous beetles (Estimate = 0.11288, SE = 0.03464, $P = 0.0013$) were found to be 3.83 times more active inside the prairie strip (Mean = 0.153 ± 0.035 SEM) compared to the control (0.040 ± 0.008; Figure 2-6B). Block was found to be significantly different for all feeding guilds ($P<0.01$; Table 2-4). Sampling week was significantly different for just the herbivorous feeding types (Estimate = 0.0152, SE = 0.0046, $P = 0.0292$).

When summarizing the species of each feeding guild, omnivorous species comprised 64.3% of the total captured species, while carnivorous species comprised 22.7% (Figure 2-5B). One-way analysis of variance showed significant differences in the number of species per sampling day by site type for all feeding guilds. On average, there were 2.34 times more omnivorous species (Estimate = 0.0864, SE = 0.0198, $P \leq 0.0001$) in prairie strips (Mean = 0.150 ± 0.020 SEM) compared to control fields (0.064 ± 0.008; Figure 2-6C). For carnivorous species (Estimate = 0.0311, SE = 0.0063, $P \leq 0.0001$), there were 2.5 times more carnivore species in the prairie strip (Mean = 0.514 ± 0.006 SEM) compared to control fields (0.020 ± 0.003; Figure 2-6B). On average, 0.009 ± 0.002 herbivorous species were collected in the prairie strips compared to 0.001 ± 0.001 in the control fields (Estimate = 0.00790, SE = 0.00207, $P = 0.00018$; Figure 2-

6A). All feeding guilds showed significant differences by block (*P* ≤ 0.001). Additionally, sampling week was significantly different for omnivorous feeders (*P* = 0.0002).

When summarizing activity-density of carabids by adult breeding periods, the spring (56.0%) and all season (34.1%) breeders were the most abundant in both site types (Fig. 2-7A). A one-way analysis determined significant differences in activity-density of spring and all-season breeders by field type (Table 2-4). On average, there were 4.82 times (Estimate= 0.2480, SE=0.0605, *P*<0.0001) more active spring breeding beetles in the prairie strip (Mean= 0.313 ± 0.062 SEM) compared to the control (0.065 ± 0.014; Figure 2-8A left). When summarizing the all season breeders, there were 3.00 times (Estimate = 0.3349, SE=0.1541, *P*=0.0307) more all season breeders active in the prairie strip (Mean = 0.504 ± 0.154 SEM) than the control (0.169 ± 0.029; Figure 2-8C left). Further analysis revealed that block was significant for the all-season breeders and unknown breeding types (P<0.0001).

When summarizing the number of active species belonging to different breeding periods, the spring (44.5%) and all season (36.2%) breeding species made up most of the breeding types (Fig. 2-7B). On average, there were 3.70 times (Estimate = 0.0813, SE=0.0134, *P*<0.0001) more active spring breeding beetle species in the prairie strip (Mean = 0.111 ± 0.013 SEM) compared to the control (0.030 ± 0.054; Figure2-8A right). When summarizing the all season breeders, there were 1.57 times (Estimate = 0.0274, SE=0.0121, *P*=0.0242) more all-season breeding beetle species in the prairie strip (Mean = 0.074 ± 0.011 SEM) than the control (0.047 ± 0.008; Figure 2-8C right). One-way analysis also revealed that species with unknown breeding types were significant by field type (Estimate = 0.0219, SE=0.0070, *P*=0.0019). Block was significant for the activity-density of spring breeders (Estimate = 0.0163, SE=0.0069, *P*<0.0001). Sampling week was found to be significantly different for just the all season breeders.

Discussion

Overall, we observed that the establishment of prairie strips in a conventional crop field significantly increased the activity-density and species richness of carabids when compared to a similar location in a field without a prairie strip. Although the reported means are small, they represent means that were calculated over prolonged periods. The number of individual beetles and species richness were 3.78-fold and 2.48-fold larger, respectively, for fields with prairie strips than the control crop fields per sampling day. This increase was not uniform over the course of a growing season. When observing the community of carabids, we found statistical differences in species richness and variation when analyzed by sampling periods. The majority of beetles were collected after tilling and planting activities had ceased and crops had reached reproductive maturity. Peak activity-density and richness occurred in the middle of the growing season (July and August), which has also been found in similar studies (de Heij and Willenborg 2020). This is also the period of the growing season when prairie plant communities are robustly growing, and grass and forb cover reaches its maximum.

Our results suggest that prairie strips can contribute to a CBC program, as the most abundant beetles collected were omnivorous and carnivorous. Furthermore, omnivorous and carnivorous beetles were significantly more abundant in the prairie strip compared to the control. The four most collected species are classified as omnivorous and carnivorous species, including *H. pensylvanicus,* the most abundant species caught in both year's field types. This species is widespread throughout North America, from Canada to northern Mexico, and is known to feed on seeds, roots, and above-ground vegetation (Lindroth 1969). *Amara sanctaecrucis* is primarily a predator of weed seeds and occurs congruent with *H. pensylvanicus* (White et al. 2007, Kirk 1975). Although this species was not prevalent in 2017, it was the second most abundant in our study. Both have been considered potential natural enemies of weeds in the Midwest and predators of agricultural pests (Busch et al. 2021, Lindroth 1969). *Poecilus chalcites* is an exclusive predatory ground beetle known to eat many agricultural insects and weed pests (Kirk 1975), a native to North America and distributed throughout the United States and Southern Canada (Lindroth 1969). The extent to which the activity of these species may spill-over into the adjacent crop is unclear. Carabid species may prefer different vegetation types. For example, *P. melanarius* prefers crop fields (Renkema et al. 2012), while *Harpalus* spp. prefer more natural areas (Goosey et al. 2015). We did not measure the extent to which species feed on pests like *P. melanarius* (Loughridge and Luff, 1983, Hajek et al. 2007), which may spill-over from a prairie strip into the adjacent crop field. Future studies of the contribution of prairie strips to pest management should include a focus on if and to what extent this spill-over results in an increase in pest mortality.

The timing of carabid spill-over into the adjacent crop and possible ecosystem service delivery may occur later in the growing season, given the phenology of carabid activity and diversity. The general pattern of carabid activity-density observed in this study partially reflects the breeding habits of carabid species, with two distinct peaks in spring and autumn (Lovei and Sunderland 1996). Based on the classifications of Den and Den Boer-Daanje (1990), we summarized the community of carabids collected in this study as either spring breeders or fall breeders. From our collection, 35 species can be considered as spring breeders. Of the common species, three species can be described as fall breeders (*Amara obesa*, *Harpalus erythropus*, *H. faunus*). For our most abundant species, *A. sanctaecruci*s is a spring breeder. Due to the variability of breeding in *H. pensylvanicus*, *P. melanarius* and *P. chalcite*s can be classified as all season breeders (Table 2-5.).

The study of the impact of non-crop vegetation on carabid conservation has shown that diverse vegetation can hold a diverse assemblage of ground beetles and potentially increase their capacity to disperse (Lee et al. 2001, Eyre et al. 2016, Rischen et al. 2021). Perennial vegetation at the edge of a field is a refuge for carabids from agricultural management occurring in the adjacent crop field (Lee et al. 2001, Weibull et al. 2003). These non-crop habitats played a role in several studies that conserved some beetle assemblage after tillage and the application of insecticides. Non-crop habitats can protect beetles from disturbances and provide an area for carabids to breed (Rischen et al. 2021). These features also increased the activity of ground beetles with a capacity for dispersal into crop fields (Eyre et al. 2016; Rischen et al. 2021).

The surrounding landscape around crop fields can influence carabid activity-density and dispersal ability (Menalled et al. 1999, Gardiner et al. 2010, Martin et al. 2019, Philpott et al. 2019). While carabids primarily disperse via walking, they also possess the ability to fly, depending on their wing morphology. Within carabid species, wing morphology can be polymorphic, with individuals exhibiting either brachypterous (reduced wings) or macropterous (fully developed wings) wing types. Evidence suggests that wing polymorphism can be influenced by the surrounding landscape (Martin et al. 2019, Philpott et al. 2019). Although we did not measure the complexity of the landscapes surrounding our study fields, it could contribute to the observed variation in activity-density in certain fields and contribute to the significant effect of block in our study. The landscapes around the fields in our study ranged from other agricultural fields to oak savanna and riparian areas. The variation in the simplicity and complexity of these surrounding landscapes likely played a role in the dispersal of carabids into crop fields, thereby increasing their activity-density.

It is important to mention that Iowa experienced extreme weather in 2017, including both drought and higher-than-average temperatures (Zhang et al. 2022). This drought affected other insect-plant interactions, including foraging by honey bees (Zhang et al. 2022). Honey bees were able to find pollen in prairie plants that were drought tolerant, limiting the impact of the drought stress on their nutritional needs. To what extent this extreme weather contributed to year-to-year variation in our study is not clear, nor if prairie strips act as a refuge for carabids from this stress. While we found significant variation in species richness by year, we did not for activity-density. Prairie strip size and drought periods could have affected carabid assemblages (Brose 2003, Weibull et al. 2003, Goosey et al. 2015, 2019). Drought was shown to decrease species richness in wetland and forest areas (Kirichenko-Babko et al. 2020, Weiss et al. 2024). These factors may have limited the value of prairie strips for carabids potentially suffering from weather-induced stress.

Conclusion

This study adds to a growing body of research demonstrating that diverse vegetation cover positively affects beneficial insects in crop fields (Thies and Tscharntke 1979, Landis et al. 2000, Batáry et al. 2012, Marja et al. 2022). Overall, we found that prairie strips significantly increase the activity-density and species richness of carabids inhabiting corn and soybean crop fields in Iowa. Prairie strips support a more robust community of carabids, particularly carnivorous and omnivorous feeding guilds. These can function as natural enemies and provide carabid-related ecosystem services in adjacent crop fields. As a result, prairie strips may comprise a viable CBC practice for farms. By promoting carabid activity-density, species richness, and diverse feeding guilds, prairie strips can contribute to sustainable agriculture, integrated pest management, and biodiversity conservation.

Acknowledgments

We thank F. Kordbacheh, M. Liebman, and M. Harris for their leadership in the initial study design and field data collection and their willingness to share their data and methods with us. Foster Purrington performed all identification and measurements. Funding for data collection was provided by the USDA Agriculture and Food Research Initiative (Project 2015-67019-23002). Andres Vargas was supported by Iowa State University College of Agriculture and Life Sciences. We thank G. Courtney and A. Tucker for their comments to improve the initial version of this chapter.

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Tables and Figures

Table 2-1. Study field location, size, and management in Iowa.

County	Block	Year: Crop	Date Seeded	Prairie strip field size (ha)	Native species	Control field size (ha)
Pottawattamie	ARM	2016: Soy 2017: Corn	2014-11-20	8.09	41	28.16
Linn	EIA	2016: Soy 2017: Corn	2015-05-22	20.23	29	24.78
Marshall	RHO	2016: Corn 2017: Corn	2015-06-03	18.84	42	23.12
Guthrie	WHI	2016: Corn 2017: Soy	2015-12-18	31.4	NA	23.18

Table 2-2. Pitfall trap deployment and contents recovery dates. The time period between visits represents the sampling period, which varied by each site and year. These sampling periods are grouped into six three-week periods.

Site	Year	Sampling dates					
		Week 18-22	Week 23-25	Week 26-28	Week 29-31	Week 32-34	Week 35-37
EIA	2016		05/18-06/1, 06/1-06/15	06/15-06/30, 06/30-07/14	07/14-07/26,	07/26-08/9, 08/9-08/26	
	2017	05/12-05/29	05/29-06/13	06/13-07/12		07/12-08/6	08/6-09/15
ARM	2016		05/19-06/02, 06/02-06/16	06/16-07/15	07/15-07/27	07/27-08/10, 08/10-08/25	
	2017	05/6-05/22	05/22-06/15	06/15-07/10	07/10-7/31		7/31-09/04
WHI	2016		05/29-06/09, 06/09-06/23	06/23-07/07	07/07-07/20, 07/20-08/04	08/04-08/13, 08/13-08/17	
	2017	05/02-05/16	05/16-06/08	06/08-07/06	07/06-07/31		07/31-09/08
RHO	2016			06/14-06/28, 06/28-07/14	07/14-07/29	07/29-08/12	08/12-08/29
	2017	05/05-05/18	05/18-06/14		06/14-07/17, 07/17-08/01		08/01-09/04

Table 2-3. Carabid activity-density and species richness statistical results.

Model	**Intercept**	**df**	**Estimate**	**F ratio**	**Chi^2**	***P*-value**
Activity-Density	Year	1	-0.25497	1.268	1.268	0.26017
	Block	3	0.52900	7.650	22.950	<0.0001
	Field type	1	0.70516	13.043	13.043	0.00030
	Days	20	-0.61400	4.217	84.340	<0.0001
Species Richness	Year	1	-0.48480	7.979	7.979	0.00473
	Block	3	0.41500	12.718	38.154	<0.0001
	Field type	1	0.67210	44.331	44.331	<0.0001
	Days	20	0.53500	3.762	75.240	<0.0001

Table 2-4. Carabid feeding guild and larvae type one-way ANOVA statistical results.

Model		**Activity-density**						**Species richness**					
		df	**Estimate**	**Sum Sq.**	**Mean Sq.**	**F ratio**	***P*-value**	**df**	**Estimate**	**Sum Sq.**	**Mean Sq.**	**F ratio**	***P*-value**
Herbivorous	Block	3	0.00462	0.02448	0.008161	5.7668	0.00078	3	0.00142	0.00450	0.00150	5.1720	0.00173
	Week	5	-0.00618	0.01793	0.003868	2.5344	0.02919	5	-0.00418	0.00278	0.00056	1.9164	0.09195
	Field type	1	0.01521	0.01562	0.015623	11.0387	0.00102	1	0.00789	0.00420	0.00420	14.4832	0.00018
	Residuals	260		0.367692	0.001415			260		0.07544	0.00029		
Carnivorous	Block	3	0.01640	1.5146	0.50487	6.2338	0.00042	3	-0.00778	0.03770	0.01257	4.6274	0.00359
	Week	5	-0.09050	0.4997	0.09994	1.2340	0.29352	5	-0.01620	0.02393	0.00479	1.7626	0.12092
	Field type	1	0.11288	0.8601	0.86007	10.6196	0.00127	1	0.03108	0.06519	0.06519	24.0070	<0.0001
	Residuals	260		21.0571	0.08099			260		0.70606	0.00272		
Omnivorous	Block	3	0.31000	31.77	10.5915	4.3823	0.00497	3	-0.01950	0.6541	0.21802	8.2666	<0.0001
	Week	5	-0.45700	21.06	4.2124	1.7429	0.12517	5	-0.03600	0.6805	0.13609	5.1602	0.00016
	Field type	1	0.52830	18.84	18.8393	7.7949	0.00563	1	0.08640	0.5038	0.50383	19.1040	<0.0001
	Residuals	260		628.39	2.4169			260		6.8570	0.02637		
Unknown feeding	Block	3	0.00476	0.12153	0.040510	7.7597	<0.0001	3	0.00205	0.03643	0.01214	8.4500	<0.0001
	Week	5	-0.02620	0.02642	0.005283	1.0120	0.41101	5	-0.01570	0.00986	0.00197	1.3728	0.23485
	Field type	1	0.02670	0.04813	0.048130	9.2193	0.00264	1	0.01367	0.01261	0.01261	8.7723	0.00334
	Residuals	260		1.35734	0.005221			260		0.37362	0.00144		
Spring breeder	Block	3	0.04610	6.531.7	2.1771	8.8226	<0.0001	3	0.01630	0.07340	0.02447	2.0254	0.1107
	Week	5	-0.05900	2.785	0.5571	2.2576	0.04918	5	-0.06890	0.08440	0.01688	1.3975	0.2255
	Field type	1	0.24803	4.153	4.1526	16.8286	<0.0001	1	0.08134	0.44658	0.44658	36.9717	<0.0001
	Residuals	260		64.157	0.2468			260		3.14052	0.01208		
Fall breeder	Block	3	-0.00694	0.00973	0.00324	0.8520	0.4666	3	-0.00288	0.00084	0.00028	1.8951	0.13079
	Week	5	-0.00925	0.03489	0.00698	1.8326	0.1068	5	-0.00049	0.00138	0.00028	1.8826	0.09769
	Field type	1	0.01016	0.00697	0.00697	1.8298	0.1773	1	0.00232	0.00036	0.00036	2.4640	0.11770
	Residuals	260		0.98988	0.00381			260		0.03820	0.00015		
All season breeder	Block	3	0.21300	14.67	4.8908	3.0499	0.02916	3	-0.05750	0.35983	0.11994	12.1648	<0.0001
	Week	5	0.07520	14.63	2.9256	1.8244	0.10838	5	-0.00529	0.39019	0.07804	7.9146	<0.0001
	Field type	1	0.33489	7.57	7.5704	4.7209	0.03070	1	0.02739	0.05065	0.05065	5.1373	0.02424
	Residuals	260		416.93	1.6036			260		2.56360	0.00986		
Unknown breeder	Block	3	0.01970	1.041	0.34688	2.0001	0.11440	3	0.00150	0.09873	0.03291	10.0264	<0.0001
	Week	5	-0.06230	0.858	0.17155	0.9891	0.42482	5	-0.01050	0.03226	0.00645	1.9655	0.08414
	Field type	1	0.08844	0.528	0.52801	3.0445	0.08219	1	0.02190	0.03238	0.03238	9.8657	0.00188
	Residuals	260		45.093	0.17343			260		0.85344	0.00328		

Table 2-5. Carabid species collected during 2016-2017 by site type (C: control, PS: prairie strip, Both: control and prairie strip), feeding guild, breeding type (S: spring, F: fall, AS: all season, U: unknown breeding), and breeding period. Species feeding guild and adult breeding are presented based on the information provided by Larochelle (1990) and Lindroth (1961; 1963-1969), respectively. Species not discussed in the respected literature are marked as unknown.

