EVALUATING HOW WETLAND PRESENCE AND RESTORATION EFFECTS LANDSCAPE AND RESOURCE USE OF POLLINATOR COMMUNITIES IN AN AGRICULTURAL MATRIX

By

CYNTHIA N. PARK

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Thesis Approved:

Dr. Loren Smith

Thesis Adviser

Dr. Scott McMurry

Dr. Kristopher Giles

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Name: CYNTHIA PARK

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Title of Study: EVALUATING HOW WETLAND PRESENCE AND RESTORATION EFFECTS LANDSCAPE AND RESOURCE USE OF POLLINATOR COMMUNITIES IN AN AGRICULTURAL MATRIX

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Abstract: Pollination is critical for ensuring biodiversity and human food supplies. However, wild pollinator populations are declining due to fragmentation and loss of habitat. These concerns are apparent in the Rainwater Basin of Nebraska, where more than 90% of the region has been cultivated. The small number of playa wetlands and their adjacent uplands present in this region are the only natural habitat available for pollinators. My objective was to document wild pollinating insects in south-central Nebraska and observe how they utilize the landscape for habitat and food resources. I used blue vane traps to passively collect insects and insect nets to obtain actual habitat and foraging information from April through October in 2014 and 2015. I compared pollinator abundance, richness, and diversity by insect order in wetlands and uplands within three land uses: cropland, reference condition, and restored sites implemented through the Wetlands Reserve Program. Net data for dominant pollinating families were analyzed using a Principle Response Curve to observe the effects of land use, watershed position, and dominant food plant on foraging habits. Additionally, vegetation data were collected using the step-point intercept method to determine differences in plant community among land uses. Dominant plant species were analyzed using a Partial Canonical Correspondence Analysis.

Numerous insect orders were collected, but bees were dominant. Trap data showed bees used restored and reference uplands over wetlands and croplands, most likely due to nesting resources only being available in watershed grasslands. Net collections showed bees foraged more in wetlands than uplands, especially in wetlands that have undergone restoration. However, in September, bees foraged in uplands and crop wetlands more than restored or reference wetlands in order to feed on late season forbs. Apidae exhibited strong associations with smartweeds and goldenrods in late summer, neither of which were associated with restored sites. To ensure viable pollinator communities throughout the growing season, restoration practices should provide more diverse wetland flora and additional late season upland forbs than is being currently provided. Additional pollinating orders discussed include Diptera, Coleoptera, and Lepidoptera.

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CHAPTER I

INTRODUCTION

Pollination is crucial to the biodiversity of the natural world and for the productivity of many agricultural crops (NRC 2007; James-Pitts & Singer 2008). About 180,000 species of the flowering plants require animal assisted pollination to successfully carry pollen from the male to the female parts of the flower for reproduction (NRC 2007). Pollination by invertebrates is generally attributed to four orders: Coleoptera (beetles), Diptera (flies), Lepidoptera (moths and butterflies), and most notably Hymenoptera (bees and wasps) (NRC 2007).

At least 130,000 species of animals regularly visit flowers to drink nectar (Wilmer 2011). However, an insect can visit a flower without effectively participating in pollination. There are certain physical, behavioral, and physiological factors that invertebrates can exhibit to be a good pollinator (Wilmer 2011a). Bees are generally the most efficient and superior pollinators because their body is covered with pollen-trapping body hair, they exhibit specialized flower handling capabilities and foraging behavior, and they require floral rewards (i.e. nectar and pollen) to feed themselves and their offspring (Free 1993a). Bees visit more flowers than any other animal and transfer high amounts of pollen between visiting flowers. Plants have responded by overproducing pollen to satisfy the life history needs of bees while having enough for fertilization to be transferred to neighboring flowers (Wilmer 2011a).

Additional orders of invertebrates are also important sources of pollination. Flies (Diptera) are generally considered the second most frequent visitors to flowers behind bees, and syrphid flies are likely the most important family for pollination (Larson *et al*. 2001). Syrphids, also known as hoverflies or flower flies, are known as efficient pollinators in temperate zones, and specifically equipped to feed on flowers which adults rely almost entirely on for food (Wilmer 2011b). Moreover, all syrphids are covered in hair, sometimes branched like bees, which help them collect pollen that they then transfer or feed on (Wilmer 2011b). Beetles are another significant non-bee pollinator. While many families contain some flower visitors, Cantharidae (soldier beetles) and Cerambycidae (longhorn beetles) are noted as important and abundant pollinators because rely almost exclusively on pollen or nectar at some part of their life cycle (Wilmer 2011c).

Pollinators provide an important economic service. The annual value of pollination within the United States has been valued at $17 billion, with wild bees contributing an additional $3.07 billion (Losey & Vaughan, 2006). The service of biotic pollination, especially by the domestic honeybee (*Apis mellifera* L.), has been well documented to improve the quality and quantity of fruit, vegetable, oil, fiber, and seed crops (Delaplane & Mayer 2000a; Roubik 1995; Klein et al. 2007; NRC 2007). The monetary value of pollinator services in the United States alone, solely of crops that require insect pollination (e.g. apples, almonds, blueberries), was estimated at $15.12 billion as of 2009 (Calderone 2012). This number does not include indirect benefits such as alfalfa pollination used as hay for cattle production or the value of the milk derived from dairy cattle who consume that alfalfa (Morse & Calderone 2000).

The honeybee is the most widely used pollinator for crops, possibly comprising over 90% of managed agriculture pollinator services. Yet, there is a risk in relying solely on one species for an ecosystem service (James & Pitts-Singer 2008). As the world's population grows, the need of insect pollination for future crop production is projected to increase (Delaplane & Mayer 2000a; Calderone 2012). However, the possibility of a pollinator shortage has become an increasing concern (Steffan-Dewenter & Tscharntke 1999; Aizen *et al*. 2009; Potts *et al.* 2010). There has been a growing interest in non-*Apis,* or wild bees, because of massing losses (up to 59%) of managed honeybee colonies across the nation (Delaplane & Mayer 2000; Stokstad 2007; vanEngelsdorp *et al.* 2009).

Wild pollinators help the function and structure of natural communities through the assistance of angiosperm reproduction. Plants are the foundation of all food chains, and angiosperms provide essential nutrients and resources to other organisms in almost every ecosystem. Therefore, the natural world depends on biotic pollination maintain overall biodiversity (NRC 2007; Wilmer 2011a). Furthermore, the flower-pollinator mutualism has led plants and pollinators to evolve complex structures and biology. A diversity of pollinators is required to ensure the pollination of all plants can be completed (Wilmer 2011a). For example, there are many flowers that require a bumblebee's size or long tongue to access nectar in deep corolla tubes. Bumblebees have specialized "buzz-pollination" in which high frequency wing vibration causes pollen to be released and attached onto the bee with an electrostatic field (Corbet *et al.* 1988; Free 1993b). Wild bees can be social or solitary and inhabit a variety of different nests including burrows in old nests, wood, plant stems, or soil. Rearing wild bees is much more difficult than with honeybees, therefore management often includes conservation or enhancement of native habitat (Deplane and Mayer 2000).

Not only are honeybee populations declining— wild pollinator populations are as well (Biesmeijer *et al.* 2006, Potts *et al.* 2010). Fragmentation and depletion of habitat are thought to be the primary contributors to the losses of pollinator populations (Steffan-Dewenter & Tscharntke 1999, Potts *et al.* 2010). Fragmentation creates smaller, isolated populations that can result in genetic depression, inbreeding, and reduced species richness by removing corridors within species metapopulations and source populations for recolonization (Kearns *et al*. 1998; NRC 2007; Potts *et al.* 2010). Some bees, such as large bumblebees, can be relatively mobile, foraging up to 2.2 km from the nest (Kreyer et al. 2004). However, the majority of species do not forage at distances beyond 100-300 m from nesting sites (Zurbuchen *et al*., 2009), and some bees have been found to nest centimeters away from their preferred pollen sources (Westrich, 1996). Increased spatial separation between habitats can reduce bee populations by reducing resources needed for successful reproduction (e.g., nesting sites, nest material, and food resources) (Westrich, 1996). Close available resources are especially crucial for wild female bees that require more foraging trips from the nest to pollen sources in order to feed their young (Zurbuchen *et al*., 2009).

Pollinator populations can be closely tied with populations of native vegetation (Longley & Sotherton, 1997; Biesmeijer *et al*., 2006; NRC 2007; Potts *et al.,* 2010). Consequently, replacement of mosaic grassland flora with crop monocultures has been attributed to the extinction of entire bumblebee species in the United Kingdom, and it appears that the

United States is seeing analogous losses (Goulson *et al*., 2005, Grixti *et al*., 2009). Additionally, the use of various pesticides in agricultural landscapes also has been an underlying concern for pollinator populations since the 1870s (Johansen, 1977). As noted above, flora can greatly impact the invertebrate community; therefore, herbicide removal of forbs impacts pollinators by removing critical resources such as nectar and pollen producing flowers and nesting habitat. Pesticides not only impact the vegetation, but many insecticides directly weaken and kill beneficial species of pollinators (Alston *et al.,* 2007; Brittain *et al.,* 2010; Henry *et al.,* 2012). Systemic insecticides are of particular concern because they are absorbed by the plant and dispersed throughout the vascular system, eventually contaminating the nectar and pollen (Rortais *et al.,* 2005). Many of these insecticides, such as neonicotinoids, cause sub-lethal effects but are not thought to cause direct mortality. However, research is surfacing that illuminates the behavioral difficulties obtained such as memory and learning dysfunctions, abnormal foraging, and alteration of navigational skills (Desneux *et al*., 2007; Henry *et al.,* 2012).

Anthropogenic habitat alteration, such as large scale agriculture, often has a negative impact on pollinators due to the loss of floral resources, nesting habitat, and pesticides (Potts *et al*., 2010). However, landscape scale may be important when considering pollinator habitat (i.e. food, nesting sites, and overwinter sites) in an agriculturally dominated area. Numerous studies have shown that if suitable habitat is located near cultivated areas, pollinator diversity and abundance within croplands increases due to the adjacent availability of resources (Steffan-Dewenter & Tscharntke, 1999; Kremen *et al*., 2002, 2002b; Greenleaf & Kremen, 2006; Kim *et al*., 2006; James & Pitts-Singer, 2008). As early as 1946, Peck and Bolton stated that wild *Megachile* sp. were the most efficient pollinators of alfalfa, however, nesting resources needed to be provided. They suggested that wide strips of uncultivated land should surround the croplands, plants with hollow stems be grown on the edges, and old sunflower stems scattered for nesting habitat (Peck & Bolton, 1946). Having numerous pockets of suitable habitat located within large areas of croplands can provide fundamental resources, connect populations, and increase abundance of pollinating insects (Kremen *et al.,* 2002).

This study was in the Rainwater Basin (RWB) region of south central Nebraska, United States. This region is dominated by agriculture, primarily corn and soybean crops. Historically, the RWB consisted of mixed grasslands with abundant depressional wetlands known as playas (Kuchler, 1964; LaGrange *et al*., 2011). However, North American grasslands have declined by as much as 99% and over 90% of the wetlands in the RWB have been drained or modified for agricultural use (Samson & Knopf, 1994, LaGrange, 2005). The playa wetlands and prairie uplands that remain or have been restored may be important for pollinators to obtain resources they are unable to find elsewhere on the agriculturally dominated landscape.

My second chapter will be a taxonomic documentation of the wild bee fauna and other insects collected in the RWB in order to provide an updated distribution to many native genera historically recorded in this region. The third chapter will focus on examining the effects of watershed land use, wetland presence, and restoration on pollinator populations within playas and associated catchments across three different land use types: cropland, reference sites, and restored sites enrolled in the Wetland Reserve Program (WRP). Pollinators are more attracted to undisturbed areas because they are more likely to contain ample amounts food resources and habitat (Delaplane & Mayer

2000). Furthermore, land use has major effects on ecosystems services in the uplands and the playas, including floral biodiversity which consequently affects pollinator community composition. Therefore, I predicted that sites located within crop fields would have less pollinator abundance and biodiversity than those within reference and restored sites. Many pollinating invertebrates can be closely associated with the flora, and some time their emergence to coincide with the blooming of certain flowers. Therefore, my fourth chapter will observe variation in plant communities among land uses, as well as how pollinators are using the landscape and available resources for forage.

LITERATURE CITED

Aizen, M. A., & Feinsinger, P. 1994. Habitat fragmentation, native insect pollinators, and feral honey-bees in Argentine Chaco Serrano. Ecological Applications 4(2): 378-392.

Alston, D. G., Tepedino, V. J., Bradley, B. A., Toler, T. R., Griswold, T. L., & Messinger, S. M. 2007. Effects of the insecticide phosmet on solitary bee foraging and nesting in orchards of Capitol Reef National Park, Utah. Environmental Entomology 36(4): 811-816.

Biesmeijer, J. C., Roberts, S. P. M., Reemer, M., Ohlemuller, R., Edwards, M., Peeters, T., . . . Kunin, W. E. 2006. Parallel declines in pollinators and insect-pollinated plants in Britain and the Netherlands. Science 313(5785): 351-354.

Brittain, C. A., Vighi, M., Bommarco, R., Settele, J., & Potts, S. G. 2010. Impacts of a pesticide on pollinator species richness at different spatial scales. Basic and Applied Ecology 11(2): 106-115.

Calderone, N. W. 2012. Insect Pollinated Crops, Insect Pollinators and US Agriculture: Trend Analysis of Aggregate Data for the Period 1992-2009. Plos One 7(5).

Cane, J. H., & Tepedino, V. J. 2001. Causes and extent of declines among native North American invertebrate pollinators: Detection, evidence, and consequences. Conservation Ecology 5(1).

Corbet, S. A., Chapman, H., & Saville, N. 1988. Vibratory pollen collection and flower form: Bumble-bees on Actinidia, Symphytum, Borago and Polygonatum. Functional Ecology 2(2): 147-155.

Delaplane, K. S., & Mayer, D. F. 2000. Crop pollination by bees. New York City, New York. CABI Publishing.

Desneux, N., Decourtye, A., & Delpuech, J. M. 2007. The sublethal effects of pesticides on beneficial arthropods Annual Review of Entomology 52: 81-106.

Free, J. B. 1993. Using bumblebees as pollinators In: Insect pollination of crops (2nd ed., pp 74-83) Academic Press. San Diego, California.

Goulson, D., & Sparrow, K. 2009. Evidence for competition between honeybees and bumblebees; effects on bumblebee worker size. Journal of Insect Conservation, 13(2): 177-181.

Greenleaf, S. S., & Kremen, C. 2006. Wild bee species increase tomato production and respond differently to surrounding land use in Northern California. Biological Conservation 133(1): 81-87.

Grixti, J. C., Wong, L. T., Cameron, S. A., & Favret, C. 2009. Decline of bumble bees (Bombus) in the North American Midwest. Biological Conservation 142(1): 75-84.

Henry, M., Beguin, M., Requier, F., Rollin, O., Odoux, J. F., Aupinel, P., . . . Decourtye, A. 2012. A Common Pesticide Decreases Foraging Success and Survival in Honey Bees. Science 336(6079): 348-350.

James, R. R., & Pitts-Singer, T. L. 2008. Bee pollination in agricultural ecosystems. Oxford University Press. New York City, New York.

Johansen, C. A. 1977. Pesticides and Pollinators. Annual Review Entomology 22: 177-192.

Kearns, C. A., Inouye, D. W., & Waser, N. M. 1998. Endangered mutualisms: The conservation of plant-pollinator interactions. Annual Review of Ecology and Systematics 29: 83-112.

Kim, J., Williams, N., & Kremen, C. 2006. Effects of cultivation and proximity to natural habitat on ground-nesting native bees in California sunflower fields. Journal of the Kansas Entomological Society 79(4): 309-320.

Klein, A.-M., Vaissière, B. E., Cane, J. H., Steffan-Dewenter, I., Cunningham, S. A., Kremen, C., & Tscharntke, T. 2007. Importance of pollinators in changing landscapes for world crops. Proceedings. Biological sciences / The Royal Society 274(1608): 303.

Kremen, C., Williams, N. M., & Thorp, R. W. 2002. Crop pollination from native bees at risk from agricultural intensification. Proceedings of the National Academy of Sciences of the United States of America 99(26): 16812-16816.

Kreyer, D., Oed, A., Walther-Hellwig, K., & Frankl, R. 2004. Are forests potential landscape barriers for foraging bumblebees? Landscape scale experiments with *Bombus terrestris* and *Bombus pascuorum* (Hymenoptera, Apidae). Biological Conservation 116(1): 111-118.

Küchler, A. W. 1964. Potential natural vegetation of the conterminous United States. New York: New York, American Geographical Society.

LaGrange, T., Stutheit, R., Gilbert, M., Shurtliff, D., & Whited, P. 2011. Sedimentation of Nebraska's playa wetlands: a review of current knowledge and issues. Nebraska Game and Parks Commission, Lincoln 62.

Longley, M., & Sotherton, N. W. 1997. Factors determining the effects of pesticides upon butterflies inhabiting arable farmland. Agriculture Ecosystems & Environment 61(1): 1-12.

Losey, J.E., & Vaughan, M. 2006. The economic value of ecological services provided by insects. Bioscience 56: 311—323.

Morse, R., & Calderone, N. 2000. The value of honey bees as pollinators of U.S. crops in 2000. Bee Culture 128(3).

National Research Council. 2007. Status of pollinators in North America. Committee on the Status of Pollinators in North America. National Academies Press. Washington, D.C.

Peck, O., & Bolton, J. L. 1946. Alfalfa seed production in northern Saskatchewan as affected by bees, with a report on means of increasing the populations of native bees. Scientific Agriculture, 26, 338-418.

Potts, S. G., Biesmeijer, J. C., Kremen, C., Neumann, P., Schweiger, O., & Kunin, W. E. 2010. Global pollinator declines: trends, impacts and drivers. Trends in Ecology & Evolution 25(6): 345-353.

Rortais, A., Arnold, G., Halm, M.-P., & Touffet-Briens, F. 2005. Modes of honeybees exposure to systemic insecticides: estimated amounts of contaminated pollen and nectar consumed by different categories of bees. Apidologie 36(1): 71-83.

Roubik, D. W. 1995. Pollination of cultivated plants in the tropics. Food and Agriculture Organization of the United Nations. Rome, Italy.

Samson, F., & Knopf, F. 1994. Prairie conservation in North America. Bioscience 44(6): 418-421.

Steffan-Dewenter, I., & Tscharntke, T. 1999. Effects of habitat isolation on pollinator communities and seed set. Oecologia 121(3): 432-440.

Stokstad, E. 2007. The case of the empty hives. Science 316(5827): 970-972.

vanEngelsdorp, D., Evans, J. D., Saegerman, C., Mullin, C., Haubruge, E., Nguyen, B. K., . . . Pettis, J. S. 2009. Colony Collapse Disorder: A Descriptive Study. Plos One, 4(8).

Westrich, P. 1996. Habitat requirements of central European bees and the problems of partial habitats. In: A. Matheson, S. L. Buchmann, C. O'Toole, P. Westrich & I. H. Williams (Eds.), The Conservation of Bees (Vol. 18, pp. 1-16). Academic Press, London, England.

Wilmer, P. 2011a. Why pollination is interesting. In: *Pollination and Floral Ecology.* Princeton University Press, Princeton, New Jersey. pp. 3—10

Wilmer, P. 2011b Pollination by flies. In: *Pollination and Floral Ecology*. Princeton University Press, Princeton, New Jersey. pp. 304—321.

Wilmer, P. 2011c. Generalist flowers and generalist visitors In: *Pollination and Floral Ecology*. Princeton University Press, Princeton, New Jersey. pp. 304—321.

Zurbuchen, A., Landert, L., Klaiber, J., Muller, A., Hein, S., & Dorn, S. 2010. Maximum foraging ranges in solitary bees: only few individuals have the capability to cover long foraging distances. Biological Conservation 143(3): 669-676.

CHAPTER II

MELITTOFAUNA AND OTHER POTENTIAL POLLINATORS IN WETLANDS AND UPLANDS IN SOUTH CENTRAL NEBRASKA

ABSTRACT

Our objective was to document wild pollinating insects in south central Nebraska. This intensively cultivated region is known as the Rainwater Basin and contains some of the most endangered wetland systems in North America. We used blue vane traps to passively collect insects and insect nets to actively collect on flowering plants from April through October in 2014 and 2015. Habitat types included playa wetlands, adjacent mixed and tallgrass prairies, and agricultural fields. Over 112,000 insects were collected; Hymenoptera represented 78% of the total, and the families Apidae and Halictidae comprised 99% of the total melittofauna. Insects from 13 orders were collected, but Hymenoptera, Diptera, and Coleoptera were the most abundant potential pollinators.

INTRODUCTION

Pollination is crucial to the biodiversity of the natural world and for the productivity of many agricultural crops (Natural Research Council, 2007; James & Pitts-Singer, 2008). About 180,000 species of the flowering plants require animal assisted pollination to successfully carry pollen from male to female parts of the flower for reproduction (National Research Council, 2007). Pollination by invertebrates is generally attributed to four orders: Coleoptera, Diptera, Lepidoptera, and most notably Hymenoptera (National Research Council, 2007). Bees are generally the most efficient and superior pollinators because their body is covered with pollen-trapping body hair, they exhibit specialized flower handling capabilities and foraging behavior, and they require floral rewards to feed themselves and their offspring (Free, 1993). The domesticated honey bee (*Apis mellifera* L.) is the most widely used pollinator for crops. Honey bees are responsible for over 90% of managed pollinator services (James & Pitts-Singer, 2008). However, there is an inherent risk in relying heavily on one species for an important service such as pollination (James & Pitts-Singer, 2008). Wild pollinators can be equally important to plant reproduction and in some crops, such as alfalfa, honey bees cannot trigger the floral mechanisms required for pollination (James & Pitts-Singer, 2008).

Large scale agriculture often negatively affects wild pollinators due to the loss of wild floral resources, nesting habitat, and pesticide use (Potts *et al.*, 2010). Landscape scale and land use may be important when considering pollinator habitat in an agriculturally dominated area. Numerous studies have shown that if non-agriculture habitat is located near cultivated areas, pollinator diversity and abundance within croplands increases due to the adjacent availability of resources (Steffan-Dewenter & Tscharntke, 1999; Kremen *et al*., 2002a, 2002b; Greenleaf & Kremen, 2006; Kim *et al*., 2006; James & Pitts-Singer, 2008). Therefore, having numerous patches of native habitat located within large areas of croplands may connect pollinator populations and increase abundance of beneficial insects (Kremen *et al.,* 2002a).

This study was located in the Rainwater Basin (RWB) region of south central Nebraska, in the central United States. The RWB constitutes approximately 15,907 km^2, and is dominated by agriculture, primarily corn and soybean crops (LaGrange, 2005). Historically, the RWB consisted of mixed grasslands with abundant depressional wetlands known as playas (Küchler, 1964; LaGrange *et al*., 2011). However, it is estimated that 77% of native grasslands (Samson *et al.,* 2004) have been lost and 90% of the wetlands have been drained or modified for agricultural use in the RWB (LaGrange, 2005). Restoration through programs such as the Wetlands Reserve Program has been critical is protecting the small percentage of wetlands and upland prairie catchments that remain in the RWB. Wetland restoration practices can include planting a buffer strip of perennial cover to reduce sedimentation and nutrient runoff or the removal of sediment which can restore playa hydrology (Beas, 2013; Daniel, 2014). Cultivation has a major effect on ecosystem services, including floral biodiversity, which consequently can affect pollinator community composition (Longley & Sotherton, 1997; Cane & Tepedino, 2001; Biesmeijer *et al*., 2006; Potts *et al*., 2010). There are no data documenting pollinator composition in this intensively cultivated region. Therefore, the purpose of this paper is to document the wild bee fauna and other insects collected in the RWB and to provide an updated distribution to many native genera historically recorded in this region.

MATERIALS AND METHODS

Insects were collected from the first week of April until mid-October in 2014 and 2015 in the Rainwater Basin region of south central Nebraska. Twenty-eight different sites were sampled 14 times (twice a month) each year. Each site contained a depressional playa wetland that was embedded within one of three different land use types: reference state grasslands (n=9), restored prairie buffer strips (n=9), and row-crop agriculture (n=10). Random sampling locations were placed within the wetland and adjacent upland within each site. Insects were collected using vane traps (SpringStar™ LLC, Woodinville, WA, USA) and insect nets.

Vane traps: Vane traps were used instead of pan traps or pheromone baited funnel traps due to their reported efficacy in collecting higher bee numbers (Stephen & Rao, 2005). Additionally, the commonly used pan traps would have been easily disturbed by the frequent cattle herds present at study sites. The traps consist of a bright yellow 30 ml plastic jars fitted with a blue fabricated polypropylene screw cap funnel into which two blue cross vanes were inserted (Stephen & Rao, 2007). Blue vanes were used because they are reported to capture significantly more species than the yellow vanes (Stephen & Rao, 2007). Six traps placed within sites; three in the wetland and three in the upland. Sampling locations were located randomly towards the middle of the wetland and upland locations were hundreds of meters in the upland. Locations were purposely chosen to be away from the edges of the playa. A wooden stake was placed at each sampling location and the trap was attached with wire at the average height of the surrounding vegetation. Traps were set up between the times of 0900 and 1100 at different sites each day and then picked up the following morning during the same time period, allowing for approximately 24-hour exposure. The funnel was then replaced with a lid and the jars were placed in a freezer to kill captured specimens.

Insect nets: For the net collections, we used 30.5 cm insect nets. A 25 m long, 0.5 m wide transect was established 12 m adjacent to the vane traps. Six minutes were allocated to walking the transect and collecting insects that were actively foraging on or manipulating flowers. The timer was paused while the insect was placed in a killing jar of ethyl acetate and then placed in a plastic sample bag labeled with site, transect number, date, and plant species information. Sampling took place after 1100 after the vane traps for the day's sites had been set out.

Insect identification: All specimens were kept in a freezer at 0 °C until they were identified. Insect specimens were first identified to order by simple observation and many genera and species did not require use of keys (e.g., *Spilodiscus* sp. Lewis) due to their obvious morphological characters. Apoidae (Anthophila) were keyed to genera using Michener *et al*. (1994). Following is a list of Anthophila genera and corresponding keys used for species identifications: *Anthophora* Latreille, (Arduser, 2009; Ascher & Pickering, 2016); *Bombus* Latreille (Ellis & Golick, 2000; Ascher & Pickering, 2016); *Diadasia* Cresson (Timberlake, 1941); *Eucera* Scopoli (Timberlake, 1969); *Peponapis* (Say) (Ayala & Griswold, 2012); *Svastra* Holmberg (LaBerge, 1956; LaBerge, 1958; Ascher & Pickering, 2016); *Tetraloniella* Ashmead (LaBerge, 2001); *Augochlora* Smith, *Augochlorella* Sandhouse, and *Augochloropsis* Cockerell (Sandhouse, 1937; Ascher & Pickering, 2016); *Agapostemon* Guerin-Meneville and *Halictus* Latreille (Ascher & Pickering, 2016). Subgenera of *Megachile* Latreille and *Lasioglossum* Curtis were determined using Michener (2007). Karen Wright, Ph.D. Candidate, Department of

Biology, University of New Mexico, identified many of *Melissodes* Latreille to species and provided a reference collection. In addition to use of the *Melissodes* Latreille reference collection, species identifications were verified by referring to species descriptions in LaBerge (1956a, 1956b, & 1961) and Ascher & Pickering (2016). Apoidae wasps were identified to superfamily using Mason (1993) or to family using Triplehorn & Johnson (2005). The list of families or subfamilies are each followed by keys used for genera or species identifications: Bembicinae (Bohart & Horning, 1971); Philanthinae (Bohart & Grissell, 1975); Scoliidae (MacKay, 1987); Thynnidae (Krombein, 1937); Eumeninae (Carpenter, 2004a), Polistinae (Carpenter, 2004b).

Diptera family identifications were determined using both McAlpine (1981) and Triplehorn & Johnson (2005). Following is the list of dipteran families and corresponding keys used for genera and/or species identifications: Culicidae (Stone, 1981); Bibionidae (Hardy, 1981); Tabanidae (Pechuman & Teskey, 1981); Stratiomyidae (James, 1981); Bombyliidae (Hall, 1981); Asilidae (Wood, 1981); Syrphidae (Vockeroth & Thompson, 1987; Miranda *et al*., 2013); Tephritidae (Foote & Steyskal, 1987); Chloropidae (Sabrosky, 1987); Conopidae (Smith & Peterson, 1987); Sciomyzidae (Knutson, 1987); Muscidae and Fannidae (Huckett & Vockeroth, 1987); Anthomyiidae (Huckett, 1987); Calliphoridae (Whitworth, 2006); Sarcophagidae (Shewell, 1987); Tachinidae (Wood, 1987). Coleoptera families were determined using Triplehorn & Johnson (2005) and Ivie (2000). Keys used to determine subfamilies, genera and/or species follow family names: Carabidae (Ball & Bousquet, 2001); Dytiscidae (Roughley & Larson, 2001); Hydrophilidae (Van Tassel, 2001); Staphylinidae (Newton *et al*., 2001); Scarabaeidae (Ratcliff *et al*., 2002); Buprestidae (Bellamy & Nelson, 2002); Lampyridae

(Lloyd, 2002); Cantharidae (Fender, 1964); Dermestidae (Kingsolver, 2002); Cleridae (Barr, 1962; Opitz, 2002); Melyridae (Mayor, 2002); Nitidulidae (Habeck, 2002); Coccinellidae (Ascher & Pickering, 2016); Tenebrionidae (Aalbu *et al*., 2002); Meloidae (Enns, 1956; Arnold, 1976; Selander, 1982), Cerambycidae (Turnbow & Thomas, 2002); Chrysomelidae (Riley *et al*., 2002). Lepidoptera were difficult to identify due the complexity of keys (Triplehorn & Johnson, 2005) and that other insects in vane traps or moisture present tended to render specimens damaged with many features absent needed for identification. Identifications were determined by comparing intact specimens to plates on North American Moth Photographers Group (2011) digital guide to moth identification, and using field identification guides (Brock & Kaufman, 2003; Dole *et a*l., 2004; Eaton & Kaufman, 2007).

We are working with Oklahoma State University Department of Entomology and Plant Pathology to house reference collections in their collection of invertebrates.

RESULTS

We collected 110,779 insects in blue vane traps and 1,649 insects using nets during target collections. Insects were from 13 orders; Hymenoptera, Diptera, Coleoptera, and Lepidoptera were the most abundant. Overall, Hymenoptera composed 80% of insects sampled, followed by Diptera, Coleoptera, and Lepidoptera with 12%, 7%, and 2% respectively. However, when looking solely at targeted transect collections Diptera was the largest order represented with 32%, followed by Coleoptera, Hymenoptera, and Lepidoptera with 29%, 26%, and 8% respectively. This could be due to the bias of the blue vane traps used and the attraction that bees specifically have to them (Stephen & Rao, 2007).

Hymenoptera

Hymenopterans comprised almost 80% of all specimens caught in this study (Fig. 2.2). Over 86,500 bee species from five different families were collected during the growing seasons of 2014 and 2015. Forty-seven genera, 11 sub-genera, and 77 species of bees were identified (Table 2.1). We were unable to identify at the species level specimens of 21 genera. Apidae and Halictidae made up 99% of the samples collected, with 62% and 37% respectively. Additional families included Andrenidae, Colletidae, and Megachilidae. Apidae was the most species rich family with 55 species, including 11 *Bombus* Latreille species and 16 *Melissodes* Latreille species. The 16 *Melissodes* Latreille species made up 76% of all specimens collected within the Apidae family (Fig. 2.3). The halictids had a slightly more even distribution over the different genera; *Agapostemon* Guerin-Meneville and *Lasioglossum* Curtis comprised 41% and 33% respectively (Fig. 2.4). Results from the net collections resemble what was discovered for the blue vane traps. Three hundred seventy-five bees from five different families (Anthophora, Apidae, Colletidae, Halictidae, and Megachilidae) were caught, totaling 26% of the insects caught with nets. Apidae had the highest abundance with *Bombus* Latreille and *Melissodes* Latreille being the most common genera.

Less than 2% of Hymenopterans caught were not bees. Wasps and ants each equaled 1% of total insects. Almost 1000 ants were collected; they were not identified further than the taxonomic superfamily, Formicoidea, because they are generally not considered to be effective pollinators (Wilmer, 2011a). Wasps from 14 families were collected with the vane traps, and wasps from six families were collected with nets while utilizing flowers. Of the 676 wasp specimens collected, only 29 individuals were caught during net collections. Vespidae was the most abundant family overall, comprising 24% of all wasps caught and over half of the wasps caught during target collections.

Diptera

The second largest order represented were the flies, totaling 12% of all insects collected and 32% of insects caught during collections with nets. We collected flies from 29 families. Syrphidae comprised 65% of all flies collected, followed by Anthomyiidae with 21%. Syrphid flies were also the most abundant family for net collections, comprising 85% of flies caught. There were 13 other families caught with nets, however most of them consisted of less than 10 specimens (including Anthomyiidae). Syrphids also had the highest dipteran richness overall with 14 genera represented within the family (Table 2.2). Fifty-eight percent of syrphid flies were in the genus *Helophilus* Meigen, followed by *Parasyrphus* Matsumura and *Eristalis* Latreille with 17% and 13%, respectively (Fig. 2.5). Anthomyiids were only identified further to one species, *Delia platura* Meigen, which comprised 68% of the anthomyiids found. Most of the other 29 families each made up less than 1% of all flies collected, and 13 families could not be identified to a further taxonomic level.

Coleoptera

Although Coleoptera only totaled 7% of the total number of individuals collected, it comprised 29% of net collections and had the highest family richness with 39 families represented (Table 2.3). Fifty-eight genera were identified among 24 of the families, and 14 families could not be identified to a lower taxonomic level. Cantharidae (primarily the genus *Chauliognathus* Hentz) made up 36% of all beetles and 74% of beetles caught during net collections. Carabidae and Chrysomelidae were the next most abundant families with 17% and 10% of the beetles respectively. Chrysomelidae was also the second most abundant family during net collections with 23%. Many other families such as Cryptophagidae, Staphylinidae, Nitidulidae, and Meloidae each comprised 5–7% of all the beetles, however, most families were each less than 1% of total coleopterans.

Lepidoptera

Lepidoptera comprised less than 2% of all insects and 8% of insects caught during net collections. Fourteen families and 30 genera were identified, and the family Noctuidae constituted 48% of all lepidopterans collected. The other 13 families composed less than 5% each of the total. However, for net collections, Noctuidae only consisted of 10% of the lepidopterans. Pieridae had the highest abundance with 34%, followed by Crambidae, Lycaenidae, and Nymphalidae each comprising 16%. Twenty-seven percent of lepidopterans collected could not be taken to a lower taxonomic level than order due to damaged specimens.

DISCUSSION

Hymenoptera

There are relatively few published studies concerning non-*Apis* populations in Nebraska. Porter (2010) examined habitat management and enhancement through seed mixtures on bee diversity and abundance near Wood River in central Nebraska—as close as 30 miles away from my study area. She collected 14 bee genera in 2008 using insect nets, and 31 bee genera in 2009 using blue vane traps. Over both field seasons, we collected bees from 20 genera using insect nets. The additional bee genera we caught by net collection compared to Porter (2010) included *Andrena* F.*, Augochlorella* Sandhouse*, Dieunomia* Cockerell*, Florilegus* Robertson*, Hylaeus* F.*,* and *Sphecodes* Latreille. However, unlike Porter (2010) we did not catch *Nomada* Scopoli using nets but it was found in our trap collections. We collected 47 genera using blue vane traps. All of the genera Porter (2010) collected using vane traps were also found in our study with the exception of *Ptilothrix* Smith—which was only sited twice. Additionally, in 2014, we collected a single *Centris* sp. F. in Filmore County. This bee is generally considered to reside in Florida and the southwest United States (Roberts, 2007), and this may be a new state record for Nebraska. *Melissodes* was also the most abundant genera collected by Porter (2010), totaling 78% of the bees caught with vane traps. *Melissodes* also had the highest abundance collected in our study with 48% of the total bees caught. We had 16 species of *Melissodes* including *M. tuckeri* Cockerell and *M. tristis* Cockerell which may be uncommon in Nebraska.

In 2006 "An Update on the Distribution and Diversity of *Bombus* in Nebraska" was published by Golick and Ellis (2006) in response to the changing landscape that Nebraska has undergone over the past 50 years. They collected 3219 *Bombus* Latreille and 19 species in the state over 16 months in 2000 and 2001. No collection methods were listed. We collected 2837 *Bombus* Latrielle in 2014 and 2015. Nine out of 10 species previously documented for the region were found, and almost all of the species included new county records. *Bombus suckleyi* (Greene) was the only species that had a historical record within a sampled county that did not appear in our collections. *B. suckleyi* (Greene) had not been collected in the Golick & Ellis study either, but had been recorded by Laberge & Webb (1962). We collected one *Bombus occidentalis* Greene specimen in Kearney County in 2014. *B. occidentalis* Greene, is listed as "Imperiled" on the Xerces Society's Red List of Bees and has been petitioned to be protected under the Endangered Species Act (Xerces Society; U.S. Fish and Wildlife Service). *B. occidentalis* Greene was not included in Golick & Ellis (2006), but there have been a few documented sightings in the past 50 years (Laberge & Webb, 1962).

Ants comprised 1% of insects caught in blue vane traps, and only two individuals were caught during our net collections. Due to their attraction to nectar and high abundance, it is possible for ants to transfer pollen. However, ants lack many of the physical characteristics (e.g. mobility, hair, long proboscis) of efficient pollinators and are potentially deleterious to plants as nectar robbers (Wilmer, 2011a). Wasps also made up a very small portion (1%) of our samples. 14 families were represented and 29 wasps from six families were caught utilizing flowers during target collections. The family Vespidae comprised almost a quarter of all wasps collected. A number of wasp families, such as the vespid wasps, are known to take liquid food, such as nectar, for themselves and their nests, however they are primarily predatory insects (Wilmer, 2011a).

Diptera

Although Hymenopterans made up the largest number of individuals, Dipterans were the second largest order collected overall and the most abundant order by net. Flies are generally the second most frequent visitors to flowers, and syrphid flies are likely the most important family for pollination (Larson *et al*., 2001). Syrphids, also known as hoverflies or flower flies, comprised 65% of all dipterans collected and 85% of dipterans caught with nets. Hoverflies are known as efficient pollinators in temperate zones, and specifically equipped to feed on flowers which they rely almost entirely on for food (Wilmer, 2011b). Moreover, all syrphids are covered in hair, sometimes branched like bees, which help them collect pollen that they then transfer or feed on (Wilmer, 2011b). Flies appear to be an underrated pollinator due to their adaptation to environmental changes and ability to use a wider range of resources in modified landscapes, such as in agricultural areas (Rader *et al*., 2016). For example, anthomyiids, also known as root-maggot flies (Diptera: Anthomyiidae), are typically considered pests. However, they are known frequent flower visitors and comprised 21% of flies caught in this study (Wilmer, 2011b). Numerous other dipterans caught such as gnats, midges, and mosquitoes can also be potential pollinators, however, their numbers amounted to little of the total flies collected.