Species	Site Type	Feeding Guild	Breeding Type	Breeding Period
Agonoleptus rotundicollis (Haldeman)	C	Unknown	U	Unknown
Agonum cupripenne (Say)	PS	Omnivorous	S	May-June
Amara aenea (DeGeer)	PS	Omnivorous	S	May-June
Amara angustata (Say)	Both	Omnivorous	U	Unknown
Amara avida (Say)	PS	Omnivorous	S	June-July
Amara ellipsis (Casey)	PS	Omnivorous	S	April-June
Amara exarate Dejean	C	Unknown	S	May-June
Amara impuncticollis (Say)	Both	Omnivorous	S	April-May
Amara littoralis Dejean	PS	Omnivorous	S	May-June
Amara obesa (Say)	PS	Carnivorous	F	August-October
Anisodactylus Agricola (Say)	C	Unknown	U	Unknown
Anisodactylus harrisii LeConte	PS	Omnivorous	S	April-May
Anisodactylus nigerrimus DeJean	PS	Unknown	S	June-July
Anisodactylus ovularis (Casey)	PS	Unknown	U	Unknown
Anisodactylus rusticus (Say)	Both	Omnivorous	S	June-July
Anisodactylus sanctaecrucis (Fabricius)	Both	Omnivorous	S	May
Bembidion mimus Hayward	PS	Unknown	U	Unknown
Bembidion quadrimaculatum oppositum (Say)	Both	Omnivorous	S	May-July
Bembidion rapidum (LeConte)	C	Unknown	U	Unknown
Bradycellus rupestris (Say)	PS	Carnivorous	U	Unknown
Calathus gregarious (Say)	C	Omnivorous	S	July
Calosoma externum (Say)	PS	Carnivorous	S	June-July
Chlaenius emarginatus Say	PS	Omnivorous	S	May-July
Chlaenius nemoralis O.F. Müller	Both	Omnivorous	U	Unknown
Chlaenius platyderus Chaudoir	Both	Omnivorous	U	Unknown
Chlaenius pusillus Say	Both	Carnivorous	U	Unknown
Chlaenius tomentosus (Say)	Both	Omnivorous	S	May-June
Chlaenius tricolor tricolor Dejean	PS	Carnivorous	S	May-June
Cratacanthus dubius (Palisot de Beauvois)	Both	Carnivorous	U	Unknown
Cyclotrachelus alternans (Casey)	Both	Omnivorous	S	June-July
Cyclotrachelus seximpressus (LeConte)	Both	Unknown	U	Unknown
Dicaelus elongatus Bonelli	Both	Carnivorous	U	Unknown
Dicaelus sculptilis Say	C	Unknown	U	Unknown

Table 2-5 Continued.

Species	**Site Type**	**Feeding Guild**	**Breeding Type**	**Breeding Period**
Diplocheila obtuse (LeConte)	C	Omnivorous	U	Unknown
Discoderus parallelus (Haldeman)	C	Unknown	U	Unknown
Dyshcirius sp. Bonelli	PS	Unknown	U	Unknown
Galerita janus (Fabricius)	PS	Omnivorous	U	Unknown
Harpalus caliginosus (Fabricius)	PS	Omnivorous	AS	July and September
Harpalus erythropus Dejean	Both	Carnivorous	F	September
Harpalus faunus Say	Both	Carnivorous	F	September
Harpalus herbivagus Say	Both	Omnivorous	S	April-June
Harpalus pensylvanicus (DeGeer)	Both	Omnivorous	AS	June, August-September
Harpalus vagans LeConte	Both	Unknown	U	Unknown
Loxandrus sp. LeConte	C	Carnivorous	U	Unknown
Patrobus longicornis (Say)	C	Omnivorous	AS	July-October
Poecilus chalcites (Say)	Both	Unknown	AS	May-August
Poecilus lucublandus (Say)	Both	Unknown	S	April-July
Pterostichus femoralis (Kirby)	PS	Carnivorous	S	April
Pterostichus melanarius (Illiger)	Both	Omnivorous	AS	July-October
Pterostichus permundus (Say)	Both	Unknown	U	Unknown
Pterostichus stygicus Chaudoir	Both	Carnivorous	S	May-June
Selenophorus opalinus (LeConte)	PS	Herbivorous	U	Unknown
Stenolophus comma (Fabricius)	Both	Omnivorous	S	April-July
Stenolophus ochropezus (Say)	Both	Herbivorous	S	April-June

a)


b) Control

c) Prairie strip

Figure 2-1. Example of sites and their respective locations from one another. B) Location of sampling transect of pitfall traps in the control field. C) Location of sampling transect of pitfall traps in the treatment field red dots are the pitfall traps. Traps are on a 20 m spacing.

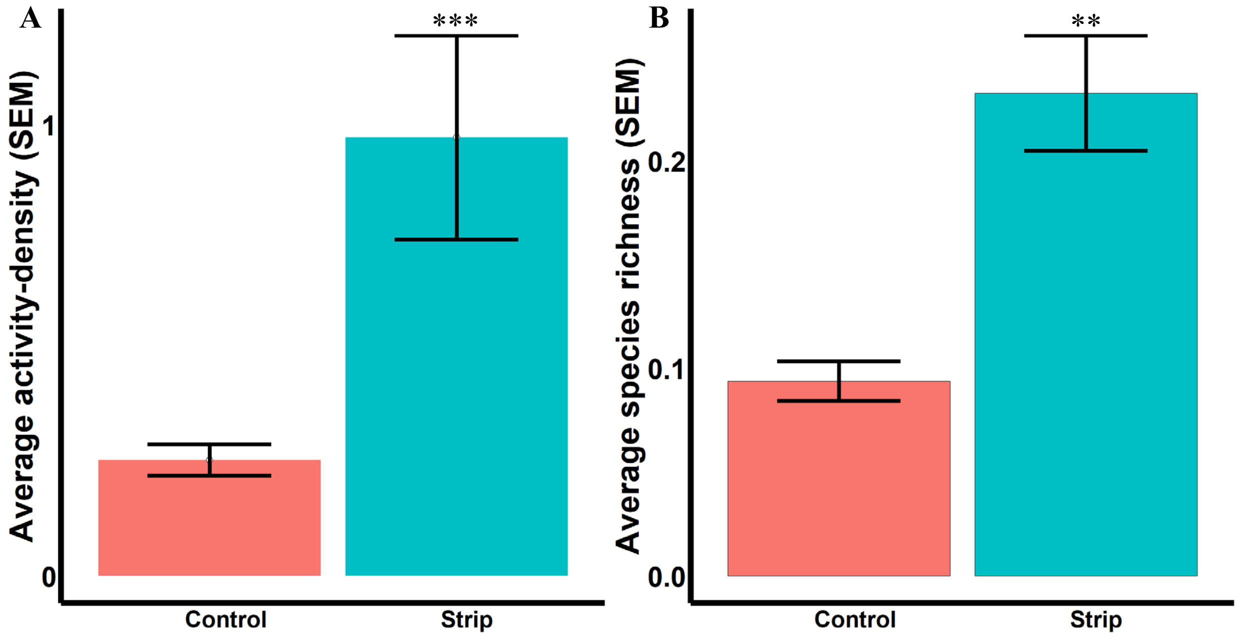

Figure 2-2. Mean (± SEM) A) carabid activity-density and B) species richness in fields without (control) and with prairie strips (n=4 per field type). Means are reported on a per sampling day per location for pitfall traps deployed in 2016 and 2017. Asterisk shows significant differences in means among site type (P ≤ **≤0.01, ***0.001).

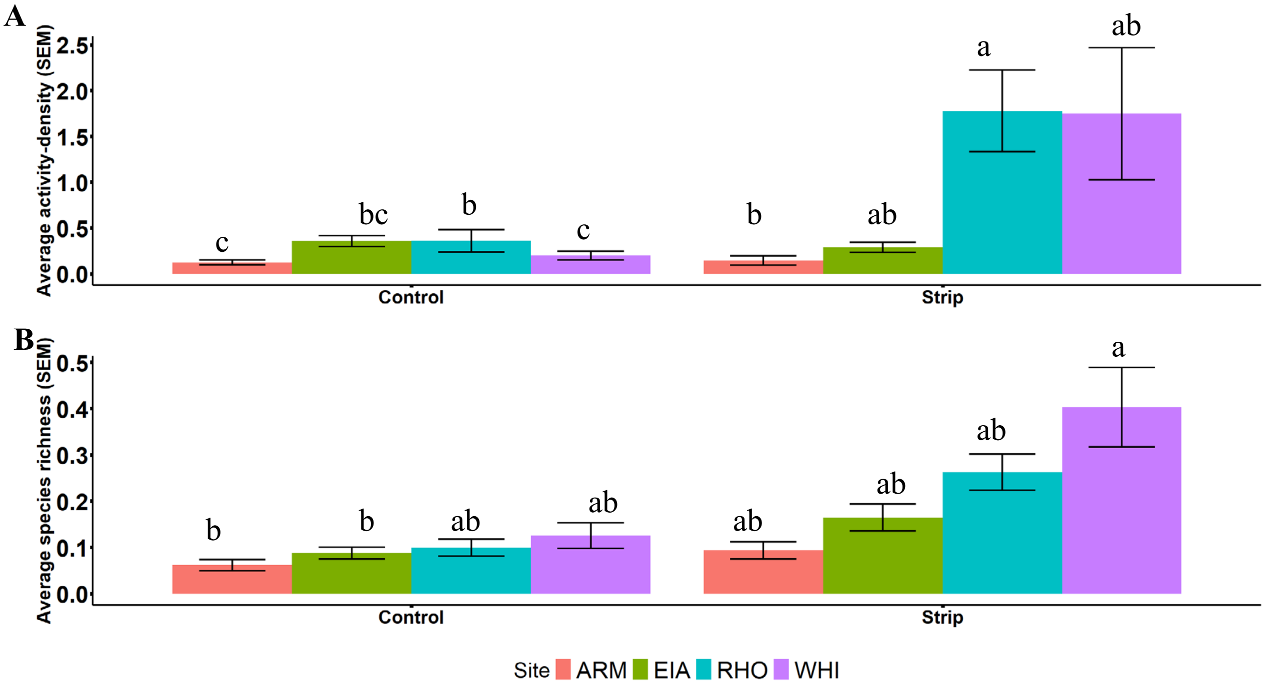

Figure 2-3. A) Mean (± SEM) activity-density and B) species richness of carabids in each block and site type averaged on a per trap basis. Lowercase letters show significance between site type and block means ($P<0.05$).

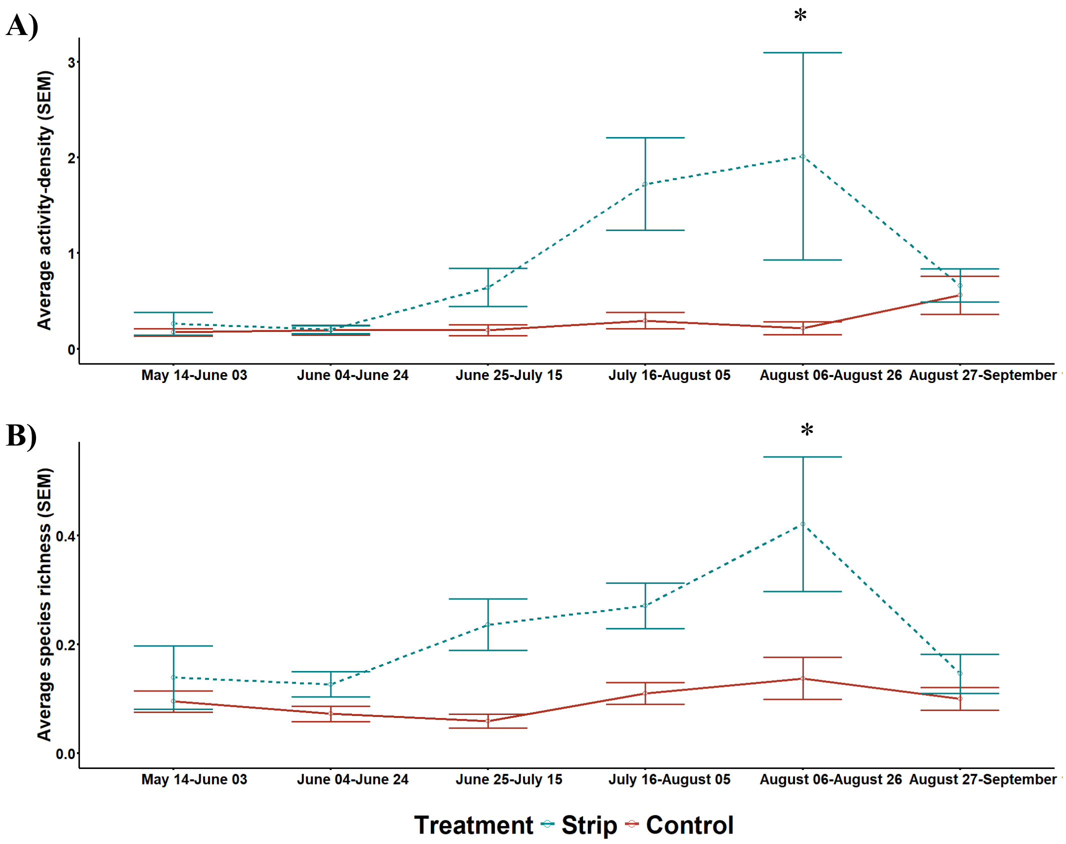

Figure 2-4. Mean (± SEM) A) beetle activity-density and B) species richness per sampling week averaged over per trap per sampling day. Asterisks indicate significant differences between site type ($P \leq 0.05$).

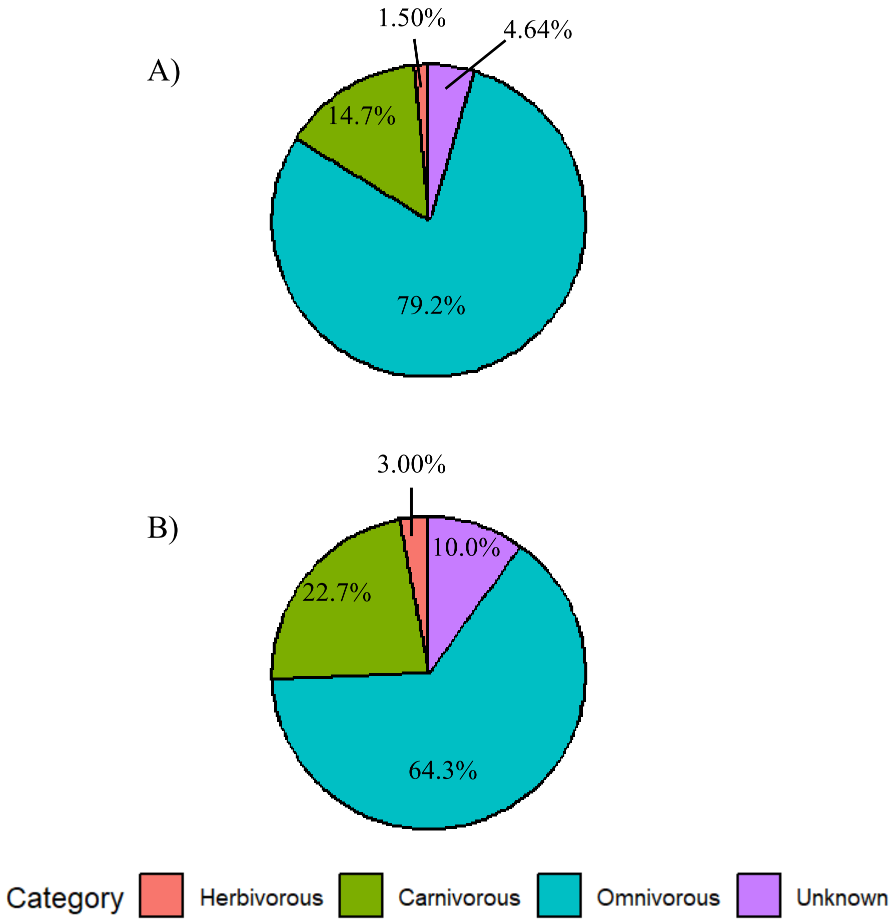

Figure 2-5. Distribution of A) total activity-density and B) species richness of beetles by feeding guilds. Percentages are calculated from all beetles captured in 2016 and 2017.

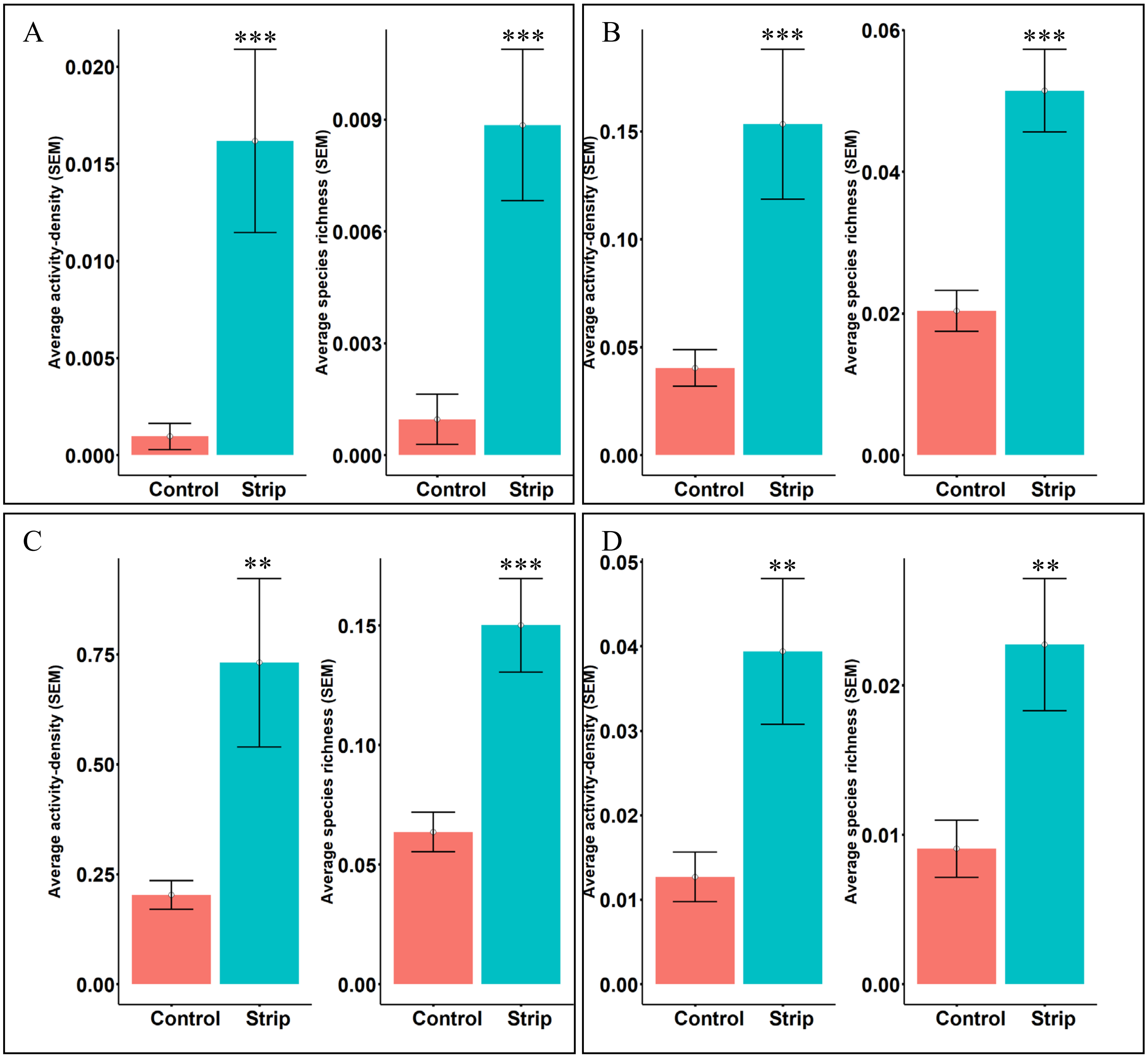

Figure 2-6**.** Mean (± SEM) for A) herbivorous, B) carnivorous), C) omnivorous, and D) unknown feeding guild. The left side of each panel is the activity density of each feeding guild, and the right side is the species richness of each guild. Means are reported as per trap per sampling day per site type for both years (2016 and 2017). Asterisks indicate significant differences within each guild between site types (* = P≤ 0.1, ** = P≤0.01, *** = P≤0.001).

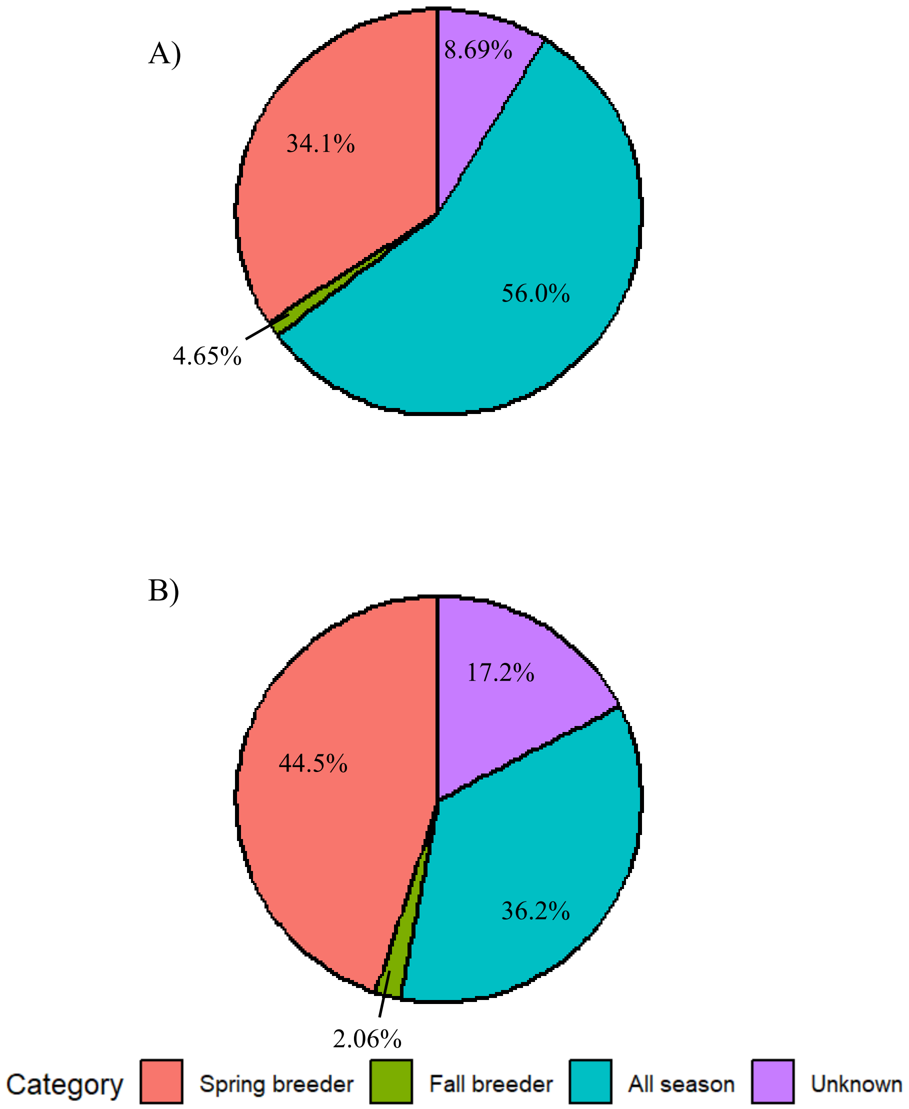

Figure 2-7. Distribution of A) total activity-density and B) species richness of beetles by breeding period. Percentages are calculated from all beetles captured in 2016 and 2017.

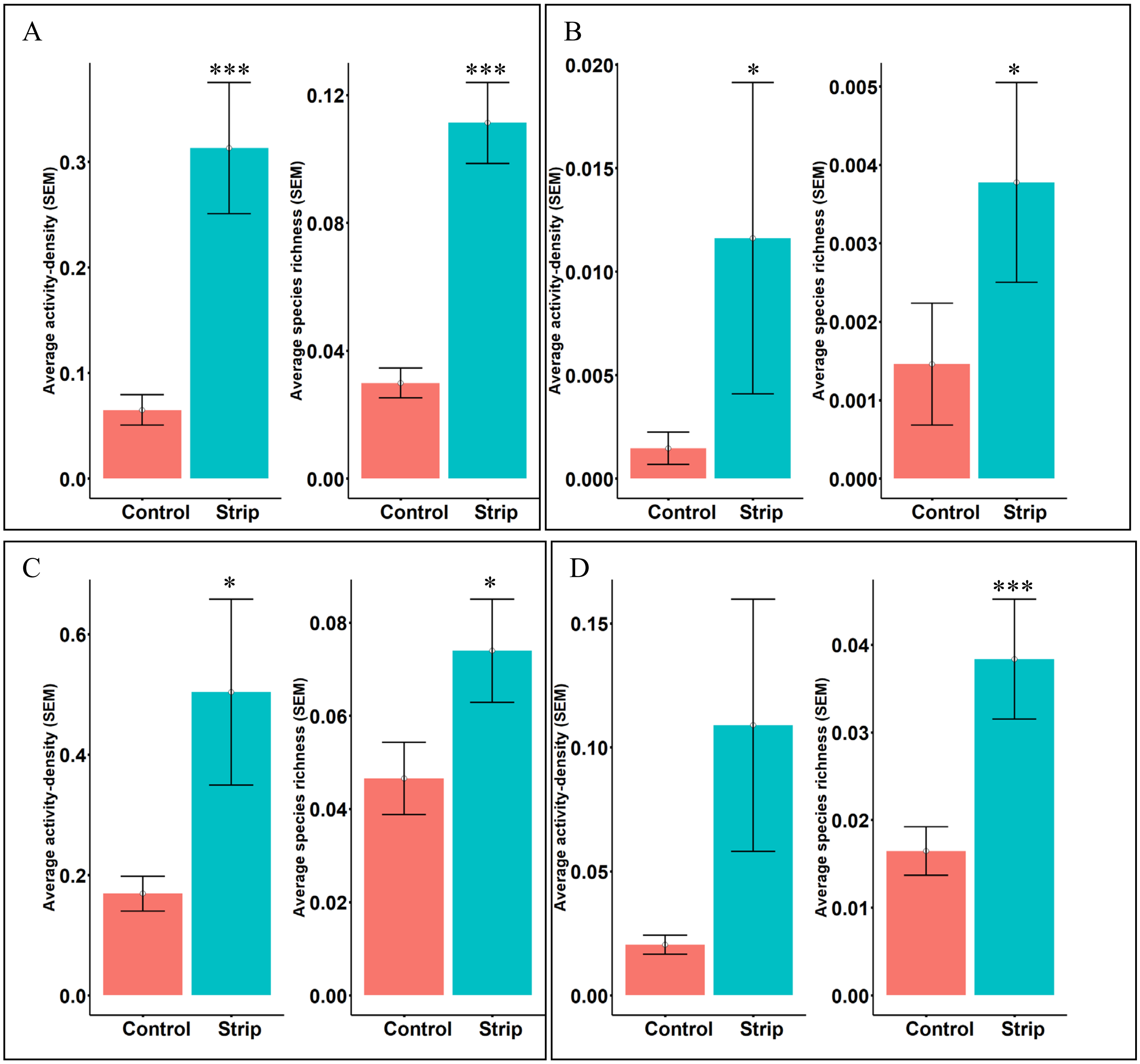

Figure 2-8. Mean (± SEM) A) spring, B) fall, C) all season, and D) unknown breeders. The left side of each panel is the activity-density of each adult breeder, and the right side is the species richness of each adult breeder. Means are reported as per trap per sampling day per site type for both years (2016 and 2017). Asterisks indicate significant differences between site types (* = P≤ 0.1, ** = P≤0.01, *** = P≤0.001).

CHAPTER 3. VEGETATIVE CONSERVATION COVER AND ITS EFFECTS ON THE CARABID BEETLE COMMUNITY IN CROPFIELDS AND POTENTIAL BIOCONTROL

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Modified from a manuscript to be submitted to *Environmental Entomology*

Abstract

Integrating perennial vegetation within annual croplands provides positive environmental benefits. Grassed waterways (CP-412) and prairie strips (CP-43), incentivized by the U.S. Department of Agriculture, offer soil and water protection benefits. Prairie strips additionally enhance biodiversity through the use of diverse, native plant species. This study sought to determine how various landscape configurations influence beneficial insects, specifically ground beetles (Coleoptera: Carabidae), and their capacity for biological control. We hypothesized that proximity to more diverse perennial vegetation would increase ground beetle activity-density, enhancing biological control. We measured the ground beetle activity-density using pitfall traps and predation based on the removal of dead European corn borer pupae (Lepidoptera: Crambidae: *Ostrinia nubilalis*) placed inside cages that excluded vertebrate predation. Data were collected during the growing season (June-August) and post-harvest (October) in central Iowa in 2022 and across Iowa in 2023. Landscape configurations with low diversity showed higher activity-density of carabids (Estimate = 0.6030, SE = 0.3350, $P < 0.0001$). The crop only configuration exhibited the highest activity in both 2022 (Mean = 6.58 ± 2.65 SEM) and 2023 (2.38 ± 0.436). Carabid activity-density and landscape configuration significantly influenced sentinel prey removal rates. The highest removal rates were observed in areas adjacent to grassed waterways (6.98 ± 0.463 pupae) and areas with a combination of grassed waterways and prairie strips (6.912 ± 0.437 pupae). The crop only configuration averaged 5.66 ± 0.418 pupae removed, while the lowest removal was in areas with multiple prairie strips (4.469 ± 0.418). Body length differences were noted by landscape configuration (Estimate = -1.9500, SE = 0.1170, *P*=0.0210) and sex (Estimate = -0.6123, SE = 0.2300, *P* = 0.0397). Female beetles in paired prairie strips (Mean = 12.11 ± 0.875 mm SEM) were larger than males in crop only configurations (9.98 ± 0.454 mm). Females also exhibited differences in body mass after lipid removal compared to males (P=0.0198). Our study provides new insight into ground beetles in crop fields and suggests the need for additional research to explain the complex relationships between beetle community characteristics, landscape characteristics, and biological control.