Coleoptera

Beetles are another significant non-bee pollinator. While many families contain some flower visitors, Cantharidae (soldier beetles) and Cerambycidae (longhorn beetles) are noted as important and abundant pollinators because rely almost exclusively on floral rewards at some part of their life cycle (Wilmer, 2011a). Although Cerambycidae only made up 3% of the beetles, Cantharidae comprised 36%. Soldier beetles, specifically *Chauliognathus* Hentz made up 35% of all beetles sampled in our study and 74% of beetles caught during net collections. These beetles consume pollen and nectar from Apiaceae and Asteraceae flowers, and in doing so indirectly pollinate (Wilmer, 2011a). Furthermore, Chrysomelidae, which was 10% of overall beetles and 23% of net collection beetles, are also known flower visitors. This family is known as leaf beetles, and are often found eating pollen on Ranunculaceae and Asteraceae plants (Wilmer, 2011a). Other potential pollinating beetle families such as Nitidulidae and Staphylinidae were found but in small amounts. Some flower visiting beetles may prove to be more destructive than beneficial to the plant. For example, Scarabaeidae, Elateridae, and Curculionidae beetles were found in our study, however, these beetles tend to eat and destroy the flower instead of beneficially transferring pollen. The second most abundant family in our study, Carabidae (ground beetles), are not considered flower visiting beetles but instead are primarily known as nocturnal predators (Triplehorn & Johnson, 2005). Of the 1354 carabids collected, only two were caught with insect nets, the rest were collected in vane traps. Possibly the ground beetles commonly found in our traps were feeding on the insects caught inside.

Lepidoptera

Lepidopterans made up only 2% of overall insects collected and 8% of insects caught during net collections. The low overall percentage collected could possibly be due to sampling bias with the use of vane traps, which have primarily been tested for beetles and bees (Stephen & Rao, 2005, 2007). Noctuids comprised 48% of all lepidopterans collected. This family primarily consists of agricultural pests such as loopers and cutworms that feed on the roots and shoots of plants (Triplehorn and Johnson, 2005). The corn earworm (*Helicoverpa zea* Boddie) was a common Noctuid moth found in our study. It is a serious pest to many crops, including corn where the larvae enter the corn ear and eat the kernels from tip of the cob (Triplehorn and Johnson, 2005). Noctuid moths had a much lower representation (10%) in the net collections on flowers. Instead, Pieridae, specifically sulphur butterflies, comprised 34% of the moths and butterflies caught with insect nets. This difference could possibly be due to the majority of moths being crepuscular or nocturnal, whereas butterflies are diurnal thus having a higher probability of being captured during net collections (which took place mid-day) (Wilmer, 2011c).

Additional Orders

It is possible that other orders collected in nets or blue vane traps could be potential pollinators. However, due to time and resource constraints we chose to focus on the orders that are most commonly attributed to the ecosystem service of pollination. A table of the additional orders collected in this study has been included at the end of the paper (Table 2.6).

CONCLUSION

Considering our extensive sampling in two growing seasons in 2014 and 2015, we consider that our species list represents a thorough approximation of the bee fauna of south central Nebraska. However, due to possible trap bias in primarily attracting bees, this study may not accurately represent the role of other orders (e.g. Diptera, Coleoptera, and Lepidoptera) in the ecosystem service of pollination. In both years, we observed a steady rise in bee abundance over the growing season, peaking in early September and then rapidly declining again before fall. *Melissodes* made up almost half of all bees caught and were also the most diverse genus in our study. Ninety-five percent of the melittofauna collected were caught using blue vane traps, however two specimens [*Calliopsis* and *Bombus vagans* (Smith)] were caught solely from net collections. The new documentation of bee species and genera represented in this study provides important distribution and abundance data of melittofauna and other potential pollinators in a region that is lacking extensive inventory of these groups.

LITERATURE CITED

Aalbu, R.L., Triplehorn, C.A., Campbell, J.M., Brown, K.W., Somerby, R.E. & Thomas, D.B. (2002). Tenebrionidae Latreille 1802. *In*: Arnett Jr., R.H., Thomas, M.C., Skelley, P.E., & Frank, J.H. (Eds.), *American Beetles. Vol. II. Polyphaga: Scarabaeoidea through Curculionidae*. CRC Press, Boca Raton, pp. 763–509.

Arduser, M. (2009). *Anthophora* of ENA (east of 100th meridian). U.S. Department of the Interior. U.S. U.S. Geological Survey. Available from: http://www.pwrc.usgs.gov/nativebees/Arduser_keys/ENA%20Anthophora%20key.pdf (accessed 7 July 2016).

Arnold, D.C. (1976). Blister beetles (Coleoptera: Meloidea) of Oklahoma. *Oklahoma State University Agricultural Experimental Station Technical Bulletin*, T-145, 1–68.

Ascher, J.S. & Pickering, J. (2016). Discover Life bee species guide and world checklist (Hymenoptera: Apoidea: Anthophila). Available from: http://www.discoverlife.org/mp/20q?guide=Apoidea_species (accessed 7 July 2016).

Ayala, R. & Griswold, T. (2012). Two new species of the bee genus *Peponapis*, with a key to the North and Central American species (Hymenoptera: Apidae: Eucerini). *Revista Mexicana de Biodiversidad,* 83, 396–406.

Barr, W.F. (1962). A key to the genera and a classification of the North American Cleridae (Coleoptera). *The Coleopterist's Bulletin*, 16 (4), 121–127.

Ball, G.E. & Bousquet, Y. (2001). Carabidae Latreille, 1810. *In*: Arnett Jr., R.H., & Thomas, M.C. (Eds.), *American Beetles. Vol. I. Archostemata*, *Myxophaga, Adephaga, Polyphaga: Staphyliniformia*. CRC Press, Boca Raton, pp. 32–132.

Beas, B., Smith, L., Lagrange, T. & Stutheit, R. (2013). Effects of sediment removal on vegetation communities in Rainwater Basin playa wetlands. *Journal of Environmental Management*, 128, 371.

Bellamy, C.L. & Nelson, G.H. (2002). Buprestidae Leach 1815. *In*: Arnett Jr., R.H., Thomas, M.C., Skelley, P.E., & Frank, J.H. (Eds.), *American Beetles. Vol. II. Polyphaga: Scarabaeoidea through Curculionidae*. CRC Press, Boca Raton, pp. 98–112.

Biesmeijer, J.C., Roberts, S.P.M., Reemer, M., Ohlemüller, R., Edwards, M., Peeters, T., Schaffers, A.P., Potts, S.G., Kleukers, R., Thomas, C.D., Settele, J. & Kunin, W.E. (2006). Parallel Declines in Pollinators and Insect-Pollinated Plants in Britain and the Netherlands. *Science,* 313 (5785), 351–354.

Bohart, R.M. & Grissell, E.E. (1975). California wasps of the subfamily Philanthinae (Hymenoptera: Sphecidae). *Bulletin of the California Insect Survey*, 19, 1–92.

Bohart, R.M. & Horning, Jr., D.S. (1971). California Bembicine sand wasps. *Bulletin of the California Insect Survey*, 13, 1–49.

Brock, J.P. & Kaufman, K. (2003). *Kaufman field guide to butterflies of North America*. Houghton Miller Company, New York, NY, 391 pp.

Cane, J.H. & Tepedino, V.J. (2001). Cause and extent of declines among native North American invertebrate pollinators: detection, evidence, and consequences. *Conservation Ecology* 5 (1), 1.

Carpenter, J.M. (2004a). *Ancistroceroides* de Saussure, a potter wasp genus new for the United States, with a new key to the genera of Eumeninae of American North of Mexico (Hymenoptera: Vespidae). *Journal of the Kansas Entomological Society*, 77 (4), 721–741.

Carpenter, J.M. (2004b). Synonymy of the genus *Marimbonda* Richards, 1978, with *Leipomeles* Mobius, 1856 (Hymenoptera: Vespidae: Polistinae), and a new key to the genera of paper wasps of the New World. *American Museum Novitates*, 3465, 1–16.

Daniel, D. W., Smith, L. M., Haukos, D. A., Johnson, L. A. & McMurry, S. T. (2014). Land use and conservation reserve program effects on the persistence of playa wetlands in the High Plains. *Environmental Science & Technology, 48*, 4282–4288.

Dole, J.M., Gerard, W.B. & Nelson, J.M. (2004). *Butterflies of Oklahoma, Kansas, and North Texas*. University of Oklahoma Press, Norman, OK, 288 pp.

Eaton, E.R. & Kaufman, K. (2007). *Kaufman field guide to insects of North America*. Houghton Mifflin Company, New York, NY, 391 pp.

Ellis, M.D. & Golick, D. (2000). EC00-1564 A Guide to identifying Nebraska bumble bee species. *Historical Materials from University of Nebraska-Lincoln Extension*, Paper 2011, 1-64.

Enns, W.E. (1956). A revision of the genera Nemognatha, Zonitis, and Pseudozonitis (Coleoptera: Meloidae) in American north of Mexico. *The University of Kansas Science Bulletin*, 37 Part II (14), 685–910.

Fender, K.M. (1964). The Chauliognathini of America north of Mexico (Coleoptera: Cantharidae) Part 2. *Northwest Science*, 38 (3), 95–106.

Foote, R.H. & Steyskal, G.C. (1987). Tephritidae. *In*: McAlpine, J.F., Peterson, B.V., Shewell, G.E., Teskey, H.J., Vockeroth, J.R., & Wood, D.M. (Eds.) *Manual of Nearctic Diptera Volume 2*. Research Branch Agriculture Canada, pp. 817–832.

Free, J.B. (1993). *Insect pollination of crops*. *2nd ed*. Academic Press. San Diego, California, pp. 18–41

Gleason, R.A, Euliss, N.H., Tangen, B.A., Laubhan, M.K., & Browne, B.A. (2011). USDA conservation program and practice effects on wetland ecosystem services in the Prairie Pothole Region. *Ecological Applications,* 21(1), 65–81.

Golick, D.A. & Ellis, M.D. (2006). An Update on the Distribution and Diversity of *Bombus* in Nebraska (Hymenoptera: Apidae). *Journal of the Kansas Entomological Society,* 79 (4), 341–347.

Greenleaf, S. & Kremen, C. (2006). Wild bee species increase tomato production but respond differently to surrounding land use in Northern California. *Biological Conservation*, 133, 81–87.

Habeck, D.H. (2002). Nitidulidae Latreille 1802. *In*: Arnett Jr., R.H., Thomas, M.C., Skelley, P.E., & Frank, J.H. (Eds.), *American Beetles. Vol. II. Polyphaga: Scarabaeoidea through Curculionidae*. CRC Press, Boca Raton, pp. 311–315.

Hall, J.C. (1981). Bombyliidae. *In*: McAlpine, J.F., Peterson, B.V., Shewell, G.E., Teskey, H.J., Vockeroth, J.R., & Wood, D.M. (Eds.) *Manual of Nearctic Diptera Volume 1*. Research Branch Agriculture Canada, pp. 589–602.

Hardy, D.E. (1981). Bibionidae. *In*: McAlpine, J.F., Peterson, B.V., Shewell, G.E., Teskey, H.J., Vockeroth, J.R., & Wood, D.M. (Eds.) *Manual of Nearctic Diptera Volume 1*. Research Branch Agriculture Canada, pp. 217–222.

Huckett, H.C. (1987). Anthomyiidae. *In*: McAlpine, J.F., Peterson, B.V., Shewell, G.E., Teskey, H.J., Vockeroth, J.R., & Wood, D.M. (Eds.) *Manual of Nearctic Diptera Volume 2*. Research Branch Agriculture Canada, pp. 1099–1114.

Huckett, H.C. & Vockeroth, J.R. (1987). Muscidae. *In*: McAlpine, J.F., Peterson, B.V., Shewell, G.E., Teskey, H.J., Vockeroth, J.R., & Wood, D.M. (Eds.) *Manual of Nearctic Diptera Volume 2*. Research Branch Agriculture Canada, pp. 1115–1132.

Ivie, M.A. (2000). Keys to families of beetles in American north of Mexico. *In*: Arnett Jr., R.H., Thomas, M.C., Skelley, P.E., & Frank, J.H. (Eds.), *American Beetles. Vol. II. Polyphaga: Scarabaeoidea through Curculionidae*. CRC Press, Boca Raton, pp. 816–835.

James, M.T. (1981). Stratiomyidae. *In*: McAlpine, J.F., Peterson, B.V., Shewell, G.E., Teskey, H.J., Vockeroth, J.R., & Wood, D.M. (Eds.) *Manual of Nearctic Diptera Volume 1*. Research Branch Agriculture Canada, pp. 497–512.

James, R.R. & Pitts-Singer T.L. (2008). *Bee Pollination in Agricultural Ecosystems.* Oxford University Press, New York City, New York, pp. 3–21.

Kim, J., Williams, N. & Kremen, C. (2006). Effects of cultivation and proximity to natural habitat on ground-nesting native bees in California sunflower fields. *Journal of Kansas Entomological Society*, 79, 309–320.

Kingsolver, J.M. (2002). Dermestidae Gyllenhal 1808. *In*: Arnett Jr., R.H., Thomas, M.C., Skelley, P.E., & Frank, J.H. (Eds.), *American Beetles. Vol. II. Polyphaga: Scarabaeoidea through Curculionidae*. CRC Press, Boca Raton, pp. 228–232.

Knutson, L.V. (1987). Sciomyzidae. *In*: McAlpine, J.F., Peterson, B.V., Shewell, G.E., Teskey, H.J., Vockeroth, J.R., & Wood, D.M. (Eds.) *Manual of Nearctic Diptera Volume 2*. Research Branch Agriculture Canada, pp. 927–940.

Kremen, C., Williams, N.M. & Thorp, R. W. (2002a). Crop pollination from native bees at risk from agricultural intensification. *Proceedings of the National Academy of Sciences,* 99 (26), 16812–16816.

Kremen, C., Bugg, R.L., Nicola, N., Smith, S.A., Thorp, R.W. & Williams, N.M. (2002b). Native bees, native plants and crop pollination in California. *Fremontia.* 30, 41–49.

Krombein, K.V. (1937). Studies in the Tiphiidae (Hymenoptera: Aculeata), I. A review of the genera of Myzininae*. Annals of the Entomological Society of America*, 30, 26–30.

Küchler, A. W. (1964). *Potential natural vegetation of the conterminous United States*. New York: New York, American Geographical Society.

LaBerge, W.E. (1956a). A revision of the bees of the genus *Melissodes* in North and Central America, Part I (Hymenoptera, Apidae). *The University of Kansas Science Bulletin*, 37 pt.2 (18), 911–1194.

LaBerge, W.E. (1958). Notes of the North and Central American bees of the genus *Svastra* Holmberg (Hymenoptera, Apidae). *Journal of the Kansas Entomological Society*, 31 (4), 266–273.

LaBerge, W.E. (1956b). A revision of the bees of the genus *Melissodes* in North and Central America, Part II (Hymenoptera, Apidae). *The University of Kansas Science Bulletin*, 38 pt. 1 (8), 533–578.

LaBerge, W.E. (1961). A revision of the bees of the Genus *Melissodes* in North and Central America, Part III (Hymenoptera, Apidae). *The University of Kansas Science Bulletin*, 42 (5), 283–663.

Laberge, W.E. & Webb, M.C. (1962). The Bumblebees of Nebraska. *Research Bulletin, University of Nebraska College of Agriculture*, 205 (33), 293–300.

LaBerge, W.E. (2001). Revision of the bees of the genus *Tetraloniella* in the New World (Hymenoptera: Apidae). *Illinois Natural History Survey*, 36 (3), 67–162.

LaGrange, T. (2005). *Guide to Nebraska's wetlands and their conservation needs*. Nebraska Game and Parks Commission, 37 (2), 17–20.

LaGrange, T., Stutheit, R., Gilbert, D., Shurtliff, D. & Whited, P.M. (2011). *Sedimentation of Nebraska's Playa Wetlands: A Review of Current Knowledge and Issues*. Nebraska Game and Parks Commission, Lincoln, Nebraska, pp. 62.

Larson, B., Kevan, P. & Inouye, D. (2001). Flies and flowers: taxonomic diversity of anthophiles and pollinators. *Canadian Entomologist,* 133 (4), 439–465.

Lloyd, J.E. (2002). Lampyridae Latreille 1817. *In*: Arnett Jr., R.H., Thomas, M.C., Skelley, P.E., & Frank, J.H. (Eds.), *American Beetles. Vol. II. Polyphaga: Scarabaeoidea through Curculionidae*. CRC Press, Boca Raton, pp. 187–196.

Longley, M. & Sotherton, N.W. (1997). Factors determining the effects of pesticides upon butterflies inhabiting arable farmland. *Agriculture, Ecosystems & Environment,* 61 (1), 1–12.

MacKay, W.P. (1987). The scoliid wasps of the southwestern United States (Hymenoptera: Scoliidae). *The Southwestern Naturalist*, 32 (3), 357–362.

Mason, W.R.M. (1993). Key to superfamilies of Hymenoptera. *In*: Goulet, H. & Huber, J.T. (Eds.), *Hymenoptera of the World: An Identification Guide to Families*. Research Branch, Agriculture Canada Publication 1894/E, Canada Communication Group-Publishing, Ottawa, Canada. pp. 65–100.

Mayor, A.J. (2002). Melyridae Leach 1815. *In*: Arnett Jr., R.H., Thomas, M.C., Skelley, P.E., & Frank, J.H. (Eds.), *American Beetles. Vol. II. Polyphaga: Scarabaeoidea through Curculionidae*. CRC Press, Boca Raton, pp. 281–304.

McAlpine, J.F. (1981). Keys to families–adults. *In*: McAlpine, J.F., Peterson, B.V., Shewell, G.E., Teskey, H.J., Vockeroth, J.R., & Wood, D.M. (Eds.) *Manual of Nearctic Diptera Volume 1*. Research Branch Agriculture Canada, pp. 89–124.

Michener, C.D. (2007). *The bees of the world, 2nd Edition*. The Johns Hopkins University Press, Baltimore, MD, 953 pp.

Michener, C.D., McGinley, R.J. & Danforth, B.N. (1994). *The bee genera of North and Central America (Hymenoptera: Apoidae).* Smithsonian Institution Press, Washington and London, 209 pp.

Miranda, G.F.G., Young, A.D., Locke, M.M., Marshall, S.A., Skevington, J.H. & Thomson, F.C. (2013). Key to the Genera of Nearctic Syrphidae. *Canadian Journal of Arthropod Identification*. Available from:

National Research Council (2007). Role and Importance of pollinators. *In:* K. Kelly & P. Whitacre (Ed), *Status of Pollinators in North America.* The National Academic Press, Washington D.C., pp. 13–33.

Newton, A.F., Thayer, M.K., Ashe, J.S. & Chandler, D.S. (2001). Staphylinidae Latreille, 1802. *In*: Arnett Jr., R.H., & Thomas, M.C. (Eds.), *American Beetles. Vol. I. Archostemata, Myxophaga, Adephaga, Polyphaga: Staphyliniformia*. CRC Press, Boca Raton, pp. 272–418.

North American Moth Photographers Group (2011). Digital guide to moth identification. Mississippi Entomological Museum, Mississippi State University. Available from: http://mothphotographersgroup.msstate.edu/WalkThroughIndex.shtml (accessed 7 July 2016).

Opitz, W. (2002). Cleridae Latreille 1804. *In*: Arnett Jr., R.H., Thomas, M.C., Skelley, P.E., & Frank, J.H. (Eds.), *American Beetles. Vol. II. Polyphaga: Scarabaeoidea through Curculionidae*. CRC Press, Boca Raton, pp. 267–280.

Pechuman, L.L. & Teskey, H.J. (1981). Tabanidae. *In*: McAlpine, J.F., Peterson, B.V., Shewell, G.E., Teskey, H.J., Vockeroth, J.R., & Wood, D.M. (Eds.) *Manual of Nearctic Diptera Volume 1*. Research Branch Agriculture Canada, pp. 463–478.

Porter, D.A. (2010). An Investigation of Wild Bee Diversity and Abundance in Plots Managed by *The Nature Conservancy* in South-Central Nebraska and of Beneficial Arthropods Associated with Native Nebraska Flora. *Dissertations and Student Research in Entomology*, 6.

Potts, S.G., Biesmeijer, J.C., Kremen, C., Neumann, P., Schweiger, O. & Kunin, W.E. (2010). Global pollinator declines: trends, impacts and drivers. *Trends in Ecology & Evolution*, 25 (6), 345–353.

Rader, R., Bartomeus, I., Garibaldi, L.A ; Garratt, M.P.D., Howlett, B.G., Winfree, R., Cunningham, S.A., Mayfield, M.M., Arthur, A.D., Andersson, G.K.S., Bommarco, R., Brittain, C., Carvalheiro, L.G., Chacoff, N.P., Entling, M.H., Foully, B., Freitas, B.M., Gemmill-Herren, B., Ghazoul, J., Griffin, S.R., Gross, C.L., Herbertsson, L., Herzog, F., Hipólito, J., Jaggar, S., Jauker, F., Klein, A., Kleijn, D., Krishnan, S., Lemos, C.Q., Lindström, S.A.M., Mandelik, Y. Monteiro, V.M., Nelson, W., Nilsson, L., Pattemore, D. E. Pereira, Natália D. Pisanty, G., Potts, S., Reemer, M., Rundlöf, M., Sheffield, C.S., Scheper, J., Schüepp, C., Smith, H.G., Stanley, D.A., Stout, J.C., Szentgyörgyi, H., Taki, H., Vergara, C.H., Viana, B.F. & Woyciechowski, M. (2016). Non-bee insects are important contributors to global crop pollination. *Proceedings of the National Academy of Sciences of the United States of America*, 113 (1), 146–51.

Ratcliff, B.C., Jameson, M.L. & Smith, A.B.T. (2002). Scarabaeidae Latreille, 1802. *In*: Arnett Jr., R.H., Thomas, M.C., Skelley, P.E., & Frank, J.H. (Eds.), *American Beetles. Vol. II. Polyphaga: Scarabaeoidea through Curculionidae*. CRC Press, Boca Raton, pp. 39–81.

Riley, E.G., Clark, S.M., Flowers, R.W. & Gilbert, A.J. (2002). Chrysomelidae Latreille 1802. *In*: Arnett Jr., R.H., Thomas, M.C., Skelley, P.E., & Frank, J.H. (Eds.), *American Beetles. Vol. II. Polyphaga: Scarabaeoidea through Curculionidae*. CRC Press, Boca Raton, pp. 617–691.

Roberts, J.D. (2007). Genus *Centris* – Centris bees. Bugguide. Web. Available from: http://bugguide.net/node/view/110919 (accessed 28 July 2016).

Roughley, R.E. & Larson, D.J. (2001). Dytiscidae Leach, 1815. *In*: Arnett Jr., R.H., & Thomas, M.C. (Eds.), *American Beetles. Vol. I. Archostemata*, *Myxophaga, Adephaga, Polyphaga: Staphyliniformia*. CRC Press, Boca Raton, pp. 156–186.

Sabrosky, C.W. (1987). Chloropidae. *In*: McAlpine, J.F., Peterson, B.V., Shewell, G.E., Teskey, H.J., Vockeroth, J.R., & Wood, D.M. (Eds.) *Manual of Nearctic Diptera Volume 2*. Research Branch Agriculture Canada, pp. 1049–1068.

Sandhouse, G.A. (1937). The bees of the genera *Augochlora*, *Augochloropsis*, and *Augochlorella* (Hymenoptera: Apoidae) occurring in the United States. *Journal of the Washington Academy of Sciences*, 27 (2), 65–79.

Selander, R.B. (1982). A revision of the genus *Pyrota*, I. The Mylabrina group (Coleoptera: Meloidae). *Journal of the Kansas Entomological Society*, 55 (4), 665–717.

Shewell, G.E. (1987). Sarcophagidae. *In*: McAlpine, J.F., Peterson, B.V., Shewell, G.E., Teskey, H.J., Vockeroth, J.R., & Wood, D.M. (Eds.) *Manual of Nearctic Diptera Volume 2*. Research Branch Agriculture Canada, pp. 1159–1186.

Simpson, M. (n.d.). Ptilothrix Bombiformis, the Rose-mallow Bee. *Ptilothrix Bombiformis, the Rose-mallow Bee*. United State Forest Service. Web. Available from: http://www.fs.fed.us/wildflowers/pollinators/pollinator-of-the-month/rosemallowbee.shtml (accessed 27 June 2016).

Smith, K.G.V. & Peterson, B.V. (1987). Conopidae. *In*: McAlpine, J.F., Peterson, B.V., Shewell, G.E., Teskey, H.J., Vockeroth, J.R., & Wood, D.M. (Eds.) *Manual of Nearctic Diptera Volume 2*. Research Branch Agriculture Canada, pp. 749–756.

Steffan-Dewenter, I. & Tscharntke, T. (1999). Effects of Habitat Isolation on Pollinator Communities and Seed Set. *Oecologia,* 121 (3), 432–440.

Stephen, W.P. & Rao, S. (2005). Unscented Color Traps for Non-Apis Bees (Hymenoptera: Apiformes). *Journal of Kansas Entomological Society*, 78 (4): 373–380.

Stephen, W.P. & Rao, S. (2007). Sampling native bees in proximity to a highly competitive food resource (Hymenoptera: Apiformes*). Journal of the Kansas Entomological Society*, 80, 369–376.

Stone, A. (1981). Culicidae. *In*: McAlpine, J.F., Peterson, B.V., Shewell, G.E., Teskey, H.J., Vockeroth, J.R., & Wood, D.M. (Eds.) *Manual of Nearctic Diptera Volume 1*. Research Branch Agriculture Canada, pp. 341–350.

Timberlake, P.H. (1941). Synoptic table of North American species of *Diadasia* (Hymenoptera, Apoidae). *Bulletin of the Brooklyn Entomological Society*, 36, 2–11.

Timberlake, P.H. (1969). A contribution to the systematics of the North American species of *Synhalonia* (Hymenoptera, Apoidea). *University of California Publications in Entomology*, 57, 1–76.

Triplehorn, C.A. & Johnson, N.F. (2005). *Borror and DeLong's Introduction to the study of insects, 7th Ed*. Thompson Brooks/Cole, Belmont, CA, 864 pp.

Turnbow, Jr., R.H. & Thomas, M.C. (2002). Cerambycidae Leach 1815. *In*: Arnett Jr., R.H., Thomas, M.C., Skelley, P.E., & Frank, J.H. (Eds.), *American Beetles. Vol. II. Polyphaga: Scarabaeoidea through Curculionidae*. CRC Press, Boca Raton, pp. 568–601.

Natural Resource Conservation Service. (2010). Restoring America's wetlands: A private lands conservation success story. U.S. Department of Agriculture, NRCS commemorative publication, pp. 1–16.

U.S. Fish and Wildlife Service (n.d.). ECOS: Endangered Species Act Petitions Received by Fish and Wildlife Service. Web. Available from: https://ecos.fws.gov/ecp/report/table/petitions-received.html (accessed 27 June 2016).

Van Tassel, E.R. (2001). Hydrophilidae Latreille, 1802. *In*: Arnett Jr., R.H., & Thomas, M.C. (Eds.), *American Beetles. Vol. I. Archostemata*, *Myxophaga, Adephaga, Polyphaga: Staphyliniformia*. CRC Press, Boca Raton, pp. 187–208.

Vockeroth, J.R. & Thompson, F.C. (1987). Syrphidae. *In*: McAlpine, J.F., Peterson, B.V., Shewell, G.E., Teskey, H.J., Vockeroth, J.R., & Wood, D.M. (Eds.) *Manual of Nearctic Diptera Volume 2*. Research Branch Agriculture Canada, pp. 731–744.

Whitworth, T. (2006). Keys to the genera and species of blow flies (Diptera: Calliphoridae) of American North of Mexico. *Proceedings of the Entomological Society of Washington*, 108 (3), 689–725.

Wilmer, P. (2011a). Generalist flowers and generalist visitors. *In:* P. Willmer (Ed), *Pollination and Floral Ecology*. Princeton University Press, pp. 288–303.

Wilmer, P. (2011b). Pollination by flies. *In:* P. Willmer (Ed), *Pollination and Floral Ecology*. Princeton University Press, pp. 304–321.

Wilmer, P. (2011c). Pollination by butterflies and moths. *In:* P. Willmer (Ed), *Pollination and Floral Ecology*. Princeton University Press, pp. 322–336.

Wood, D.M. (1987). Tachinidae. *In*: McAlpine, J.F., Peterson, B.V., Shewell, G.E., Teskey, H.J., Vockeroth, J.R., & Wood, D.M. (Eds.) *Manual of Nearctic Diptera Volume 2*. Research Branch Agriculture Canada, pp. 1193–1270.

Wood, G.C. (1981). Asilidae. *In*: McAlpine, J.F., Peterson, B.V., Shewell, G.E., Teskey, H.J., Vockeroth, J.R., & Wood, D.M. (Eds.) *Manual of Nearctic Diptera Volume 1*. Research Branch Agriculture Canada, pp. 549–574.

Xerces Society (n.d.). Red List of Bees: Native Bees in Decline. Web. Available from: http://www.xerces.org/pollinator-redlist/ (accessed from 27 June 2016).

TABLES AND FIGURES

TABLE 2.1. Bee species occurring in the Rainwater Basin Region of Nebraska. The bee sex (when possible), number of specimens, collection methods, and county collected in are indicated.

Melittofauna taxa	*Sex*	*n Specimens*[a]	*Collection Method*[b]	*County*[c]
APOIDAE				
ANDRENIDAE				
ANDRENINAE				
Andrenini				
Andrena sp.	f/m	22	Trap/Net	1, 2, 3, 4, 5, 6, 7
PANURGINAE				
Calliopsini				
Calliopsis sp.	f	2	Trap	2, 3
Perdita sp.	f/m	29	Trap	4, 6, 7
Protandrena sp.	m	1	Trap	5
Pseudopanurgus sp.	f/m	3	Trap/Net	7
APIDAE				
APINAE				
Anthophorini				
Anthophora sp.	m	2	Trap	2, 7
A. affabilis Cresson	f/m	110	Trap	1, 2, 4, 5, 6, 7
A. bomboides Kirby	f/m	2	Trap/Net	2, 5
A. californica Cresson	f	4	Trap	1, 2, 4
A. montana Cresson	f/m	23	Trap	2, 4, 6, 7
A. occidentalis Cresson	f/m	5	Trap	2, 5, 6, 7
A. terminalis Cresson	f	1	Trap	5
A. walshii Cresson	f/m	1261	Trap/Net	1, 2, 3, 4, 5, 6, 7, 8
Bombini				
Bombus sp.	f/m	16	Trap/Net	2, 3, 4, 5, 6
B. auricomus (Robertson)	f/m	13	Trap	2, 3, 4, 5, 6
B. bimaculatus Cresson	f/m	196	Trap/Net	1, 2, 3, 4, 5, 6, 7, 8
B. fervidus (F.)	f/m	12	Trap/Net	1, 2, 3, 5, 6, 7
B. fraternus (Smith)	f/m	21	Trap	1, 2, 4, 5, 6, 7
B. griseocollis (De Geer)	f/m	653	Trap/Net	1, 2, 3, 4, 5, 6, 7, 8
B. impatiens Cresson	f/m	169	Trap/Net	1, 2, 3, 5, 6, 7, 8
B. nevadensis Cresson	f	2	Trap/Net	5, 6
B. occidentalis Greene	f	1	Trap	6
B. pensylvanicus (De Geer)	f/m	1764	Trap/Net	1, 2, 3, 4, 5, 6, 7, 8
B. vagans (Smith)	f	1	Net	3

Melittofauna taxa	*Sex*	*n Specimens*[a]	*Collection Method*[b]	*County*[c]
Centridini				
Centris sp.	m	1	Trap	3
Emphorini				
Diadasia sp.	f/m	26	Trap	2, 3, 4, 6, 7
D. australis (Cresson)	f/m	50	Trap	1, 4, 6, 7
D. diminuta (Cresson)	f/m	2	Trap	4
D. enavata (Cresson)	f/m	2224	Trap/Net	1, 2, 3, 4, 5, 6, 7, 8
D. rinconis	f	33	Trap	1, 2, 4, 6, 7
Melitoma grisella (Cockerell and Porter)	f	2	Trap	2, 7
Eucerini				
Eucera hamata (Bradley)	f/m	464	Trap	1, 2, 3, 4, 5, 6, 7, 8
E. speciosa (Cresson)	f/m	11	Trap	2, 4, 6, 7
Exomalopsis sp.	m	1	Trap	7
Florilegus condingus (Cresson)	f/m	1178	Trap/Net	1, 2, 3, 4, 5, 6, 7, 8
Melissodes sp.	f/m	405	Trap/Net	1, 2, 3, 4, 5, 6, 7, 8
M. agilis Cresson	f/m	17673	Trap/Net	1, 2, 3, 4, 5, 6, 7, 8
M. bimaculata Lepeletier	f/m	436	Trap/Net	1, 2, 3, 4, 5, 6, 7, 8
M. coloradensis Cresson	f/m	577	Trap	1, 2, 3, 4, 5, 6, 7, 8
M. communis Cresson	f/m	2124	Trap/Net	1, 2, 3, 4, 5, 6, 7, 8
M. comptoides Robertson	f/m	1241	Trap/Net	1, 2, 3, 4, 5, 6, 7, 8
M. coreopsis Robertson	f/m	5269	Trap/Net	1, 2, 3, 4, 5, 6, 7, 8
M. denticulata Smith	f/m	175	Trap	1, 2, 3, 4, 5, 6, 7, 8
M. desponsa Smith	f/m	759	Trap	1, 2, 3, 4, 5, 6, 7, 8
M. intorta Cresson	f/m	64	Trap	1, 2, 4, 5, 6, 7
M. menuachus Cresson	f/m	26	Trap	1, 2, 3, 4, 7
M. rivalis Cresson	f/m	80	Trap	1, 2, 3, 4, 5, 6, 7, 8
M. trinodis Robertson	f/m	12169	Trap	1, 2, 3, 4, 5, 6, 7, 8
M. tristis Cockerell	f/m	4	Trap	2, 7
M. tuckeri Cockerell	f/m	8	Trap	1, 5, 6, 7
M. vernoniae Robertson	f/m	101	Trap/Net	1, 2, 3, 4, 5, 6, 7, 8
Peponapis sp.	f	2	Trap	3, 4
P. pruinosa (Say)	f/m	20	Trap	1, 2, 3, 4, 5, 6, 7
Svastra sp.	f/m	16	Trap/Net	1, 2, 3, 6, 7
S. atripes (Cresson)	f/m	7	Trap/Net	2, 3, 4, 5, 7, 8
S. obliqua (Say)	f/m	3537	Trap/Net	1, 2, 3, 4, 5, 6, 7, 8
Tetraloniella sp.	f/m	13	Trap	2, 3, 5, 7
T. cressoniana (Cockerell)	f/m	74	Trap	1, 2, 3, 5, 6, 7, 8
T. eriocarpi (Cockerell)	f	1	Trap	7
T. spissa (Cresson)	f/m	54	Trap	1, 2, 3, 4, 5, 6, 7

Melittofauna taxa	*Sex*	*n Specimens*[a]	*Collection Method*[b]	*County*[c]
Xenoglossa strenua (Cresson)	f/m	4	Trap	2, 7
Melectini				
Xeromelecta sp.	f/m	18	Trap	3, 4, 5, 6, 7
X. interrupta (Cresson)	f/m	40	Trap	1, 2, 3, 4, 5, 6, 7
NOMADINAE				
Ammobatoidini				
Holcopasites sp.	f	1	Trap	4
Epeolini				
Nomada sp.	f/m	30	Trap	1, 2, 3, 4, 5, 6, 7
Triepeolus sp.	f/m	266	Trap/Net	1, 2, 3, 4, 5, 6, 7, 8
Nomadini				
Epeolus sp.	f/m	4	Trap	5, 6, 7
XYLOCOPINAE				
Ceratinini				
Ceratina sp.	f/m	97	Trap/Net	1, 2, 3, 4, 5, 6, 7
Xylocopini				
Xylocopa virginica (L.)	f/m	3	Trap	3
COLLETIDAE				
COLLETINAE				
Paracolletini				
Colletes sp.	f/m	88	Trap	1, 2, 3, 4, 5, 6, 7
HYLAEINAE				
Hylaeus sp.	f/m	139	Trap/Net	1, 2, 3, 4, 5, 6, 7, 8
HALICTIDAE				
HALICTINAE				
Augochlorini				
Augochlora pura (Say)	f	13	Trap	2, 3, 6, 7
Augochlorella aurata (Smith)	f/m	1744	Trap/Net	1, 2, 3, 4, 5, 6, 7, 8
Augochloropsis metallica (F.)	f	229	Trap/Net	1, 2, 3, 4, 5, 6, 7
Halictini				
Agapostemon sp.	f/m	43	Trap	1, 2, 4, 6, 7, 8
A. angelicus Cockerell	m	386	Trap/Net	1, 2, 3, 4, 5, 6, 7, 8
A. angelicus/texanus	f	10072	Trap/Net	1, 2, 3, 4, 5, 6, 7, 8
A. coloradinus (Vachal)	m	1	Trap	8
A. femoratus Crawford	f	38	Trap	1, 2, 3, 5, 6, 7, 8
A. milliventris Cresson	m	1	Trap	2
A. splendens (Lepeletier)	f/m	34	Trap	1, 2, 3, 5, 6, 7
A. texanus Cresson	m	198	Trap/Net	1, 2, 3, 5, 6, 7, 8

Melittofauna taxa	*Sex*	*n Specimens*[a]	*Collection Method*[b]	*County*[c]
A. virescens (F.)	f/m	2125	Trap	1, 2, 3, 4, 5, 6, 7, 8
Halictus sp.	f/m	9	Trap/Net	2, 4, 7
H. parallelus Say	f/m	188	Trap/Net	1, 2, 3, 4, 5, 6, 7, 8
*H. rubicundus (*Christ)	f/m	9	Trap	1, 3, 5
H. tripartitis Cockerell	f/m	16	Trap	1, 2, 5, 6, 7
Lasioglossum sp.	f	47	Trap/Net	1, 2, 3, 4, 5, 6, 7
L. (*Dialictus*) spp.	f/m	10283	Trap/Net	1, 2, 3, 4, 5, 6, 7, 8
L. (*Lasioglossum*)	f	156	Trap/Net	1, 2, 3, 4, 5, 6, 7, 8
L. (*Sphecodogastra*)	f	15	Trap	4, 6, 7
Sphecodes sp.	f/m	116	Trap/Net	1, 2, 3, 4, 5, 6, 7
NOMINAE				
Nomia nortoni Cresson	f	1	Trap	2, 3, 6, 7, 8
N. universitatus Cockerell	m	1	Trap	7
ROPHITINAE				
Rophitini				
Duforea sp.	f	1	Trap	3, 5
MEGACHILIDAE				
MEGACHILINAE				
Anthidiini				
Anthidium sp.	m	1	Trap	6
Dianthidium sp.	f	1	Trap	3
Lithurgini				
Lithurgopsis apicalis (Cresson)	m	1	Trap	7
Osmiini				
Ashmeadiella sp.	f	7	Trap	2, 3, 5, 6, 7
Heriades sp.	f/m	4	Trap	2, 5, 6
Hoplitis sp.	f/m	364	Trap	1, 2, 3, 4, 5, 6, 7, 8
Osmia sp.	f/m	25	Trap	2, 3, 4, 6, 7
O. (*Melanosmia*) Schmeideknecht	f/m	7	Trap	1, 2, 4, 6, 7
Megachilini				
Coelioxys sp.	f/m	29	Trap/Net	2, 3, 4, 5, 6, 7, 8
Megachile sp.	f/m	114	Trap/Net	1, 2, 3, 4, 5, 6, 7, 8
M. (*Argyropile*) Mitchell	f/m	15	Trap	1, 2, 3, 5, 6, 7, 8
M. (*Litomegachile*) Mitchell	f/m	45	Trap/Net	1, 2, 3, 4, 5, 6, 7, 8
M. (*Megachile*) Latreille	f/m	114	Trap	1, 2, 3, 4, 5, 6, 7, 8
M. (*Megachiloides*) Mitchell	f/m	28	Trap/Net	1, 2, 3, 4, 5, 6, 7, 8
M. (*Sayapis*) Titus	f/m	25	Trap	1, 2, 3, 4, 6, 7, 8

Melittofauna taxa	*Sex*	*n Specimens*[a]	*Collection Method*[b]	*County*[c]
M. (*Xanthosarus*) Robertson	f/m	38	Trap/Net	2, 3, 4, 5, 6, 7

[a] n is the number of specimens

[b] Trap indicates that specimens were captured using blue vane traps; net indicates that specimens were captured with an insect net

[c] The number corresponds to what county the specimens were collected in. 1: Adams County; 2: Clay County; 3: Filmore County; 4: Franklin County; 5: Hamilton County; 6: Kearney County; 7: Phelps County; 8: York County

TABLE 2.2: Fly species captured in the Rainwater Basin Region of Nebraska.

Diptera Taxa	*n Specimens*[a]	*Collection Method*[b]	*County*[c]
“NEMATOCERA”			
TIPULOMORPHA			
TIPULIDAE	12	Trap	2, 3, 5, 6, 7
CULICOMORPHA			
CERATOPOGONIDAE	1	Trap	8
CHIRONOMIDAE	83	Trap	1, 2, 3, 4, 5, 6
CULICIDAE	91	Trap	1, 2, 3, 4, 5, 6, 7, 8
Aedes sp. Meigen	12	Trap	1, 2, 5, 6, 7
NEODIPTERA			
BIBIONOMORPHA			
BIBIONIDAE			
Bibio sp. Geoffroy	17	Trap	1, 2, 3, 4, 7
SCIARIDAE	64	Trap	1, 2, 3, 4, 5, 6, 7, 8
MYCETOPHILIDAE	53	Trap	1, 2, 3, 4, 5, 6, 7
Leia sp. Meigen	52	Trap	1, 2, 3, 4, 5, 6, 7, 8
BRACHYCERA: ORTHORRHAPHA			
TABANIDAE	1	Trap	6
Chrysops sp. Meigen	1	Net	2
STRATIOMYOMORPHA			
STRATIOMYIDAE	8	Trap	2, 5
Nemotelus sp. Geoffroy	8	Trap	1, 2, 5, 6
Hedriodiscus sp. Enderlein	14	Trap/Net	2, 5, 6
Odontomyia sp. Meigen	1	Net	2
ASILOIDEA			
BOMBYLIIDAE	2	Trap/Net	1, 2
Anastoechus sp. Osten Sacken	1	Trap	2

Diptera taxa	*n Specimens*[a]	*Collection Method*[b]	*County*[c]
Bomylius sp. L.	2	Trap	2, 4
Heterostylum sp. Macquart	2	Trap	6, 7
ASILIDAE	7	Trap	2, 6, 7
Promachus sp. (Loew)	2	Trap	2, 4
BRACHYCERA: EREMONEURA			
EMPIDOIDEA			
DOLICHOPODIDAE	7	Trap/Net	2, 5, 6
BRACHYCERA: CYCLORRHAPHA: "ASHIZA"			
PIPUNCULIDAE	7	Trap	2, 3, 6, 7
SYRPHIDAE	35	Trap/Net	2, 3, 4, 5, 6, 7
Eristalinus sp. (Scopoli)	26	Trap/Net	1, 2, 3, 7
Eristalis sp. Latreille	1031	Trap/Net	1, 2, 3, 4, 5, 6, 7, 8
Helophilus sp. Meigen	4791	Trap/Net	1, 2, 3, 4, 5, 6, 7, 8
Mellota bautias (Walker)	1	Trap	1
Syritta sp. Lepeltier & Serville	30	Trap/Net	1, 2, 3, 4, 6, 7
Parhelophilus sp. Girschner	108	Trap/Net	1, 2, 3, 4, 5, 6, 7, 8
Allograpta sp. Osten Sacken	174	Trap/Net	1, 2, 3, 4, 5, 6, 7
Eupeodes sp. Osten Sacken	70	Trap/Net	1, 2, 3, 4, 5, 6, 7
Parasyrphus sp. Matsumura	1445	Trap/Net	1, 2, 3, 4, 5, 6, 7, 8
Platycheirus sp. Lepeltier & Serville	20	Trap/Net	1, 2, 3, 6
Sphaerophoria sp. Lepeltier & Serville	34	Trap/Net	1, 2, 3, 4, 6, 7
Toxomerus sp. Macquart	502	Trap/Net	1, 2, 3, 4, 5, 6, 7, 8
Tropidia sp. Meigen	14	Trap	1, 2, 5, 6
BRACHYCERA: SCHIZOPHORA			
SEPSIDAE	7	Trap	2, 6, 7
TEPHRITOIDEA			
PIOPHILIDAE	1	Trap	6
ULIDIIDAE	2	Trap	3, 5
TEPHRITIDAE	45	Trap/Net	1, 2, 3, 4, 5, 6, 7
Tupanea sp. Guettard	1	Net	2

Diptera taxa	*n Specimens*[a]	*Collection Method*[b]	*County*[c]
Campiglossa sp. Rondani	5	Net	1, 3, 5, 6
Paracantha sp. Coquillett	1	Net	2
“ACALYPTRATAE”			
CHLOROPIDAE	44	Trap	1, 2, 3, 4, 5, 6, 7
Meromyza sp. Meigen	4	Trap	1, 4, 6
Thaumatomyia sp. Zenker	37	Trap/Net	1, 2, 3, 4, 5, 7
Elachiptera sp. Macquart	15	Trap	1, 2, 3, 4, 7
SCIOMYZOIDEA			
CONOPIDAE	1	Trap	3
Thecophora sp. Rondani	26	Trap	2, 3, 4, 5, 6, 7, 8
Zodion sp. Latreille	22	Trap	1, 2, 3, 4, 5, 6, 7
SCIOMYZIDAE	1	Trap	6
Dictya sp. Meigen	6	Trap	2, 6
SCIOMYZINAE	2	Trap/Net	2, 6
BRACHYCERA: CALYPTRATAE			
“MUSCOIDAE”			
FANNIDAE			
Fannia sp. Robineau-Desvoidy	3	Trap	6, 7
MUSCIDAE	90	Trap/Net	1, 2, 3, 4, 5, 6, 7, 8
Haematobia irritans (L.)	38	Trap/Net	1, 2, 3, 4, 5, 6, 7
Musca sp. L.	62	Trap/Net	1, 2, 3, 4, 5, 6, 7, 8
Stomoxys calcitrans (L.)	44	Trap/Net	1, 2, 3, 4, 5, 6, 7
ANTHOMYIIDAE	854	Trap/Net	1, 2, 3, 4, 5, 6, 7, 8
Delia platura (Meigen)	1842	Trap/Net	1, 2, 3, 4, 5, 6, 7, 8
SCATHOPHAGIDAE	2	Trap	2, 6
OESTROIDEA			
SARCOPHAGIDAE	28	Trap	2, 3
CALLIPHORIDAE	2	Trap	2, 7
Calliphora sp. Robineau-Desvoidy	1	Trap	2, 7
Cynomya sp. Robineau-Desvoidy	2	Trap	2, 6
Cochliomyia sp. Townsend	3	Trap	2, 7

Diptera taxa	*n Specimens*[a]	*Collection Method*[b]	*County*[c]
Lucilia sp. Robineau-Desvoidy	75	Trap/Net	1, 2, 3, 4, 5, 6, 7
Lucilia silvarum Robineau-Desvoidy	4	Trap/Net	2
Pollenia sp. Robineau-Desvoidy	16	Trap	1, 3, 4, 6, 7
TACHINIDAE	3	Trap	1, 2, 3, 4, 6, 7, 8
Gonia sp. Meigen	1	Net	2
PHASIINAE	81	Trap/Net	1, 2, 3, 4, 6, 7, 8
Cylindromyia sp. Meigen	1	Trap	7
Gymnosoma sp. Meigen	1	Trap	6
TACHINIAE	119	Trap/Net	1, 2, 3, 4, 5, 6, 7
Archytas sp. Jaennicke	17	Trap/Net	1, 2, 3, 4, 6, 7
Tachina sp. Meigen	1	Net	6

[a] n is the number of specimens

[b] Trap indicates that specimens were captured using blue vane traps; net indicates that specimens were captured with an insect net

[c] The number corresponds to what county the specimens were collected in. 1: Adams County; 2: Clay County; 3: Filmore County; 4: Franklin County; 5: Hamilton County; 6: Kearney County; 7: Phelps County; 8: York County

TABLE 2.3: Coleopterans captured in the Rainwater Basin Region of Nebraska.

Coleoptera taxa	*n Specimens*[a]	*Collection Method*[b]	*County*[c]
ADEPHAGA			
CARABIDAE	1123	Trap/Net	1, 2, 3, 4, 5, 6, 7, 8
BRACHININAE			
Brachinus sp. Weber	20	Trap	1, 2, 5, 6, 7, 8
CICINDELINAE			
Cicindela sp. L.	4	Trap	2, 6, 8
ELAPHRINAE			
Elaphrus sp. F.	1	Trap	6
HARPALINAE			
Colliuris pensylvanica (L.)	2	Trap	2, 7
Lebia sp. L.	30	Trap/Net	1, 2, 4, 5, 6, 7
L. bivittata (F.)	3	Trap	2, 7
Stenolophus sp. DeJean	164	Trap	1, 2, 3, 4, 5, 6, 7
DYTISCIDAE	4	Trap	2, 5
LACCOPHILINAE			
Laccophilus sp. Leach	3	Trap	2, 7

Coleoptera taxa	*n Specimens*[a]	*Collection Method*[b]	*County*[c]
POLYPHAGA			
STAPHYLINIFORMIA			
HYDROPHILOIDEA			
HYDROPHILIDAE	227	Trap	1, 2, 3, 4, 5, 6, 7, 8
HYDROPHILINAE			
Hydrophilus sp. Geoffroy	1	Trap	5
Sphaeridium sp. F.	16	Trap	2, 3, 4, 5, 7, 8
HISTERIDAE	8	Trap	2, 7
HISTERINAE			
Spilodiscus sp. Lewis	2	Trap	4
STAPHYLINOIDEA			
STAPHYLINIDAE	309	Trap	
OMALIINAE	128	Trap	1, 3, 8
OXYTELINAE	2	Trap	4, 6
SCAPHIDIINAE	1	Trap	5
TACHYPORINAE	17	Trap	1, 2, 3, 4, 5, 6, 7
PTILIIDAE	3	Trap	7
SCARABAEIFORMIA			
SCARABAEIODEA			
GEOTRUPIDAE	1	Trap	2
SCARABAEIDAE	5	Trap/Net	6, 7
APHODIINAE	81	Trap	1, 2, 3, 4, 5, 6, 7, 8
CETONIINAE			
Euphoria sp. Burmeister	8	Trap	2, 3, 4, 7
E. inda (L.)	3	Trap	2, 3, 6
E. sepulcralis F.	2	Trap	2, 7
DYNASTINAE			
Tomarus sp. Erichson	4	Trap	1, 2, 4, 7
MELOLONTHINAE			
Macrodactylus sp. Latreille	1	Trap	6
Phyllophaga sp. Harris	12	Trap	1, 2, 6, 7, 8
PAPILIONINAE			
Popillio japonica Newman	27	Trap	1, 5, 6
RUTELINAE	49	Trap	2, 3, 4, 5, 6, 7, 8
Strigoderma arbicola F.	4	Trap/Net	1, 2, 4, 7
SCARABAEINAE	5	Trap	4, 6, 7
Onthophagus sp. Latreille	3	Trap	3, 6, 7
ELATERIFORMIA			
BUPRESTOIDEA			
BUPRESTIDAE			
POLYCESTINAE			
Acmaeodera sp. Eschsholtz	1	Trap	4
BYRRHOIDEA			
HETEROCERIDAE			

Coleoptera taxa	*n Specimens*[a]	*Collection Method*[b]	*County*[c]
ELATEROIDEA			
ELATERIDAE	49	Trap	1, 2, 3, 4, 5, 6, 7, 8
LYCIDAE			
LYCINAE			
Calopteron reticulatumata (F.)	1	Trap	2
LAMPYRIDAE			
LAMPYRINAE			
Photinus sp. LaPorte	1	Trap	7
Photuris sp. LaConte	10	Trap	1, 2, 3, 7
CANTHARIDAE	1	Trap	5
CANTHARINAE			
Atalantycha bilineata (Say)	45	Trap	1, 2, 3, 4, 6, 7
Podabrus sp. Westwood	5	Trap	2,
CHAULIOGNATHINAE			
Chaliognathus sp. Hentz	122	Trap	2, 3, 6, 7
C. marginatus (F.)	58	Trap	2, 3, 4, 5, 6, 7
C. pensylvanicus (De Geer)	2694	Trap/Net	1, 2, 3, 4, 5, 6, 7, 8
BOSTRICHIFORMIA			
BOSTRICHOIDEA			
DERMESTIDAE	27	Trap	4, 5, 6, 7
DERMESTINAE			
Dermestes lardaris L.	2	Trap	2, 6
MEGATOMINAE			
Cryptorhopalum sp. Guérin	44	Trap	1, 2, 3, 4, 5, 6, 7
BOSTRICHIDAE	1	Trap	1
CUCUJIFORMIA			
CLEROIDEA			
CLERIDAE	2	Trap	2, 8
HYDNOCERINAE			
Phyllobaenus sp. Dejean	19	Trap	2, 3, 4, 6, 7
MELYRIDAE			
MALCHIINAE			
Collops sp. Eichson	24	Trap	2, 3, 4, 5, 7
CUCUJOIDEA			
NITIDULIDAE	20	Trap	
CARPOPHILINAE			
Carpophilus sp. Stephens	136	Trap	1, 2, 3, 4, 5, 6, 7, 8
CRYPTARCHINAE			
Glischrochilus sp. Reitter	224	Trap	1, 2, 3, 4, 5, 6, 7, 8
SILVANIDAE			
PHALACRIDAE			
CRYPTOPHAGIDAE			

Coleoptera taxa	*n Specimens*[a]	*Collection Method*[b]	*County*[c]
COCCINELLIDAE			
COCCINELLINAE			
Coccinella septempunctata L.	8	Trap	1, 2, 4, 5, 7
Coleomegilla maculate (De Geer)	4	Trap	2, 3, 7, 8
Harmonia axyridis (Pallas)	7	Trap	1, 2, 4, 5, 6, 8
Hippodamia convergens Guérin	45	Trap/Net	1, 2, 3, 5, 6, 7, 8
SCYMINAE			
Hyperaspis sp. Redtenbacher	1	Trap	2
TENEBRIONOIDEA			
MORDELLIDAE	4	Trap/Net	4
MORDELLINAE			
Mordella L.	3	Trap	1
Mordellistena Costa	19	Trap/Net	1, 2, 3, 4, 5, 7
TENEBRIONIDAE	4	Trap	3, 5
ALLECULINAE			
Hymenorus sp. Mulsant	3	Trap	1
MELOIDAE	1	Trap	5
MELOINAE			
Epicauta sp. Dejean	24	Trap	2, 4, 5, 6, 7
E. atrata (F.)	357	Trap/Net	1, 2, 3, 4, 5, 6, 7, 8
E. ferruginea (Say)	3	Trap/Net	2, 3, 4, 5, 6, 7
E. sericans LeConte	16	Trap	3, 4, 5, 6, 7
E. vittata (F.)	2	Trap	4, 5
Pyrota discoidea LeConte	1	Trap	5
NEMOGNATHINAE			
Nemognatha sp. Illiger	1	Trap	6
Zonitis sp. F.	4	Trap/Net	1, 2, 7
ANTHICIDAE			
NOTOZINAE			
Notoxus calcaratus Horn	10	Trap	2, 3, 4, 7
ADERIDAE	89	Trap	1, 2, 3, 4, 5, 6, 7, 8
SCRAPTIIDAE	20	Trap	1, 2, 3, 6, 7
CHRYSOMELOIDEA			
CERAMBYCIDAE	6	Trap	2, 3, 5, 6, 7
CERAMBYCINAE			
Neoclytus sp. Thomson	1	Trap	3
LAMIINAE			
Dectes sp. LeConte	1	Trap	2
Tetraopes sp. (Dalman)	1	Trap	2
LEPTURINAE			

Coleoptera taxa	*n Specimens*[a]	*Collection Method*[b]	*County*[c]
Typocerus sp. LeConte	216	Trap	2, 3, 4, 5, 6, 7, 8
CHRYSOMELIDAE	195	Trap	1, 2, 3, 4, 5, 6, 7, 8
BRUCHINAE			
Bruchini	112	Trap	1, 2, 3, 4, 5, 6, 7, 8
GALERUCINAE			
Alticini	178	Trap/Net	1, 2, 3, 4, 5, 6, 7, 8
Diabrotica barberi Smith & Lawrence	5	Trap	2, 3
D. cristata (Harris)	164	Trap/Net	1, 2, 3, 4, 5, 6, 7
D. undecimpunctata (Mannerheim)	163	Trap/Net	1, 2, 3, 4, 5, 6, 7, 8
D. virgifera LeConte	6	Trap	2, 5, 7
Systena frontalis (F.)	1	Net	1, 2
CURCULIONOIDEA			
ATTELABIDAE	49	Trap/Net	1, 2, 3, 4, 6, 7, 8
RHYNCHITINAE			
Merhynchites sp. Sharp	2	Net	2
CURCULIONIDAE	77	Trap	1, 2, 3, 4, 5, 6, 7
DRYOPTHTHORINAE			
Rhodobaenus tredecimpunctata Illiger	1	Trap	2
Sphenophorus sp. Schönherr	18	Trap	1, 2, 3, 4, 5, 7
SCOLYTINAE			
Scolytus sp. Geoffroy	13	Trap	2, 6

[a] n is the number of specimens

[b] Trap indicates that specimens were captured using blue vane traps; net indicates that specimens were captured with an insect net.

[c] The number corresponds to what county the specimens were collected in. 1: Adams County; 2: Clay County; 3: Filmore County; 4: Franklin County; 5: Hamilton County; 6: Kearney County; 7: Phelps County; 8: York County

TABLE 2.4: Lepidopterans captured in the Rainwater Basin Region of Nebraska.

Lepidoptera taxa	*n Specimens*[a]	*Collection Method*[b]	*County*[c]
APODITRYSIA			
GELECHIOIDEA			
GELECHIIDAE	12	Trap	1, 2, 3, 4, 5, 6, 7
PTEROPHOROIDEA			
PTEROPHORIDAE	13	Trap	1, 2, 3, 4, 5, 7, 8
OBTECTOMERA			
PAPILIONOIDEA			
HESPERIIDAE	39	Trap/Net	1, 2, 3, 4, 6, 7
HESPERIINAE			
Ancyloxpha numitor (F.)	2	Trap/Net	2, 3
Atalopedes campetris (Boisduval)	33	Trap/Net	1, 2, 4, 5, 6, 7
Atrytone logan (Edwards)	13	Trap	1, 2, 4, 6, 7
PYRGINAE			
Epargyreus clarus (Cramer)	1	Trap	4
Pholisora catullus (F.)	4	Trap/Net	4, 8
PAPILIONIDAE	1	Trap	2
PIERIDAE			
COLIADINAE			
Colias sp. F.	10	Trap/Net	1, 2, 6, 7
C. eurytheme Boisduval	46	Trap/Net	1, 2, 3, 4, 5, 6, 7
C. philodice Godart	14	Trap/Net	1, 2, 3, 7, 8
PIERINAE			
Pontia protodice (Boisduval & LeConte)	2	Net	5, 7
LYCAENIDAE	2	Net	1, 2
LYCAENINAE			
Echinargus Isola (Reakirt)	1	Net	2
Lycaena dione (Scudder)	5	Trap	2, 7
POLYOMMATINAE			
Cupido comyntas (Godart)	16	Trap/Net	2, 5, 7, 8
THECLINAE			
Strymon melinus (Hübner)	1	Net	6
NYMPHALIDAE			
DANAINAE			
Danaus plexippus (L.)	4	Trap/Net	2, 8
NYMPHALINAE			
Phyciodes tharos (Drury)			2
Vanessa cardui (L.)			1, 2, 3, 5, 6, 7, 8
PYRALOIDEA			
PYRALIDAE	49	Trap/Net	1, 2, 3, 4, 5, 6, 7, 8
CRAMBIDAE	39	Trap/Net	1, 2, 3, 4, 5, 6, 7, 8

Lepidoptera taxa	*n Specimens*[a]	*Collection Method*[b]	*County*[c]
PYRAUSTINAE			
Ostrinia nubilalis Hübner	20	Trap/Net	1, 2, 3, 5, 6, 7, 8
BOMBYCOIDEA			
SPHINGIDAE	1	Trap	2
MACROGLOSSINAE			
Hemaris diffinis (Boisduval)	4	Trap	2, 7
Hyles lineata (F.)	55	Trap	1, 2, 3, 4, 5, 6, 7
GEOMETROIDEA			
GEOMETRIDAE	1	Trap	5
STERRHINAE			
Haematopis grataria (F.)	2	Net	6, 8
NOCTUOIDEA			
EREBIDAE	31	Trap	2, 3, 4, 5, 6, 7, 8
ARCTIINAE			
Arctiini	3	Trap	6, 7
EREBINAE			
Caenurgina erechtea (Cramer)	60	Trap	1, 2, 3, 4, 5, 6, 7, 8
NOCTUIDAE	269	Trap/Net	1, 2, 3, 4, 5, 6, 7, 8
ACONTIINAE	6	Trap/Net	2, 3, 6, 7
CUCULLINAE			
Cucullia sp. Schrank	1	Trap	2
HELIOTHINAE			
Helicoverpa zea (Boddie)	170	Trap/Net	1, 2, 3, 4, 5, 6, 7, 8
Schinia sp. Hübner	1	Trap	2
S. lucens (Morrison)	1	Trap	7
NOCTUINAE			
Agrotina Harris	364	Trap	1, 2, 3, 4, 5, 6, 7, 8
Caradrinini	1	Net	2
Dargida diffusa (Walker)	6	Trap	3, 4, 5, 6, 7
Striacosta albicosta Smith	43	Trap	1, 2, 4, 5, 6, 7, 8
PLUSIINAE	14	Trap/Net	1, 2, 4, 6, 7
Anagrapha falcifera Kirby	93	Trap/Net	1, 2, 3, 4, 5, 6, 7
Syngrapha sp. Hübner	5	Trap	1, 2, 4, 7

[a] n is the number of specimens

[b] Trap indicates that specimens were captured using blue vane traps; net indicates that specimens were captured with an insect net

[c] The number corresponds to what county the specimens were collected in. 1: Adams County; 2: Clay County; 3: Filmore County; 4: Franklin County; 5: Hamilton County; 6: Kearney County; 7: Phelps County; 8: York County

TABLE 2.5: Additional Hymenoptera captured in the Rainwater Basin Region of Nebraska.

Additional Hymenoptera	*n Specimens*[a]	*Collection Method*[b]	*County*[c]
"SYMPHYTA"			
TENTHREDINOIDEA			
TENTHREDINIDAE	10	Trap	2, 3, 6
"PARASITICA"			
CYNIPOIDEA	7	Trap	1, 2, 3, 4, 6
CHALCIDOIDEA	5	Trap/Net	3, 5, 7
LEUCOSPIDAE			
Leucospis sp. F.	12	Trap	1, 5, 6, 7
TORYMIDAE	1	Trap	2
ICHNEUMONOIDEA			
BRACONIDAE	55	Trap	1, 2, 3, 4, 5, 6, 7
CHELONINAE	45	Trap/Net	1, 2, 3, 4, 5, 6, 7
ICHNEUMONIDAE	12	Trap	1, 2, 3, 5, 6, 7
ACULEATA			
APOIDEA			
CRABRONIDAE	3	Trap/Net	6, 7
BEMBICINAE			
Bembix sp. F.	1	Trap	6
Strizoides sp. Guérin-Méneville	5	Trap	3, 6, 7
CRABRONINAE			
Larrini Latreille	9	Trap/Net	1, 2, 3, 4, 5, 6, 7
Crabronina Latreille	32	Trap/Net	1, 2, 3, 5, 6, 7
PHILANTHINAE			
Cerceris sp. Latreille	28	Trap	2, 3, 4, 5, 6, 7
Philanthus sp. F.	12	Trap	1, 2, 3, 5, 6, 7
SPHECIDAE			
AMMOPHILINAE	12	Trap	3, 5, 6, 7, 8
SPHECINAE	1	Trap	5
CHRYSIDOIDEA			
CHRYSIDIDAE			
CHRYSIDINAE			
Chrysis sp. L.	5	Trap	2, 5, 6, 7
FORMICOIDEA			
FORMICIDAE	967	Trap/Net	1, 2, 3, 4, 5, 6, 7, 8
POMPILOIDEA			
POMPILIDAE	9	Trap	6, 7
POMPILINAE	4	Trap	1, 5, 6, 7
SCOLIOIDEA			
SCOLIIDAE			
SCOLIINAE			
Campsomeris sp. Guérin	2	Trap	4, 7

Additional Hymenoptera	*n Specimens*[a]	*Collection Method*[b]	*County*[c]
THYNNOIDEA			
THYNNIDAE			
MYZININAE			
Myzinum sp. Latreille	110	Trap/Net	1, 2, 3, 4, 5, 6, 7
TIPHIOIDEA			
TIPHIIDAE	3	Trap/Net	1, 2
VESPOIDEA			
VESPIDAE			5
EUMENINAE	42	Trap	1, 2, 3, 4, 5, 6, 7, 8
Eumenes sp. Latreille	1	Trap	1
E. *aureus* Isely	8	Trap	1, 2, 3, 5
E. fraternus Say	2	Trap	1, 2
Euodynerus sp. Dalla Torre	53	Trap	1, 2, 3, 4, 5, 6, 7, 8
Pterocheilus sp. Klug	19	Trap	1, 2, 4, 6, 7, 8
Stenodynerus sp. De Saussure	118	Trap/Net	1, 2, 3, 4, 5, 6, 7
POLISTINAE			
Polistes sp. Latreille	46	Trap/Net	1, 2, 3, 4, 5, 6, 7, 8
P. dominula (Christ)	3	Trap	7

TABLE 2.6: Additional orders captured in the Rainwater Basin Region of Nebraska.

Additional Orders	*n Specimens*[a]	*Collection Method*[b]	*County*[c]
ARANEAE	284	Trap/Net	1, 2, 3, 4, 5, 6, 7, 8
CHILOPODA	3	Trap	1, 2, 3, 6, 7, 8
DIPLOPODA	20	Trap	6, 7
HEMIPTERA	771	Trap/Net	1, 2, 3, 4, 5, 6, 7, 8
NEUROPTERA	414	Trap/Net	1, 2, 3, 4, 5, 6, 7, 8
ODONATA	5	Trap	2, 5, 6
OPILIONES	12	Trap	5, 6, 7
ORTHOPTERA	194	Trap/Net	1, 2, 3, 4, 5, 6, 7, 8
THYSANOPTERA	2	Trap	2, 4

[a] n is the number of specimens

[b] Trap indicates that specimens were captured using blue vane traps; net indicates that specimens were captured with an insect net

[c] The number corresponds to what county the specimens were collected in. 1: Adams County; 2: Clay County; 3: Filmore County; 4: Franklin County; 5: Hamilton County; 6: Kearney County; 7: Phelps County; 8: York County

Figure Legends

Figure 2.1. Aerial imagery of a reference site, Alberding Lagoon National Wildlife Management Area (WMA), Clay County, Nebraska. The surrounding matrix is predominately cropland, however, the WMA is rangeland with a playa wetland located in the middle. Three traps were placed in the wetland (represented by triangle points) and three traps in the upland (represented by square points).

Figure 2.2. The percentage of individuals within each taxonomic order collected in 2014 and 2015 combined.

Figure 2.3. The percentage of individuals within the genera of the Apidae family collected in 2014 and 2015.

Figure 2.4. The percentage of individuals within the genera of the Halictidae family collected in 2014 and 2015.

Figure 2.5 A**)** The percentage of individuals within the families of the order Diptera collected in 2014 and 2015 combined. B) The percentage of individuals within the genera of the family Syrphidae collected in 2014 and 2015 combined.

FIGURE 2.1

FIGURE 2.2

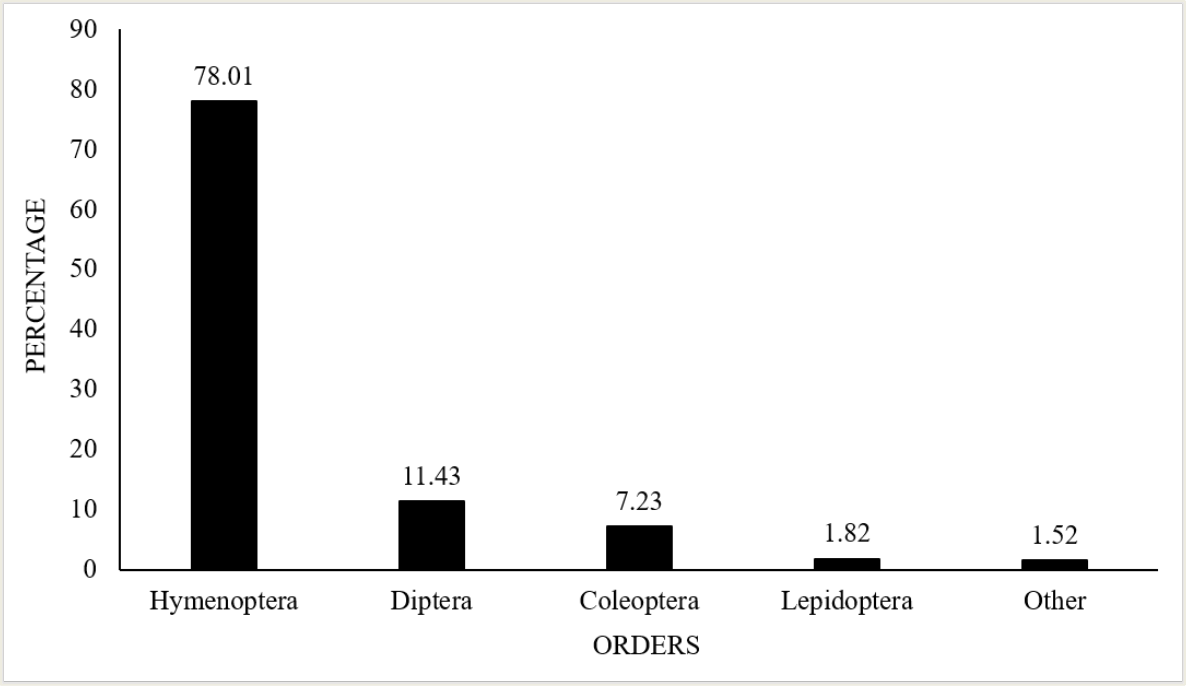


FIGURE 2.3

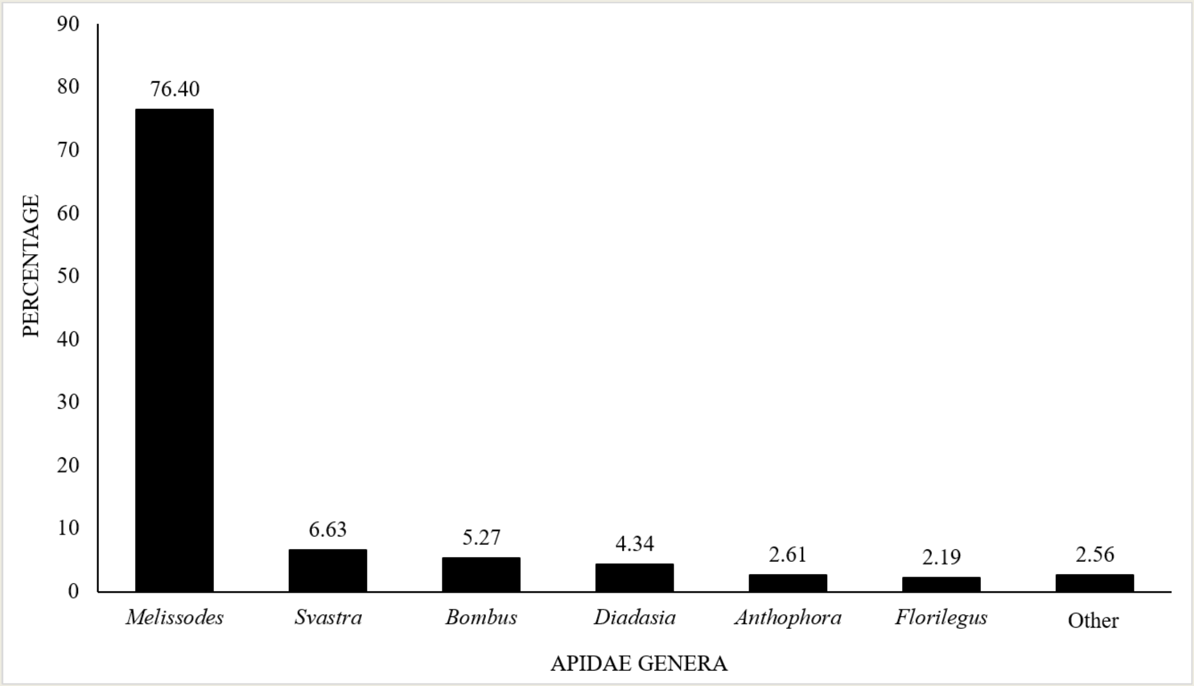


FIGURE 2.4

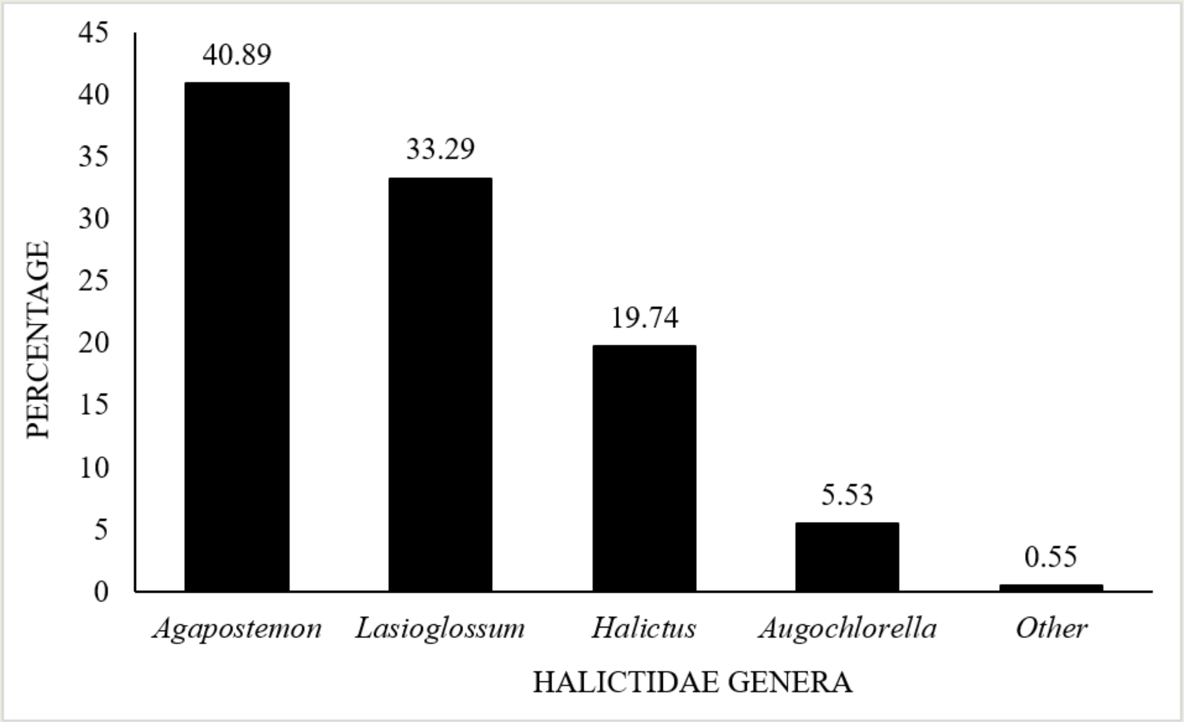
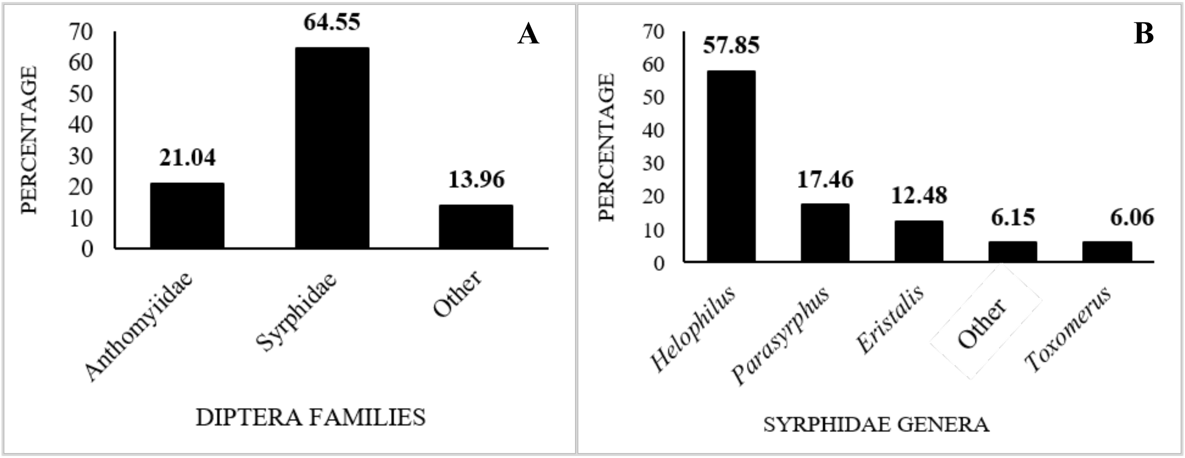


FIGURE 2.5



CHAPTER III

EFFECTS OF WETLAND PRESENCE AND UPLAND LAND USE ON WILD POLLINATOR POPULATIONS IN SOUTH CENTRAL NEBRASKA

ABSTRACT

There is growing concern that the global pollination ecosystem service is in jeopardy, and decreasing trends in wild pollinator populations are primarily attributed to habitat loss, fragmentation, and degradations within their environment. These concerns are apparent in the Rainwater Basin of Nebraska, where more than 90% of the region has been cultivated. The small number of playa wetlands and their adjacent uplands present in this region are the only natural habitat available for pollinators. Therefore, I compared pollinator abundance, richness, and diversity by insect orders in wetlands and uplands within three land uses: cropland, reference state playas and prairies, and restored wetlands and uplands implemented through the Wetlands Reserve Program (WRP). Insects were collected from April through mid-October. I used blue vane traps to capture the representative local pollinator fauna and insect nets to provide actual habitat and foraging information. Numerous insect orders were collected, but bees were dominant. Net collections showed bees foraged more in wetlands than uplands, especially in wetlands that have undergone restoration. However, in September, bees foraged in uplands more than wetlands in order to feed on late season forbs such as goldenrods.