Keywords: Insect Ecology, Ecosystem Services, Integrated Pest Management, Landscape Ecology

Introduction

Pest regulation provided by beneficial insects is estimated to be worth more than 400 billion dollars worldwide (Rusch et al. 2010). In many agriculture systems, biological control is an underutilized mechanism to reduce pest pressure due to reliance on synthetic insecticides (Shields et al. 2019). The increasing costs and decreasing effectiveness of synthetic insecticides, as well as societal concerns about the extent of their use, underscore a need for additional research to support biological control (Bale et al. 2008). Greater biological control of agricultural landscapes could reduce the inputs that farmers use on their landscapes and increase profits (Tooker et al. 2020).

Cropland management can affect the delivery of insect-derived ecosystem services in multiple ways. Growing crops in monocultures over large expanses tends to have negative effects because such landscapes do not provide quality habitat for beneficial insects (Cardinale et al. 2006). Landis et al. (2008) found that the ability of beneficial insects to suppress the soybean aphid (*Aphis glycines* Matsumura [Hemiptera: Aphididae]), an economically important pest of soybean (*Glycine max*), decreased as the amount of corn (*Zea mays*) in the landscape increased. Monocultures typically require synthetic insecticides to maintain high yields (Meehan et al. 2011). While these insecticides are not intended to target beneficial insects, they often have direct negative effects on their populations and their ability to provide ecosystem services (Sánchez-Bayo 2021). For example, Douglas et al. (2015) documented that neonicotinoid use in soybean seeds traveled through the food chain via herbivorous slugs, resulting in a cascading effect that caused mortality in ground beetles (Coleoptera: Carabidae) and decreased the predation of herbivorous slugs.

Integrating perennial vegetation can enhance insect-derived ecosystem services to adjacent farmland, especially when the vegetation consists of diverse flowering species (Isaacs et al. 2009). Although conserving natural enemies in crop fields is essential for increasing biocontrol (Snyder 2019), the immediate impact of such efforts is not always apparent. Vegetative conservation areas in crop fields tend to experience fewer agriculture disturbances (i.e., harvest) compared to adjacent cropland. This cover can provide food, overwintering sites, and shelter for insects, creating a stable population that can occupy the adjacent crop field (Gontijo 2019, Tooker et al. 2020). This stable population in vegetative cover areas can potentially offer biological control in the adjacent cropland as pest populations increase during the growing season, thus enhancing predation spillover and prey removal (Tscharntke et al. 2005).

Perennial vegetative cover in crop fields not only increases the abundance and species richness of beneficial insects but also enhances the biological control of pests. For example, Cardinale et al. (2006) found that non-crop habitat use increases species richness, which in turn lowers the abundance of aphids in crop fields. Vegetative conservation cover can provide an alternative prey host for predators as agricultural disturbance increases (e.g., harvesting). Vegetative perennial habitats increase the activity-density and species richness of carabids, which may play a role in providing shelter for this family during conventional disturbances in crop fields (Marja et al. 2022, Boetzl et al. 2024).

Beetles in the family Carabidae are especially important to conserve as biological control agents (Kromp 1999, Duelli and Obrist 2003). *Harpalus rufipes* (DeGeer) was shown to feed on aphids, potentially reducing their population density in crop fields (Loughridge and Luff 1983). Another study observed that *Pterostichus melanarius* (Illiger) was an important biological control agent against slugs (Bohan et al. 2000). In the U.S. Midwest, carabid species—both native and non-native—were found to feed on a new soybean pest, *Resseliella maxima* (Melotto et al. 2023). Carabids not only feed on insect pests, but they can also provide biological control through weed seed predation (Kulkarni et al. 2015). *Harpalus pensylvanicus* (DeGeer) and *Anisodactylus sanctaecrucis* (Fabricius) are predators of weed seeds in crop fields and reduce the weeds inside these landscapes (Menalled et al. 2007, White et al. 2007).

While carabids are well known for consuming crop pests, the impact of vegetation type and coverage on their activity-density and effectiveness in providing biological control in conventional crop fields is not well understood. To fill this knowledge gap, we established an experiment to evaluate the activity-density of beetles based on vegetation cover in crop fields and analyze the removal of sentinel prey in the adjacent crop. We predict positive relationships between the type and amount of perennial vegetation, carabid activity-density, and biological control (Figure 3-1). The perennial vegetation types we evaluated included grassed waterways and prairie strips—practices incentivized by the U.S. Department of Agriculture (USDA) that farmers and farmland owners typically establish on their fields to protect soil, but especially prairie strips can additionally provide biodiversity conservation benefits (Chapter 2, Schulte et al. 2017, Kordbacheh et al. 2020). Grassed waterways (CP 412) are areas established to cool-season grasses, typically smooth brome (*Bromus inermis*), oriented to intercept and channel water runoff from crop fields and protect soil from the erosive power of water. Prairie strips (CP 43) are plantings of native perennial vegetation within row crops that occupy about 25% of the cropland (USDA 2019). Because our initial results differed from our expectations, we extended the study to determine whether carabid morphology and physiology differed based on the type and amount of perennial vegetation.

Methods

Study area

This study was conducted in Iowa, a highly agricultural state located at the center of the U.S. Corn Belt. In 2022, our study initially focused on one field in Iowa, where soybeans were planted in May and harvested in October. In 2023, we expanded our study to four fields, where corn was planted in April and harvested in October. Our study sites are located in agricultural landscapes with undulating topography. The elevation ranges 305-380 m above sea level across these sites. Iowa's climate is humid continental with four seasons. Temperature data were collected from the Ames weather station, which served as the base for our data collection team.

In 2022, the lowest recorded temperature was -25.56ºC on January 21st, while the highest was 36.11ºC on June 14th (Iowa Environmental Mesonet 2024). In 2023, temperatures ranged from a minimum of -22.78ºC on January 31st to a maximum of 35.56ºC on August 24th (Iowa Environmental Mesonet 2024). The Ames weather station receives an average annual rainfall of approximately 821.44 mm. In 2022, total precipitation amounted to 748.54 mm, and in 2023, it totaled 682.24 mm (Iowa Environmental Mesonet 2024).

While our study focused on agricultural landscapes, it encompasses both non-crop habitats and croplands to capture carabid beetles across various biomes in Iowa. Carabids inhabit diverse environments, found in both native and anthropogenic biomes. Ninety-one species can be found in native prairies around Iowa (Larsen et al. 2003).

Site selection

Study sites were crop fields selected based on four criteria: use of conventional agronomic practices during the past five years, crop type, the presence of at least two grassed waterways and at least two prairie strips, and proximity to Ames, Iowa. Conventional agronomic practices in the study region include a corn-soybean rotation using conventional tillage (e.g., chisel plot, deep rip, and moldboard plow) and synthetic fertilizer and pesticides. We avoided farms using cover crops and USDA-certified organic practices because these practices are not yet common in the study region and affect the community and abundance of carabids (Purtauf et al. 2005, Adhikari and Menalled 2018, Gareau et al. 2020). Excluding such fields in our study allowed us to estimate the impact of vegetation cover in the absence of these practices. To test our hypotheses, we only considered sites where the perennial conservation practices—at least two grassed waterways and at least two prairie strips—had been established for at least three years. As a perennial practice dominated by native grassland species, prairie strips require at least three years to establish (Harris and Neal 2015). Proximity to Ames, Iowa, was a criterion for logistical reasons: to minimize driving time and eliminate the need for overnight travel to conduct fieldwork. Some of our study sites were also used in a previous study of insect response to prairie strips (Chapter 2, Kordbacheh et al. 2020).

In 2022, we selected a single conventional row crop field with multiple grassed waterways and prairie strips for study (Figure 3-2). The arrangement of vegetation types (i.e., annual crop, monocultural perennial grass, diverse native grasses, and forbs) produced five distinct landscape configurations for sampling. The first landscape configuration, referred to as ‘crop only,’ were locations within the field surrounded for at least 30 m by only crop. The second landscape configuration, termed ‘grassed waterway,’ was composed of an established grassed waterway and surrounding croplands. Sampling points were established in the grassed waterway (distance = 0 m) as well as at three distances (5 m, 15 m, and 30 m) into the adjacent cropland. The third landscape, ‘lone prairie strip,’ was composed of a prairie strip and surrounding cropland, with additional prairie strips located at least 40 m away. Sampling occurred both within the prairie strip (distance = 0 m) and at the three distances (5 m, 15 m, and 30 m) in adjacent cropland. The fourth landscape configuration included two adjacent prairie strips and the intervening cropland. Sampling occurred in one of the prairie strips (distance = 0) and adjacent cropland at three distances (5 m, 15 m, and 30 m) extending out toward the second prairie strip. The fifth and final landscape configuration was cropland bordered by both a grassed waterway and prairie strips. We called this the ‘combo’ landscape. Sampling only occurred in the cropland in the ‘combo’ landscape, which was 30 m from both configurations.

We randomly selected sampling locations within each of these landscape configurations. Conditions to be selected for sampling required that the crop only, grassed waterway, or prairie strip was located at least 45 m away from another field, field border, and other perennial vegetation. Once these areas were identified, we used ArcMap (ArcMap version 10.8.2, ESRI, Redlands, California) to trace the area and divide them into 45 m sections. To choose random locations in the crop, we used the random point tool in ArcMap that chose random points within the traced area that were 45 m away from each other. If there were multiple prairie strips or waterways, each was numbered, and then one was randomly selected. Once we selected the prairie strip and waterway, each was divided into approximately 45 m sections. Sections within 45 m of another crop field, other grassy features, or roads were eliminated from the pool of potential sampling locations. For each 45 m section, we chose each section's centroid using the ArcMap's centroid tool. We randomly selected centroids to place a point for sampling.

In 2023, we expanded our study to three additional sites in Iowa. Because initial data analysis indicated few to no differences with distance from perennial vegetation into the crop, we only sampled at the 0 m and 5 m distances in the grassed waterway, lone prairie strip, and paired prairie strip landscapes. Dropping the 15 m and 30 m sampling distances allowed us to increase the number of samples from three to five in all landscape configurations in this year.

Field methods

Measurements of plant cover and soil residue were conducted at each trap location within both cropland and perennial vegetation. In cropland areas, assessments included crop residue, plant growth stage, plant height, canopy cover, and defoliation. Crop residue was quantified by measuring the percentage of leftover crop material covering the soil surface within a designated area (1 ft by 1 ft; Integrated crop management C-488 (8) -- May 13, 2002 issue). Plant growth stage is evaluated by counting the trifoliate leaves on crop plants throughout the growing season (Soybean Growth and Development PM 1945). Plant height was measured in centimeters using a measuring stick from the base of the plant to the top of the plant. Plant canopy cover was visually assessed as a percentage using visual disks. The assessment involved standing over a point and measuring the percentage of ground covered by the plant canopy visible through the disk. Defoliation was measured as a percentage by examining three leaves per plant at separate locations of the plant alternating sides. (Train your eyes for soybean defoliation, Hodgson 2022). Within perennial vegetation, only plant height and canopy cover were measured because other parameters cannot be measured inside them. Although the parameters were collected, they were not included in the model because they did not enhance its statistical performance.

Carabids are cursorial insects, meaning they are adapted for running. However, their movement can be impeded by dense vegetation on the soil surface (Thomas et al. 2006). Thus, activity-density, which is measured by the number of carabids collected in pitfall traps, depends on both their movement through the vegetation and their population density (Thomas et al. 1998). The activity-density of carabids was estimated with pitfall traps using methods modified from Prasifka et al. (2006). Traps were constructed from plastic cups (11.5 cm diameter SOLO, Dart Container Corporation, Mason, Michigan) and placed in a hole in the ground such that the top of the trap was even with the topsoil. Pitfall traps were filled with at least 7 cm of a solution of 95% ethanol and a drop of dish soap (Dawn, Proctor and Gamble, Cincinnati, Ohio) to kill captured beetles to prevent them from feeding on each other. Cups were recharged once daily during sampling periods when there was no canopy cover and a high likelihood of evaporation. Pitfall traps were recovered after 48 hours. Pitfall traps were deployed four times: three times during the growing season (June, July, and August) and once during post-harvest (October). Ground beetles were identified to species using keys in Lindroth (1969) and Bousquet (2010).

Predatory activity in each landscape configuration was estimated by measuring the amount of sentinel prey removed during the same 48-hour period that pitfall traps were deployed. To prevent predation by vertebrates, the sentinel prey was protected with a cage (i.e., 'predation cages') constructed from a 1.3 cm wire mesh that was 9 cm high and 14.5 cm in diameter following the same methods as Prasifka et al. (2006). We also placed sentinel prey in predation cages wrapped in plastic (SaranTM Premium wrap, S. C. Johnson and Son, Racine, WI) to prevent predation by both vertebrates and invertebrates. These ‘control cages’ allowed us to estimate experimental error (i.e., loss due to handling and weather events).

We use sentinel prey to estimate the potential for biological control of insect pests to be affected by the various landscape configurations. Therefore, cages were only deployed in the crop portion of the field. In 2022, cages were placed 5 m, 15 m, and 30 m away from the perennial vegetation (e.g., prairie strips, grassed waterways). We placed predation cages 14-20 cm away from the control predation cage. Predation cages were placed 2 m away from each pitfall trap. In each cage, sentinel prey was glued to cards of sandpaper (3M, 80 grit) using a spray adhesive (3MTM, Super 77TM Multipurpose Spray Adhesive, 3M Manufacturing Company, Maplewood, Minnesota). Sentinel prey used in this study were European corn borer (*O. nubilalis*) pupae provided by the USDA National Laboratory for Agriculture and the Environment Corn Insects and Crop Genetics Research lab at Iowa State University. Pupae were stored in a freezer (-16°C) until glued to the sandpaper cards and placed in the field. The sandpaper was cut into 10.5 by 7 cm sections to fit inside a cage. Ten pupae were glued onto each sandpaper card. These cards were placed inside plastic bags and frozen until ready to deploy in the field. After cages were recovered from the field, each sandpaper card was returned to the lab. Each sandpaper card was viewed under a microscope, and pupae were analyzed to determine whether there was evidence of feeding. If there was evidence of any feeding, pupae were counted as pupae removed. The number of prey removed was recorded for each card and summarized for each landscape configuration. The average number of prey removed was reported as an estimate of predation activity.

Sampling dates were selected based on a previous study of carabid activity in Iowa crop fields and prairie strips (Chapter 2). We sampled four times per growing season (June through October), with dates chosen based on when ground beetle adults were most active and based on agronomic practices before planting, after planting with plants in vegetative stages, plants in reproductive stages and post-harvest. Wind speed, temperature, and cloud cover measurements were taken during sampling and recorded using the iPhone AccuWeather app using the Ames Municipal Airport, IA weather station.