Furthermore, trap collections showed uplands had higher abundance, richness, and diversity of pollinators than wetlands over the entire growing season. This is most likely due to nesting resources for bees only being available in uplands.

Additional pollinating orders included Diptera, Coleoptera, and Lepidoptera. Abundance of individuals within pollinating orders was almost always higher in restored and reference sites than in croplands. Dipteran trap and net collections primarily consisted of hoverflies. Hoverflies were more abundant in wetlands than uplands, likely because wetlands are utilized for larval habitat. Trap data for beetles were similar to flies, however many beetles collected in vane traps were not pollinators. Net data for beetles showed that they foraged in restored sites more than other land uses, and used wetlands and uplands at varying degrees during the growing season. Vane traps were also not efficient in capturing pollinating Lepidopterans. Net collections of Lepidopterans suggests that moths and butterflies were not heavily impacted by land use differences. However, net data showed moths and butterflies were found foraging in wetlands more than uplands. All of the pollinators included in this study used playas and uplands for resources. It is important to maintain playas and uplands of native prairie to protect the full diversity of pollinators in the RWB. Further conservation in this region should focus on watershed restoration and promoting native forb communities via wetland sediment removal and buffer strip planting, such implemented by the WRP.

INTRODUCTION

Pollinators provide an essential ecosystem service. Approximately 180,000 species of flowering plants require animal assisted pollination (NRC, 2007). Pollination by invertebrates is generally attributed to four orders: Coleoptera (beetles), Diptera (flies), Lepidoptera (moths and butterflies), and most notably Hymenoptera (bees and wasps) (NRC, 2007). Bees are generally considered the most valuable pollinator because their body is covered with branched hair to trap pollen, they exhibit specialized flower handling capabilities, and they visit more flowers than any other animal, transferring high amounts of pollen between visiting flowers (Free, 1993). Additionally, bees pollinate over two thirds of agricultural crops, and are thus responsible for approximately one third of human food production (Kremen *et al.,* 2002).

The domestic honey bee (*Apis mellifera* L.) is the most widely used pollinator for agriculture, however wild pollinators are also important to crop reproduction (James & Pitts-Singer, 2008). For example, bumble bees will forage at temperatures too low for honey bees and are often regarded as the most efficient pollinators of numerous crops, such as alfalfa, blueberry, eggplant, tomatoes, and others (Deleplane & Mayer, 2000; Free, 1993). Furthermore, wild pollinators may become increasingly important due to losses of managed honey bee colonies (Stokstad, 2007; vanEngelsdorp *et al.*, 2009). Decreasing trends in wild pollinator populations have also been noted and attributed to environmental degradation (Biesmeijer *et al.*, 2006; Potts *et al.*, 2010).

Most bee species successfully reproduce if their habitat provides nest sites, building materials, and food plants in close proximity (Westrich, 1996; James & Pitts-Singer, 2008). Approximately two-thirds of wild bees are solitary, and the majority of those burrow in the ground to nest (James & Pitts-Singer, 2008). However, a variety of nesting resources is needed to accommodate a diverse bee population; bees can burrow directly into a variety different substrates, nest in cavities within wood or rocks, or burrow in stems of forbs or wood (Westrich, 1996). Furthermore, a variety of specific materials can be used to create nests and brood cells. Some bees are generalists and only require leaves, whereas others are very specific about the vegetation material, substrate and plant resin used (Westrich, 1996).

Pollen, as a food source, provides bees with protein and small amounts of starch, lipids, and minerals (Wilmer, 2011b). The majority of pollen feeders are polylectic, meaning that they forage from a wide spectrum of plants; this includes honey bees, most bumble bees, and many sweat bees (Halictids). Generalist feeders have an easier time surviving in dynamic landscapes than specialists (Rader *et al*., 2016). Specialist feeders, the oligolectic bees, can be at great risk if a floral community shifts (Winfree, 2010). Some oligolectic bees visit only a single plant species or small group of similar species (Westrich, 1996). There is an advantage to both the insect and plant to have a specialized mutualistic relationship. The plant will have higher reproductive success if a bee will visit the same species of plant (thus ensuring conspecific pollen is taken and received), and the bee will have less competition over their preferred food source (Wilmer, 2011a).

Nectar is a food source that even oligolectic bees feed on, even if they may never collect pollen from that plant. Nectar is an energy rich fuel source necessary to fuel all activities of bees and is a component of the larval food (in addition to pollen) (Westrich, 1996). Females of many bee species make numerous foraging trips to obtain nectar and pollen provisions for the brood. Therefore, it is necessary to have both nectar and pollen food sources near nesting sites of females (Westrich, 1996).

Home range size often varies depending on the size of the bee. Some bees, such as large bumble bees, can be relatively mobile, foraging up to 2.2 km from the nest (Kreyer *et al.*, 2004). However, the majority of species do not forage at distances farther than 100-300 m from nesting sites (Zurbuchen *et al.*, 2009), and some bees have been found to nest centimeters away from their preferred pollen sources (Westrich, 1996). Increased spatial separation between habitats can reduce bee populations by removing resources needed for successful reproduction (Westrich, 1996). Furthermore, fragmentation creates smaller, isolated populations that can result in genetic depression, inbreeding, and reduced species richness by removing corridors within species metapopulations and source populations for recolonization (Kearns *et al.*, 1998; NRC, 2007; Potts *et al.*, 2010).

Most insect pollinators are more attracted to undisturbed areas than croplands because they are more likely to contain ample amounts of beneficial food plants, nesting habitat, and nesting material (Delaplane & Mayer, 2000). Therefore, playas and grasslands in the Rainwater Basin (RWB) of Nebraska may be important because they can provide crucial resources in an area primarily dominated by croplands. Additionally, grassland catchments provide a buffer strip of vegetation around wetlands, which reduces erosion, increases soil permeability, and decreases velocity of runoff (Skagen *et al.*, 2008; Daniel *et al.*, 2015). The subsequent lack of volume loss in wetlands fosters a more stable hydroperiod and can potentially promote a more beneficial wetland plant community (Luo *et al.*, 1997; Beas *et al.*, 2013).

Playas are a crucial component of the Great Plain ecoregion because they provide ecosystem services such as flood water attenuation, recharging of the Ogallala aquifer, water quality improvement, and biodiversity support (Haukos & Smith, 2003; Smith *et al.*, 2011). Playas have unpredictable hydroperiods that depend on the amount of precipitation and runoff received, and therefore is primarily influenced by watershed size/slope, vegetation, and soil characteristics (Bolen *et al.*,1989). The wet/dry cycles that are indicative of many wetland systems have created unique biotic communities that are adapted to the harsh and ever-changing hydroperiods (Haukos & Smith, 1994). The variation in environmental condition results in a flora and fauna community composition that can vary considerably among wetlands, providing enhanced overall diversity on the landscape (Haukos & Smith 2003; Smith, 2003).

The conversion of the surrounding watershed to row-crop agricultural lands has led to multiple negative consequences, one of the most detrimental being the physical alterations and filling in of playa wetlands with eroded sediment from the watershed (Smith, 2003). Occasionally, playas are filled intentionally to cultivate the area; however, it is usually the unintentional consequence of the surrounding upland soil eroding into the lowest point (i.e. the playa) that is the greatest ecosystem threat to the persistence and function of RWB wetlands (Luo *et al.*, 1997; Tsai *et al.*, 2007). Accumulated sediments alter the natural hydroperiod by forcing water to spread over a larger area, increasing evaporation loss and burial of hydric soils (Luo *et al.*, 1997). Sedimentation can also alter the vegetation community by burying the seed bank and allowing non-native, invasive species to colonize an area (Smith & Haukos 2002; O'Connell *et al.*, 2012). Furthermore, contaminants may also be present in runoff that enters playas, especially when surrounded by cropland (Belden *et al.*, 2012).

Watersheds in crop monocultures, accompanied with eroded soil and other runoff, sacrifice floral diversity in uplands and downslope wetland communities, consequently influencing the abundance and diversity of plants for pollinating insects (Kearns *et al.*, 1998; O'Connell *et al.*, 2012). Native landscapes historically provided a diversity of floral resources that sustained equally diverse mutualistic pollinator-plant relationships (Potts *et al.*, 2010). Although some generalists can survive in a changing habitat, many native species of pollinators cannot (Steffan-Dewenter & Tscharntke, 1999). If loss of biodiversity and key species becomes significant enough, an ecosystem may suffer from a loss of pollination services and the collapse of pollinator mutualisms (Aizen & Feinsinger, 1994).

My research focused on how wetland presence, restoration, and watershed land use of playas may influence pollinator populations in a landscape completely altered by anthropogenic use. I studied playa wetlands and their upland watersheds within three different dominant land uses: croplands, reference state playas and prairies, and restored wetlands and planted buffer strips. Restored sites have been enrolled in the Wetlands Reserve Program (WRP). The WRP offers landowners conservation easements to protect, restore and enhance wetland ecosystems with the assistance of the Natural Resource Conservation Service (NRCS). Conservation practices can include planting a filter strip of perennial cover to reduce sedimentation and nutrient runoff and/or the removal of sediment which can improve hydrology and plant communities (Gleason *et al.*, 2011; Beas *et al.*, 2013).

MATERIALS AND METHODS

Study Area

My study was conducted in one of the most productive cropland regions in the world, the Rainwater Basin (RWB) located in the Northern High Plains (Smith *et al*., 2011). The RWB comprises of approximately 15,907 km^2 in south-central Nebraska, just south of the Platte River (LaGrange, 2005). Historically, the landscape was flat to gently rolling plains with abundant natural playa wetlands which form where depressions hold rain and runoff water (LaGrange *et al.*, 2011). Grasslands in this region historically consisted of mixed grasses including bluestems (*Andropogon* spp.), wheatgrasses (*Agropyron* spp.), and needle grass (*Stipa* spp.), and tallgrass plant communities in the extreme eastern portion including bluestems along with switchgrass (*Panicum virgatum*), and Indian grass (*Sorgastum nutans*) (Kuchler, 1964). However, North American grasslands have declined by as much as 99% and less than 10% of playa wetlands are estimated to remain in the RWB (Samson & Knopf, 1994; LaGrange, 2005). Currently, the RWB has been overwhelmingly converted to soybean and corn production (Smith, 2003).

While conservation programs that focus on upland restoration are rare in the RWB, wetland restoration programs, such as the Wetland Reserve Program (now known as the Agricultural Conservation Easement Program), are prominent (Smith *et al*., 2011). This program offers financial and technical support to landowners for taking part of their land out of production and enhancing, restoring, or protecting wetlands and the immediate watershed (NRCS, 2008a).

Even with the great loss of wetlands, the RWB is a focal point of the Central Flyway that over 170 different species of birds rely on (NRCS, 2008b). Waterfowl hunting and bird watching are significant sources of income for this area, as over 400,000 sandhill cranes (*Grus canadensis*) and millions of ducks and geese migrate through this region (LaGrange, 2005; USFWS, 2007; NRCS, 2008b). Consequently, RWB conservation primarily focuses on providing wetland habitat and critical food resources for mid-continental migrating waterfowl (Webb *et al.*, 2010). State and federal wildlife agencies have secured over 2,500 ha of playa wetlands since the 1960s (Walker, 2016). Over 75% of that number is protected in the form of Waterfowl Production Areas and Wildlife Management Areas and the remainder consist of conservation easements such as WRP wetlands (Grosse, 2014).

Field collection

Insects were collected from the first week of April until mid-October in 2014 and 2015 in the Rainwater Basin region. Twenty-eight different sites were sampled 14 times (twice a month) each year (Table 3.1). Each site contained a playa wetland that was embedded within one of three different land use types- reference condition grasslands (n=9), restored prairie uplands enrolled in the WRP (n=9), and row-crop agriculture (n=10). Nebraska Game and Parks Commission biologists classified sites using the Hydrogeomorphic Wetland Classification System. Three random sampling locations were placed within both the wetland and adjacent upland at each site. Insects were collected using vane traps (SpringStar™ LLC, Woodinville, WA, USA) and insect nets (Stephen & Rao, 2005; Stephen & Rao, 2007).

Vane traps: Traps consisted of a bright yellow 30 ml plastic jars fitted with a blue fabricated polypropylene screw cap funnel into which two cross vanes were inserted (Fig 3.1) (Stephen & Rao, 2007). Six traps placed within sites; three in the wetland and three in the upland. Sampling locations were located randomly towards the middle of the wetland and upland locations were hundreds of meters in the upland. Locations were purposely chosen to be away from the edges of the playa. A wooden stake was placed at each sampling location and the trap was attached with wire at the average height of the surrounding vegetation. Traps were set up between 0900 and 1100 at different sites each day and then picked up the following morning during the same time period, allowing for approximately 24-hour exposure. The funnel was then replaced with a lid and the jars were placed in a freezer to kill captured specimens.

Insect nets: For net collections, we used 30.5 cm diameter insect nets. A 25 m long, 0.5 m wide transect was established 12 m adjacent to each vane trap. Six minutes were allocated to walking the transect and collecting insects on either side that were foraging on or manipulating flowers. The timer was paused while the insect was placed in a killing jar of ethyl acetate and then placed in a plastic sample bag labeled with site, transect number, date, and plant species information. Sampling took place at 1100 after the vane traps for the day's sites had been set out.

Insect identification

All specimens were kept in a freezer at 4 °C until they were identified. Insect specimens were first identified to order by simple observation and many genera and species did not require use of keys due to their obvious morphological characters. A complete list of taxonomic keys utilized can be found in chapter two. Additional orders were collected, but not included in this analysis nor identified further because they are not considered pollinators. However, their abundances were included in chapter two (Table 2.6). Multiple resources were used to determine whether or not an insect was considered a noted pollinator. The primary texts utilized were Michener (2007), Triplehorn & Johnson (2005), and Wilmer (2011c, 2011d, 2011e).

Statistical analysis

Abundance, richness, and diversity (Shannon-Weiner index) of pollinator communities were compared among land uses and landscape positions. Insects collected in the three traps within each landscape position (upland or wetland) were combined for analyses. A three-way analysis of variance (ANOVA) (Minitab 17 Statistical Software, State College, PA) was used to compare the main effects and interactions of sampling period, landscape position, and land use type for insect net and vane trap sampling techniques separately. Year and site were random variables. Tukey's pairwise comparisons were used following significant F-tests to examine differences in means. An alpha of 0.1 was used to minimize the chance for type I error. A chi-square test was conducted on the most abundant orders caught in traps and insect nets to determine if the number of insects caught were independent of capture method.

RESULTS

We collected 110,779 insects in blue vane traps and 1,649 insects in nets. Insects were from 13 orders; Hymenoptera, Diptera, Coleoptera, and Lepidoptera were most abundant. For a detailed list of collected specimens, see tables one through six in chapter two. Hymenoptera comprised 79% of pollinating individuals sampled in traps, followed by Diptera, Coleoptera, and Lepidoptera with 12%, 7%, and 2%, respectively. Net collections had a more even distribution. Diptera was the largest order represented in net collections with 32%, followed by Coleoptera, Hymenoptera, and Lepidoptera with 29%, 26%, and 8%, respectively. Insects caught were not independent of the sampling methods (x2=548, df=19, p <0.001).

Overall Trap Results

Abundance: There was an interaction between land use and landscape position (Table 3.2). Therefore, differences in landscape position (i.e. upland and wetland) were compared among land uses. Abundance was higher in reference and restored uplands than in crop uplands, however there was no difference among land uses in wetlands (Fig. 3.2A) Sampling period and year were both significant (Table 3.2). Year 2014 ($\bar{x}$ = 96.73) had twice the abundance of insects as 2015 ($\bar{x}$ = 48.55). Period 12 ($\bar{x}$ = 191.86), in early September, had the highest abundance of insects caught over the entire growing season.

Richness: There was an interaction between land use and landscape position (Table 3.2). Therefore, differences in landscape position were compared among land uses. Restored uplands had higher species richness than reference uplands and crop wetlands (Fig. 3.2B). Richness in wetland sites did not differ among land uses. Crop uplands had the lowest species richness than other upland land uses (Fig. 3.2B). Sampling period and year were both significant (Table 3.2). In 2014 ($\bar{x}$ =15.47) there was 1.7 times greater richness than 2015 ($\bar{x}$ =8.96). Sampling periods in the months of August ($\bar{x}$ =18.26, $\bar{x}$ =17.16) and September ($\bar{x}$ =18.16, $\bar{x}$ =17.72) had higher richness than the rest of the growing season.

Diversity: There was an interaction between land use and landscape position (Table 3.2). Therefore, differences in landscape position were compared among land uses. Restored ($\bar{x}$ =1.62) and reference ($\bar{x}$ =1.61) uplands had higher species diversity than crop uplands ($\bar{x}$ =1.45). Diversity of pollinators in wetlands did not differ among land uses. Year and sampling period were also significant (Table 3.2). The year 2014 ($\bar{x}$ =1.74) had 1.3 times higher species diversity than 2015 ($\bar{x}$ =1.32). July through October had the higher diversity than early summer. Late September ($\bar{x}$ =2.08) had the highest diversity—significantly higher than early September ($\bar{x}$ =1.73)

Hymenoptera Trap Results

Hymenopterans comprised almost 80% of all specimens caught. Over 86,500 bees from five different families were collected. Apidae and Halictidae made up 99% of the Hymenopteran samples collected, with 62% and 37% respectively. Additional families included Andrenidae, Colletidae, and Megachilidae. Apidae was the most species rich family with 55, including 11 *Bombus* and 16 *Melissodes* species. The 16 *Melissodes* species made up 76% of all specimens collected within Apidae. Less than 2% of Hymenopterans caught were not bees; wasps and ants each equaled 1% of total insects. Hymenoptera insects captured were not independent of sampling method (p<0.001). Two bee families, Andrenidae and Megachilidae, and the wasp family Vespidae had greater representation in net collections than traps. However, Halictidae was greater in the trap collections and Apidae and Colletidae were not different between the two sampling techniques.

Abundance: There was an interaction between land use and landscape position (Table 3.3). Therefore, differences in landscape position were compared among land uses. Reference uplands had higher Hymenoptera abundance than crop uplands (Fig. 3.3A). Year and sampling period were also significant (Table 3.3). In 2014 ($\bar{x}$ =78.71) there was 2.24 times greater Hymenoptera abundance than 2015 ($\bar{x}$ =35.16). Additionally, early September had higher abundance than all other periods (Fig. 3.3B).

Richness: There was an interaction between land use and landscape position (Table 3.3). Therefore, differences in landscape position were compared among land uses. Restored and reference uplands had higher Hymenoptera richness than crop uplands and all wetlands (Fig. 3.3C). Year and sampling period were also significant (Table 3.3). In 2014 ($\bar{x}$ =9.22) there was 1.74 times higher Hymenoptera richness than 2015 ($\bar{x}$ =5.31). Early August had higher richness than all other sampling periods except early September and late July (Fig. 3.3D).

Diversity: There was an interaction between land use and landscape position (Table 3.3). Therefore, differences in landscape position were compared among land uses. As with richness, restored ($\bar{x}$ =1.29) and reference ($\bar{x}$ =1.23) uplands had higher Hymenoptera diversity than crop uplands and all wetlands ($\bar{x}$ =1.03). Diversity did not differ between uplands and wetlands within each land use. Year and sampling period were significant (Table 3.3). The year 2014 ($\bar{x}$ =1.31) had 1.4 times higher Hymenoptera diversity than

2015 ($\bar{x}$ =0.93). Sampling periods 10 ($\bar{x}$ =1.75) and 9 ($\bar{x}$ =1.68) in early August and late July had the highest diversity.

Diptera Trap Results

The second largest order represented were the flies, totaling 12,266 specimens and 12% of all insects collected in traps. Syrphidae comprised 65% of all flies collected, followed by Anthomyiidae with 21%. Most of the other 29 families each made up less than 1% of all flies collected, and 13 families were not identified to a lower taxonomic level because they were not noted pollinators (Wilmer 2011c).

Abundance: There was an interaction between land use and sampling period (Table 3.4). Therefore, differences in land use were compared within each period. Diptera abundance was highest among all land uses in early October. Land use was different in two sampling periods, periods three (early May) and 13 (late September). In early May, restored sites had greater abundance than croplands. However, in late September, cropland sites had greater abundance than restored sites (Fig. 3.4A). Landscape position was also significant (Table 3.4). Wetlands had higher abundance than uplands (Fig. 3.4B).

Richness: There was an interaction between land use and sampling period (Table 3.4). Therefore, differences in land use were compared within each period. Diptera richness spiked in early summer and again in the fall (Fig. 3.4C). Sampling period 14, in early October, had the highest Diptera richness among sampling periods. Similar richness was reported for periods five, 13, and 14. Year was significant as well (Table 3.4). In the year 2014 ($\bar{x}$ =2.48) there was 1.5 times higher Diptera richness than 2015 ($\bar{x}$ =1.66).

Diversity: There was an interaction between land use and sampling period (Table 3.4). Therefore, differences in land use were compared between sampling periods. Land uses during sampling period 14 (Crop: $\bar{x}$ =0.97, Res: $\bar{x}$ =0.87, Ref: $\bar{x}$ =0.74) in October had the higher diversity than all other land use combinations except for land uses in periods five and 13, crop sites in periods six-eight, reference sites in period six, and restored sites in seven. In other words, there were similar peaks of high diversity among all land uses during May and late September-early October. Year was also significant (Table 3.4). In 2014 ($\bar{x}$ =0.62) there was 1.8 times higher diversity than 2015 ($\bar{x}$ =0.35).

Coleoptera Trap Results

Coleoptera totaled 7% of insects collected in traps. Fifty-eight genera were identified from 24 families. Fourteen families were not identified to a lower taxonomic level because there were not noted pollinators (Triplehorn & Johnson, 2005; Wilmer, 2011d). Cantharidae (primarily the genus *Chauliognathus*) made up 36% of all Coleoptera, followed by Carabidae with 17% and Chrysomelidae with 10%.

Abundance: There was a three-way interaction among land use, landscape position, and sampling period (Table 3.5). Therefore, to compare differences in abundance, I performed additional two-way ANOVAs within each independent variable. Landscape position and sampling period were compared within the three land use types: cropland, reference, and restored; similarly, land use and sampling period were analyzed within wetlands and uplands, and landscape position and land use were analyzed within each sampling period. The greatest Coleoptera abundance was in late summer during sampling periods 11 and 12 (Fig. 3.5A). Within peak abundance, crop wetlands had higher abundance than all other uplands and wetlands. Year was also significant (Table 3.5). In the year 2014 ($\bar{x}$ =7.09) there was 2.23 times higher Coleoptera abundance than in 2015 ($\bar{x}$ =3.18).

Richness: There was an interaction between land use and sampling period (Table 3.5). Therefore, differences in land use were compared within each period. Cropland sites during sampling period five in early June had the highest richness, followed by crop sites in (Fig. 3.5B). Year was also significant (Table 3.5), with 2014 ($\bar{x}$ =2.16) having twice the species richness as 2015 ($\bar{x}$ =1.03).

Diversity: Main effects year and sampling period were significant for Coleoptera diversity (Table 3.5). The year 2014 ($\bar{x}$ =0.54) had 2.35 times higher Coleoptera diversity than 2015 ($\bar{x}$ =0.23). There is not a consistent pattern in higher diversity within sampling periods. Sampling period five ($\bar{x}$ =0.65) in early June had the highest diversity which was similar to sampling periods in early July and late August/early September.

Lepidoptera Trap Results

Lepidoptera comprised less than 2% of all insects collected. Fourteen families and 30 genera were identified, and the family Noctuidae constituted 48% of all lepidopterans collected (Chapter 2). Twenty-seven percent of lepidopterans collected could not be taken to a further taxonomic level than order due to damaged specimens.

Abundance: There was a three-way interaction of land use, landscape position, and sampling period (Table 3.6). Therefore, I performed additional two-way ANOVAs within each independent variable. Landscape position and sampling period were compared within the three land use types: cropland, reference, and restored; similarly, land use and sampling period were analyzed within wetlands and uplands, and landscape position and land use were analyzed within each sampling period. There is a peak in Lepidoptera abundance in restored wetlands during sampling period nine (late July), and a second peak in both wetlands and uplands among all land uses in period 12 (early September) (Fig. 3.6A). Furthermore, reference sites had lower abundance than cropland sites. Year was also significant; in 2014 ($\bar{x}$ =1.58) there was 1.75 times higher Lepidoptera abundance than in 2015 ($\bar{x}$ =0.91).

Richness: There was an interaction between land use and sampling period effect on Therefore, differences in land use were compared within each period. Lepidoptera richness (Table 3.6). Lepidoptera richness was highest in September; restored and reference sites were slightly higher than crop sites in early September, but reference contained the highest richness in late September (Fig. 3.6B). Year was also significant; in 2014 ($\bar{x}$ =0.74) there was 1.58 times greater species richness than 2015 ($\bar{x}$ =0.47).

Diversity: There was an interaction between land use and sampling period (Table 3.5). Therefore, differences in land use were compared within each period. Reference sites during sampling period 13 ($\bar{x}$ =0.53) had higher diversity than all other land uses throughout the growing season, followed by cropland ($\bar{x}$ =0.30) and restored sites in period 12 ($\bar{x}$ =0.37) and restored sites in sampling period 13 ($\bar{x}$ =0.29). Year was also significant; in the year 2014 ($\bar{x}$ =0.15) there was 1.76 times greater diversity than 2015 ($\bar{x}$ =0.08).

Overall Results from Collections with Nets

A complete list of plants that pollinators were caught feeding on has been provided (Table 3.7). The abundance of pollinators per land use and landscape position for both years combined is included.

Abundance: There was an interaction between land use and landscape position (Table 3.8). Therefore, differences in landscape position were compared among land uses. Restored wetlands had higher pollinator abundance than all other wetland types and all upland land uses. Abundance in reference uplands and wetlands did not differ, but crop uplands had lower abundance than all wetlands and uplands (Fig. 3.7A). There was also an interaction of land use and sampling period (Table 3.8). Restored sites in August had higher abundance than cropland sites. Additionally, reference sites were higher than cropland sites during early September (Fig. 3.7B). Finally, there was an interaction between landscape position and sampling period. The only difference was during period 11, in late August, when wetlands ($\overline{x}$ =8.44) had higher pollinator abundance than uplands ($\overline{x}$ =2.22).

Richness: There were interactions among land use and sampling period, as well as landscape position and sampling period (Table 3.8). Therefore, differences in land use and landscape position were separately compared within each period. For both interactions, sampling periods 10 and 11 in August were the only periods that had differences. During August, restored sites had higher species richness than cropland sites (Fig. 3.7C). Additionally, wetlands ($\overline{x}$ =1.61, $\overline{x}$ =4.31) had higher richness than uplands ($\overline{x}$ =0.60, $\overline{x}$ =0.71).

Diversity: There was an interaction between land use and sampling period for species diversity (Table 3.8). Therefore, differences in land use were compared within each period. Within period 10, restored sites ($\bar{x}$ =0.54) had higher diversity than cropland sites ($\bar{x}$ =0.11). There was also an interaction between landscape position and sampling period (Table 3.8). In August, wetlands ($\bar{x}$ =0.44, $\bar{x}$ =0.96) had higher insect diversity than the uplands ($\bar{x}$ =0.17, $\bar{x}$ =0.16)

Hymenoptera Results from Collections with Nets

Hymenoptera comprised 26% of insects collected with nets; 93% of that were bees. Three hundred seventy-five bees from five different families (Andrenidae, Apidae, Colletidae, Halictidae, and Megachilidae) were caught on flowers. Apidae had the highest abundance with *Bombus* and *Melissodes* being the most common genera. Twenty-nine wasps from six families were collected. Vespidae had the most individuals overall, comprising over half of the wasps caught.

Abundance: There was a three-way interaction among land use, landscape position, and sampling period (Table 3.9). Therefore, I performed additional two-way ANOVAs within each independent variable. Landscape position and sampling period were compared within the three land use types; similarly, land use and sampling period were analyzed within wetlands and uplands, and landscape position and land use were analyzed within each sampling period. Abundance peaked in mid-July/early August; restored wetlands had the overwhelming majority of bees collected, compared to other wetland types (Fig. 3.8A). During a second peak in early September, reference uplands had the higher abundance than all other land use/position combinations. Reference and restored wetlands had lower abundance in early September than their upland counterparts, however, crop wetlands continued to have higher abundance than crop uplands (Fig. 3.8A).

Richness: There was a three-way interaction among land use, landscape position, and sampling period (Table 3.9). Therefore, I performed additional two-way ANOVAs within each independent variable. Landscape position and sampling period were compared within the three land use types: cropland, reference, and restored; similarly, land use and sampling period were analyzed within wetlands and uplands, and landscape position and land use were analyzed within each sampling period. There was a peak in Hymenoptera richness that began in July and decreased after August (Fig. 3.8B). During late July and August, restored wetlands had higher richness than wetlands and uplands in all other land uses. (Fig. 3.8B).

Diversity: Diversity results were similar to richness and abundance. There was a three-way interaction between land use, landscape position, and sampling period (Table 3.9). Therefore, I performed additional two-way ANOVAs within each independent variable. Within cropland sites only, the interaction of landscape position and sampling period was significant ($p<0.001$). In late July, the interaction of land use and landscape position was significant ($p=0.070$); restored wetlands ($\bar{x}=0.19$) had the higher Hymenoptera diversity than reference and crop wetlands and crop uplands. During period 11, late August, the individual variables of land use ($p=0.010$) and landscape position ($p<0.001$) were significant. Restored sites ($\bar{x}=0.33$) had higher diversity than reference ($\bar{x}=0.15$) and cropland ($\bar{x}=0.09$) sites. Wetlands ($\bar{x}=0.34$) had higher diversity than uplands ($\bar{x}=0.04$). Lastly, in early September, there was an interaction between land use and landscape position (*p*=0.020); restored uplands ($\bar{x}$ =0.25) had higher Hymenoptera diversity than crop uplands ($\bar{x}$ =0.00).

Diptera Results from Collections with Nets

Diptera, totaling 32% of all net specimens caught, represented the largest order collected with nets. Five hundred and three individuals from 14 families were collected (Chapter 2). Syrphidae comprised the vast majority of Dipterans collected, with 85% of the total. Ten syrphid genera were identified. *Eristalis* and *Helophilus* had the highest abundance with 47% and 22%, respectively.

Abundance: There was an interaction between land use and sampling period (Table 3.10) Therefore, differences in land use were compared within each period. Restored sites within period seven, late June/early July, had the highest Diptera abundance among the land uses throughout the growing season (Fig 3.9A). There was a second peak in abundance during the month of August, but there were no differences in abundance among land uses. There was an interaction between landscape position and sampling period (Table 3.10). Wetlands during the months of July and August had higher abundance than uplands (Fig. 3.9B).

Richness: There was an interaction between land use and sampling period (Table 3.10). Therefore, differences in land use were compared within each period. During early August, restored sites had the highest richness. However, crop and reference sites rose to the similar richness in the following sampling period (Fig. 3.9C). There was also an interaction between landscape position and sampling period (Table 3.8). Richness peaked in late August before declining in September; wetlands had higher richness than uplands during mid-July through August (Fig. 3.9D).

Diversity: There was an interaction between landscape position and sampling period (Table 3.10). Therefore, differences in land use were compared within each period. Mid-July through August and late September had the highest Diptera diversity among all land uses, however diversity peaked in wetland transects during sampling period 11 in August ($\overline{x}$ =0.31). Land use was also significant (Table 3.10). Restored sites ($\overline{x}$ =0.06) had higher Dipteran richness than cropland ($\overline{x}$ =0.02).

Coleoptera Results from Collections with Nets

Beetles comprised 29% of insects collected with nets. Cantharidae, primarily the genus *Chauliognathus*, made up 74% of beetles caught (Chapter 2). The second most abundant family was Chrysomelidae, which comprised 23% of beetles collected.

Abundance: There was an interaction between land use and landscape position (Table 3.11). Therefore, differences in landscape position were compared among land uses. Reference and restored uplands were the highest land use/landscape position combination; all wetlands had similar abundance and crop uplands had the lowest amount of Coleoptera (Fig. 3.10A). There was also an interaction between land use and sampling period (Table 3.11). During late August, restored sites had higher abundance than crop sites. However, in early September, reference sites had higher abundance than crop and restored sites (Fig. 3.10B). Finally, there was an interaction between landscape position and sampling period. The greatest difference was in early August, when uplands had higher abundance than wetlands (Fig. 3.10C).

Richness: There was an interaction between land use and sampling period (Table 3.11). Coleoptera richness peaked in late August, and restored sites had the highest Coleoptera richness compared to reference and cropland (Fig. 3.10D). Restored and reference sites also had higher richness than cropland sites during early September. There was an additional interaction between landscape position and sampling period (Table 3.11). Therefore, the effects of position were compared within each period. During period 11, wetlands had higher Coleoptera richness than uplands. However, uplands had higher richness during period 12 (Fig. 3.10E).

Diversity: There was an interaction between land use and sampling period (Table 3.11). Therefore, the differences of land use were compared within each period. Restored ($\bar{x}$ =0.16) and reference sites ($\bar{x}$ =0.11) during period 11 (late August) and reference sites during period 12 (early September) ($\bar{x}$ =0.07) had higher diversity than any other land use during the growing season. There was also an interaction between landscape position and sampling period (Table 3.11). Therefore, the differences of position were compared within each period. Wetlands during sampling period 11 ($\bar{x}$ = 0.15) had higher Coleoptera diversity among all other wetlands and uplands during the growing season, with the exception of uplands during sampling period 12 ($\bar{x}$ =0.6).

Lepidoptera Results from Collections with Nets

Butterflies and moths comprised 8% of insects collected with nets. Pieridae had the highest abundance with 34%, followed by Crambidae, Lycaenidae, and Nymphalidae each comprising 16%. Noctuidae, which comprised 48% of Lepidopterans collected with traps, only made up 10% of Lepidopteran net collections (Chapter 2).

Abundance: There was an interaction between landscape position and sampling period (Table 3.12). Therefore, the differences of position were compared within each period. There were differences during August (periods 10 and 11) and early September (period 12). Wetlands during August and early September had higher abundance than uplands (Fig. 3.11A). Year was also significant (Table 3.12). There was higher Lepidoptera abundance in 2015 ($\bar{x}$ =0.12) than in 2014 ($\bar{x}$ =0.05).

Richness: There was an interaction between landscape position and sampling period (Table 3.12). Richness was highest in late August (sampling period 11), and wetlands had higher abundance than uplands during August and September (Fig. 3.11B). Year was also significant. In the year 2015 ($\bar{x}$ =0.09) there was three times higher Lepidoptera richness than in 2014 ($\bar{x}$ =0.03).

Diversity: There was a three-way interaction between land use, landscape position, and sampling period (Table 3.12). Therefore, to compare differences in diversity, I performed additional two-way ANOVAs within each independent variable. Landscape position and sampling period were compared within the three land use types: cropland, reference, and restored; similarly, land use and sampling period were analyzed within wetlands and uplands, and landscape position and land use were analyzed within each sampling period. Within cropland sites only, wetlands ($\bar{x}$ =0.02) had higher Lepidopteran diversity than uplands ($\bar{x}$ =0.002) (p=0.013). For restored sites only, wetlands ($\bar{x}$ =0.16) had higher diversity than uplands in early August (p=0.010). In early September, wetlands ($\bar{x}$ =0.03) had higher diversity than uplands ($\bar{x}$ =0.000, p=0.095). Year was also significant (Table 3.12). Diversity was higher in 2015 ($\bar{x}$ =0.016) than 2014 ($\bar{x}$ =0.002).

DISCUSSION

Overall Pollinators Collected

Reference and restored uplands had higher pollinator abundance than all wetlands and crop uplands in the trap collections. High abundance in reference and restored uplands was primarily driven by the large number of bees collected in vane traps. Bees comprised almost 80% of the trap collections (Park *et al.*, 2017), and they were found in higher abundance in reference and restored uplands than in wetlands or crop uplands. This is most likely due to the vane traps in reference and restored uplands being in close proximity to suitable nesting habitat within the grasslands. Species richness and diversity of pollinators in trap collections were also higher in restored and reference uplands than in crop uplands and most wetlands—the exception being crop wetlands, which had similar richness and diversity to restored and reference uplands. This suggests that grassland uplands contain more pollinators than wetlands. However, wetlands contain more pollinators than uplands when the surrounding catchment is a crop field.

Net collection data showed a higher abundance of pollinators foraging in restored wetlands than in uplands or wetlands in other land uses. Furthermore, restored sites had the highest richness and diversity of foraging pollinators, especially during late summer. Net collections were not as biased towards bees as vane traps, and consequently encompassed a more even distribution among noted pollinating orders (e.g., Diptera and Coleoptera). The higher abundance in restored wetlands is most likely due to the prevalence of forbs available. Restoration practices, such as sediment removal, can promote growth of native annual forbs (Beas *et al.*, 2013). Additionally, the WRP seeks to restore the entire watershed, not solely the wetland (USDA, 2009). Therefore, the restoration and diverse seed mixtures in the upland may facilitate more diversity in foraging pollinators within the entire watershed. In an agricultural matrix, natural habitat is often restricted to relatively small areas, however, they are important to the overall species richness for a landscape (Hendricks *et al*., 2007). The landscape heterogeneity provided by restored and reference sites versus the cropland inherently allowed a greater diversity of pollinators.

These results encompassed hundreds of different species— many of them not pollinators and all of which have different life histories and habitat requirements. Consequently, they respond to landscape structure and land use intensity differently (Hendricks *et al*., 2007). Therefore, it is important that we focus on each pollinating order individually to observe how they respond in the landscape.

Hymenoptera

Hymenoptera, primarily bees, comprised almost 80% of insects collected with blue vane traps, and therefore were the largest driver of trap results. Reference and restored uplands had the highest abundance, but not statistically higher than wetlands. All wetlands, no matter the land use, had similar abundance, richness, and diversity in trap collections; suggesting that surrounding land use does not appear to affect use of those wetlands by bees. Based on trap data, reference and restored uplands had higher species richness than wetlands and crop fields. Therefore, although wetlands in all land uses have similar abundances of bees, grasslands may be providing additional resources (i.e., nesting habitat) for a wider array of bee species that are not found in wetlands. However, traps may attract bees that nest in the uplands, thereby causing a sampling bias by intercepting them before they have the opportunity to forage elsewhere.