Morphology and physiological measurements

We analyzed the morphology, sex, and lipid content of *Poecilus chalcites,* the most active beetle found in all landscape configurations in both years of our study, to determine if there are morphological and physiological differences among configurations. We randomly selected five *P. chalcites* from each configuration and sampling date for measurement; we analyzed all *P. chalcites* individuals if fewer than five were collected. We measured five different anatomical traits using a Leica Microsystem (LAS X) to assess the body size of the beetles: 1) whole-body length, which was measured from the tip of the labrum to the most distal end of the elytra; 2) pronotum length, which was measured from the center of the pronotum from the proximal to the distal end of the pronotum, at the start of the elytra; 3) pronotum width was measured from one lateral side to the other lateral side from the center of the pronotum; 4) elytra length, which was measured from the most proximal to the most distal end from the center of the elytra; and 5) elytra width, which was measured from one lateral side to the other, from the center of the elytra (Weiss and Linde 2022, Knapp et al. 2024). Each of these measurements was taken for all *P. chalcites* that were collected for this morphological study (n=99, females=61, males=38). Each *P. chalcites* was sexed following the procedure described in Lundgren et al. (2005).

Lipids were extracted from each beetle using a 2:1 chloroform-methanol solution (Ramos-Bueno et al. 2016, Saini et al. 2021). Beetles were dried for at least 24 hours before extracting lipids because beetles were stored in 95% ethanol. Body weight measurements were taken before (body mass before lipid removal) and after beetles were dried (body mass after lipid removal). After 24 hours, beetles were placed in 20 ml glass vials with one microliter of the chloroform-methanol solution. Each vial was weighed before placing beetles and solution inside them. Beetles were kept in the chloroform-methanol solution for 48 hours. After 48 hours, beetles were removed and placed in a clean vial and allowed to dry. The vial with the chloroform-methanol solution was left to dry and evaporate any traces of the solution. After 48 hours, beetles and glass vials with the dried solution were weighed. After weighing, we calculated the difference in beetles before and after the chloroform-methanol solution (difference between body mass before and after lipid removal). We also calculated the difference between vials before and after the chloroform-methanol solution was placed inside them (dried lipid mass).

Statistical methods

We used R studio (R Core Team 2022) and packages “lme4” and “glmmTMB” to perform analyses on the relationship between carabids and predation of European corn borer pupae. We chose to analyze activity-density and richness for 2022 and 2023 data sets separately due to the transects that were involved in sampling for 2022. In 2023, we did not involve the transect, and distance measurements were not used to analyze these data sets. We estimated activity-density using a generalized mixed model with a Poisson distribution with landscape configuration and trap location as predictor variables. Trap locations are pitfall traps either inside the cropland or in the non-crop areas. For 2023, we estimated activity-density using a similar model as 2022, but block, landscape configuration, and trap location were used as predictor variables. Both models used Julian date and replication nested in each block and landscape configuration. The nested structure was used to account for the randomness associated with each pitfall trap in each landscape configuration and block. Each pitfall trap was treated as an observation, and means are reported on a per-trap, per-day basis.

A persistent but small amount of predation was observed in the control cages that were unaccounted for. To account for this predation, we summarized the amount of predation at an experimental unit (i.e., the combined closed and open predation cages) by calculating the difference between these two cages. We used this difference in our subsequent statistical analysis to determine if predation varied by landscape configuration and time. We estimated the number of pupae removed per cage using a Binomial GLM, including fixed effects of landscape configuration and distance. For 2023, we used a similar model as 2022, and included block and landscape configuration. Random effects in each model were date, beetle activity-density, and replication nested within each block and landscape configuration. A pairwise comparison was performed using the "pairs" function from the “emmeans” package to estimate differences between activity-density and predation means among landscape configurations. To determine if activity-density of carabids explained variation in predatory activity, we added activity-density as a covariate in the GLM model. Similar to the activity-density model, each predation cage was treated as an observation, and means were reported on a per-day basis.

To analyze the various morphological and physiological measurements, we used multiple analyses of variance (ANOVA) to investigate statistical differences in body size and lipid content. We used multiple one-way analyses to determine which morphological measurement and if lipid content from beetles was significant by landscape configuration, sex, and trap location. We used a pairwise comparison to observe differences in anatomical measurements and lipid content among landscape configurations and between sexes. Interactions between sex and landscape configurations were not included in our final model, as they did not prove to be significant in the initial analysis. Since there was a limited number of beetles collected for this study, we chose to analyze all beetles without their respective distance. This allowed us to have a robust sample size for each landscape configuration.

Results

Plant cover

In 2022, vegetation sampling was conducted at one location on August 11th, following the protocol described in English's master's thesis from 2020. In the prairie strip, we identified a total of 28 species, compared to 8 species in the grassed waterway. Dominant species in the prairie strip included switchgrass (*Panicum virgatum*), Canada wild rye (*Elymus canadensis*), and grey-headed coneflower (*Ratibida pinnata*; 21.3%, 20.0%, and 15.7% of the vegetation per quadrat, respectively). In the grassed waterway, the predominant species were smooth bromegrass (Bromus inermis), reed canary grass (Phalaris arundinacea), and Kentucky bluegrass (Poa pratensis), making up 72.5%, 5.0%, and 1.3% of the vegetation per quadrat, respectively. Both the prairie strip and grassed waterway exhibited a large portion of bare ground and dead plant cover. In the prairie strip, the average coverage per quadrat was 27.8% bare ground and 29.1% dead plant cover. In the grassed waterway, the averages were 28.5% bare ground and

33.3% dead plant cover. In 2023, our study expanded to include three additional sites, with prairie vegetation details available in English's master's thesis from 2020.

Activity-density and species richness

2022

In 2022, when research was conducted on only a single farm, we found significant variation in mean carabid activity-density among landscape configurations. More beetles were captured in the 'crop only' configuration of the field than in the vegetation (Figure 3-3A). The effects of distance from perennial vegetation (0 m, 5 m, 15 m, 30 m) on carabid activity-density varied significantly among grassed waterway (Estimate = -0.5174, SE = 0.6031), lone prairie strip (-0.3191, SE = 0.5394), and paired prairie (-1.0195, SE = 0.6457) strip configurations (Table 3-2). Comparisons revealed significant differences in activity-density in the lone prairie strip configuration at 15 (0.550 ± 0.551) and 30 m (1.332 ± 0.535; Figure 3-5) compared to all other distances and configurations.

In 2022, a total of 317 beetles were captured across all landscape configurations. Overall, for 2022, 16 total species were found (Table 3-2A) with *Poecilus chalcites* the most abundant species captured in each of the five landscape configurations, comprising 86% of the community. *Clivina bupustulata* was overall the second most abundant species (3%) and second most abundant in the crop only, grassed waterway, lone prairie strip, and combo configuration (4%, 4%, 2%, and 9%). The third most abundant species overall was *Elaphropus anceps* (3%) and the second most abundant in the paired prairie strip (7%). Combined, these three species accounted for 93% of all the species captured in 2022.

Although no statistically significant differences were found in species richness among the different landscape configurations (Estimate = 0.6570, SE = 0.2970, *P* = 0.1217), noteworthy patterns in species richness were observed. Seven species were observed in the non-crop area of the lone prairie strip configuration, while in the combo configuration, we collected three species (Table 3-2A). Similarly, there were no statistically significant differences observed in species diversity across varying distances from perennial vegetation (Estimate = 0.7100, SE = 0.2800, *P* = 0.2225).

2023

During 2023, we observed lower activity-density compared to our findings from the single field used in 2022. Across all dates in 2023, the greatest activity-density was observed in the crop (Estimate = 0.1064, SE = 0.3998) and grassed waterway (Estimate = -0.2253, SE = 0.2212, *P* < 0.0001) compared to other landscape configurations (Figure 3-3B). The crop only (Mean = 2.38±0.436 SEM), grassed waterway (2.26±0.316), and combo configuration (1.07±0.235) showed, on average, more activity-density compared to the lone prairie strip and paired prairie strip configuration per trap per sampling date. The lowest amount of activity-density in 2023 was observed in the lone (Mean = 0.561±0.089) and paired prairie strip (0.423±0.073) configurations. Trap location, whether in cropland or non-crop areas, showed marginal significance for beetle activity-density (Estimate = 0.1838, SE = 0.1006, *P* = 0.0677; Table 3-2). The grassed waterway configurations displayed higher activity-density in both crop (Mean = 1.98 ± 0.460) and non-crop (2.58 ± 0.429) trap locations (Figure 3-4B).

In 2023, 616 carabids were collected across all landscape configurations. Overall, 22 species were found (Table 3-2B), with *P. chalcites* being the most abundant species captured in each of the five landscape configurations, comprising 47% of the community. In the crop only, grassed waterway and paired prairie strip landscape configurations, *Poecilus lucublandus* was the second most abundant (11%, 13%, and 2%). In the lone prairie strip, *Harpalus pensylvanicus* was the second most abundant (19%). Finally, in the combo configuration, *Pterostichus melanarius* was the second most abundant (25%). Combined, these four species accounted for 78% of all the beetles captured in 2023.

In 2023, the grassed waterway landscape configuration yielded the highest species diversity, with a total of 17 species captured. Within this configuration, 12 species were found in the cropland adjacent to the grassed waterway, while 15 species were found within the grassed waterway itself (non-crop area). Conversely, the combo configuration exhibited the lowest species diversity, with only seven species captured (Table 3-4). Statistical analysis revealed significant differences in species richness among landscape configurations (Estimate = 0.6280, SE = 0.1520, $P < 0.00001$). Specifically, the grassed waterway (Mean = 1.01 ± 0.093 SEM) and crop only (0.862 ± 0.109) landscape configurations had significantly more species on average per trap per sampling date. In contrast, the paired prairie strip configuration had the fewest species (Mean = 0.338 ± 0.054 SEM), as shown in Figure 3-5B. In 2023, no statistical differences in species richness were found when comparing trap locations (i.e., cropland vs non-crop).

Predation

2022

In 2022, no significant variation in predation activity was observed among landscape configurations at a single farm (Estimate = -0.9750, SE = 0.4910, P=0.5851; Table 3-4). Analysis of predation by distance into the adjacent crop was conducted only in 2022 and focused on the grassed waterway (Estimate = 0.4978, SE = 0.5070), lone prairie strip (Estimate = -0.1400, SE = 0.2141), and paired prairie strip (Estimate = -0.5401, SE = 0.2203) configurations (Figure 3-7). Comparisons revealed significant differences in predation by distance. Highest predation was observed at 15 m away from the grassed waterway (Mean = 6.00±0.957 SEM) and lone prairie strip (6.75±0.760). The lowest amount of predation was observed at the 5 m distance from the paired prairie strip (Mean = 2.55±0.957 SEM). When activity-density was included as a covariate in the GLM model for 2022, there was a significant effect of activity-density on predation activity (Estimate = 0.0619, SE = 0.0193, $P = 0.00135$).

2023

In 2023, we observed statistical differences in predation among landscape configurations. (Estimate = 0.4440, SE = 0.1590, $P < 0.0001$; Figure 3-6b). The greatest amount of predation was observed in the cropland adjacent to the grassed waterway (Mean = 6.98±0.463 SEM) and combo configuration (6.91±0.437). The lowest amount of predation was observed in the paired prairie strip configuration (Mean = 4.69±0.418 SEM). Predation activity also varied by block (Estimate = -0.9830, SE = 0.3590, $P = 0.0452$), with significant differences between MCCB (Mean = 7.40±0.586 SEM) and ARM (3.02±0.315; P=0.0459). When adding activity-density as a covariate in the 2023 GLM model, there was a significant effect of activity-density on predation activity (Estimate = 0.0901, SE = 0.0307, $P = 0.0030$).

Morphology and lipid content

We measured a total of 99 individual beetles (n = 61 females and n = 38 males) to understand variations in morphological measurements and lipid content of *P. chalcites*. In our multiple one-way analyses, we did not include the interaction between sex and landscape configuration because it did not yield significant results. Linear regressions revealed statistical differences in mean body length between landscape configurations (Estimate = -1.950, SE = 0.1170, $P = 0.0309$) and sexes (Estimate = -0.6123, SE = 0.2299, $P = 0.0223$; Table 3-5). Beetles from the paired prairie strip had 1.08 times larger body size (Mean= 11.9 ± 0.233 mm; n = 13), respectively, compared to those from the crop only configuration (11.0 ± 0.338 mm; n = 21; Figure 3-8A). Furthermore, females in the paired prairie strip configuration exhibited 1.21 and 1.12 times larger body size (Mean = 12.1 ± 0.309 mm SEM; n = 8), respectively, compared to males found in the crop-only (9.98 ± 0.454 mm; n = 4) and lone prairie strip configurations (10.8 ± 0.342 mm; n = 10).

Pronotum length also varied by landscape configuration (Estimate = -0.5170, SE = 0.0741, *P* = 0.0366; Table 3-5), with beetles in the paired prairie strip configuration exhibited 1.26 times larger pronotum length (Mean = 2.87 ± 0.348 mm (SEM)) compared to the crop-only (2.34 ± 0.076 mm) and lone prairie strip configurations (2.34 ± 0.57 mm; Figure 3-8B). Pronotum width showed marginal significance among landscape configurations (Estimate = -0.5170, SE = 0.07410, *P* = 0.0645), with marginal differences observed between the paired prairie strip (Mean = 3.90 ± 0.444 mm SEM) and both the lone prairie strip (3.25 ± 0.085 mm) and crop-only configurations (3.23 ± 0.104 mm).

Body mass after lipid removal differed significantly by sex (Estimate = -3.730, SE= 1.3680, P = 0.0076) and trap location (Estimate = 4.4900, SE= 0.6890, P = 0.0144; Table 3-5). Female beetle body mass after lipid removal was 1.16 times greater (Mean = 24.2 ± 0.925 mg SEM) compared to male body mass (20.8 ± 0.949 mg; Figure 2-8C). On average, non-crop beetle body mass was 1.27 times greater (Mean = 27.8 ± 2.47 mg SEM) compared to beetles in the cropland (21.9 ± 0.574 mg). Marginal significance in body mass after lipid removal among landscape configurations was also observed (Estimate = -4.4780, SE = 0. 6980, *P* = 0.0708), with the largest body mass post-lipid extraction found in the grassed waterway (Mean = 25.2 ± 1.73 mg SEM; n = 30) and the lowest in the combo configuration (20.8 ± 0.877 mg; n = 11).

Discussion

Overall, the number of individual carabids (933) and the number and type of species (25) captured in our study are similar to those of previous studies investigating carabids and ecosystem service delivery using similar methods and sampling intensity (Prasifka et al. 2006). The most common captured species, *P. chalcites*, is frequently found in soybean fields of the Midwest, including Iowa (Gardiner et al. 2010). *Harpalus pensylvanicus* is common inside crop fields across Iowa and often used to explain weed seed predation (O'Rourke et al. 2008). *Poecilus lucublandus* is a generalist found in both crop fields and prairie (Larsen et al. 2003). All species that were caught are native except for *P. melanarius* (Bousquet 2010), a species originally from Europe that is found common in agriculture fields in both its native and introduced range (Larsen et al. 2003, Busch et al. 2021). All but four of these species collected (*Amara littoralis* Mannerheim*, Anisodactylus merula* (Germar)*, Anisodactylus nigrita* Dejean*, Clivina bupustalata* (Fabricius)) were also found in the Larsen et al. (2003) study, which focused on quantifying ground beetle assemblages across various biomes across Iowa.

Although the total number of species was approximately half of what was captured in fields with prairie strips (Chapter 2), the sampling protocol was not as extensive. We targeted a 48-hour period when predation was also being estimated in an attempt to account for the ecosystem service delivered by carabids. Unlike previous studies that attempted to survey the ground beetle community and measure their response to a conservation feature, we focused on whether ground beetles were spilling over from a conservation feature into the adjacent crop.