Results from net captures suggest that bees utilize wetlands more than uplands for forage. Bees were found foraging in wetlands more than uplands during July and August. However, in September, there is a switch to foraging in the uplands. The abundance in wetlands during mid-summer could be due to the prevalence of smartweed (*Polygonum* spp. and *Persicaria* spp.) and plains coreopsis (*Coreopsis tinctoria*) available. The shift to upland use may be to take advantage late season forbs (e.g. goldenrods [*Solidago* spp. and sunflowers [*Helianthus* spp.]) blooming in the watershed during late summer (Chapter 4).

There was temporal variation in the year sampled and time of the season sampled. Of the 86,314 bees collected with traps, 68% were in 2014. I cannot be sure what caused this change in insects collected, as there are many factors that can contribute (e.g., natural population dynamics, pathogens, weather). Some playas that had received relatively low amounts of water in 2014 had been flooded to nearly two meters in early summer 2015 and lacked vegetation for part of the season. Another explanation could be that we over sampled by setting traps out twice a month instead of the more commonly used protocol of once a month (Stephen & Rao, 2005; Kimoto *et al.*, 2012; Geroff *et al.*, 2014), but we feel that this is unlikely over annual periods. As expected, there was also great temporal variation within the sampling season. Sampling began the first week of April when frosts are still common. All metrics of Hymenoptera were consistently low through May and again in October. Abundance and richness were highest in July through September.

The use of blue vane traps is most likely sufficient for collecting a more complete representation of the local bee taxa. The traps collected mostly Hymenopterans; 98% of which were bees, most likely due to the noted attraction bees have to blue vane traps (Stephen & Rao, 2007). Additionally, traps were set out for a 24-hour period and therefore were able to capture bee species that forage during different parts of the day. Net collections may be more useful in providing habitat and foraging information. However, the limited time and space sampled influences the number of species captured. Furthermore, the analysis of Hymenoptera families indicate that the individuals caught within families were not independent of sampling method. Some families had greater representation in nets, others had greater numbers in traps. My recommendation for sampling bees would be to use blue vane traps at each site once a month to obtain a representation of the bee community in addition to sampling with targeted net collections every two weeks to determine foraging use.

Bees utilized wetlands for food and water resources, but uplands are also important for forage and nesting habitat. Wild bees provide for their young by building brood cells and providing pollen and nectar for food. Consequently, female bees require floral and nesting resources within range of the flight distance from their nest (Westrich, 1996; James & Pitts-Singer, 2008). Playa wetland ecosystems provide these necessary habitat requirements if there is a prairie upland available such as in reference and restored sites. Conversely, although crop wetlands provide food resources, the lack of nesting habitat in the uplands may cause these sites to function as population sinks (Jauker *et al*., 2009).

While reference and restored sites provided habitat for a diverse community of bees, the concern for future management is determining if populations are sustainable. Bees need large areas of natural areas that contain abundant flowers to provide pollen and nectar throughout the flight season (Hatfield *et al*., 2012). Bees are considered central habitat foragers and exhibit distance decay (Jauker *et al*., 2009). Therefore, as distance increases from the nest site there is a steep decline in bee abundance and richness. Consequently, linear corridors attempting to connect isolated populations can be ineffective (Osborne *et al*., 2008; Jauker *et al.*, 2009). The amount of area needed to promote a diverse bee community is difficult to determine given the wide array of life histories and requirements for different bee species. However, bumble bees can be used as an indicator species in determining habitat requirements because they are sensitive to fragmentation and have longer flight distances than most wild bees (therefore requiring more habitat) (Biesmeijer *et al*., 2006; Zurbuchen *et al.*, 2010; Hatfield *et al.*, 2012). Hatfield *et al.* (2012) and Hoffman Black *et al*. (2011) provided bumble bee management guidelines in grassland ecosystems that can be applied to prairie catchments in the RWB. Both focused on providing flowers for forage, nesting habitat, and overwintering sites. These guidelines stress that management techniques such as mowing, fire, and grazing should not be used on more than a third of a site, and preferably not conducted during the growing season (Hoffman Black *et al*., 2011; Hatfield *et al*., 2012).

Bumble bees and most solitary bees that nest near or below the surface in abandoned rodent holes, grass tussocks, empty rock or wood cavities. Therefore, to protect burrowing bees, near-surface or subsurface disturbance must be limited (Westrich, 1996; Hatfield *et al.*, 2012). To protect nesting bees, managers should keep vegetation management tools such as mowing, fire, or grazing at a low intensity (i.e. don't mow below a foot of vegetation, avoid high intensity fires, and graze for short periods of time).

For any technique, it is imperative that there are still large patches left for animals to seek refuge and eventually recolonize the treated area (Hoffman Black *et al.*, 2011; Hatfield *et al.*, 2012).

Diptera

Although flies only comprised 12% of the trap data, they had the most individuals in net collections (32%). The largest Dipteran family was Syrphidae, or hoverflies— often a Hymenoptera mimicker and an efficient pollinator in temperate zones (Wilmer, 2011c). In trap collections, flies had higher abundance in wetlands than in uplands, most likely due to many genera depositing eggs in water (Gilbert, 1986). This was also observed in net collections, especially during mid-summer. Larvae from genera such as *Eristalis* and *Helophilus* filter food from stagnant water that contain decomposing materials (Gilbert, 1986). Mature larvae leave the water and pupate below the soil surface. When the adults emerge, they feed on pollen to obtain nutrients needed to develop their reproductive system (Gilbert, 1986).

Both net and trap abundance, richness, and diversity varied throughout the season. However, wetlands almost always had higher abundance of flies than uplands. Abundance and richness peaked in May/early June, declined in summer, and then increased again in September. Syrphids annually produce two or three generations (Gilbert, 1986). The peaks in abundance and richness may be due to generations of larvae hatching in late spring and fall when playas typically have more water present. The increase could also be due to different species emerging at various times throughout the season.

Dipterans utilized all land uses, not just those with grassland watersheds. Restored sites had higher Dipteran abundance than crop and reference sites in trap collections during in early summer, but lower abundance than crop sites in late September. Restored sites also had higher abundance and richness in net collections during mid-summer (possibly because of water or food availability) than crop and reference sites, which rarely differed from one another.

Flies are not as sensitive as bees to fragmentation and disturbance (Rader *et al*., 2016). Flies, such as syrphids, serve as important pollinators in heavily disturbed areas due to their ability to adapt to environmental change and ability to use a wider range of resources in modified landscapes (Rader *et al*., 2016). Syrphids are often one of the most frequent flower visitors, second to bees (Larson, 2008). Syrphids are efficient at pollination because they are covered in hair, sometimes branched like bees, they are specifically equipped to feed on flowers, and they rely almost entirely on a diet of nectar for food (Wilmer, 2011c). However, syrphids and bees differ in their life history characteristics and foraging habits. Unlike bees, hoverflies are not central habitat foragers and they do not care for their young. After they deposit their eggs, they have no need to return to that site and can move linearly through a landscape (Jauker *et al.*, 2009). Consequently, field margins and roadside ditches can serve as corridors between patches of natural habitat, such as playas, that are necessary for reproduction. Hoverfly larvae need rotting organic matter in wetlands that can be provided by playas. They can even benefit from cattle manure that may be present in many RWB wetlands (Jauker *et al.*, 2009). Although playas, even when surrounded by crop fields, can provide reproductive sites for hoverflies, pollen and nectar producing forbs are still required to complete their life cycle. Therefore, promoting forb production by removing sediment from the wetland and planting a forb-rich buffer strip can assist resilient pollinators, such as hoverflies, to persist in an agriculturally dominated landscape.

Although relative abundance of Dipterans was low in trap collections, 86% of flies that were collected in traps were from two families (Syrphidae and Anthomyiidae) that are documented as pollinators (Wilmer, 2011c). Blue vane traps may be efficient in collecting pollinating flies if there was also an interested in capturing bees—which combined, totaled 91% of insects collected in traps. If one was only interested in sampling pollinating flies, net collections would be the more efficient method. Syrphidae comprised 85% of Dipteran net collections. Less than 10 individuals of Anthomyiidae were captured using nets, even though they were the second most abundant fly in the trap collections. Anthomyiidae are noted pollinators (Wilmer, 2011c), therefore we would expect to find them in the net collections. The low abundance of Anthomyiidae in net collections may be due to their small size and the inability to see or capture them.

Coleoptera

Of the 39 beetle families, Cantharidae- primarily the genus *Chauliognathus*- made up the largest proportion of beetles in traps (31%) and net collections (74%). This is most likely because *Chauliognathus,* or soldier beetles, are noted pollinators and rely on pollen and nectar for part of their life cycle (Wilmer, 2011d). The effect of land use and landscape position on Coleoptera abundance varied throughout the season. For traps, there tended to be more beetles collected in the wetlands than uplands in the early season. Later, during August and September, crop wetlands had higher abundance than any land use/position combination. June had the highest beetle species richness and diversity over the growing season, with cropland watersheds having the highest richness among all land uses. It is not clear what is driving differences in abundance, richness, and diversity due to the variety of beetle species, all with various life histories.

Multiple beetle species found in our study eat pollen, however, many eat and destroy the flower without assisting pollination (Triplehorn & Johnson, 2005). Furthermore, traps collected many beetle families that do not utilize pollen or nectar. For example, the second most abundant family in our study, Carabidae, are not considered flower visiting beetles but instead are primarily known as nocturnal predators (Triplehorn & Johnson, 2005). Only two carabids were captured with nets, and the carabids that were collected in vane traps were probably there to feed on the insects caught inside. Therefore, vane traps are likely not efficient in sampling for pollinating beetles. Coleopterans only comprised 7% of the trap collections, although they were the second most abundant order in net collections. Therefore, collections with nets are recommended to sample pollinating beetles.

Net captures had different results than vane traps. For example, whereas traps collections had the highest richness in June, no beetles were collected with nets before July. Additionally, crops had the lowest numbers across all metrics in net surveys, which is different than trap collections. Restored and reference uplands had the highest abundance of Coleopterans caught with nets among all land uses and landscape positions. Wetlands among all land uses had similar abundance, and wetland abundance was higher than uplands when in croplands—likely because there are no flowers for beetles to feed on in crop uplands.

Net captures show beetle abundance and richness were highest during late August, and reference and restored sites had higher abundance than crop sites. Additionally, wetlands among all land uses have higher richness in late August than uplands. Net data show a higher diversity of beetles foraging in wetlands on annual forbs such as coreopsis, numerous smartweed species, and various sunflowers. However, in early September, uplands had higher abundance and richness than wetlands. Furthermore, during the same time period, reference had higher abundance than restored and crop sites. This was driven by two genera of beetles— *Chauliognathus* (soldier beetles) and *Diabrotica* (leaf beetles)—which were almost exclusively the only beetles collected with nets during early September. Both genera eat pollen from Asteraceae, and were almost always found in uplands feeding on sunflowers or goldenrods during early September (Wilmer, 2011d). *Chauliognathus* and *Diabrotica* were also abundant in August. However, August had a higher variety of plant species and a larger, more diverse beetle community. As wetland plants begin to senesce, common pollinating beetles may shift foraging to uplands for late season forbs.

Beetles are not generally regarded as efficient pollinators and can possibly be destructive (Wilmer, 2011d). However, beetles are noted for their fidelity to the same flower, therefore when they do feed there is a greater chance of passing pollen on to the same species. For example, many flowering plants, primarily in the tropics, have evolved to be pollinated primarily by beetles (Bernhardt, 2000; Wilmer, 2011d). With concern over losing pollination services as the landscape becomes more fragmented and converted from natural habitat, providing any pollination service is beneficial.

Lepidoptera

Moths and butterflies comprised less than 2% of total insects collected, and over a quarter of them could not be identified past order due to damage. Of the Lepidopterans that were collected with traps, almost half were from Noctuidae— which mostly consists of agricultural pests and are not considered pollinators (Triplehorn & Johnson, 2005). In July and August, Lepidopterans had higher abundance in restored wetlands than all other land use/position combinations. Additionally, reference and restored sites had higher Lepidoptera richness and diversity than cultivated sites.

Because few Lepidopterans were found in vane traps and many were pests, net collections are better sampling method for Lepidopterans. It is possible that pollinating butterflies found in the net collections were either not attracted to the blue vane traps or were too large to fit inside. In addition, blue vane traps were not designed for moths and butterflies (Stephen & Rao, 2005; Stephen & Rao, 2007). Furthermore, the majority of moths are crepuscular or nocturnal, whereas butterflies are diurnal thus have a higher probability of being captured in nets (which took place mid-day) (Wilmer, 2011e). Pieridae, specifically pollinating sulphur butterflies, were the largest group of Lepidopterans collected with nets. Land use did not have an effect on Lepidopteran abundance, richness or diversity; however, landscape position did effect abundance and richness. In June and early July, uplands had slightly more Lepidopterans than wetlands. Conversely, during August and September, when Lepidopteran abundance and richness were highest, wetlands had more species and individuals than uplands. In August, there were some individuals foraging on a number of different plants in the upland. However, it was the availability of flowering plants prevalent in wetlands that allowed for high abundance and species richness.

CONCLUSION AND RECOMMENDATIONS

Pollinating insects are using playa ecosystems, including grassland watersheds, for habitat resources in an agricultural matrix. Net collections show that bees are foraged in wetlands, especially those that had undergone restoration. However, trap data showed bees used restored and reference uplands over wetlands, most likely due to nesting habitat availability. Additionally, bees switched from primarily foraging in wetlands during mid-summer to foraging in uplands in September. Other taxa, such as flies, exhibited higher abundance in wetlands rather than uplands. Flies are not as sensitive to fragmentation and utilized crop sites as well as restored and reference sites. Trap data for beetles showed similar results to flies. However, many species of beetles captured do not pollinate. Targeted net collections of pollinating beetles showed that they preferred restored sites, and utilized the restored uplands and wetlands at different times of the season. Trap data also collected many Lepidopterans that are not pollinators. Net data showed that pollinating moths and butterflies utilized wetlands for forage more than the uplands, but land use did not have an effect on Lepidopteran forage.

Future monitoring efforts should focus on bee populations as they are considered the most valuable pollinator and are sensitive to environmental degradation. Blue vane traps are useful to acquire a representation of local bee fauna; however, they attract a large number of bees and should be used conservatively. A single trap placed at each site per month of the growing season should be sufficient to provide community composition information and turnover throughout the year. If other pollinating orders are of interest, such as flies or butterflies, insect nets can be used to sample. Additionally, net collections can be used to obtain foraging data for bees and other pollinators. Over sampling is not generally a concern with net collections. If resources allow, sampling can be done on multiple transects twice a month for each site. For both capture methods, precaution should be taken to sample on days of no precipitation and low winds.

Pollinators encompass many different taxa, all with different life histories and habitat requirements. Therefore, taxa use the landscape differently. Playa ecosystems in the RWB are the primary remaining natural habitats available to provide necessary resources to pollinators. However, they are a small fraction of the landscape—approximately 0.4% (Walker 2016). The Wetlands Reserve Program has been critical in protecting and enhancing the few remaining playas in the RWB. Restoration practices for playas such as sediment removal are important for restoring the natural hydroperiod, removing invasive species, and allowing the native seed bank to establish, thus providing more forage for pollinators. Furthermore, restoring the watershed appears to have been helpful to pollinators, especially for bees who need grasslands for nest sites, nest material, and overwintering habitat (Westrich, 1996).

In the RWB, cattle are often used to manipulate vegetation in uplands and playas, and if used appropriately, it can be beneficial in controlling invasive species and maintaining a forb-dominated plant community (Hoffman Black et al., 2011). However, when utilizing grazing, it is recommended to graze no more than a third of the habitat at a low-medium level intensity for a short time (preferably in the fall), followed by a long recovery period

(Hoffman Black et al., 2011). This is consistent with the recommended wildlife management for playa wetlands, where over grazing can reduce flora biodiversity, increase undesirable species, and increase erosion of the watershed (Guthery & Stormer, 1984; Haukos & Smith, 1996).

In the agricultural matrix of the RWB, playa wetlands and adjacent uplands are providing important habitat (i.e. food, nesting resources, and overwintering sites) for bees. In order to maintain the ecosystem service of bee pollination, it is critical to promote programs such as the WRP which are restoring wetlands through watershed development, diverse forb plantings, and enhancement of wetland seed banks through sediment removal. Playas void of buffer strips are beneficial for habitat generalists such as hoverflies, but lack the necessary resources to sustain bee populations. Consequently, wetlands located directly within row-crop agriculture may actually be population sinks for bees. Continuing to protect and enhance the entire playa ecosystem, including the watershed, is essential in promoting pollination services and protecting the full diversity of pollinators in the RWB.

LITERATURE CITED

Aizen, M. A., & Feinsinger, P. (1994). Habitat fragmentation, native insect pollinators, and feral honey bees in Argentine 'Chaco Serrano'. *Ecological applications*, *4*(2), 378—392.

Beas, B. J., Smith, L. M., LaGrange, T. G., & Stutheit, R. (2013). Effects of sediment removal on vegetation communities in Rainwater Basin playa wetlands. *Journal of environmental management*, *128*, 371—379.

Belden, J. B., Hanson, B. R., McMurry, S. T., Smith, L. M., & Haukos, D. A. (2012). Assessment of the effects of farming and conservation programs on pesticide deposition in high plains wetlands. Environmental science & technology, *46*(6), 3424—3432.

Bernhardt, P. (2000). Convergent evolution and adaptive radiation of beetle-pollinated angiosperms. In *Pollen and Pollination* (pp. 293—320).

Bolen, E. G., Smith, L. M., & Schramm, H. L. (1989). Playa lakes: prairie wetlands of the Southern High Plains. *BioScience*, *39*(9), 615—623.

Biesmeijer, J. C., Roberts, S. P., Reemer, M., Ohlemüller, R., Edwards, M., Peeters, T., ... & Settele, J. (2006). Parallel declines in pollinators and insect-pollinated plants in Britain and the Netherlands. *Science*, *313*(5785), 351—354.

Cariveau, A. B., Pavlacky Jr, D. C., Bishop, A. A., & LaGrange, T. G. (2011). Effects of surrounding land use on playa inundation following intense rainfall. *Wetlands*, *31*(1), 65—73.

Daniel, D. W., Smith, L. M., & McMurry, S. T. (2015). Land use effects on sedimentation and water storage volume in playas of the rainwater basin of Nebraska. *Land Use Policy*, *42*, 426—431.

Delaplane, K. S., & Mayer, D. F. 2000. *Crop pollination by bees*. CABI Publishing.

Free, J.B. 1993a. *Insect pollination of crops*. (No. Ed. 2). Academic Press.

Geroff, R. K., Gibbs, J., & McCravy, K. W. (2014). Assessing bee (Hymenoptera: Apoidea) diversity of an Illinois restored tallgrass prairie: methodology and conservation considerations. *Journal of insect conservation*, *18*(5), 951—964.

Gilbert, F.S. 1986. *Hoverflies*. Cambridge University Press.

Gleason, R. A., Euliss, N. H., Tangen, B. A., Laubhan, M. K., & Browne, B. A. (2011). USDA conservation program and practice effects on wetland ecosystem services in the Prairie Pothole Region. *Ecological Applications*, *21*(3), S65—S81.

Grosse, R. Re: “Number and ownership of Rainwater Basin wetlands”. Message to Cynthia Park. 13 August 2014. E-mail. Rainwater Basin Joint Ventures.

Guthery, F. S., & Stormer, F. A. (1984). Wildlife management scenarios for playa vegetation. *Wildlife Society Bulletin (1973-2006)*, *12*(3), 227—234.

Hatfield, R., Jepsen, S., Mader, E., Black, S. H., & Shephard, M. (2012). Conserving Bumble Bees: Guidelines for Creating and Managing Habitat for Americas Declining Pollinators. The Xerces Society for Invertebrate Corporation.

Haukos, D. A., & Smith, L. M. (2003). Past and future impacts of wetland regulations on playa ecology in the Southern Great Plains. *Wetlands*, *23*(3), 577-589.

Haukos, D. A., & Smith, L. M. (1994). The importance of playa wetlands to biodiversity of the Southern High Plains. *Landscape and Urban Planning*, *28*(1), 83-98.

Hoffman Black, S. H., Shepherd, M., & Vaughan, M. (2011). Rangeland management for pollinators. *Rangelands*, *33*(3), 9-13.

James, R., & Pitts-Singer, T. L. (2008). *Bee pollination in agricultural ecosystems*. Oxford University Press.

Jauker, F., Diekötter, T., Schwarzbach, F., & Wolters, V. (2009). Pollinator dispersal in an agricultural matrix: opposing responses of wild bees and hoverflies to landscape structure and distance from main habitat. *Landscape Ecology*, *24*(4), 547—555.

Kearns, C. A., Inouye, D. W., & Waser, N. M. (1998). Endangered mutualisms: the conservation of plant-pollinator interactions. *Annual review of ecology and systematics*, *29*(1), 83—112.

Kimoto, C., DeBano, S. J., Thorp, R. W., Rao, S., & Stephen, W. P. (2012). Investigating temporal patterns of a native bee community in a remnant North American bunchgrass prairie using blue vane traps. *Journal of Insect Science*, *12*(108), 1—23.

Kremen, C., Williams, N. M., & Thorp, R. W. (2002). Crop pollination from native bees at risk from agricultural intensification. *Proceedings of the National Academy of Sciences*, *99*(26), 16812—16816.

Kreyer, D., Oed, A., Walther-Hellwig, K., & Frankl, R. (2004). Are forests potential landscape barriers for foraging bumblebees? Landscape scale experiments with Bombus terrestris and Bombus pascuorum (Hymenoptera, Apidae). *Biological Conservation*, *116*(1), 111—118.

Kuchler, A.W. 1964. Potential natural vegetation of the conterminous United States. American Geographical Society.

LaGrange, T. (2005). *Guide to Nebraska's wetlands and their conservation needs*. Nebraska Game and Parks Commission.

LaGrange, T. G., Stutheit, R., Gilbert, M., Shurtliff, D., & Whited, P. M. (2011). Sedimentation of Nebraska’s playa wetlands: a review of current knowledge and issues. Nebraska Game and Parks Commission.

Larson, D.L. 2008. Invasive plants and pollinator interactions. Endangered Species Bulletin, *25*(3), 46—48.

Luo, H. R., Smith, L. M., Allen, B. L., & Haukos, D. A. (1997). Effects of sedimentation on playa wetland volume. *Ecological Applications*, *7*(1), 247—252.

Michener, C.D. (2007) *The bees of the world, 2nd Edition*. The Johns Hopkins University Press, Baltimore, MD, 953 pp.

National Research Council. (2007). *Status of pollinators in North America*. National Academies Press.

Natural Resource Conservation Service (NRCS). (2008a). At a Glance: Wetlands Reserve Program. United States Department of Agriculture.

Natural Resource Conservation Service (NRCS). (2008b). The Wetlands Reserve Program Supports Migrating Waterfowl in Nebraska's Rainwater Basin Region. United States Department of Agriculture.

O’Connell, J. L., Johnson, L. A., Beas, B. J., Smith, L. M., McMurry, S. T., & Haukos, D. A. (2013). Predicting dispersal-limitation in plants: optimizing planting decisions for isolated wetland restoration in agricultural landscapes. *Biological conservation*, *159*, 343—354.

Park, C.N, Overall, L.M., Smith, L.M., LaGrange, T., McMurry, S. (2017). Melittofauna and Other Potential Pollinators in Wetland and Uplands in South Central Nebraska (Insecta: Apoidea). *Zootaxa*, *4242*(2), 255—280.

Potts, S. G., Biesmeijer, J. C., Kremen, C., Neumann, P., Schweiger, O., & Kunin, W. E. (2010). Global pollinator declines: trends, impacts and drivers. *Trends in ecology & evolution*, *25*(6), 345—353.

Rader, R., Bartomeus, I., Garibaldi, L. A., Garratt, M. P., Howlett, B. G., Winfree, R., ... & Bommarco, R. (2016). Non-bee insects are important contributors to global crop pollination. *Proceedings of the National Academy of Sciences*, *113*(1), 146—151.

Samson, F., & Knopf, F. (1994). Prairie conservation in north america. *BioScience*, *44*(6), 418—421.

Skagen, S., Melcher, K., & Haukos, C. (2008). Reducing sedimentation of depressional wetlands in agricultural landscapes. *Wetlands, 28*(3), 594-604.

Smith, L.M (2003). *Playas of the Great Plains*. Austin, TX, University of Texas Press.

Smith, L. M., & Haukos, D. A. (2002). Floral diversity in relation to playa wetland area and watershed disturbance. *Conservation Biology*, *16*(4), 964—974.

Smith, L. M., Haukos, D. A., McMurry, S. T., LaGrange, T., & Willis, D. (2011). Ecosystem services provided by playas in the High Plains: potential influences of USDA conservation programs. *Ecological Applications*, *21*(3), S82—S92.

Steffan-Dewenter, I., & Tscharntke, T. (1999). Effects of habitat isolation on pollinator communities and seed set. *Oecologia*, *121*(3), 432—440.

Stephen, W. P., & Rao, S. (2005). Unscented color traps for non-Apis bees (Hymenoptera: Apiformes). *Journal of the Kansas Entomological Society*, *78*(4), 373-380.

Stephen, W. P., & Rao, S. (2007). Sampling native bees in proximity to a highly competitive food resource. *Journal of the Kansas Entomological Society*, *80*(4), 369-376.

Stokstad, E. (2007). The case of the empty hives. *Science*, *316*(5827), 970-972.

Stutheit, R. G., Gilbert, M. C., Whited, P. W., & Lawrence, K. L. (2004). *A regional guidebook for applying the hydrogeomorphic approach to assessing wetland functions of rainwater basin depressional wetlands in Nebraska*. Corps of Engineers.

Triplehorn, C. A. J., Borror, N. F., Triplehorn, D. J., & Johnson, N. F. (2005). *Borror and DeLong's Introduction to the study of insects*. (No. Ed. 7). Thompson Brooks/Cole.

Tsai, J. S., Venne, L. S., McMurry, S. T., & Smith, L. M. (2007). Influences of land use and wetland characteristics on water loss rates and hydroperiods of playas in the Southern High Plains, USA. *Wetlands*, *27*(3), 683—692.

United States Department of Agriculture (USDA). (2009). Wetland Reserve Program: Final Programmatic Environmental Assessment. Natural Resource Conservation Service.

U.S. Fish and Wildlife Service (USFWS). 2007. Comprehensive Conservation Plan, Rainwater Basin Wetland Management District. Department of the Interior. Kearney, NE

Walker, Nathan. Re: "Current Acreage Enrolled in WRP in the Rainwater Basin." Message to Cynthia Park. 16 Feb. 2016. E-mail. Natural Resource Conservation Service. Lincoln, NE.

Webb, E. B., Smith, L. M., Vrtiska, M. P., & Lagrange, T. G. (2010). Effects of local and landscape variables on wetland bird habitat use during migration through the Rainwater Basin. *Journal of Wildlife Management*, *74*(1), 109-119.

Westrich, P. (1996). Habitat requirements of central European bees and the problems of partial habitats. In *Linnean Society symposium series, (18),* 1—16.

Wilmer, P. 2011a. Why pollination is interesting. In: *Pollination and Floral Ecology.* Princeton University Press, Princeton, New Jersey. pp. 3—10

Wilmer, P. 2011b. The biology of pollen. In: *Pollination and Floral Ecology*. Princeton University Press, Princeton, New Jersey. pp. 154—189.

Wilmer, P. 2011c Pollination by flies. In: *Pollination and Floral Ecology*. Princeton University Press, Princeton, New Jersey. pp. 304—321.

Wilmer, P. 2011d. Generalist flowers and generalist visitors. In: *Pollination and Floral Ecology.* Princeton University Press, Princeton, New Jersey. pp. 288—303.

Wilmer, P. 2011e. Pollination by butterflies and moths. In: *Pollination and Floral Ecology*. Princeton University Press, Princeton, New Jersey. pp. 322—336.

Zurbuchen, A., Landert, L., Klaiber, J., Müller, A., Hein, S., & Dorn, S. (2010). Maximum foraging ranges in solitary bees: only few individuals have the capability to cover long foraging distances. *Biological Conservation*, *143*(3), 669—676.

TABLES AND FIGURES

Table 3.1: Dates of sampling periods during 2014 and 2015.

2014 Sampling Dates	**Period**	**2015 Sampling Dates**
March 31 - April 11	1	April 6 - April 17
April 14 - April 25	2	April 20 - May 1
April 28 - May 9	3	May 4 - May 15
May 12 - May 23	4	May 18 - May 29
May 26 - June 6	5	June 1 - June 12
June 9 - June 20	6	June 15 - June 26
June 23 - July 4	7	June 29 - July 10
July 7 - July 18	8	July 13 - July 24
July 21 - August 1	9	July 27 - August 7
August 4 - August 15	10	August 10 - August 21
August 18 - August 29	11	August 24 - Sept 4
Sept 1 - Sept 12	12	Sept 7 - Sept 18
Sept 15 - Sept 26	13	Sept 21 - Oct 2
Sept 29 - October 10	14	Oct 5 - Oct 16

Table 3.2: Overall insect abundance, richness, and diversity collected with blue vane traps in the Rainwater Basin of Nebraska during the growing seasons of 2014 and 2015. ANOVA analyses were used to compare three fixed effects (land use, landscape position, and sampling period) and two random variables (year and site).

	Source	df	F-value	P-value
Abundance	Land use	2	0.58	0.560
	Position	1	0.48	0.487
	Period	13	26.87	0.000
	Year	1	85.93	0.000
	Land use*Position	2	4.19	0.015
	Land use*Period	26	1.21	0.214
	Position*Period	13	0.58	0.873
	Land use*Position*Period	26	0.58	0.955
Richness	Land use	2	1.34	0.261
	Position	1	6.86	0.009
	Period	13	60.20	0.000
	Year	1	270.35	0.000
	Land use*Position	2	4.85	0.008
	Land use*Period	26	1.15	0.275
	Position*Period	13	0.26	0.996
	Land use*Position*Period	26	0.36	0.999
Diversity	Land use	2	3.28	0.038
	Position	1	5.63	0.018
	Period	13	94.29	0.000
	Year	1	160.45	0.000
	Land use*Position	2	2.68	0.069
	Land use*Period	26	1.37	0.100
	Position*Period	13	0.74	0.723
	Land use*Position*Period	26	0.35	0.999

Table 3.3: Hymenoptera abundance, richness, and diversity collected with blue vane traps in the Rainwater Basin of Nebraska during the growing seasons of 2014 and 2015. ANOVA analyses were used to compare three fixed effects (land use, landscape position, and sampling period) and two random variables (year and site).

	Source	df	F-value	P-value
Abundance	Land use	2	0.75	0.464
	Position	1	2.06	0.154
	Period	13	29.03	0.000
	Year	1	84.80	0.000
	Land use*Position	2	4.03	0.018
	Land use*Period	26	1.25	0.209
	Position*Period	13	0.68	0.855
	Land use*Position*Period	26	0.51	0.983
Richness	Land use	2	5.64	0.003
	Position	1	19.30	0.000
	Period	13	94.94	0.000
	Year	1	257.26	0.000
	Land use*Position	2	7.60	0.001
	Land use*Period	26	1.00	0.444
	Position*Period	13	0.52	0.908
	Land use*Position*Period	26	0.52	0.981
Diversity	Land use	2	10.87	0.000
	Position	1	18.75	0.000
	Period	13	135.96	0.000
	Year	1	177.29	0.000
	Land use*Position	2	5.84	0.003
	Land use*Period	26	1.04	0.407
	Position*Period	13	0.97	0.477
	Land use*Position*Period	26	0.64	0.916

Table 3.4: Diptera abundance, richness, and diversity collected with blue vane traps in the Rainwater Basin of Nebraska during the growing seasons of 2014 and 2015. ANOVA analyses were used to compare three fixed effects (land use, landscape position, and sampling period) and two random variables (year and site).

	Source	df	F-value	P-value
Abundance	Land use	2	0.40	0.668
	Position	1	2.18	0.140
	Period	13	11.78	0.000
	Year	1	0.50	0.479
	Land use*Position	2	2.25	0.106
	Land use*Period	26	1.65	0.022
	Position*Period	13	0.95	0.504
	Land use*Position*Period	26	0.44	0.994
Richness	Land use	2	1.65	0.192
	Position	1	0.15	0.698
	Period	13	25.08	0.000
	Year	1	68.68	0.000
	Land use*Position	2	1.10	0.334
	Land use*Period	26	1.67	0.019
	Position*Period	13	0.96	0.493
	Land use*Position*Period	26	0.49	0.986
Diversity	Land use	2	3.01	0.050
	Position	1	0.12	0.732
	Period	13	19.05	0.000
	Year	1	118.17	0.000
	Land use*Position	2	0.76	0.487
	Land use*Period	26	1.79	0.011
	Position*Period	13	0.58	0.874
	Land use*Position*Period	26	0.58	0.956

Table 3.5: Coleoptera abundance, richness, and diversity collected with blue vane traps in the Rainwater Basin of Nebraska during the growing seasons of 2014 and 2015. ANOVA analyses were used to compare three fixed effects (land use, landscape position, and sampling period) and two random variables (year and site).

	Source	df	F-value	P-value
Abundance	Land use	2	0.92	0.399
	Position	1	3.77	0.052
	Period	13	10.64	0.000
	Year	1	28.53	0.000
	Land use*Position	2	4.41	0.012
	Land use*Period	26	1.18	0.247
	Position*Period	13	0.90	0.557
	Land use*Position*Period	26	1.82	0.007
Richness	Land use	2	0.11	0.900
	Position	1	0.76	0.383
	Period	13	12.62	0.000
	Year	1	148.70	0.000
	Land use*Position	2	2.06	0.128
	Land use*Period	26	1.46	0.065
	Position*Period	13	0.92	0.532
	Land use*Position*Period	26	0.51	0.980
Diversity	Land use	2	1.06	0.347
	Position	1	0.60	0.437
	Period	13	9.14	0.000
	Year	1	145.74	0.000
	Land use*Position	2	0.71	0.493
	Land use*Period	26	1.29	0.152
	Position*Period	13	0.67	0.790
	Land use*Position*Period	26	0.41	0.996

Table 3.6: Lepidoptera abundance, richness, and diversity collected with blue vane traps in the Rainwater Basin of Nebraska during the growing seasons of 2014 and 2015. ANOVA analyses were used to compare three fixed effects (land use, landscape position, and sampling period) and two random variables (year and site).

	Source	df	F-value	P-value
Abundance	Land use	2	3.04	0.025
	Position	1	3.53	0.037
	Period	13	16.48	0.000
	Year	1	19.67	0.000
	Land use*Position	2	3.90	0.010
	Land use*Period	26	1.70	0.003
	Position*Period	13	1.68	0.039
	Land use*Position*Period	26	1.69	0.005
Richness	Land use	2	2.59	0.051
	Position	1	1.08	0.427
	Period	13	27.61	0.000
	Year	1	39.75	0.000
	Land use*Position	2	1.08	0.331
	Land use*Period	26	1.34	0.077
	Position*Period	13	0.46	0.941
	Land use*Position*Period	26	0.56	0.959
Diversity	Land use	2	0.63	0.473
	Position	1	0.39	0.645
	Period	13	16.54	0.000
	Year	1	20.06	0.000
	Land use*Position	2	0.51	0.652
	Land use*Period	26	1.43	0.046
	Position*Period	13	0.24	0.994
	Land use*Position*Period	26	0.95	0.500

Table 3.7: Number of insects collected in the Rainwater Basin during 2014 and 2015 while feeding on specific plants among the three land uses and two landscape positions. Asterisks indicate that species was not observed.

Plant Species	Ag Upland	Ag Wetland	Reference Upland	Reference Wetland	Restored Upland	Restored Wetland
Achillea millefolium	*	*	9	*	2	1
Ambrosia artemisiifolia	*	*	1	*	*	*
Amorpha canescens	*	*	*	1	10	*
Asclepias verticillata	2	*	*	*	*	*
Aster ericoides	*	*	4	*	17	*
Astragalus canadensis	*	*	1	*	*	*
Boltonia asteroides	5	1	*	*	5	39
Carduus nutans	*	1	*	*	3	*
Cirsium altissimum	*	18	2	2	8	*
Cirsium arvense	*	*	*	*	4	1
Convolvulus arvensis	7		11	2	13	*
Coreopsis tinctoria	3	24	4	15	20	190
Dalea candida	*	*	2	*	*	*
Dalea purpurea	*	*	2	2	1	1
Erigeron strigosus	*	*	15	*	*	19
Helianthus annuus	*	27	47	37	7	63
Helianthus maximiliani	*	*	21	3	6	2
Helianthus pauciflorus	*	*	*	*	2	*
Helianthus rigida	*	*	*	*	48	*
Lactuca canadensis	*	2	*	*	*	*
Lespedeza capitata	*	*	1	*	5	*
Leucanthemum superbum	*	*	*	*	1	*
Medicago sativa	*	*	*	*	1	*
Melilotus officinalis	*	*	*	*	2	*
Mimosa microphylla	*	*	*	*	3	*
Monarda fistulose	*	*	*	*	6	*
Nepeta cataria	*	*	1	*	*	*
Persicaria hydropiper	*	4	*	11	*	3
Persicaria pennsylvanica	*	40	*	64	*	31
Polygonum bicorne	*	91	*	52	21	114
Polygonum coccineum	1	47	*	63	*	51
Polygonum lapathifolia		14	*	13	*	14
Ratibida columnifera	*	*	*	*	1	*
Ratibida pinnata	*	*	7	*	*	*
Rosa arkansas	*	*	2	*	11	*

Plant Species	Ag Upland	Ag Wetland	Reference Upland	Reference Wetland	Restored Upland	Restored Wetland
Rudbeckia hirta	*	*	*	*	8	*
Sagitaria latifolia	*	*	*	*	*	1
Silphium laciniatum	*	*	1	*	9	*
Solidago canadensis	*	*	121		36	*
Solidago gigantea	*	*	*	*	4	*
Taraxacum officinale	1	1	2	*	5	*
Trifolium pratense	*	*	11	*	3	11
Trifolium repens	*	*	2	*	*	*
Verbena stricta	*	*	28	*	*	*
Vernonia baldwinii	*	*	*	2	*	*

Table 3.8: Overall insect abundance, richness, and diversity collected with targeted net sampling in the Rainwater Basin of Nebraska during the growing seasons of 2014 and 2015. ANOVA analyses were used to compare three fixed effects (land use, landscape position, and sampling period) and two random variables (year and site).

	Source	df	F-value	P-value
Abundance	Land use	2	13.44	0.000
	Position	1	11.83	0.001
	Period	13	20.96	0.000
	Year	1	0.10	0.757
	Land use*Position	2	3.49	0.031
	Land use*Period	26	2.22	0.000
	Position*Period	13	7.01	0.000
	Land use*Position*Period	26	1.30	0.142
Richness	Land use	2	16.96	0.000
	Position	1	27.53	0.000
	Period	13	26.88	0.000
	Year	1	0.00	0.948
	Land use*Position	2	1.82	0.162
	Land use*Period	26	1.60	0.020
	Position*Period	13	13.70	0.000
	Land use*Position*Period	26	1.06	0.129
Diversity	Land use	2	16.18	0.000
	Position	1	25.72	0.000
	Period	13	24.11	0.000
	Year	1	0.04	0.559
	Land use*Position	2	1.22	0.295
	Land use*Period	26	1.52	0.047
	Position*Period	13	12.35	0.000
	Land use*Position*Period	26	1.16	0.267

Table 3.9: Hymenoptera abundance, richness, and diversity collected with targeted net sampling in the Rainwater Basin of Nebraska during the growing seasons of 2014 and 2015. ANOVA analyses were used to compare three fixed effects (land use, landscape position, and sampling period) and two random variables (year and site).

	Source	df	F-value	P-value
Abundance	Land use	2	8.76	0.000
	Position	1	8.77	0.003
	Period	13	9.32	0.000
	Year	1	0.20	0.653
	Land use*Position	2	2.29	0.101
	Land use*Period	26	2.24	0.000
	Position*Period	13	5.11	0.000
	Land use*Position*Period	26	1.86	0.006
Richness	Land use	2	13.44	0.000
	Position	1	11.35	0.001
	Period	13	16.96	0.000
	Year	1	1.32	0.251
	Land use*Position	2	0.20	0.817
	Land use*Period	26	1.88	0.005
	Position*Period	13	7.77	0.000
	Land use*Position*Period	26	1.60	0.029
Diversity	Land use	2	10.52	0.000
	Position	1	8.72	0.003
	Period	13	11.70	0.000
	Year	1	3.33	0.068
	Land use*Position	2	0.04	0.958
	Land use*Period	26	1.50	0.051
	Position*Period	13	7.06	0.000
	Land use*Position*Period	26	1.84	0.006

Table 3.10: Diptera abundance, richness, and diversity collected with targeted net sampling in the Rainwater Basin of Nebraska during the growing seasons of 2014 and 2015. ANOVA analyses were used to compare three fixed effects (land use, landscape position, and sampling period) and two random variables (year and site).

	Source	df	F-value	P-value
Abundance	Land use	2	5.09	0.006
	Position	1	25.92	0.000
	Period	13	5.63	0.000
	Year	1	0.58	0.448
	Land use*Position	2	0.99	0.372
	Land use*Period	26	1.71	0.015
	Position*Period	13	4.96	0.000
	Land use*Position*Period	26	0.75	0.811
Richness	Land use	2	6.92	0.002
	Position	1	31.49	0.000
	Period	13	9.93	0.000
	Year	1	0.73	0.394
	Land use*Position	2	0.69	0.503
	Land use*Period	26	1.47	0.059
	Position*Period	13	9.94	0.000
	Land use*Position*Period	26	0.82	0.729
Diversity	Land use	2	5.33	0.005
	Position	1	21.24	0.000
	Period	13	6.06	0.000
	Year	1	1.39	0.239
	Land use*Position	2	1.54	0.215
	Land use*Period	26	1.27	0.167
	Position*Period	13	6.55	0.000
	Land use*Position*Period	26	0.95	0.537

Table 3.11: Coleoptera abundance, richness, and diversity collected with targeted net sampling in the Rainwater Basin of Nebraska during the growing seasons of 2014 and 2015. ANOVA analyses were used to compare three fixed effects (land use, landscape position, and sampling period) and two random variables (year and site).

	Source	df	F-value	P-value
Abundance	Land use	2	4.95	0.007
	Position	1	1.15	0.284
	Period	13	11.57	0.000
	Year	1	2.89	0.089
	Land use*Position	2	3.09	0.046
	Land use*Period	26	2.38	0.000
	Position*Period	13	1.82	0.035
	Land use*Position*Period	26	1.36	0.108
Richness	Land use	2	10.01	0.000
	Position	1	1.04	0.307
	Period	13	22.79	0.000
	Year	1	2.21	0.137
	Land use*Position	2	2.30	0.101
	Land use*Period	26	2.42	0.000
	Position*Period	13	5.25	0.000
	Land use*Position*Period	26	1.05	0.390
Diversity	Land use	2	4.45	0.012
	Position	1	0.26	0.609
	Period	13	11.18	0.000
	Year	1	2.56	0.110
	Land use*Position	2	1.46	0.233
	Land use*Period	26	1.77	0.010
	Position*Period	13	3.56	0.000
	Land use*Position*Period	26	0.85	0.681

Table 3.12: Lepidoptera abundance, richness, and diversity collected with targeted net sampling in the Rainwater Basin of Nebraska during the growing seasons of 2014 and 2015. ANOVA analyses were used to compare three fixed effects (land use, landscape position, and sampling period) and two random variables (year and site).

	Source	df	F-value	P-value
Abundance	Land use	2	0.28	0.755
	Position	1	3.58	0.059
	Period	13	6.13	0.000
	Year	1	7.86	0.005
	Land use*Position	2	1.35	0.261
	Land use*Period	26	1.03	0.424
	Position*Period	13	2.18	0.009
	Land use*Position*Period	26	1.28	0.157
Richness	Land use	2	0.53	0.590
	Position	1	3.47	0.063
	Period	13	6.70	0.000
	Year	1	14.41	0.000
	Land use*Position	2	2.28	0.103
	Land use*Period	26	0.92	0.579
	Position*Period	13	1.71	0.052
	Land use*Position*Period	26	1.26	0.168
Diversity	Land use	2	0.61	0.544
	Position	1	1.90	0.168
	Period	13	2.93	0.000
	Year	1	8.17	0.004
	Land use*Position	2	1.41	0.245
	Land use*Period	26	0.67	0.896
	Position*Period	13	1.30	0.203
	Land use*Position*Period	26	1.65	0.021

Figure Legends

Figure 3.1. A photo of a blue vane trap set up to collect insects at an upland sampling location.

Figure 3.2. Differences in total invertebrates collected in the Rainwater Basin of Nebraska from blue vane traps sampled in 2014 and 2015. Letter designations signify statistical differences between groups, and asterisk indicates the variables with highest significance. A) Abundance among three land use types and two landscape positions. B) Species richness among three land use types and two landscape positions.

Figure 3.3. Differences in Hymenoptera insects collected in the Rainwater Basin of Nebraska from blue vane traps sampled in 2014 and 2015. Letter designations signify statistical differences between groups, and asterisk indicates the variables with highest significance. A) Abundance among three land use types and two landscape positions. B) Abundance over the 14 sampling periods. C) Hymenoptera species richness among three land use types and two landscape positions. D) Richness over the 14 sampling periods.

Figure 3.4. Differences in Diptera insects collected in the Rainwater Basin of Nebraska from blue vane traps sampled in 2014 and 2015. Letter designations signify statistical differences between groups. A) Abundance among three land use types across the 14 sampling periods. B) Abundance between two landscape positions. C) Dipteran richness among three land use types across the 14 sampling periods.

Figure 3.5. Differences in Coleoptera insects collected in the Rainwater Basin of Nebraska from blue vane traps sampled in 2014 and 2015. A) Three-way interaction

showing Coleoptera abundance of land use*landscape position over the 14 sampling periods. B) Richness among three land use types across the 14 sampling periods.

Figure 3.6. Differences in Lepidoptera insects in the Rainwater Basin of Nebraska from blue vane traps sampled in 2014 and 2015. Letter designations signify statistical differences between groups. A) Three-way interaction showing Lepidoptera abundance of land use*landscape position over the 14 sampling periods. B) Species richness among three land use types across the 14 sampling periods.

Figure 3.7. Differences in total invertebrates collected in the Rainwater Basin of Nebraska from targeted net collections in 2014 and 2015. Letter designations signify statistical differences between groups, and asterisk indicates the variable with highest significance. A) Abundance among three land use types and two landscape positions. B) Abundance among three land use types over the 14 sampling periods. C) Species richness among three land use types over the 14 sampling periods.

Figure 3.8. Differences in Hymenoptera insects collected in the Rainwater Basin of Nebraska from targeted net collections in 2014 and 2015. A) Three-way interaction showing Hymenoptera abundance of land use*landscape position over the 14 sampling periods. B) Three-way interaction showing Hymenoptera richness of land use*landscape position over the 14 sampling periods.

Figure 3.9. Differences in Diptera insects collected in the Rainwater Basin of Nebraska from targeted net collections in 2014 and 2015. A) Abundance among three land use types over the 14 sampling periods. B) Abundance among two landscape positions over

the 14 sampling periods. C) Richness among three land uses over the 14 sampling periods. D) Richness among two landscape positions over the 14 sampling periods.

Figure 3.10. Differences in Coleoptera insects collected in the Rainwater Basin of Nebraska from targeted net collections in 2014 and 2015. A) Abundance among three land use types and two landscape positions. B) Abundance among three land uses over the 14 sampling periods. C) Abundance among two landscape positions over the 14 sampling periods. D) Richness among three land use types across sampling periods six through 14. E) Richness among landscape positions across sampling periods six through 14. No Coleoptera insects were collected in periods one through five.

Figure 3.11. Differences in Lepidoptera insects collected in the Rainwater Basin of Nebraska from targeted net collections in 2014 and 2015. A) Abundance among two landscape positions across the 14 sampling periods. B) Richness among two landscape positions across the 14 sampling periods.

Figure 3.1

Figure 3.2

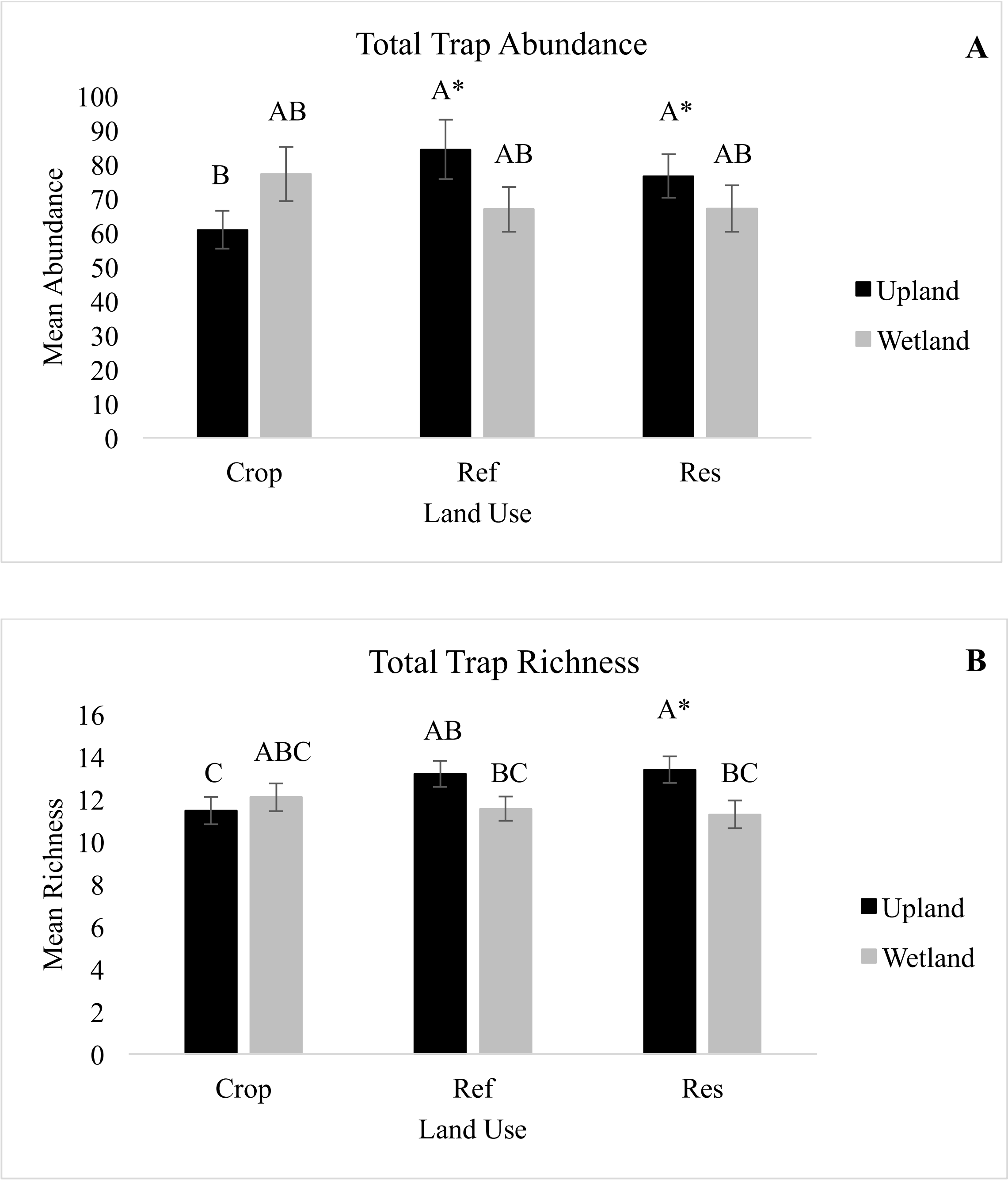
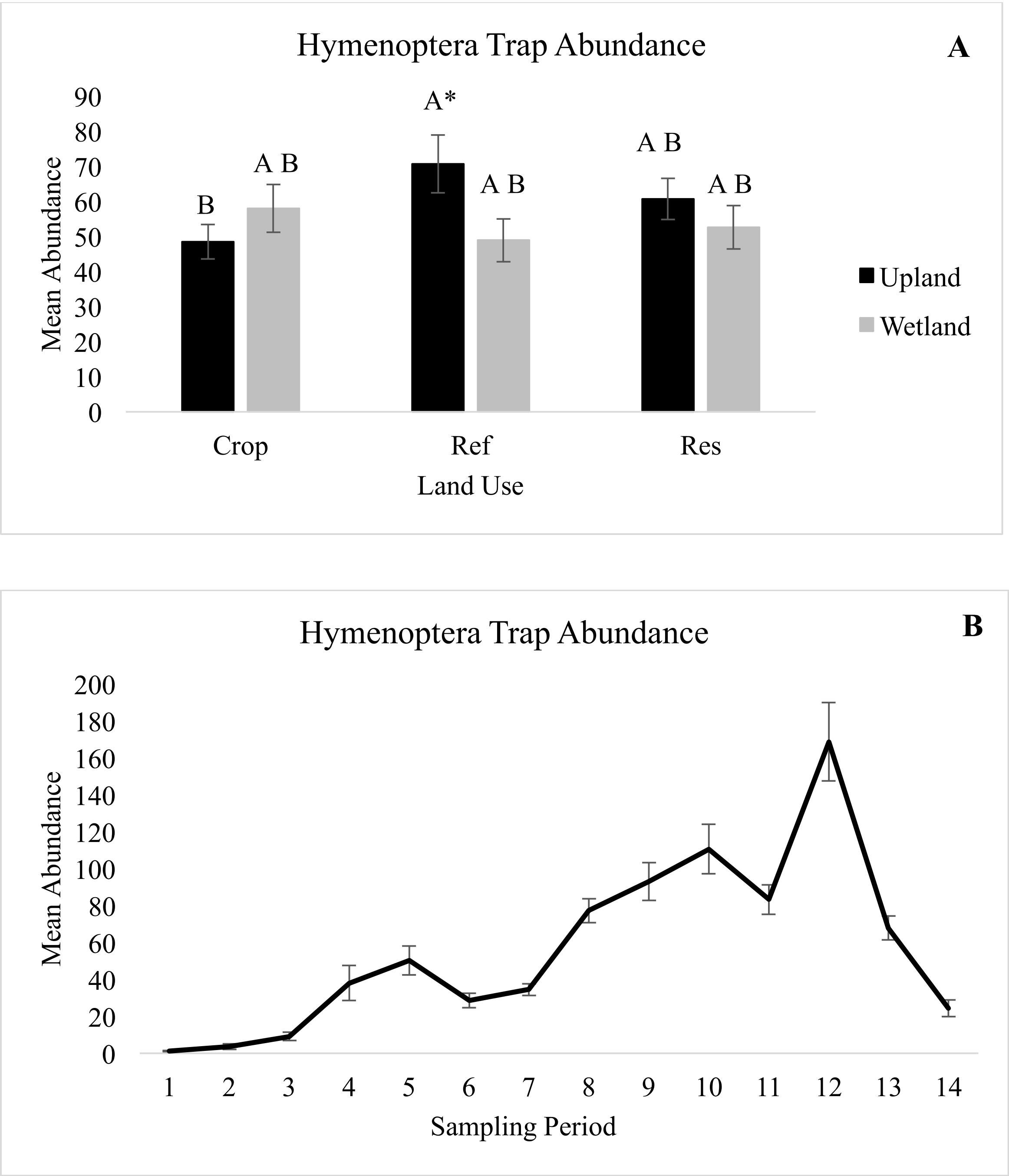
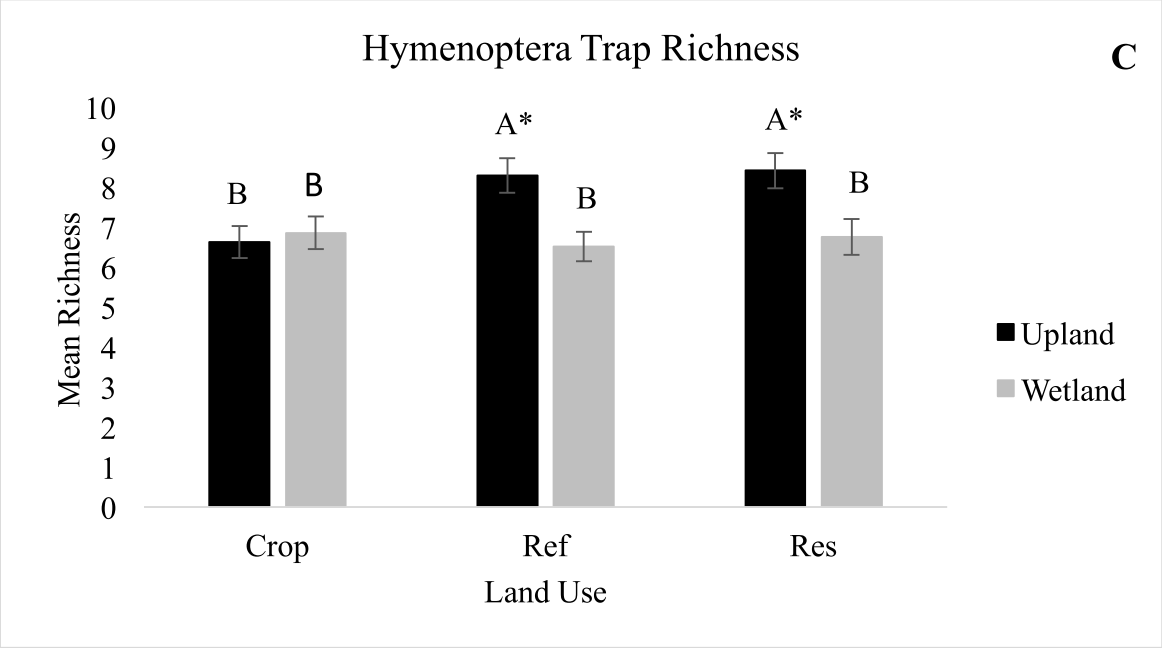

Total Trap Abundance
A
Mean Abundance
100
90
80
70
60
50
40
30
20
10
0
B
AB
A*
AB
A*
AB
Crop
Ref
Res
Land Use
■ Upland
■ Wetland
Total Trap Richness
B
Mean Richness
16
14
12
10
8
6
4
2
0
C
ABC
AB
BC
A*
BC
Crop
Ref
Res
Land Use
■ Upland
■ Wetland

Figure 3.3


Hymenoptera Trap Abundance
A
Mean Abundance
90
80
70
60
50
40
30
20
10
0
B
A B
A*
A B
A B
A B
Crop
Ref
Res
Land Use
■ Upland
■ Wetland
Hymenoptera Trap Abundance
B
Mean Abundance
200
180
160
140
120
100
80
60
40
20
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Sampling Period


Hymenoptera Trap Richness
C
10
9
8
7
6
5
4
3
2
1
0
Mean Richness
B
B
A*
B
A*
B
Crop
Ref
Res
Land Use
■ Upland
■ Wetland

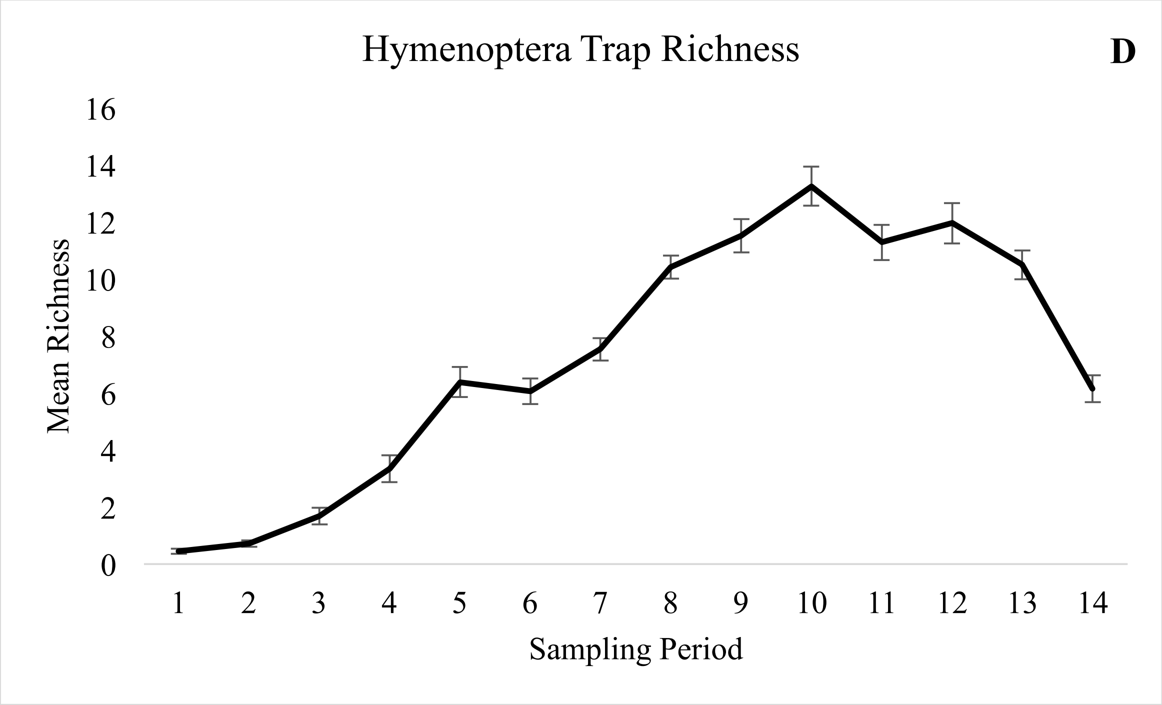
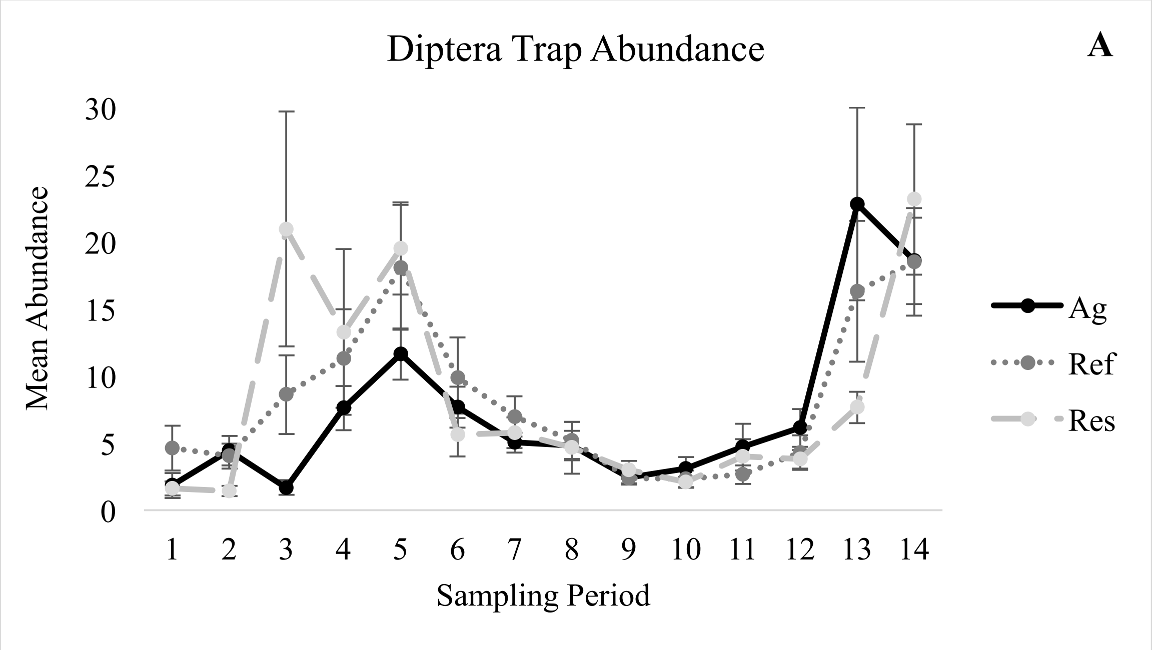
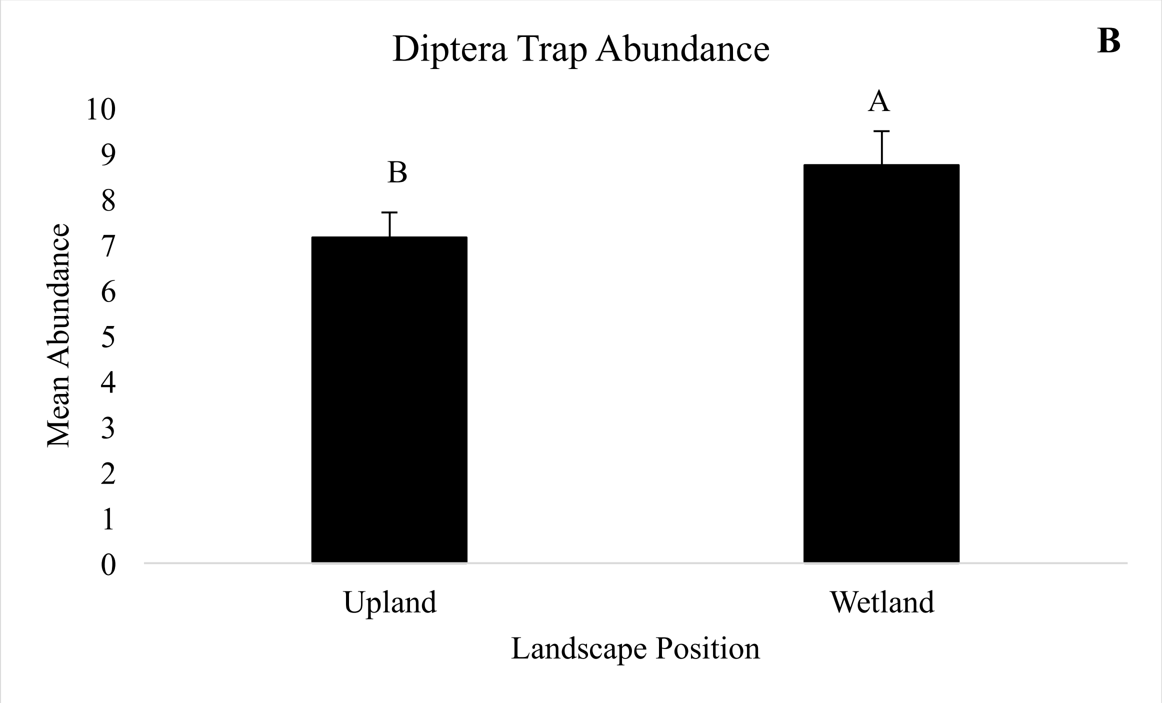

Hymenoptera Trap Richness
D
16
14
12
10
8
6
4
2
0
Mean Richness
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Sampling Period

Figure 3.4


Diptera Trap Abundance
A
Mean Abundance
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Sampling Period
Ag
Ref
Res


Diptera Trap Abundance
B
Mean Abundance
10
9
8
7
6
5
4
3
2
1
0
B
A
Upland
Wetland
Landscape Position

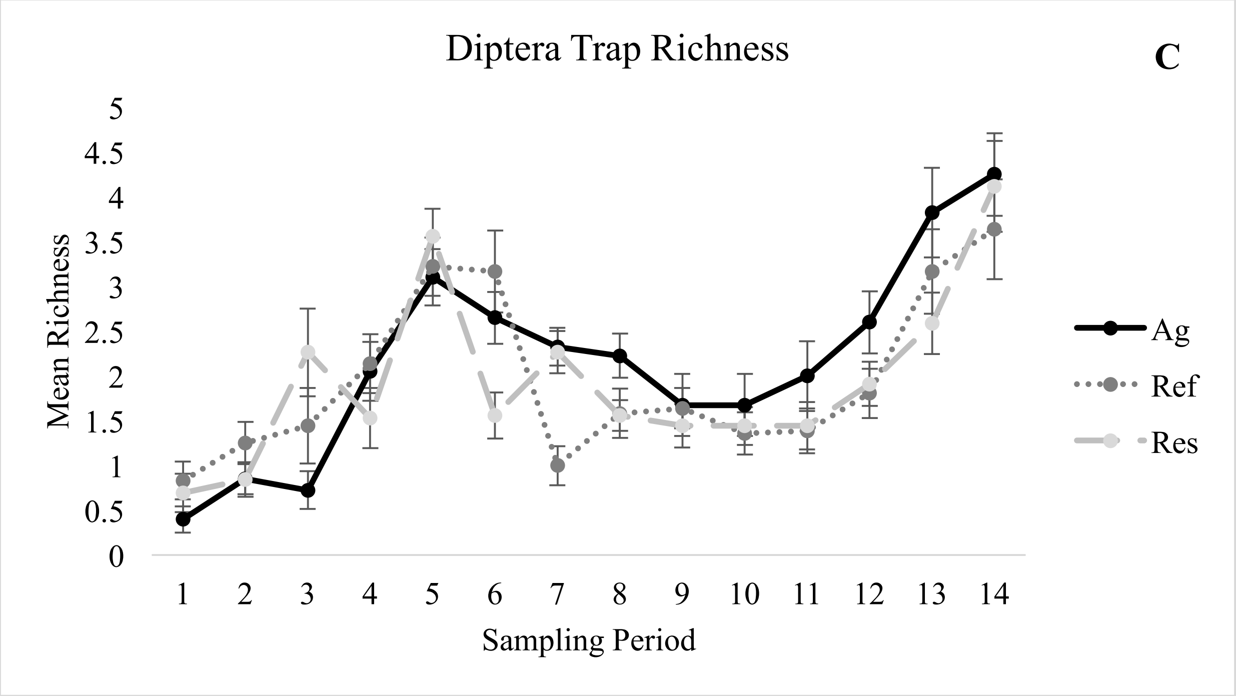
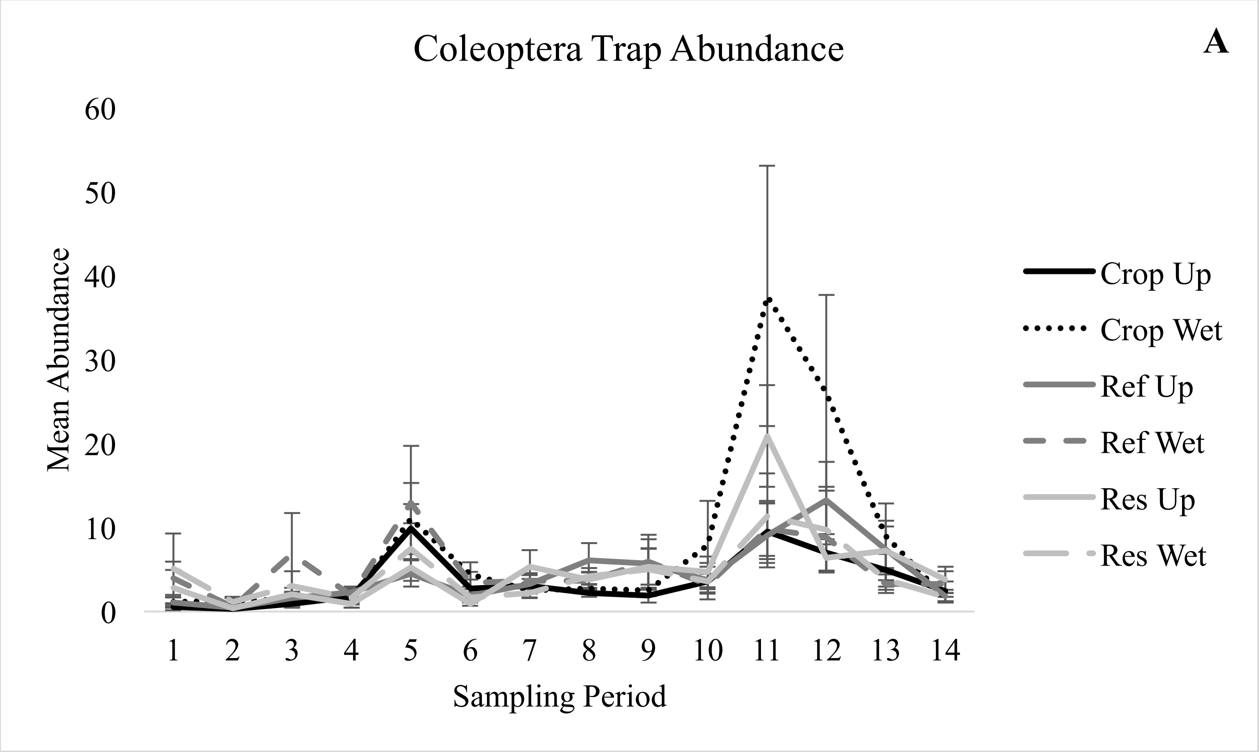

Diptera Trap Richness
C
Mean Richness
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Sampling Period
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Ag
Ref
Res

Figure 3.5


Coleoptera Trap Abundance
A
Mean Abundance
0
10
20
30
40
50
60
Sampling Period
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Crop Up
Crop Wet
Ref Up
Ref Wet
Res Up
Res Wet

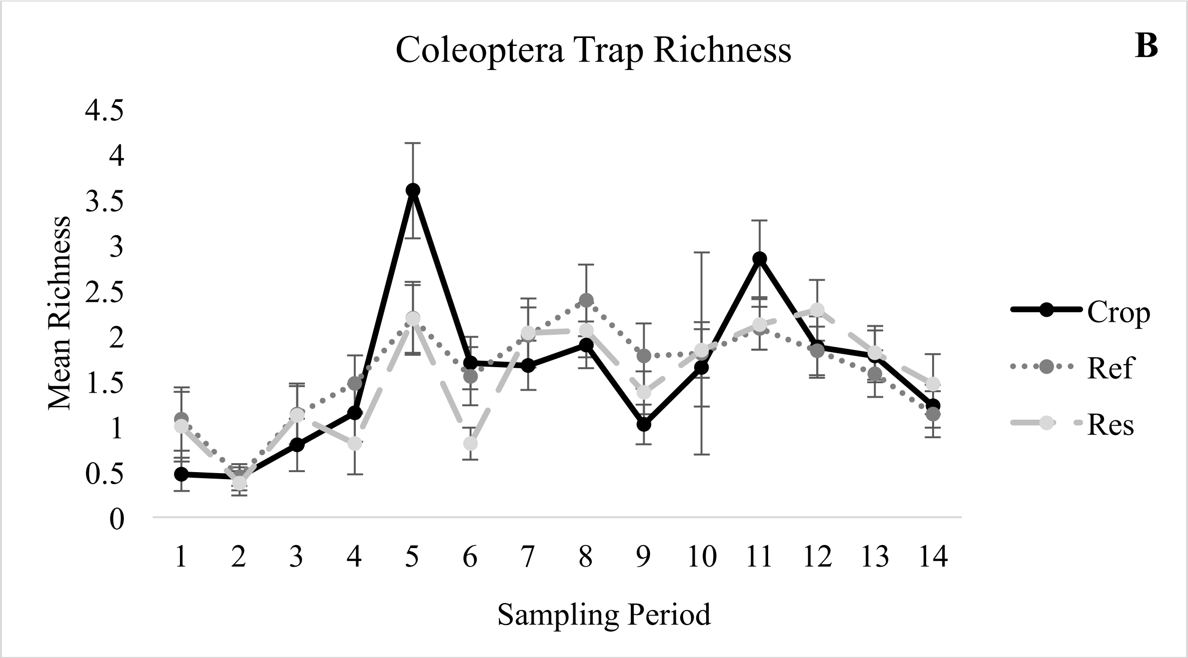
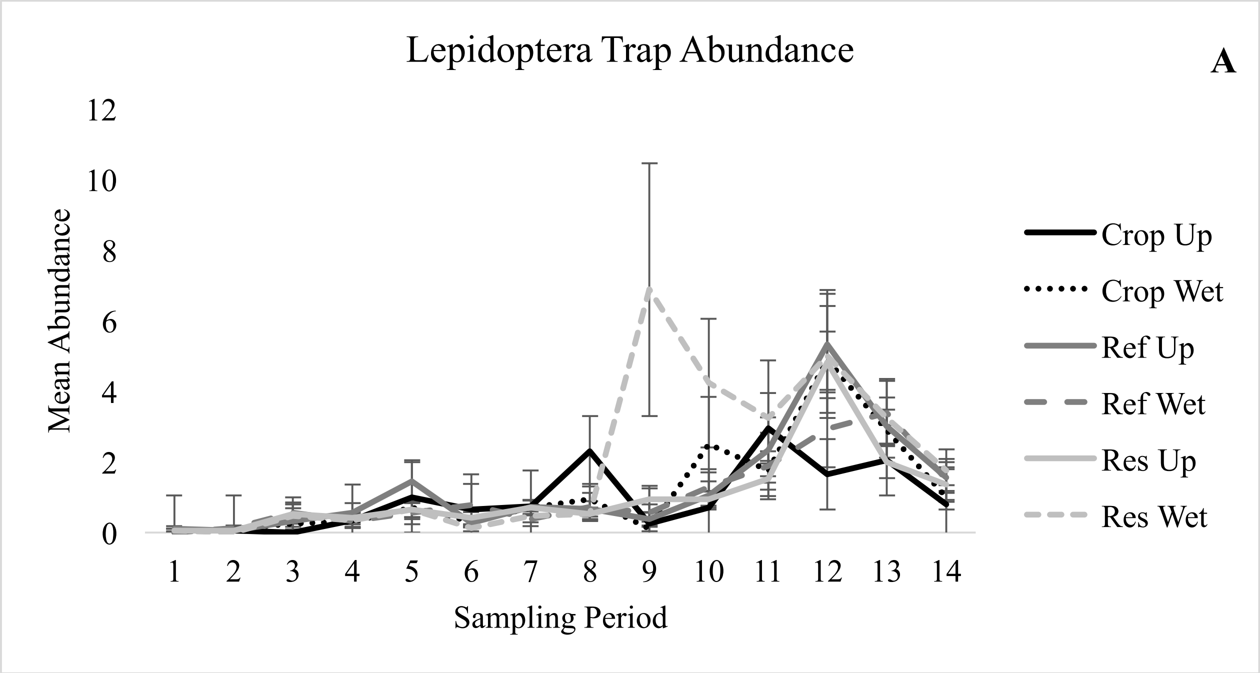