Our first prediction was directed at determining if carabid activity-density in the adjacent crop varied by the type, amount, and distance from two conservation features found in Iowa, grassed waterways and prairie strips. We observed evidence that the conservation practices did affect carabid activity-density, but the nature of this effect was counter to our predictions. Our models for each year did find significant differences among landscape configurations and trap locations (cropland or non-crop). We found that the crop only had high activity-density (25% of the overall total) in both years, which was surprising as these locations had the least amount of perennial vegetation around the pitfall traps. On the opposite extreme, pitfall traps assigned to the paired prairie strip configuration had the lowest activity-density (9% of the overall total). Our model revealed differences in species richness among landscape configurations. Again, counter to our prediction, the fewest number of species were captured in configurations that had more vegetative diversity, i.e., the lone and paired prairie strip configurations. These data suggest that our initial prediction does not accurately account for the use of perennial vegetation by carabids in this cropping system.

Overall, our data did not reveal evidence that significant spillover (i.e., movement from perennial vegetation into an annual crop field) occurred at the scales measured within this study. If anything, a remarkable amount of activity-density was observed in the portion of the field primarily comprised of crops (i.e. crop only configuration). Despite these contrary data, there is evidence that after disturbance events, fields with non-crop habitats increase the activity-density of carabids in an adjacent crop (Lee et al. 2001). Such spill-over requires an increase in activity by adult carabids directed toward crop fields. Carabids have been observed to disperse from non-crop habitat into cultivated areas (Duelli and Obrist 2003), with this spillover into cropped fields ranging from 10-60 m (Baker et al. 2009, Roume et al. 2011, Boetzl et al. 2019, Gallé et al. 2020). One of the species we captured, *P. melanarius*, has been observed to travel as adults at a rate of 2.4 m per hour, with a range of 0.4 - 44m in a crop field (Wallin and Ekbom 1988). Individual *P. melanairus* has been observed to travel up to 500 m in 14 weeks (Firle et al. 1998).

If the dispersal capacity of *P. melanarius* is consistent with the other commonly collected species we captured (e.g., *P. chalcites*), then the distances within our transects and between prairie strips and the crop only configuration are possible. Spillover may have been inhibited by vegetation either within the conservation areas or later in the season when the crop was established. Vegetative structure can be a factor in carabid activity-density by either plant density or food availability (Thomas et al. 2006). Life history of individual species could also be a factor in carabid activity-density, which, depending on the time of year, could influence their activity and predation rates (Philpott et al. 2019).

Ours is not the first study to reveal a negative relationship between perennial vegetation and carabid activity-density. In a 2-year, 4-state study of carabid communities in soybean fields of the US Midwest, Gardiner et al. (2010) observed a decline in carabid activity-density in soybean fields surrounded by an abundance of grassland habitat. This relationship was most noticeable in *P. chalcites*, which was least abundant in soybean fields located within grassland-rich landscapes. This relationship was measured on a 1.5 km scale, with commercial soybean fields as the experimental unit. Some carabids, like *P. chalcites*, are considered to thrive in environments where agriculture is widely practiced (Larsen et al. 2003). It is unclear from our study if *P. chalcites* benefit from the presence of either grassed waterways or prairie strips.

Our second prediction compared predation activity in the cropped portions of the various landscape configurations. Our model revealed significant differences in predation among configurations for 2023, but like the activity-density data, we did not observe data that supported our prediction. The lowest amount of prey removal was in the paired prairie strip configuration, consistently less than what was observed in all other configurations. These findings are consistent with a limited number of studies that found that as landscape diversity increased, lower predation activity was observed (Carcamo and Spence 1994, Jonason et al. 2013). Inversely, landscape diversity was correlated with higher predation than fields with low landscape diversity (Gardiner et al. 2011).

Regardless of the difference in the amount of predation observed across the landscape configuration, overall, 50-60% of pupae were removed per configuration. When expressed in this manner, 10% fewer pupae were removed from the paired prairie strip configuration. Pairwise comparisons revealed higher predation in the grassed waterway and combo configuration compared to all other landscape configurations. These results partially support our prediction that vegetative cover increases predation activity. When we explicitly accounted for carabid activity-density on predation, models revealed a significant interaction for both years.

Our final prediction was to test for differences in carabid morphology based on the amount of vegetation in a crop field. We observed larger body size in areas with higher vegetation diversity. We also observed that female beetles have larger body size and weight, which is similar to other studies (Benítez et al. 2020, Ananina et al. 2021). Body size can be a functional trait for fitness and an indicator of habitat quality (Firle et al. 1998, Eyre et al. 2016). Resources for carabids during the larval stage could play an important role in fitness and building fat reserves (Thiele 1977, Juliano 1986, Nelemans 1987). Our data revealed larger female body size in the paired prairie strip configuration, which, if true, could have larger fat preserves and have a higher fitness compared to other configurations. Starved beetles tend to move shorter distances but make more movements in their dispersal activities compared to other beetles (Wallin and Ekbom 1988). These results could reveal a role in the activity-density of carabids found in our study. The availability of resources could be greater in the paired prairie strip increasing fitness and would require less activity of adults. This could explain the activity-density in areas that have less or no perennial vegetation, where resources could be scarce for carabids.

Conclusions

Our results suggest that carabid activity-density and predation in a crop field are affected by conservation practices. However, the nature of this relationship is counter to what we predicted. We anticipated observing the greatest activity-density and predation closest to these practices, especially those with the greatest amount of plant diversity (prairie strips). It is unclear what the primary response of carabids to the conservation practices studied herein. If carabids were utilizing grassed waterways and prairie strips as a refuge from agricultural disturbances, we expected more predation closest to the conservation features. However, this was not consistently observed; for some configurations, the opposite was observed. The relationship between carabids and habitat, whether in crop fields or adjacent to perennial vegetation, is likely driven by multiple factors unaccounted for within this study design. One such unexplored factor is the morphological and nutritional state of the individual carabids collected in this study. Predator behavior is driven by hunger or food deprivation (Adar et al. 2016, DeMars and Boutin 2018), which, if high, can lead to more activity and greater prey removal. We hypothesize that adult carabids found within or near grassed waterways and prairie strips have their nutritional needs met, which explains the greater diversity observed in previous studies. However, as the distance from perennial habitat increases and the availability of prey decreases, carabids' nutritional needs may not be immediately met. Such a state would result in more active adults which are more likely to encounter sentinel prey, like that offered in this study. Future studies should also measure morphological and physiological features associated with the nutritional state of individuals to determine if practices like prairie strips result in beneficial insects with fewer signs of hunger or nutritional constraints. Carabid species should also be evaluated individually to account for the difference in phenology and life history traits which could affect the activity-density and predation in crop fields. We observed a limited community of carabids, comprised primarily of agricultural specialists, that have been observed to respond negatively to perennial vegetation in previous studies. Species like *P. chalcites* may be capable of procuring resources within a disturbed environment like a corn or soybean field, limiting the benefit they receive from perennial vegetation found in prairie strips. If there is value in such habitats for *P. chalcites*, it may be revealed in a difference in size or fat-body content, both indicators of nutritional constraints.

Acknowledgments

Funding for data collection was provided by USDA Agriculture and Food Research Initiative (Project 2020-68012-31824). Andres Vargas was supported by Iowa State University College of Agriculture and Life Sciences. We thank P. Hollenberg, M. Pfab, J. Hollenberg, E. Heidt, B. Miller, M.J Pfleging, C. Tanwell, and B. Kolbe for field data collection. Russell Jurenka provided protocol for lipid extraction, and Y. Leon collected lipid data. We thank G. Courtney and A. Tucker for their comments to improve an earlier version of this chapter.

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Tables and Figures

Table 3-1. Statistic output for Poisson for models used for 2022 and 2023 data sets for total activity-density and species richness**.**

2022 Activity-density	**df**	**Estimate**	**F ratio**	**Chisq.**	***P*-value**
Landscape configuration	4	0.25000	14.625	58.500	<0.0001
Trap location	1	-1.0234	21.512	21.512	<0.0001
2022 Activity-density by distance					
Landscape configuration	2	0.37300	4.640	9.280	0.00970
Distance	3	0.55800	13.136	39.408	<0.0001
Landscape configuration*Distance	6	0.35400	3.172	19.032	0.00410
2022 Species richness					
Landscape configuration	4	0.65700	1.821	7.284	0.12170
Trap location	1	-0.39148	2.001	2.001	0.1572
2022 Species richness by distance					
Landscape configuration	2	0.34800	2.4450	4.8900	0.08670
Distance	3	0.71000	1.463	4.3890	0.22250
Landscape configuration*Distance	6	0.71000	0.58800	3.5280	0.74010
2023 Activity-density					
Block	3	0.30800	1.587	4.761	0.19020
Landscape configuration	4	0.62100	17.676	70.704	<0.0001
Trap location	1	0.18381	3.338	3338	0.06770
2023 Species Richness					
Block	3	0.62800	0.925	2.775	0.42750
Landscape configuration	4	0.62800	11.926	47.704	<0.0001
Trap location	1	0.22930	2.825	2.825	0.09280

Table 3-2A. List of carabid activity-density and species caught in all landscape configurations and distances in 2022.

Species	Total	Crop only	Grassed waterway				Lone prairie strip				Paired prairie strip				Combo configuration
			Non-crop	Cropland			Non-crop	Cropland			Non-crop	Cropland			
Distance (M)		30	0	5	15	30	0	5	15	30	0	5	15	30	30
Number of samples (n)*	168	12	12	12	12	12	12	12	12	12	12	12	12	12	12
Total individuals	317	79	11	16	15	25	8	8	32	70	4	4	11	11	23
Total species	16	5	4	3	3	2	7	1	3	4	4	3	4	1	3
Poecilus chalcites (Say)	275	72	8	12	12	24	2	8	29	67	1	2	8	11	20
Clivina bipustulata (Fabricius)	11	3		2	1				1	1		1			2
Elaphropus anceps (LeConte)	10	2		1	2				2			1	1		1
Poecilus lucublandus (Say)	4	1					1			1					
Cyclotrachelus sodalis (LeConte)	3		1								1		1		
Galerita janus (Fabricius)	2						1				1				
Pterostichus femoralis (Kirby)	2		1				1								
Pterostichus melanarius (Illiger)	2					1				1					
Pterostichus permundus (Say)	1						1								
Pterostichus stygicus (Say)	1		1												
Harpalus caliginosus (Fabricius)	1						1								
Dicaelus elongatus Bonelli	1												1		
Anisodactylus sanctaecrucis (Fabricius)	1	1													
Bembidion versicolor (LeConte)	1						1								
Anisodactylus rusticus (Say)	1										1				
Bembidion quadrimaculatum oppositum Say	1			1											

*Total number of samples collected in each landscape configuration across all sampling dates.

Table 3-2B. Total carabid activity-density and species richness for all landscape configurations in 2023.

Species	Overall	Crop only	Grassed waterway		Lone prairie strip		Paired prairie strip		Combo configuration
			Non-crop	Cropland	Non-crop	Cropland	Non-crop	Cropland	
Number of samples (n)*	490	85	59	65	57	57	65	65	76
Total Individuals	617	155	142	139	37	27	25	30	61
Total Species	22	9	15	12	10	12	10	8	7
Poecilus chalcites (Say)	291	82	80	94	6	6	1	8	24
Poecilus lucublandus (Say)	85	17	25	12	5	6	6	5	9
Harpalus pensylvanicus (DeGeer)	61	17	3	12	8	4	5	4	8
Pterostichus melanarius (Illiger)	44	11	5	8		1	1	3	15
Cyclotrachelus sodalist (LeConte)	32	11	2	3	4	1	5	3	3
Pterostichus permundus (Say)	28	14	2	3	1	3	1	3	1
Pterostichus stygicus (Say)	17	1	14	1		1			
Galerita janus (Fabricius)	14		1		8		4	1	
Harpalus caliginosus (Fabricius)	9		3	2	1	1	1		1
Amara littoralis Mannerheim	9		8	1					
Anisodactylus harrisii (LeConte)	5		2		1	1			
Harpalus somnulentus Dejean	5		3	1		1			
Anisodactylus merula (Germar)	3				2	1			
Chlaenius tomentosus (Say)	3	1					1	1	
Dicaelus elongatus Bonelli	3		1		1	1			
Pterostichus femoralis (Kirby)	1			1					
Anisodactylus sanctaecrucis (Fabricius)	1							1	
Bembidion versicolor (LeConte)	1			1					
Anisodactylus rusticus (Say)	1		1						
Anisodactylus nigrita Dejean	1		1						
Chlaenius pusillus Say	1	1							
Scarites quadriceps Chaudoir	1		1						

*Total number of samples collected in each landscape configuration across all sampling dates.

Table 3-4. Statistical output for binomial model to measure predation activity in 2022 and 2023.

2022 Predation activity	**df**	**Estimate**	**F ratio**	**Chisq.**	***P*-value**
Landscape configuration	4	-0.975	0.724	2.896	0.58510
2022 Predation by distance					
Landscape configuration	2	-0.45400	3.152	6.304	0.04280
Distance	2	-0.5600	18.123	36.246	<0.0001
2023 Predation activity					
Block	3	0.15400	2.680	8.040	0.04520
Landscape configuration	4	0.44400	6.581	26.324	<0.0001

Table 3-5. Carabid morphology and lipid content one-way ANOVA statistical results.

Body Length	**df**	**Estimate**	**Sum Sq**	**Mean Sq**	**F ratio**	***P*-value**
Sex	1	-0.61230	6.255	6.2545	5.3994	0.02235
Landscape configuration	4	-1.9500	14.102	3.35254	3.0434	0.02098
Trap location	1	0.40060	2.031	2.0313	1.7535	0.18871
Residuals	77		106.571	1.1584		
Pronotum width						
Sex	1	0.10285	0.33200	0.33212	0.7197	0.39843
Landscape configuration	4	-0.51700	4.2480	1.06206	2.3016	0.06447
Trap location	1	0.00863	0.00100	0.00094	0.0020	0.96403
Residuals	77		42.453	0.46145		
Pronotum length						
Sex	1	0.10937	0.3160	0.31598	1.1650	0.28330
Landscape configuration	4	-0.34600	2.9045	0.72612	2.6771	0.03660
Trap location	1	0.04325	0.0237	0.02367	0.0873	0.76830
Residuals	77		24.9537	0.27124		
Elytra width						
Sex	1	-0.18936	0.73380	0.73381	2.2945	0.13330
Landscape configuration	4	-0.7700	0.54260	0.13566	0.42420	0.79080
Trap location	1	-0.01812	0.00420	0.00416	0.50130	0.90950
Residuals	77		29.4226	0.31981		
Elytra length						
Sex	1	-0.2670	0.87800	0.87757	1.3890	0.24160
Landscape configuration	4	-1.2700	4.4890	1.12214	1.7761	0.14030
Trap location	1	0.17840	0.40300	0.40286	0.63760	0.42660
Residuals	77		55.126	0.63181		
Body mass before lipid removal						
Sex	1	-3.8935	278.1	278.109	1.5222	0.22040
Landscape configuration	4	-1.2700	1068.5	267.136	1.4622	0.22010
Trap location	1	-0.07542	0.1	0.07200	0.0004	0.98420
Residuals	77		16808.3	182.698		
Body mass after lipid removal						
Sex	1	-3.7300	305.7	305.655	7.4536	0.00759
Landscape configuration	4	-4.4780	367.3	91.833	2.2394	0.07077
Trap location	1	4.4900	255.2	255.176	6.2226	0.01440
Residuals	77		3772.7	41.008		
Difference between body mass before and after lipid removal						
Sex	1	0.28860	7.200	7.241	0.06930	0.79300
Landscape configuration	4	-4.3200	371.40	92.860	0.88860	0.47410
Trap location	1	-3.7635	179.30	179.253	1.7153	0.19360
Residuals	77		9614.0	104.501		
Dried lipid mass						
Sex	1	-735.00	44466654	44466654	0.63060	0.42920
Landscape configuration	4	-927.00	229016322	57254080	0.81200	0.52070
Trap location	1	-190.20	457885	457885	0.00650	0.93590
Residuals	77		6487048320	70511395		

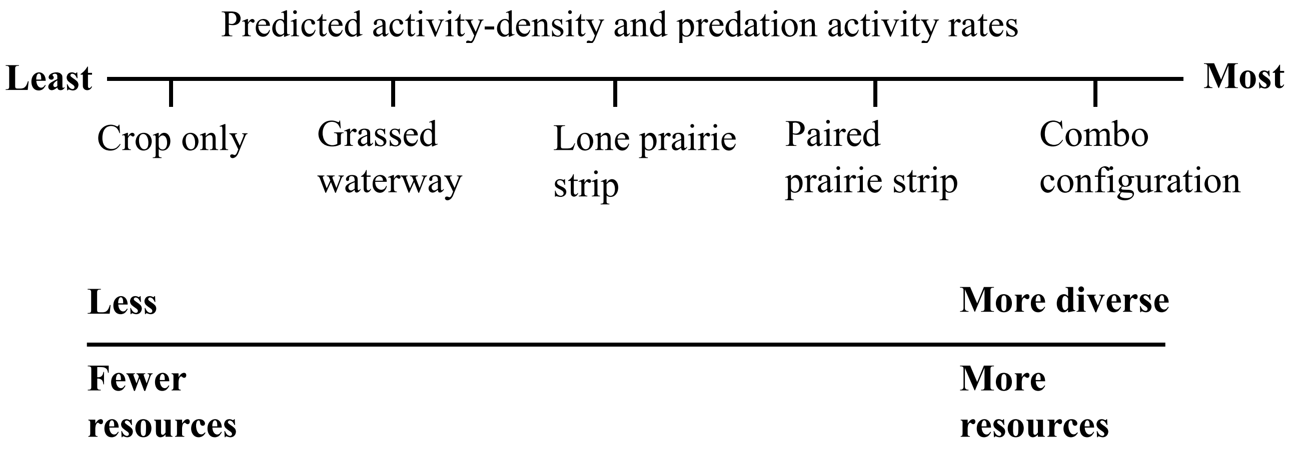

Figure 3-1. Schematic of our predictions for how carabid activity density and predation will differ based on vegetation diversity. We expect areas with lower vegetation diversity to have fewer resources available to carabids and, as a result have lower activity-density and lower pest predation.

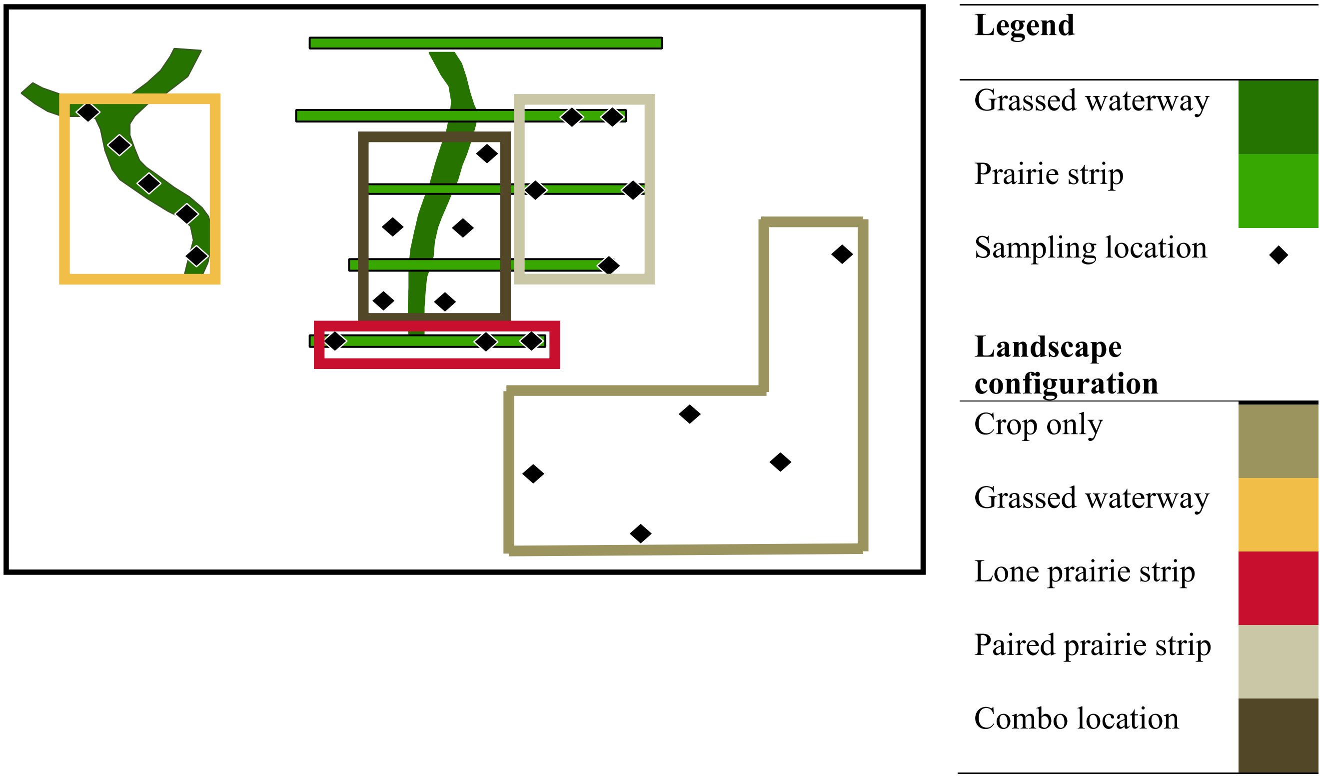

Figure 3-2. Field schematic of sampling locations. Diamonds depict the location of traps and cages used for data collection.

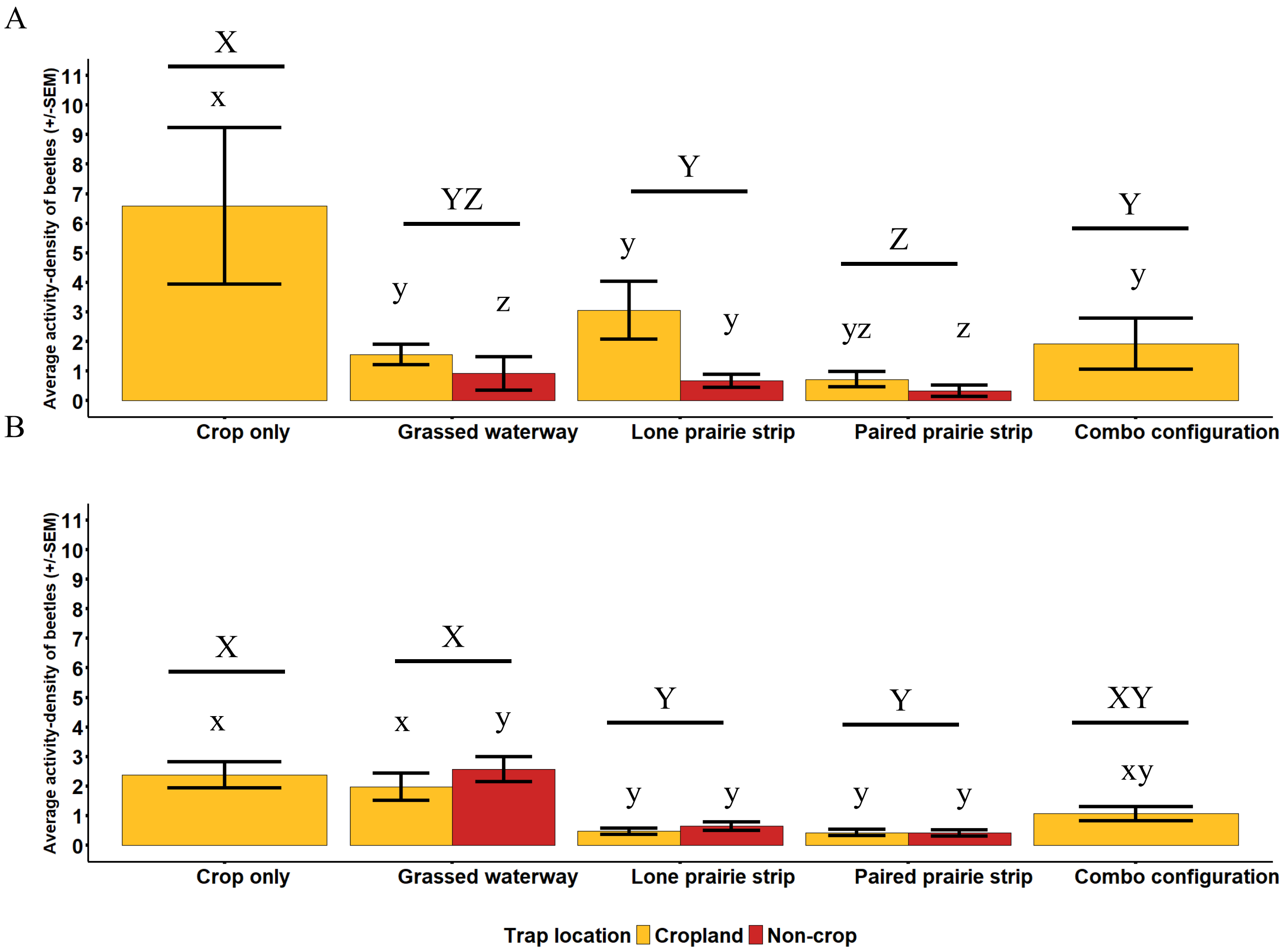

Figure 3-3 Mean (±SEM) A) 2022 activity-density for one field and B) 2023 activity-density of ground beetles among all sites, landscape configurations, and trap location. Cropland (gold) were beetles caught inside the crop field. Non-crop (red) were beetles caught inside the perennial vegetation (prairie strip and grassed waterway). Capital letters show significant differences in means among treatments. Lowercase letters show significant differences among trap locations. Significance level *P*≤0.05.

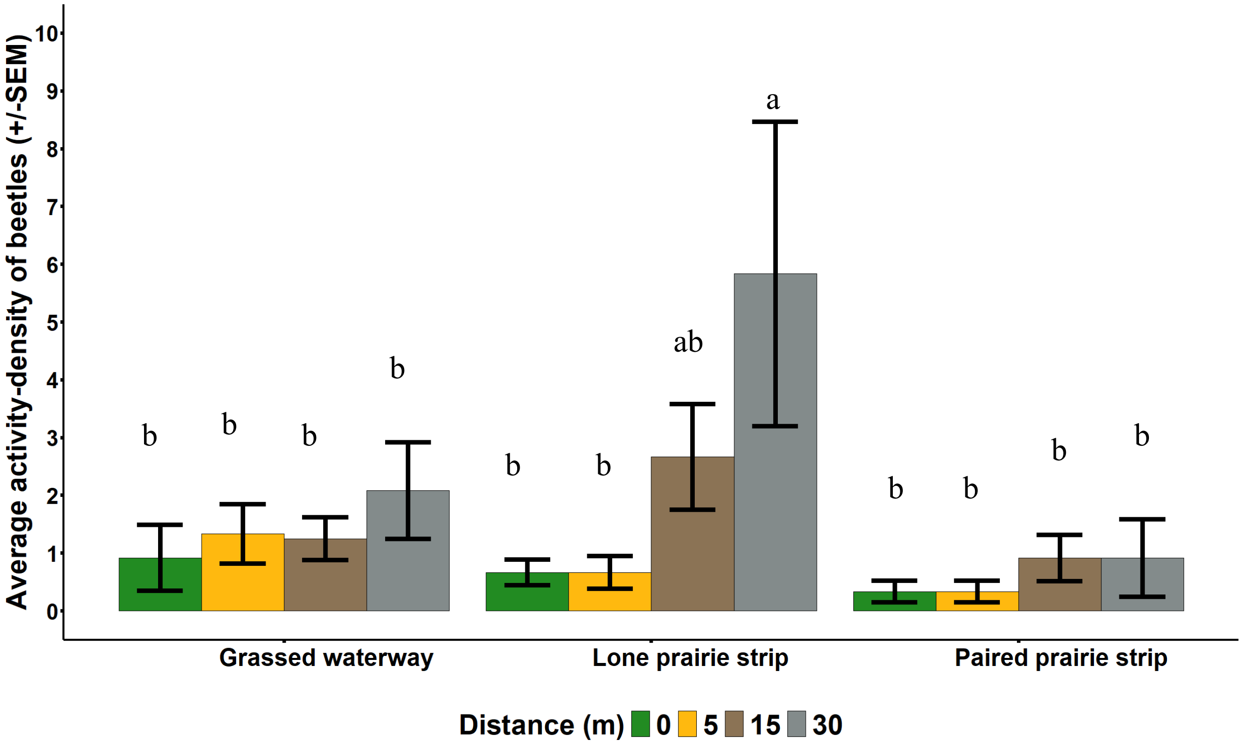

Figure 3-4**.** Mean (± SEM) activity-density with distance from landscape configuration. Data were collected at a single farm in central Iowa in 2022. Means are reported on a per trap per sampling date basis. Lowercase letters indicate significant differences among distances at the *P*≤0.05 level.

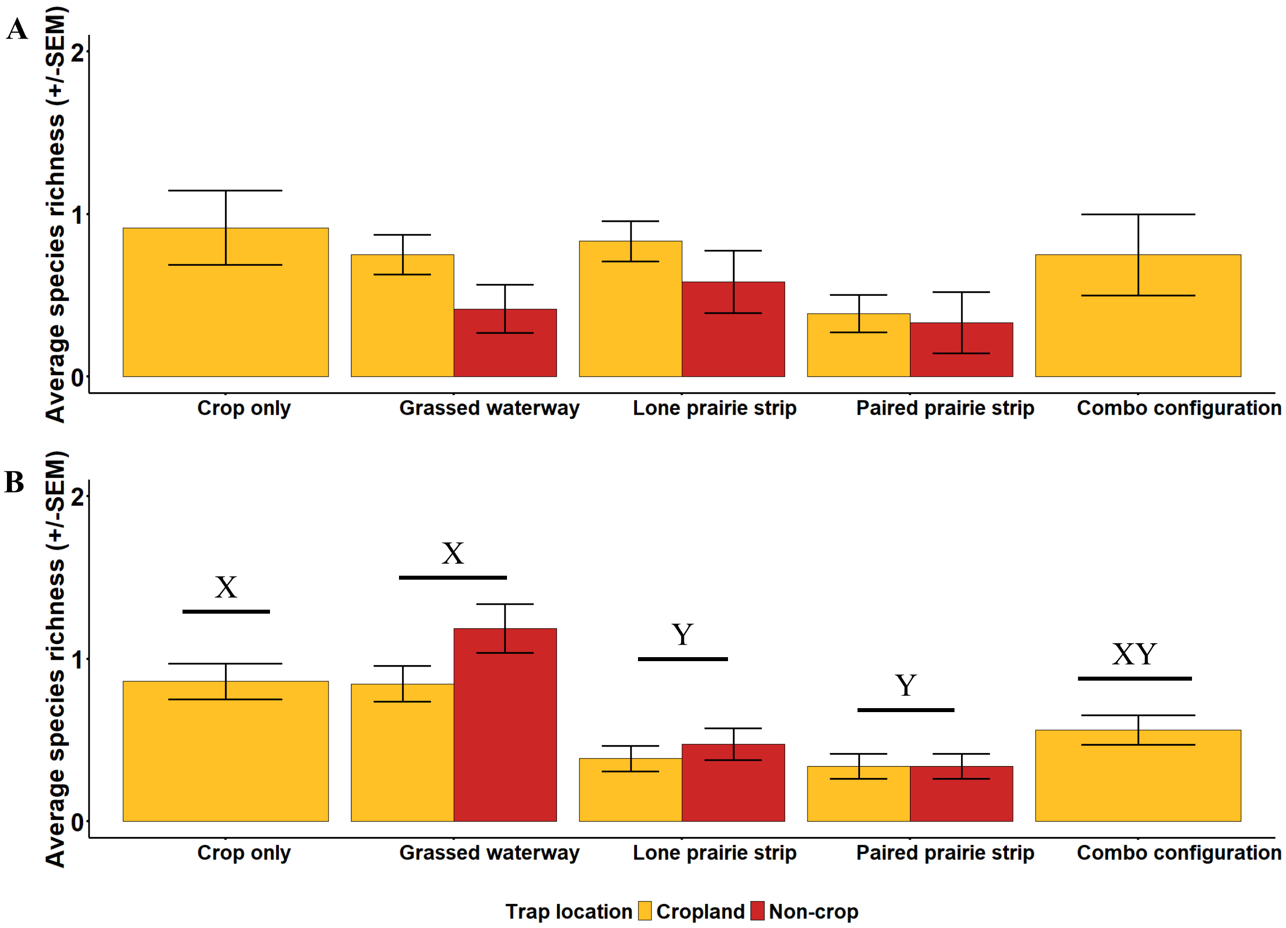

Figure 3-5. Mean (± SEM) species richness in A) 2022 and B) 2023 in each landscape configuration and trap location. Means are reported on a per trap per sampling date basis across 2022 (single farm) and 2023 (four farms) data sets. Capital letters show significant differences in means among landscape configurations at the *P*≤0.05 level.