Coleoptera Trap Richness
B
Mean Richness
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Sampling Period
Crop
Ref
Res

Figure 3.6


Lepidoptera Trap Abundance
A
Mean Abundance
12
10
8
6
4
2
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Sampling Period
Crop Up
Crop Wet
Ref Up
Ref Wet
Res Up
Res Wet

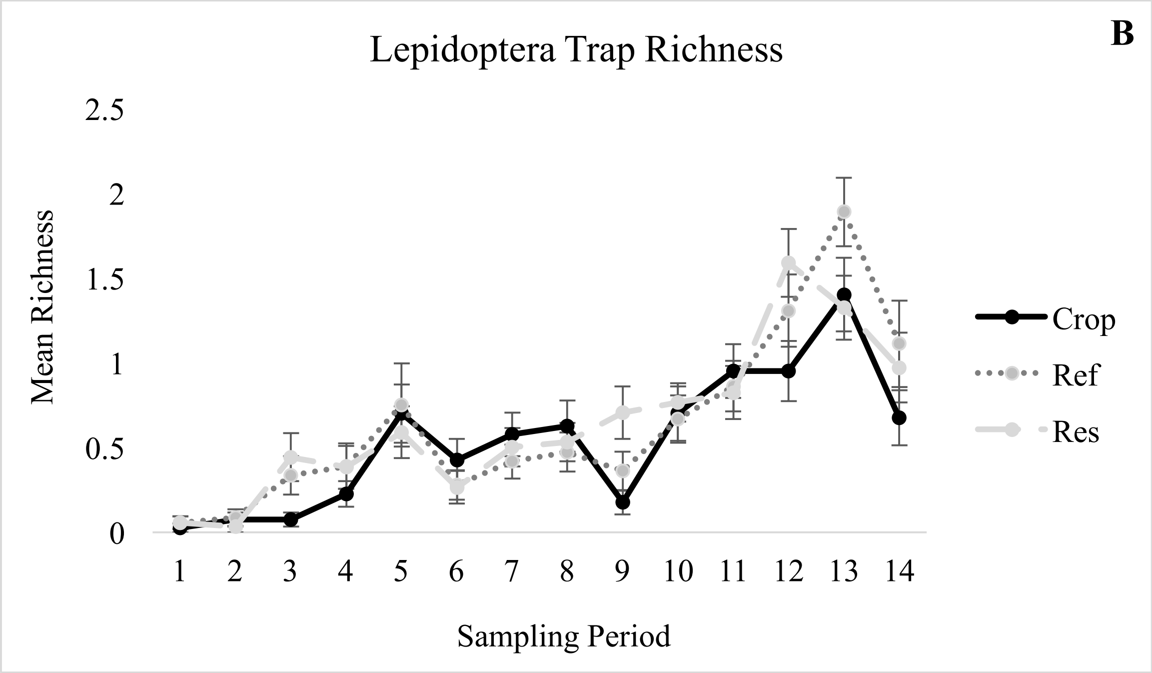
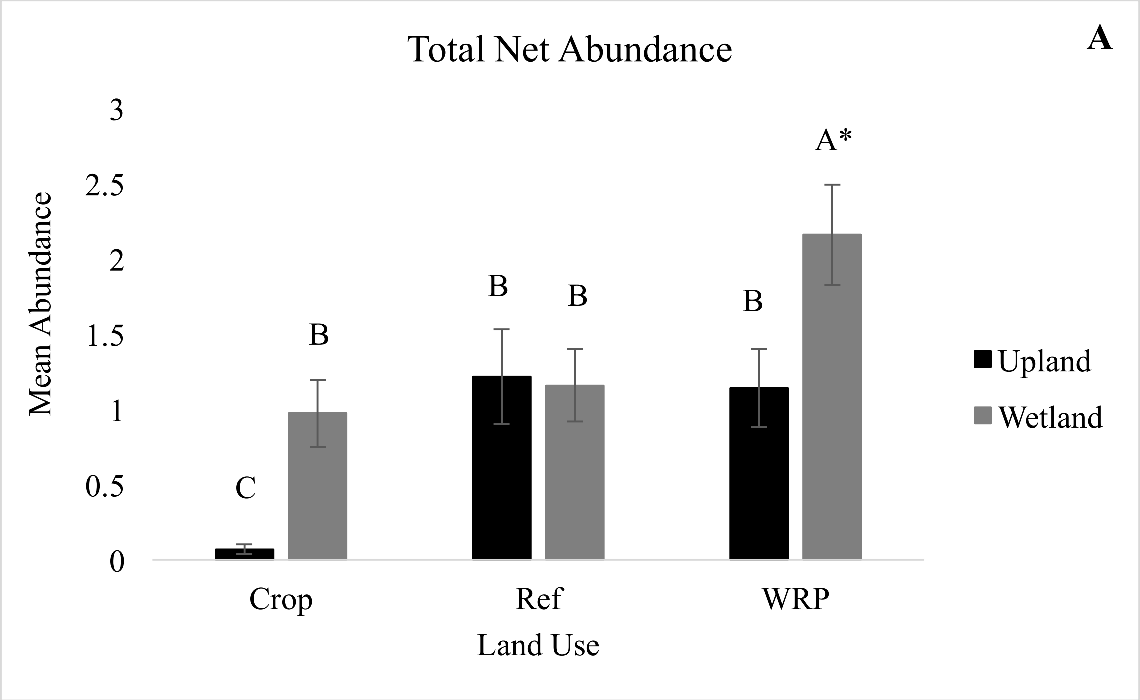
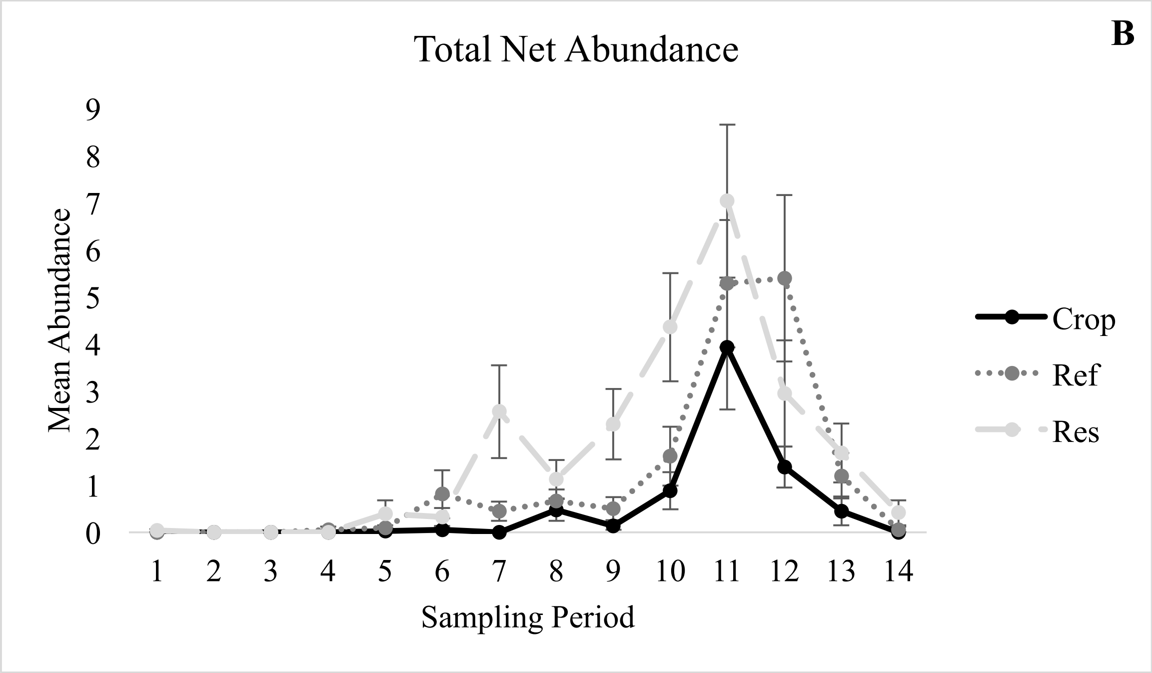

B
Lepidoptera Trap Richness
Mean Richness
2.5
2
1.5
1
0.5
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Sampling Period
Crop
Ref
Res

Figure 3.7


Total Net Abundance
A
Mean Abundance
3
2.5
2
1.5
1
0.5
0
C
B
B
B
B
A*
Crop
Ref
WRP
Land Use
Upland
Wetland


Total Net Abundance
B
Mean Abundance
0
1
2
3
4
5
6
7
8
9
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Sampling Period
Crop
Ref
Res

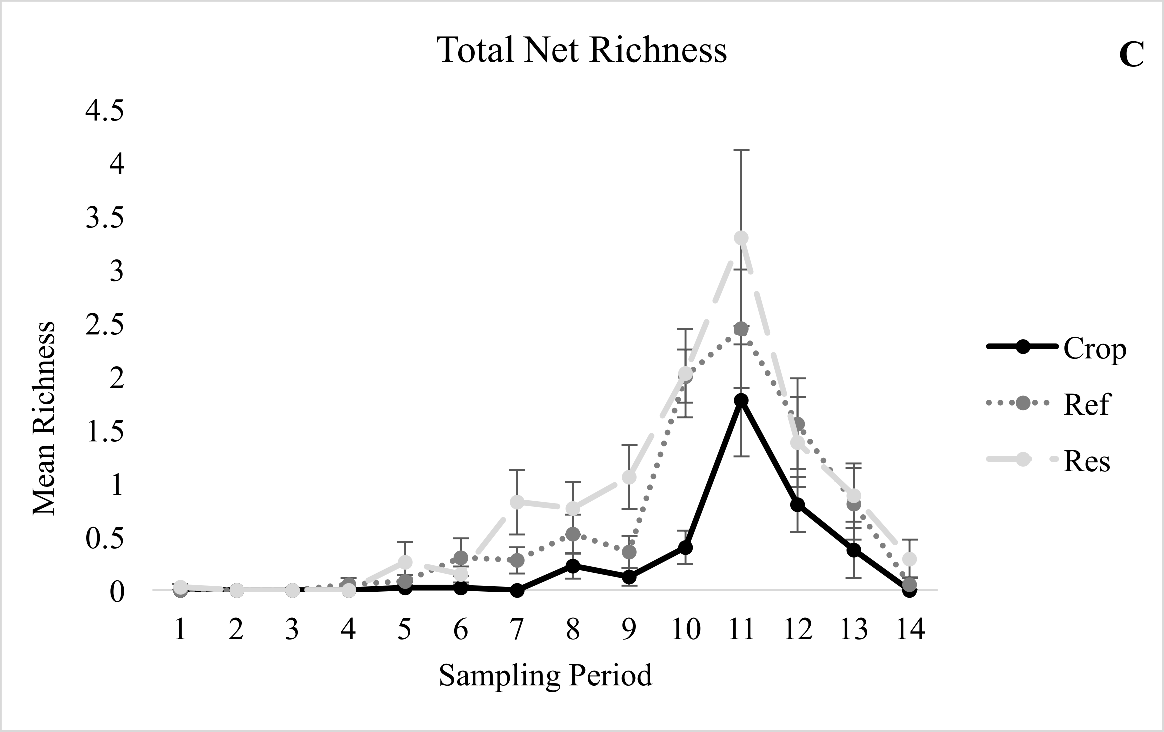
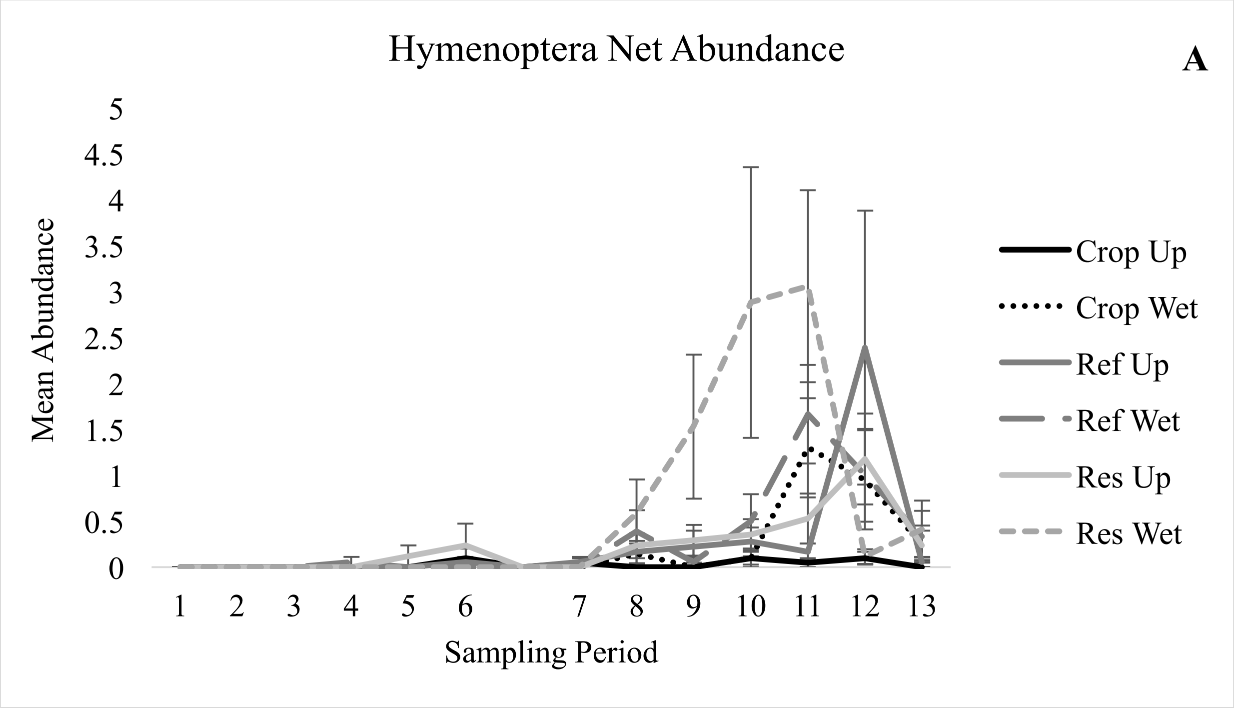

Total Net Richness
C
Mean Richness
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Sampling Period
Crop
Ref
Res

Figure 3.8


Hymenoptera Net Abundance
A
Mean Abundance
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1
2
3
4
5
6
7
8
9
10
11
12
13
Sampling Period
Crop Up
Crop Wet
Ref Up
Ref Wet
Res Up
Res Wet

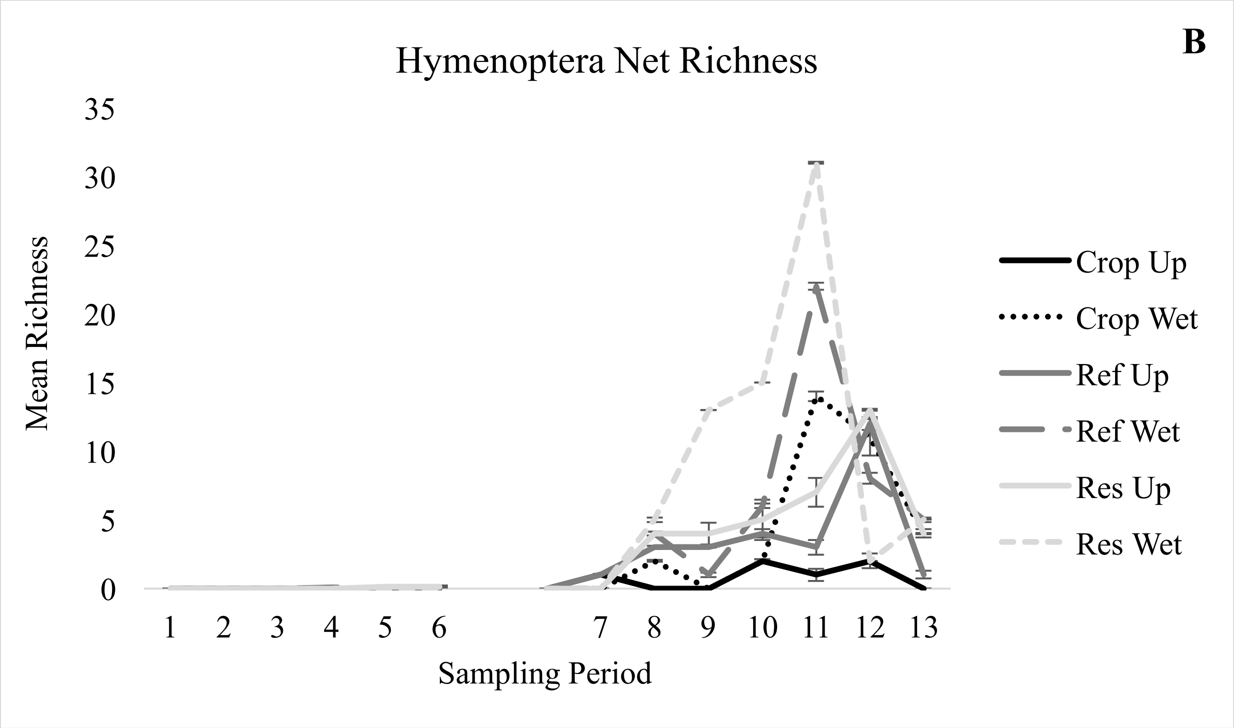
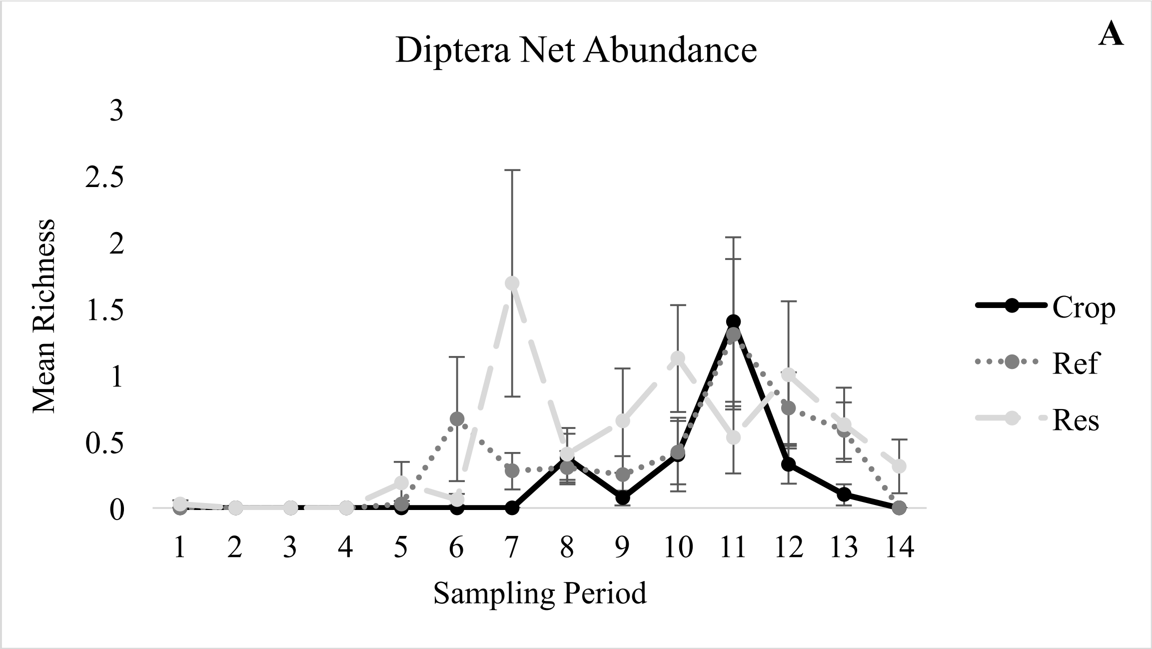
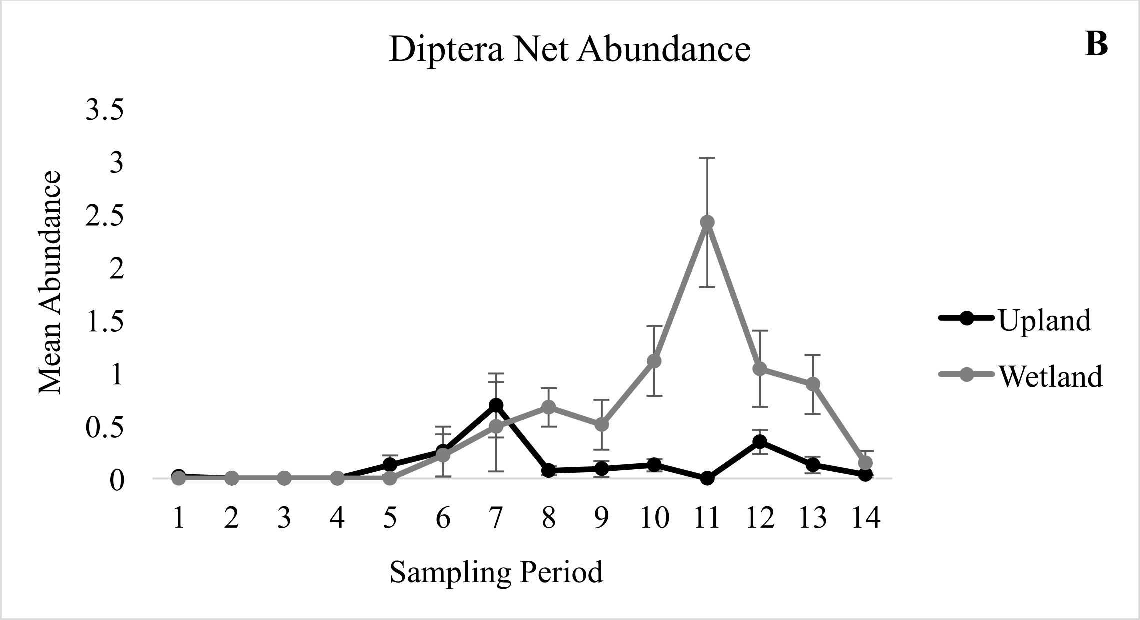
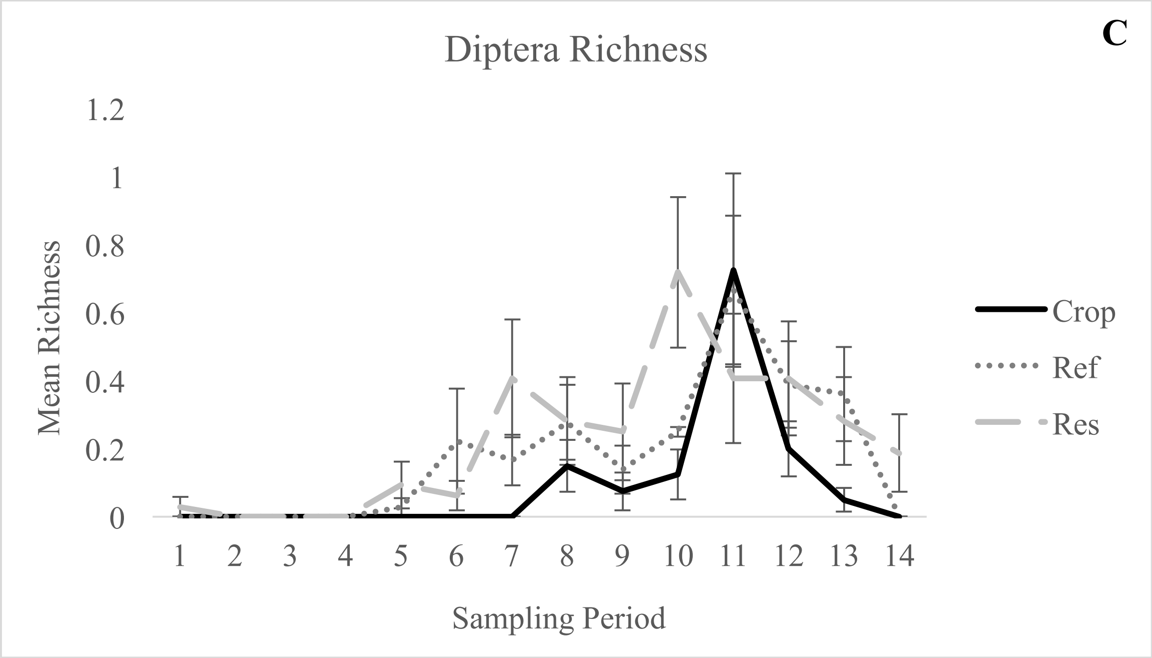

Hymenoptera Net Richness
B
Mean Richness
35
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9
10
11
12
13
Sampling Period
Crop Up
Crop Wet
Ref Up
Ref Wet
Res Up
Res Wet

Figure 3.9


Diptera Net Abundance
A
3
2.5
2
1.5
1
0.5
0
Mean Richness
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Sampling Period
Crop
Ref
Res


Diptera Net Abundance
B
3.5
3
2.5
2
1.5
1
0.5
0
Mean Abundance
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Sampling Period
Upland
Wetland


Diptera Richness
C
Mean Richness
1.2
1
0.8
0.6
0.4
0.2
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Sampling Period
Crop
Ref
Res

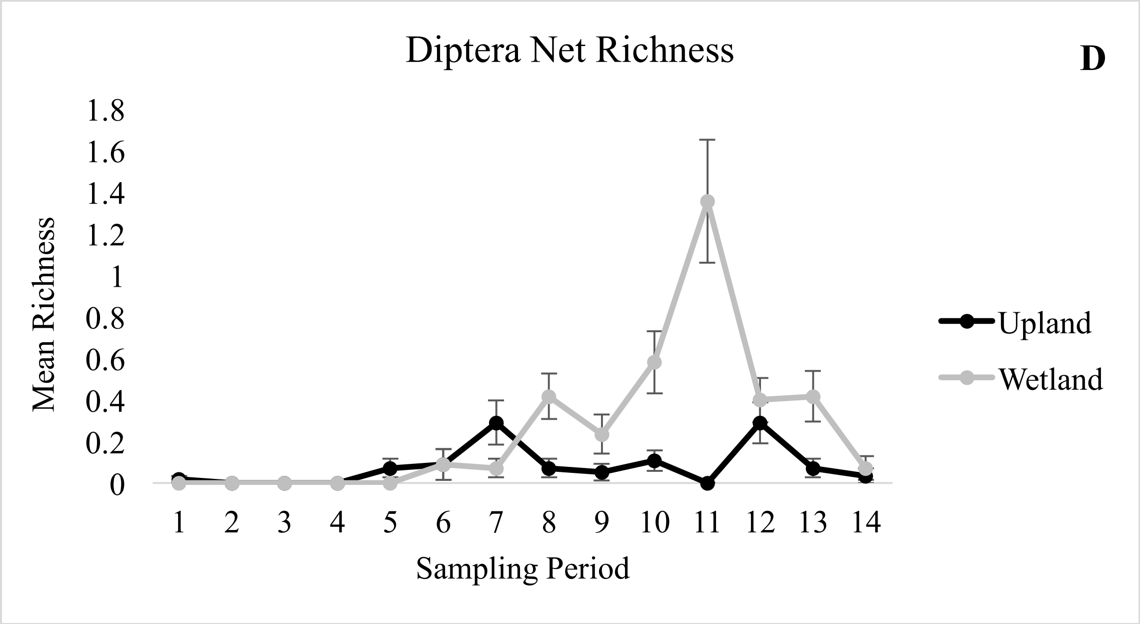
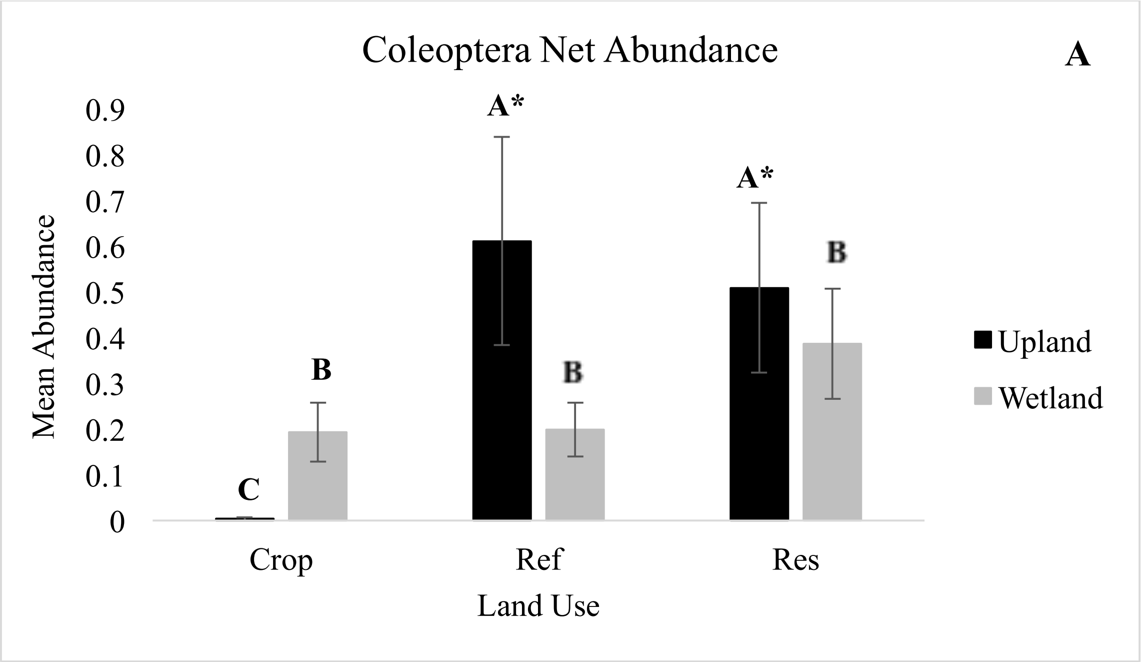
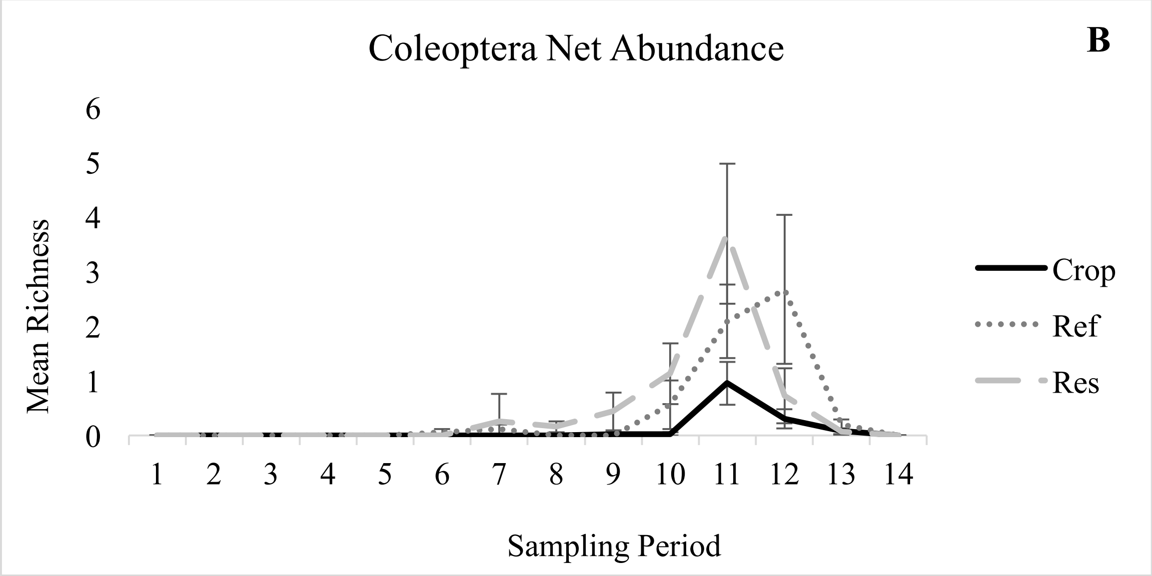
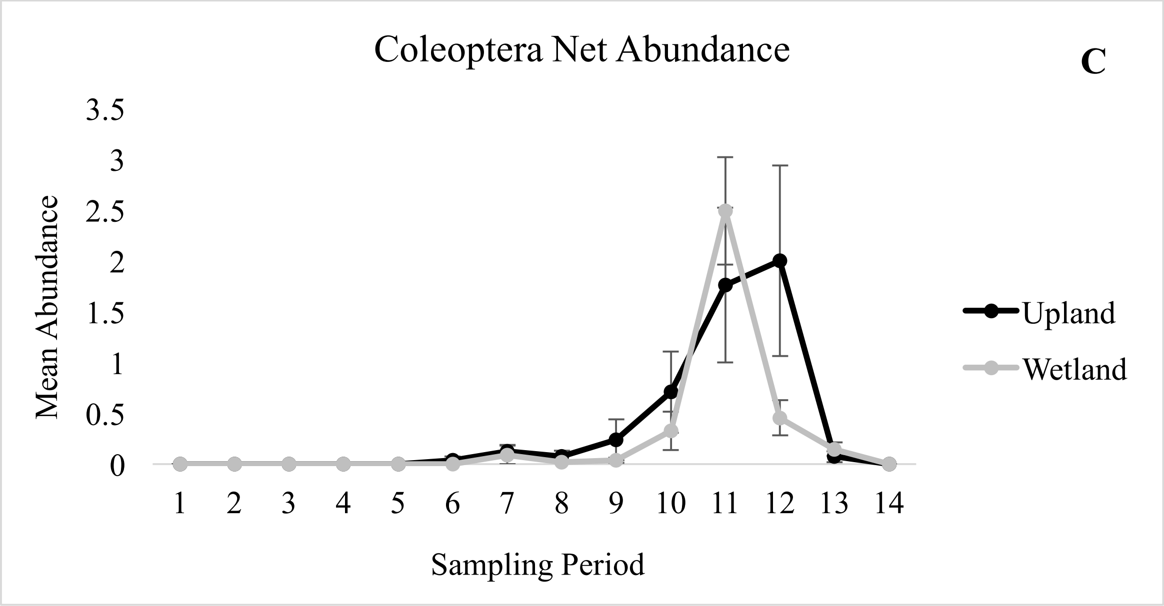
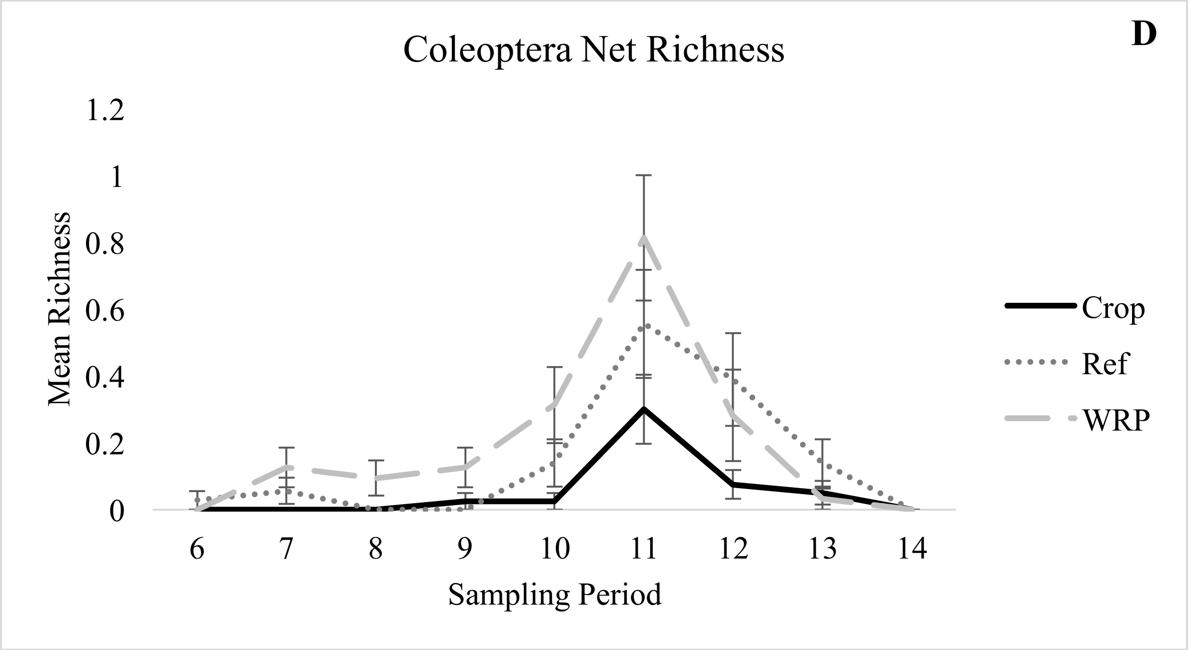

Diptera Net Richness
D
Mean Richness
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Sampling Period
Upland
Wetland

Figure 3.10


Coleoptera Net Abundance
A
Mean Abundance
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
C
B
A*
B
A*
B
Crop
Ref
Res
Land Use
Upland
Wetland


Coleoptera Net Abundance
B
Mean Richness
6
5
4
3
2
1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Sampling Period
Crop
Ref
Res


Coleoptera Net Abundance
C
Mean Abundance
3.5
3
2.5
2
1.5
1
0.5
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Sampling Period
Upland
Wetland


Coleoptera Net Richness
D
Mean Richness
1.2
1
0.8
0.6
0.4
0.2
0
6
7
8
9
10
11
12
13
14
Sampling Period
Crop
Ref
WRP