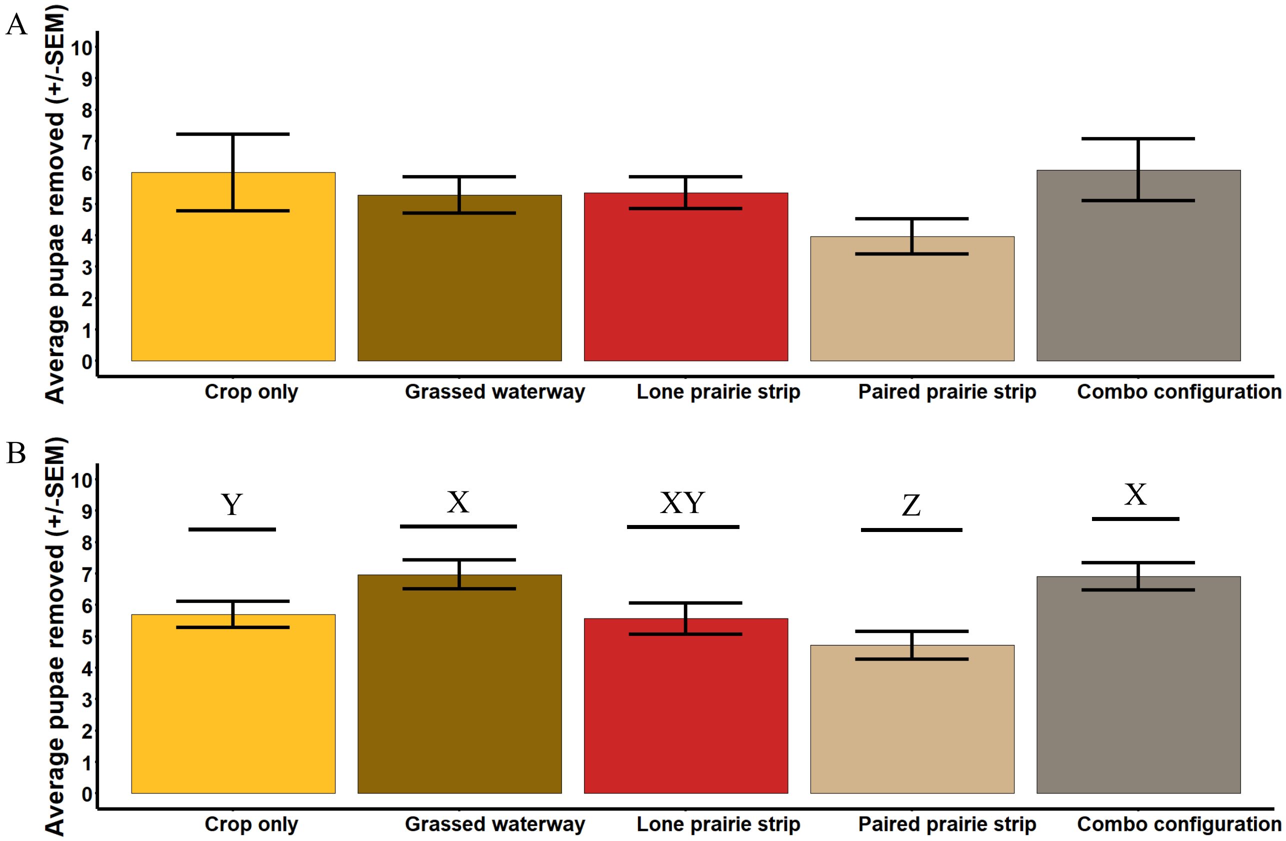

Figure 3-6. Mean (± SEM) predation (pupae removed per card per day) in A) 2022 (single farm) and B) 2023 (four farms) across all landscape configurations. Capital letters show significant differences among configurations at the *P*≤0.05 level.

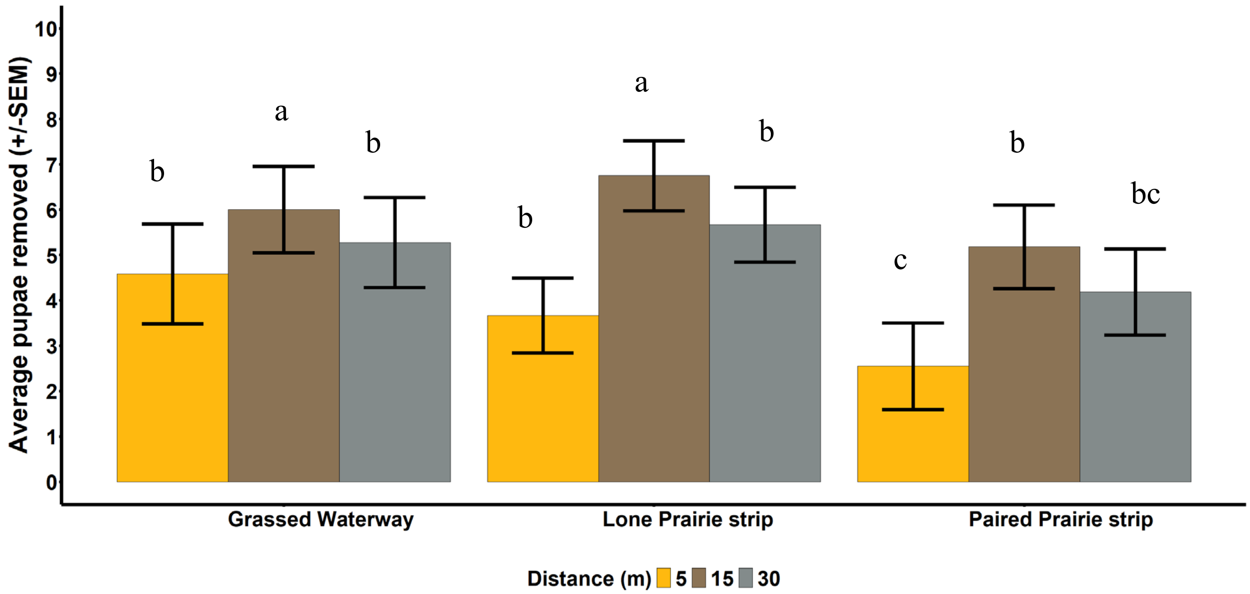

Figure 3-7. Mean (± SEM) predation (pupae removed per card per day) at three distances from the perennial vegetation configuration types at one farm in 2022. Capital letters show significant differences among configurations. Lowercase letters show significant differences among distances at the *P*≤0.05 level.

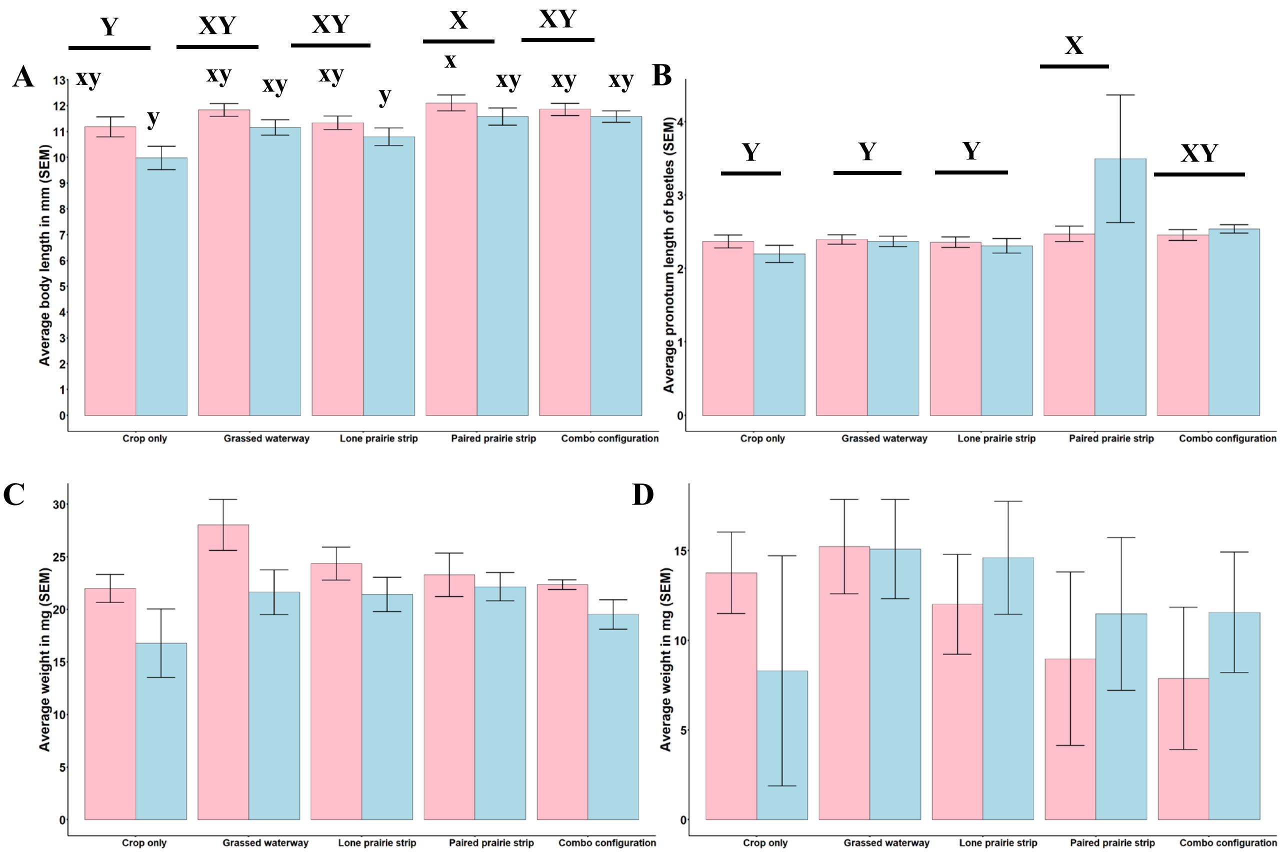

Figure 3-8. *Poecilius chalcites* mean (± SEM) A) body length, B) pronotum length, C) body mass after lipid removal, and D) difference of mass before and after lipid removal in each landscape configuration in 2022 and 2023 based on sex. Capital letters show significant differences in means among treatments at the $P \leq 0.05$ level. Lowercase letters show significant differences among sexes at the $P \leq 0.05$ level.

CHAPTER 4. GENERAL CONCLUSIONS

My research objectives for this thesis were to (1) characterize the ground beetle community in fields with and without prairie strips, (2) evaluate carabid activity-density based on vegetation cover in crop fields, and (3) evaluate the ecosystem service provided by carabids in the adjacent crop field.

In Chapter 2, I evaluated my first objective using data collected from eight crop fields (corn or soybean), with four fields incorporating prairie strips and four without. I discovered that prairie strips significantly influence the carabid community in crop fields, although the extent of this effect varies by location. Notably, sites RHO and WHI exhibited higher activity and species richness. Activity-density appeared to be seasonally dependent, peaking in late summer. I observed almost two and a half times more carabid species in the prairie strips compared to the control fields. Analyzing the community further by feeding guilds and adult breeding activity revealed a dominance of omnivorous and carnivorous beetles. Additionally, beetles that breed in the spring and throughout the season were among the most collected in this study. This study aligns with Kordbacheh et al. (2020) and provides additional evidence that prairie strips increase the activity-density and species richness of insects. Prairie strips have the potential to enhance the ecosystem delivery of carabids in adjacent crop fields by increasing species richness and the diversity of feeding guilds.

In Chapter 3, I evaluated my second and third objectives using five landscape configurations with different amounts of perennial vegetation cover. Configurations with minimal diverse vegetation cover had high activity-density and species richness. Additionally, activity-density was higher in the cropland adjacent to non-crop areas and often increased with distances away from these areas. Species richness in each landscape configuration followed similar trends as activity-density.

The presence of prairie strips in crop fields had minimal influence on predation activity. However, predation activity was highest in configurations with a grassed waterway and those combining a grassed waterway and prairie strip. In contrast, configurations with multiple prairie strips did not significantly influence predation rates. This provides evidence that additional research needs to be conducted in order to understand how vegetation cover influences ecosystem service delivery.

I evaluated the morphological and physiological differences in *P. chalcites* in order to understand the patterns in activity-density and predation activity. I found that individuals in configurations with multiple prairie strips had larger body sizes and pronotum lengths. Larger body size can indicate better resource availability during larval development, which could explain the lower activity-density and predation activity observed in the paired prairie strip configuration.

Some of my results were contrary to expectations and highlighted gaps in scientific knowledge regarding how vegetative conservation contributes to insect-associated ecosystem service delivery in crop fields. The phenology of beetles could play a crucial role in the activity-density rates found in crop fields, suggesting that further research on beetle phenology could provide valuable insights. Individual species' life history, like breeding periods and dispersal abilities, could play a role in various surges in activity-density throughout the growing season. Life history should be taken into account while observing activity-density and predation activity in crop fields. Additionally, quantifying beetle health through morphological and physiological measurements could offer a deeper understanding of predation activity. Assessing the crop environment in terms of vegetation density, crop residue cover, and soil attributes could help explain the availability of food for beetles and their ease of movement. Finally, molecular analysis of beetle gut contents could reveal specific feeding habits and provide key ecological information about the food web in the study system. Expanding research in these areas could help clarify the interactions between carabids, vegetative cover, and ecosystem service delivery in crop fields. Understanding how carabids utilize vegetative cover will be crucial for advancing sustainable agriculture practices.

In summary, this research lays the groundwork for expanding integrated pest management strategies to include prairie strips, aiding farmers in creating ecologically sound agricultural practices in the U.S. Midwest and beyond. Prairie strips can increase the community of carabids in Midwestern crop fields and potentially enhance the ecosystem service delivery of biological control. Further research is needed to unravel the complexity of carabid interactions with agricultural environments to provide specific management recommendations on the effectiveness of vegetative cover practices in biological control.