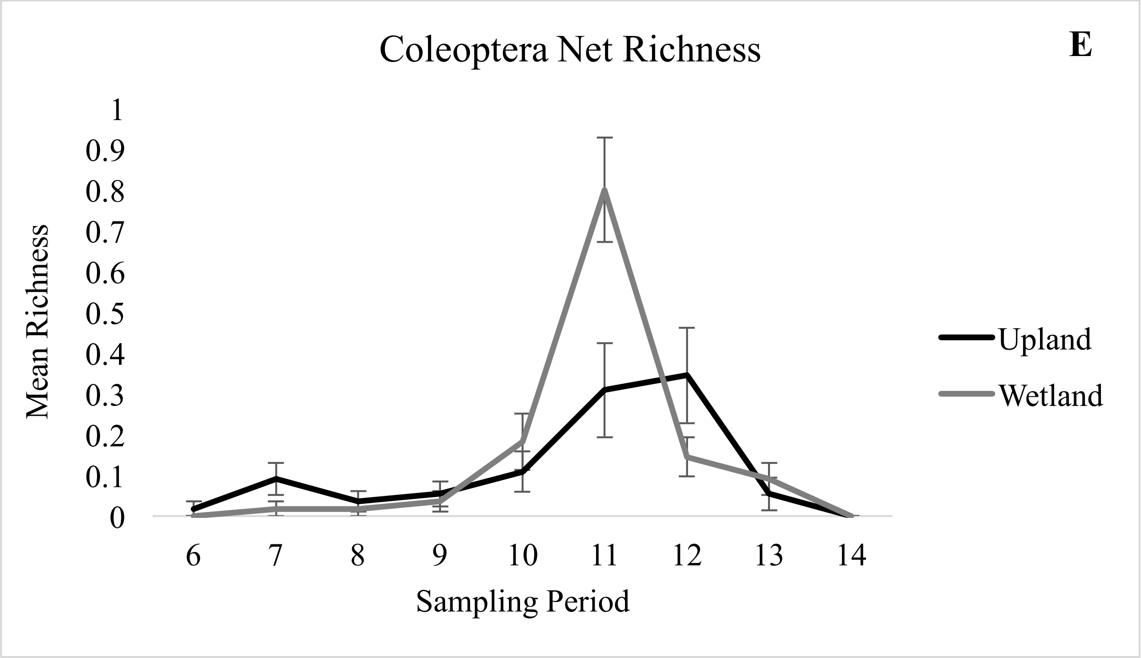
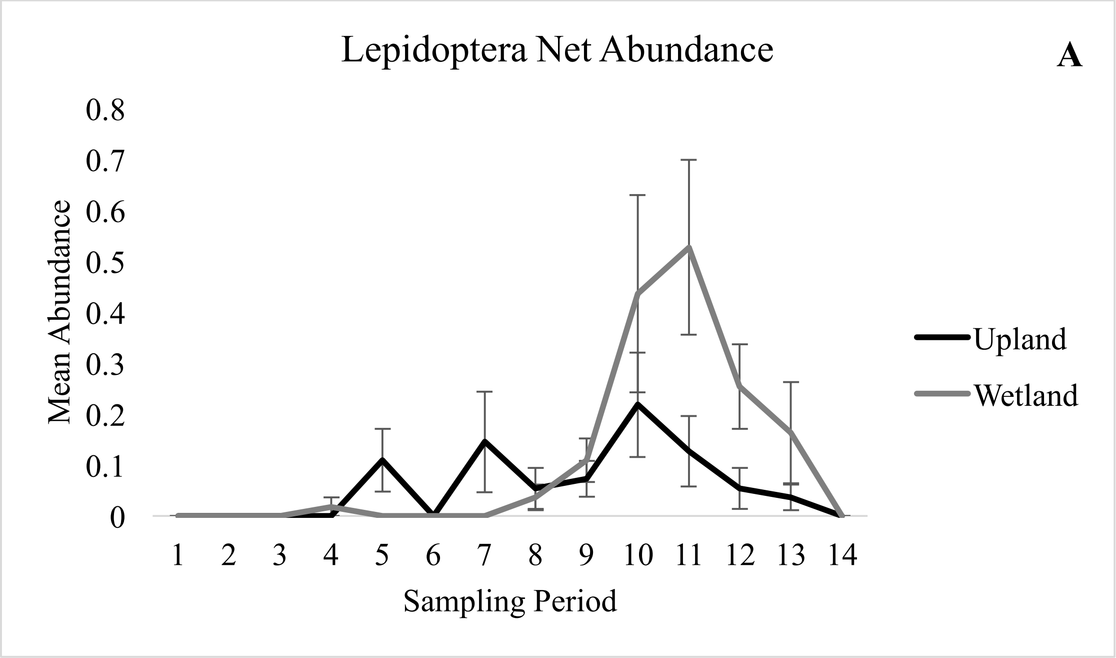
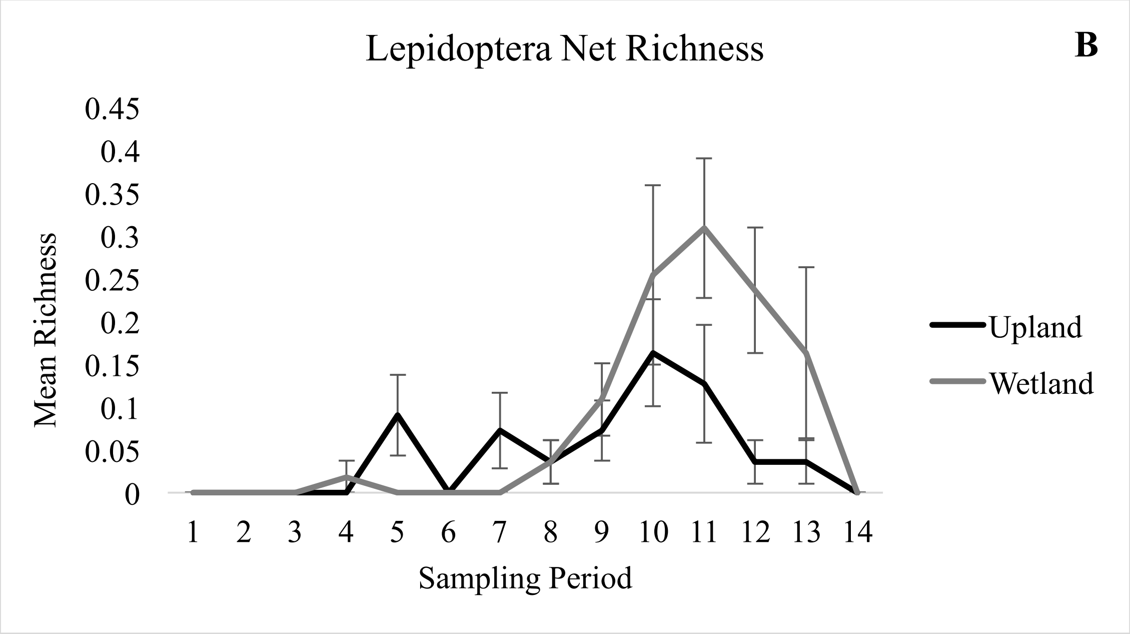

Coleoptera Net Richness
E
Mean Richness
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
6
7
8
9
10
11
12
13
14
Sampling Period
Upland
Wetland

Figure 3.11


Lepidoptera Net Abundance
A
Mean Abundance
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Sampling Period
Upland
Wetland


Lepidoptera Net Richness
B
Mean Richness
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Sampling Period
Upland
Wetland

CHAPTER IV

INFLUENCE OF RESTORATION AND WETLAND PRESENCE ON POLLINATOR COMMUNITIES AND THEIR USE OF VEGETATION IN AN AGRICULTURAL MATRIX

ABSTRACT

Pollination is critical for ensuring biodiversity and human food supplies. However, wild pollinator populations are declining due to fragmentation and loss of habitat. This concern is apparent in the Rainwater Basin, one of the most agriculturally productive regions in the world. Therefore, my objective was to examine pollinator use of the landscape and available resources in this agriculturally dominated region. Vegetation and pollinator data were collected in wetlands and uplands within restored, reference condition, and farmed land uses. Vegetation data were collected using the step-point intercept method to determine differences in plant community among land uses. Dominant plant species were analyzed using a Partial Canonical Correspondence Analysis (pCCA). Pollinating insects were collected with insect nets while foraging on flowers. Pollinator data were analyzed using a Principle Response Curve (PRC) in order to incorporate treatments (i.e., land use, watershed position, and dominant food plant) as well as time over the growing season.

Restored sites had more native grasses and aster species, whereas reference and cultivated sites had more legumes, smartweed, and invasive grasses. Apid bees foraged in highest abundance within restored wetlands versus all uplands and wetlands within crops or reference sites. This is most likely due to the abundance of forbs and restoration of nesting habitat in the surrounding watershed. However, restored sites did not provide preferred food plants throughout the entire growing season. Apidae exhibited a strong association with smartweeds and goldenrods in late summer, neither of which were associated with restored sites. Apid bees appeared to mobilize to other land uses in order to obtain food in September. To ensure viable pollinator communities throughout the growing season, restoration practices should provide more diverse wetland flora and additional late season upland forbs than is being currently provided.

INTRODUCTION

Angiosperms account for about one-sixth of described species on Earth (Wilmer, 2011a), and require animal assisted pollination to reproduce (National Research Center [NRC], 2007). There are multiple orders of insects that forage for nectar in flowers, and thus may indirectly pass pollen from one plant to another. However, bees are generally considered the most efficient pollinators (James & Pitts-Singer, 2008). Bees visit more flowers than any other animal because they solely rely on flowers for food for themselves and their brood (Wilmer, 2011a). Additionally, bees, in particular, show a high flower constancy, meaning that they are likely to visit flowers of the same species—thus transferring conspecific pollen between plants (Wilmer, 2011a).

In order to encompass a diverse bee population, it is imperative to provide a variety of pollen and nectar sources close to the nest of female bees. Nesting and overwintering habitat is equally important to bees as food plants (Hatfield *et al*., 2012). Most native bees are solitary ground-nesters, with each female building and provisioning a nest for her brood (Westrich, 1996). Ground-nesters generally prefer south-facing, unstable slopes that are sparsely vegetated or completely bare. Other bees may burrow into dead wood, stems of forbs and pithy twigs, or nest within rock cavities (Westrich, 1996). Most of the native bees that are not solitary consist of social bumble bees. Bumble bees live in annual colonies, with only the queen surviving through the winter by hibernating within soft soil (Hatfield *et al*., 2012). When the queen emerges in spring, she finds a new nest site and begins collecting pollen to build and provision her nest (Hatfield *et al*., 2012).

Bees are central foragers, meaning they only feed within a varying radius of their nest. Female bees make numerous daily foraging trips around their nest to provide food for her young. (Westrich, 1996). Home range size often varies depending on the size of the bee. Some bees, such as large bumble bees, can be relatively mobile, foraging over 800 meters from the nest (Hatfield *et al.* 2012). However, the majority of species do not forage at distances farther than 100-300 m from nesting sites (Zurbuchen *et al*., 2009), and some bees have been found to nest within centimeters from their preferred pollen sources (Westrich, 1996).

Although generalists tend to survive in a changing habitat, many native pollinators cannot (Steffan-Dewenter & Tscharntke, 1999). Linear feeders, such as hoverflies, have an easier time surviving in dynamic landscapes because they do not need to continuously return to a nest. Therefore, they are not restricted to an area and can utilize corridors across a landscape. Central foragers such as bees, however, are negatively affected by fragmentation because their available habitat become more restricted (Jauker *et al*., 2009). Agricultural intensification has been identified as one of the leading causes of habitat loss and fragmentation (Kremen *et al*., 2002; Krewenka *et al*., 2011). The increase in spatial isolation can lead to inbreeding depression, lowered species richness, and increased risk of localized extinction (Kearns *et al.*, 1998). Furthermore, crop monocultures decrease floral diversity and consequently pollinator resources (O'Toole, 1993). If the loss of plant biodiversity and key pollinating species becomes significant, an ecosystem may suffer from a loss of pollination services (Aizen & Feinsinger, 1994).

In the Rainwater Basin (RWB) region of Nebraska, the landscape is heavily cultivated with few natural areas (Smith, 2003; LaGrange, 2005). Often the only habitat available are playa wetlands and sometimes their associated catchments (Smith *et al*., 2011). Playas are depressional wetlands that only receive water from precipitation and catchment runoff (Smith, 2003). The conversion of the surrounding watershed to row-crop agriculture has led to multiple negative consequences, including the filling in of playa wetlands with eroded sediment from the watershed (Luo *et al*., 1997). Accumulated sediments alter the natural hydroperiod by forcing water to spread over a larger area, increasing evaporation loss and burial of hydric soils—ultimately effecting plant species composition (Smith & Haukos, 2002; O'Connell *et al*., 2012). Watersheds in crop monocultures sacrifice floral diversity in uplands and downslope wetland communities (O'Connell *et al*., 2012), and consequently influence diversity of pollinating insects (Kearns *et al*., 1998).

To re-establish wetland plant communities, removal of sediment and placement of a buffer strip to prevent further sedimentation is necessary (Smith *et al.*, 2011). Grassland catchments provide a buffer strip of vegetation around wetlands, which reduces erosion, increases soil permeability, and decreases velocity of runoff (Skagen *et al*., 2008; Smith *et al.*, 2011). This fosters a more natural hydroperiod and can promote a beneficial wetland plant community (Luo *et al*., 1997; Beas *et al*., 2013). Additionally, if the uplands are seeded with native grasses and forbs, the watershed could sustain diverse pollinator-plant relationships (Potts *et al*., 2010). Grasslands also provide nesting and over wintering habitat (Westrich, 1996; Hatfield *et al*., 2012) that would not be available in an inundated wetland. Therefore, playa watersheds have the potential to provide habitat for a sustainable wild pollinator community.

The RWB playas that are surrounded by mixed-tallgrass prairie are generally either owned by government wildlife agencies or are privately owned and enrolled in the Wetlands Reserve Program (WRP) (Grosse, 2014). The WRP focuses on restoring the watershed and wetland (USDA, 2009). This includes upland restoration by promoting a diverse native and forb-rich vegetation community in the catchment. WRP wetland practices commonly involves self-design restoration, which consists of sediment removal and natural reestablishment of the native wetland seed bank (O'Connell *et al*., 2012).

Beas *et al*. (2013) observed plant community differences among RWB cropland, reference, and restored wetlands, with hydrological restoration primarily consisting of sediment removal. They found that restored and reference wetlands had higher plant species richness, including more natives, perennials, and annual species than crop wetlands. However, restored wetlands contained a greater proportion of mud-flat annuals versus a plant community of deep-water perennials in reference wetlands (Beas *et al*., 2013). If different land uses are dominated by varying plant guilds, it stands to reason that pollinating insects whom rely on flowering forbs may be effected.

The objective of this study was to assess the pollinator community's response to variation in Rainwater Basin habitat. Multivariate analyses were used to determine the influence of landscape position (i.e. upland or wetland) and surrounding land use on the dominant plant community, and subsequently, on the pollinator community. I used insect nets to collect pollinators feeding on plants in wetlands and their adjacent uplands croplands, reference state playas and prairies, and restored wetlands and uplands enrolled in the WRP. Vegetation data were collected to determine the plants pollinators were feeding on, as well as which plants dominated the different land uses.

MATERIALS AND METHODS

Study Area

The RWB comprises of approximately 15,907 km^2 in south-central Nebraska, just south of the Platte River (LaGrange, 2005). It is characterized by flat to gently rolling loess plains with numerous closed basins containing playa wetlands (Stutheit *et al*., 2004). The average annual precipitation ranges from 460 mm in the western part of the region to 710 mm in the east. Eighty percent of the rainfall occurs between April through September, with the heaviest rainfall occurring in late spring and early summer (Stutheit *et al*., 2004). The grasslands in this region historically consisted of mixed grasses is the western portion and tallgrass plant communities in the east (Kuchler 1964). However, the area has been intensively cultivated with soybean and corn crops.

Field collection

Insects were collected from the first week of April until mid-October in 2014 and 2015 in the Rainwater Basin region of south central Nebraska. Twenty-eight different sites were sampled 14 times (twice a month) each year (Table 4.1). Each site contained a depressional playa wetland that was embedded within one of three different land use types: reference condition grasslands (n=9), restored prairie buffer strips (n=9), and cropland (n=10). Nebraska Game and Parks Commission biologists classified sites using the Hydrogeomorphic Wetland Classification System. Three random sampling locations were placed within the wetland and adjacent upland at each site.

Vegetation surveys

Vegetation surveys were conducted at each site to estimate community composition among different land uses. Surveys were performed in mid-June and mid-August each year to capture both early and late season plant communities. The step-point intercept method was conducted on six 25 m transects (three in uplands, three in wetlands). Transects were combined with their respective landscape position, giving a total of 75 m vegetation survey in uplands and wetlands. The step-point intercept survey consists of walking the transect and identifying plant species found on the right boot tip at each step (Bonham, 2013). *The Flora of Nebraska* (Kaul *et al.*, 2006) was used for nomenclature and life history information. Plant codes utilized in the analyses are the first three letters of the genus and first three letters of the epithet. Additional plant guild classification was adapted from previous studies conducted in RWB wetlands (Beas *et al*., 2013; O'Connell *et al.*, 2013).

Insect Net Collections

To collect insects foraging on flowers, we used 30.5 cm diameter aerial insect nets attached with 24 X 20 mesh bags. Six 25 m long, 0.5 m wide transects were established within each site (three in wetlands, three in uplands). Collections were combined according to their respective landscape position within each site. Six minutes were allocated to walking the transect and collecting insects that were actively foraging on or manipulating flowers. The timer was paused while the insect was placed in a killing jar of ethyl acetate and then placed in a plastic sample bag labeled with site, transect number, date, and plant species information. If no flowers were present, we would not walk the transect for the full six minutes, as there was no data to collect. Sampling took place at approximately 1100 each sampling day.

Insect identification

All specimens were kept in a freezer at 0 °C until they were identified. Insect specimens were first identified to order by simple observation, and then identified using numerous taxonomic keys. For a complete list of taxonomic keys utilized see Park *et al*. (2017). For purposes of this study, we selected the most abundant pollinating insect families; n>100 was used to represent the dominant pollinator community. Information on all insects collected can be found in Park *et al*. (2017).

Statistical analysis

Partial Canonical Correspondence Analysis (pCCA) (CANOCO 4.5, Biometris, Wageningen, The Netherlands) was used to examine plant community variation among restored, reference, and cultivated land uses. pCCA factors out variation from covariates—in this instance, early/late season and year—and shows the results of variation in plant community among the main effect (i.e. land use). Transects at each site were combined by landscape position, and the most common plant was chosen to represent the dominant species in wetland or upland plant communities. However, the factor of landscape position was not included in the model because preliminary data analysis showed plant species ordinated to either upland or wetland and not along land use gradients. Therefore, variation explained by land use could not be determined if landscape position was included. Furthermore, only focusing on land use allows for interpretation of which plants were available for pollinators in the entire watershed. However, both upland and wetland plant communities are still represented within the pCCA.

The option to down-weight rare species in CANOCO was utilized to ensure species with small sample sizes did not bias the output. Results were plotted using biplot scaling. A Monte Carlo permutation, using 999 permutations, was used to identify axes with significant values. Two pCCAs were conducted. One pCCA included all vegetation types, such as grasses, forbs, and wetland monocots. The second pCCA focused solely on the dominant forbs present in order to interpret what food plants were most abundant for pollinators. For visual interpretation of analyses, similar plant guild designations were used from previous RWB wetland studies (O’Connell *et al.* 2012; Beas *et al*. 2013). Gray boxes represented perennial species guilds, black stars—annual species, and gray circles—shallow and deep-water perennial species.

Principal Response Curves (PRC) (Van den Brink & ter Braak, 1999) were used to determine the relative influence of land use, landscape position (i.e. upland or wetland), and vegetation pollinating insect communities from net data. An analysis was also conducted on blue vane trap collections, but the results were redundant to the analysis of variance in chapter 3 (available in Appendix 4.1). This analysis focused on insects from the most abundant families found foraging on flowering plants, Apidae, Halictidae, Syrphidae, and Cantharidae.

PRCs are used to evaluate the effect of experimental treatments with a temporal scale associated with the design (Van den Brink & ter Braak, 1999). Insect communities, abundance, and resource use are influenced by season (Chapter 3). Therefore, a PRC was chosen in order to capture differences over the growing season. Only sampling periods five (late May) through 13 (late September) were included because no insects from the four dominant families were collected in April, early May, or October. The output of a PRC shows one or multiple treatment response curves, each representing a regression line of a treatment through the temporal X axis (i.e. sampling period). The response curves are compared to one of the treatments that acts a baseline. The baseline treatment is set to a constant score of zero on the Y axis, while all other treatments may fluctuate below or above the baseline through time. In addition to the treatment response curves, a Redundancy Analysis (RDA) axis is placed to the right side of the PRC that represents a species response axis. This allows for the interpretation of a family's response to a treatment for a given sampling period relative to the baseline treatment.

A PRC was used to compare pollinator foraging in wetlands and uplands within each land use. The multivariate data consisted of the abundance from each family collected with nets as the dependent variable, and land use, landscape position, and sampling period as independent variables. The treatment lines were combinations of land use (i.e. reference, restored, or crop) and landscape position (i.e. wetland or upland). Crop uplands were not included in the PRC, because none of the dominant pollinators were found foraging in crop fields. Restored uplands were set as the baseline, because it was the only land use/landscape position combination that had insects collected in every sampling period.

An additional PRC compared pollinator foraging response to the most common plants foraged on within each land use. For each site, we combined transects for each landscape position to determine the most common forb insects were foraging on within uplands and wetlands. The dependent variable was the abundance from each family collected with nets and the independent variable was the most common plant foraged on within each land use. The most abundant food plants consisted of two plant families: Asteraceae and Polygonaceae. Asters were dominated by plains coreopsis, sunflowers, and goldenrods. Polygonaceae species were all the smartweeds in the Rainwater Basin. Another treatment is included where the dominant plant is titled as “other”, which consisted of plants such as prairie rose, hoary vervain, or legumes that were not abundant enough to justify their own treatment response curve. The response curves (i.e. independent variable) consisted of land use and plant type. The baseline was set to Ref_smart (i.e. smartweeds in reference sites) because this was the only treatment that had insects collected for every sampling period.

RESULTS

Vegetation Community Analysis

Overall dominant vegetation community: Land use accounted for 3.3% of the variation among dominant plant communities (F=3.39, *p*=0.001). Axis one in the pCCA accounted for 71.5% of the explained 3% variation, and represented a gradient of cultivated watersheds to restored and reference watersheds (Fig. 4.1). Axis two in the pCCA accounted for 28.5% of the explained variation, and represents the gradient between restored and reference land uses. Restored, reference, and cultivated sites have different plant communities associated with them. Nuisance wetland grasses such as foxtail barley (*Horedeum jubatum*), reed canary grass (*Phalaris arundinacea*), orchard grass (*Dactylis glomerata*), and barnyard grass (*Echinochloa crus-galli*) were associated with farmed sites. Perennial wetland species lacking pollinator resources such as sedges (*Carex* sp.), softstem bulrush (*Schoenoplectus tabernaemontani*), and water clover fern (*Marsilea vestita*) were also more associated with farmed sites than reference or restored sites. Deep water species such as water smartweed (*Polygonum coccineum*), perennial smartweed (*P. pennsylvanicum*), and river bulrush (*Schoenoplectus fluciatilis*) were associated with reference sites. The invasive grass, Kentucky bluegrass (*Poa pratensis*) was strongly associated with reference sites. No deep-water perennials or non-native grasses were associated with restored sites. Most native perennial grasses such as Canada wildrye (*Elymus canadensis*), indiangrass (*Sorghastrum nutans*), and western wheatgrass (*Pascopyrum smithii*), were associated with restored sites. Plains coreopsis (*Coreopsis tinctoria*), a prolific annual aster, was strongly associated with restored sites.

Dominant Forb Community: Land use accounted for 4.8% of the variation among dominant forb communities (F=4.78, *p*=0.001). Axis one in the pCCA accounted for 53% of the explained variation, and represented a gradient of reference and restored systems to cultivation (Fig. 4.2). Axis two in the pCCA accounted for 47% of the variation, and represents the gradient between restored and reference land uses (Fig. 4.2). No forbs were strongly associated with farmed sites—only pale smartweed (*Polygonum lapathifolium*) was weakly associated with this land use. The category "No Forb", was also associated with farmed sites, meaning that there were no forbs present on the vegetation transects, either due to high water, dominance of grasses, or complete lack of vegetation.

Restored and reference sites have different dominant forb species associated with them, however, there is not a clear pattern based on plant life history traits (i.e. annual vs perennial). Both land uses had mostly perennial species with one or two annual species. However, dominant families differed. Most plants associated with restored sites were in the Asteraceae family, such as rigid goldenrod (*Oligoneuron rigidum*), Maximilian sunflower (*Helianthus maximiliani*), heath aster (*Aster ericoides*), common sunflower (*Helianthus annuus*), and plains coreopsis. Reference sites had a higher diversity of plant families than restored sites. Plants within the Fabaceae family, such as leadplant (*Amorphos canescens*), deer vetch (*Lotus pershiana*), and red clover (*Trifolium pratenes*) were associated with reference sites; as were goldenrods (*Solidago* sp.), yarrow (*Achillea millefolium*), and hoary vervain (*Verbena stricta*).

Pollinator Community Analysis

Land use and landscape position: All pollinator family responses had a positive score, therefore they all had a positive association with treatments above the baseline and negative association with treatments below the baseline. Apidae had a much higher response score than the other families. Therefore, while all pollinator families exhibited the same response to the treatments, Apidae has a more extreme response. For example, while all families had a positive association with restored wetlands during periods eight through 11, Apidae appears to be almost exclusively foraging in restored wetlands.

Pollinators had a positive association with foraging in restored wetlands through most of the growing season. However, in early September, restored wetlands fell below the baseline, and pollinators then had a negative association with restored wetlands and a positive association with reference uplands and wetlands. Additionally, pollinators rarely had positive associations with crop wetlands. However, in late September, farmed crops were the only treatment where pollinators exhibited a positive association.

The overall trend of the PRC analysis shows restored wetlands, and occasionally reference and crop wetlands, had the highest use by the dominant pollinator families. However, reference uplands are still occasionally being utilized for forage, especially in late summer. Another way to interpret this graph is to look below the baseline, where treatments have a negative association relative to restored uplands. Reference sites and crop wetlands had a negative association for pollinator foraging trips relative to restored uplands through most of the growing season.

Land use and food plants: All of the families had a positive association with treatments above the baseline (i.e. smartweeds within reference sites) (Fig. 4.4). Apidae had the highest score on the response axis. Therefore, Apidae had the strongest response to different food plants available among land uses. The other pollinating families did not show strong associations; therefore, the results will focus on Apidae.

In late July and August, Apidae had a strong association with smartweeds in restored wetlands relative to smartweeds within reference sites. The association with smartweed within restored wetlands was so strong that it suggests Apidae were selecting for smartweed when it was available within these sites. Additionally, in September, only smartweed in reference and cropland sites had a positive association. The association to smartweed in crop wetlands was so strong that appears Apidae was exclusively foraging there instead of in reference or restored sites.

Overall, Apidae had strong associations with smartweeds in mid-late summer in all land uses. The strong associations suggest that smartweed flowers may be important forage for apid bees. All families of pollinators did use other plant types during different parts of the growing season. For example, there was a positive association with the “restored other” category in early summer. This primarily consisted of pollinators foraging on legumes in restored uplands. Asters were not as strongly associated with any pollinator family as was seen with smartweed. However, all pollinators fed on asters in early summer, and in September when goldenrods and sunflowers were in bloom.

DISCUSSION

Dominant plant communities and available forbs among land uses

Plant communities differed among land uses in the Rainwater Basin, and are thus expected to affect the pollinating insects that rely on them. No flowering plants were strongly associated with farmed sites. Beas *et al*. (2013) found that only narrow-leaf cattail (*Typha angustifolia*) was associated with crop wetlands, whereas this study found that wetland grasses, sedges, and roundstem bulrush were the dominant vegetation associated with crop wetlands (Fig. 4.1). These species lack nectar resources and have little value to pollinators (Wilmer 2011c).

Wetlands that lack buffer strips, such as playas within crop fields, have few plants for pollinators to forage on and are subject to excessive sediment loads (Daniel *et al*., 2015). Sedimentation affects playa hydrology by shortening hydroperiods and burying hydric soils (Luo *et al*., 1997, Tsai *et al*., 2007). Sedimentation can also lead to colonization of nuisance and invasive species, (Smith & Haukos, 2002). Furthermore, catchments dominated by crop fields, lack nesting resources for bees, such as grass tussocks and dead wood for burrowing (Westrich, 1996; Svensson *et al*., 2000).

Many bee species burrow into the soil and need bare ground for nesting sites (Westrich, 1996; United States Department of Agriculture [USDA], 2007). Therefore, bare ground available in crop fields may seem like suitable nest habitat. However, bees need untilled, well-drained soil without the soil compaction, herbicide, and plowing from cultivation (Delaplane & Meyer, 2000; Sardinas & Kremen, 2014). Daniel (2015) found compaction was higher in cropland that the other land uses within the RWB. The annual harvest and cultivation of crop fields disturbs ground nesting bees and eliminates nesting habitat (Moradin *et al.* 2007). Furthermore, depressional wetlands surrounded by crop fields contain higher amounts of pesticides (Belden *et al*. 2012; Main *et al*. 2014). Main et al. (2014) found that prairie potholes surrounded by crop fields contained higher concentrations of neonicotinoids—a systemic insecticide known to be toxic to bees (Blacquiere *et al*. 2012).

Restored and reference sites contained more native grasses and forbs than farmed sites. Bare ground for nesting habitat was not measured, but the presence of grasses and forbs can provide food as well as nest sites and building materials (Westrich, 1996). Reference and restored sites contained different flowering species. However, there was no distinct difference in life history traits present within each land use. This differs from Beas *et al*. (2013), who found that RWB restored wetlands had more annual species than reference wetlands.

Many forb species associated with reference sites were within Fabaceae family such as leadplant, deer vetch (*Lotus purshianus*), and red clover. The majority of forbs associated with restored sites were within Asteraceae family, such as plains coreopsis, sunflowers, heath aster, and dandelion. Both families contain flowers attractive to pollinators (Wilmer, 2011b). However, Fabaceae plants may be a preferred pollen source for many bumble bee species (Goulson *et al*., 2005). Goulson *et al*. (2005) observed that rare, long-tongued bumble bees may specialize in Fabaceae flowers, which often contain deep corollas. Asteraceae plants were rarely visited for pollen and only received 2.2% of pollen-collecting visits. Bees frequently visited Asterceae flowers for nectar collecting (Goulson *et al*., 2005). Goulson and Darvill (2004) theorized that nitrogen-fixing

Fabaceae plants may dispense pollen that is richer in protein than pollen from Asteraceae plants.

While some bees may not prefer Asteraceae pollen, there are others that almost exclusively collect pollen from Asteraceae flowers. For example, *Melissodes* bees, also known as sunflower bees, are oligolectic feeders on sunflowers (Parker *et al*., 1981). *Melissodes* were also the most abundant genus of bee collected in this study (Park *et al*., 2017). Therefore, a diversity of forbs should be available, especially near nesting sites, to encompass the pollen preferences of different bee species.

More native tall-grass species, such as Canada wild rye and indiangrass, were associated with restored than reference sites. Kentucky bluegrass was strongly associated with references sites (Fig. 4.1). While there is debate whether Kentucky bluegrass is native or introduced (Kual *et al*., 2006), it is generally considered invasive (Grant *et al*., 2009). Kentucky bluegrass and brome (*Bromus* spp.) have been invading northern prairies—including those managed by federal agencies, such as the U.S. Fish and Wildlife Service (Grant *et al*., 2009). Invasive plants displace native grasses and forbs that pollinators use as food or nesting material (Stout & Morales, 2009; Lindsay *et al*., 2011). Conversion of diverse prairie to a monoculture of invasive species can affect pollination services and, ultimately, pollinator community composition (Stout & Morales, 2009).

The differences in upland plant communities between restored and reference sites is due to the restoration practice of planting native grasses and forbs in the associated catchment (USDA, 2009). The WRP, now the Agricultural Conservation Easement Program (USDA, 2014), seeks to restore hydrology and restoration of associated uplands. The practice of planting a diverse native plant community was re-enforced for the purposes of pollinator habitat following the Presidential Memorandum, issued by President Obama. The memorandum set a goal to restore or enhance millions of hectares of land for pollinators through public agencies and programs such as the WRP (United States Forest Service [USFS], 2015; USDA, 2015). The most common seed mixture utilized for WRP restoration in Nebraska included over a hundred species of flowering plants (Walker, 2017). Seed mix lists were provided by NRCS (Appendix 4.2, 4.3). The mesic mix (Appendix 4.2) is seeded on all new WRP (now ACEP) sites and almost half of the individual species are composites. Fabaceae species only comprise 15% of the seed mixture (Walker, 2017).

Beas *et al*. (2013) found that mud-flat annuals, such as plains coreopsis, were associated with restored RWB wetland plant communities. Annuals were also strongly associated with restored sites in this study. O'Connell *et al*. (2013) also reported more annuals in restored wetlands in the RWB compared to reference sites. Beas *et al*. (2013) also found that reference sites had more deep-water, emergent perennials, such as smartweed, than restored or farmed sites. Smartweeds, in total, were not exclusively associated with any single land use in this study. Water smartweed and perennial smartweed were associated with reference sites, and pale smartweed was weakly associated with crop wetlands, but all other smartweeds were not associated with any single land use.

Sediment removal and self-design restoration (i.e. the natural reestablishment of wetland plants following sediment removal) was used in playa restoration in the RWB (O'Connell *et al*., 2013). However, O'Connell *et al*. (2013) suggested that the lack of perennial species in restored sites may be due to dispersal limitation, and that inoculation of perennial species may be necessary for wetland restoration. Beas *et al*. (2013) also theorized the lack of perennial species could be due to limited seed availability following sediment removal or management differences within different land uses. Therefore, self-design restoration practices in the RWB can affect forage availability for pollinators, and may be driving the prevalence of plains coreopsis and lack of perennial forbs in restored wetlands. However, many WRP sites have received wetland seed mixes along the edges which include species of smartweed (Appendix 4.3) (Walker, 2017). Therefore, it may be the management of WRP sites that is limiting management activities, as Beas *et al*. (2013) suggested, that is driving the differences.

Plains coreopsis was a prevalent species in RWB wetlands, and highly associated with restored sites. Cusser and Goodell (2014) conducted a study on the importance of specific plants, such as coreopsis, in establishing pollinator-pollinator networks at restoration sites. A centrality index was utilized, which weights the importance of a plant species to a community by taking into account the number of pollinators and frequency of visitation it receives. Coreopsis was seeded as a part of restoration efforts in their study, and had the highest centrality index of the 34 plants in the analysis. Moreover, pollinators were more attracted to coreopsis when they were abundant (Cusser & Goodell, 2014).

Pollinator use of the landscape and vegetation for forage

Within an agricultural matrix, natural habitat within restored and reference sites were utilized more than areas dominated by cultivation. Furthermore, pollinators foraged in wetlands more than in uplands. However, there was rarely a positive association with wetlands surrounded by cultivation, and no insects from the dominant pollinator families were found foraging in crop fields. While there are different habitat and vegetation associations throughout the growing season for the pollinator families analyzed, all families showed similar responses. Apidae had the most extreme response even though Syrphidae and Cantharidae had higher abundances. Therefore, Syrphidae (hoverflies) and Cantharidae (soldier beetles) were more generalists in where forage and what they forage on, whereas Apidae may be more selective.

Soldier beetles can be mobile generalist feeders and are known to utilize a wide variety of plants for nectar and pollen (Jolivet, 2004). Pollination by beetles is considered most prevalent in the tropics, and is not as widely noted in temperate North America (Wilmer 2011c). Hoverflies are minimally affected by environmental variables such as land use, habitat fragmentation, or landscape structure (Schweiger *et al*., 2007). Hoverflies that exhibit generalist traits are less likely to be affected by agricultural intensification and may perceive a fragmented landscape as sufficiently connected (Thomas, 2000; Schweiger *et al*., 2007). Unlike bees, hoverflies do not nest or provide for their young. Therefore, they can move linearly through a landscape, feeding and depositing eggs over greater distances (Jauker *et al*., 2009). Additionally, flies can use field margins and roadside ditches for near unsuitable habitat, whereas bees need preferred floral resources centrally located around nesting sites (Jauker *et al*., 2009).

Halictidae bees, commonly known as sweat bees, are considered generalists (Danforth *et al*., 2008). However, Broussard (2012) found that individual halictid bees, on average, only foraged on 2-3 plant species. This is lower than expected, given that halictids have relatively short foraging distances, which would necessitate a polylectic foraging strategy. Broussard (2012) also found that halictid bees had the ability to adapt their diet to the most abundant plants within different habitats. In this study, sweat bees exhibited a low species response score which would suggest that, like hoverflies and soldier beetles, sweat bees are generalists. Halictidae also exhibited the lowest abundance (10% of insects used for this analysis). Therefore, it is too difficult to determine if the minimal change between treatments is due to low abundance numbers or generalist foraging habits.

Apidae, however, appear to be more selective in their use of the landscape and food resources. Apid bees foraged in restored wetlands more than uplands or wetlands among other land uses. There are few studies that focus on wetlands as bee habitat. Bees are considered upland species and bee diversity is thought to be highest in warm, dry grasslands (Michener, 2000). However, wetlands contain flowering species, and therefore need pollination services. Hatfield and LeBuhn (2007) studied bumble bees foraging in montane wet meadows and found that bumble bee foraging increased with the measured meadow wetness. An increase in water allowed for flowering vegetation to be more abundant in wet meadows than in dry meadows. Additionally, Moroń *et al*. (2008) found that wet meadows contained more oligolectic species that specialized on plants only found in those systems.

There is little information on nesting habitat in the aforementioned studies. However, RWB playas are frequently inundated and cannot provide nesting habitat for the 80% of ground-dwelling bees when the soil is saturated (Westrich, 1996). Although wetlands appear to be a primary source for forage, nesting habitat is still necessary to maintain sustainable populations of bees. Morandin *et al.* (2007) compared bumble bee populations in canola fields with pastureland within 800 m of crop fields. They found that the pastureland was the only area providing nesting habitat for bumble bees, even though they were foraging on the canola (Morandin *et al*., 2007). Upland restoration in restored watersheds appears be having a positive effect on bee abundance due to the increase in quality of nesting and overwintering habitat. However, restored sites appear to lack preferred forage for bees in the late growing season.

As noted, of the pollinator families we studied, Apidae had the strongest association with restored wetlands. However, Apidae also had a strong association with smartweed, which was not associated with restored wetlands. WRP sites are dominated by plains coreopsis, which pollinators appear to avoid after peak bloom in July. However, the apparent avoidance of coreopsis may be because apid bees peaked in abundance during late summer (Chapter 3), when the peak bloom period for coreopsis had lapsed. Restored sites provided asters and legumes in early summer for forage. However, in late summer, foraging shifted from restored sites to reference sites for goldenrods and crop wetlands for smartweed—neither of which were associated with WRP sites. When smartweed was present in restored wetlands, Apidae had a strong association with it.

This study cannot say if smartweed is a preferred food plant in wetlands for wild pollinators. There is little literature on smartweed as a food resource for bees. Loose *et al*. (2015) ranked nectar and pollen resources for flowering species surrounding cranberry beds in Maine. On a scale of two, 1 being “minor nectar or pollen source” and 2 being “major nectar or pollen source”, Water-pepper (*Polygonum hydropiper)* and pale smartweed were both ranked 1.2 for nectar source and 1.25 for pollen source. Additionally, Krochmal (2016) noted the honey production capability from domestic honey bees foraging on various smartweed species.

While bees are not selective about nectar sources, they can be particular in their pollen sources (Wilmer, 2011b). It is possible that during late summer when bees are reproducing more (Hatfield & Lebuhn, 2007), smartweed pollen may contain additional nutrients, as Goulson and Darvill (2004) theorized for Fabaceae. However, the RWB landscape has limited natural habitat, and smartweed may simply be the most abundant food source available during the late summer.

CONCLUSION AND RECOMMENDATIONS

Apidae had a positive association with restored sites, most likely due to restoration of nesting habitat in the uplands and the availability of food plants within the entire watershed. Bees had the strongest association with restored wetlands for forage during mid-summer. However, restored sites may be missing plant species needed during the late growing season. Bees utilized sites within other land uses to forage on species such as goldenrods and smartweeds that were not represented in restored sites. This suggests that bees mobilized to find food because it was not being provided within restored sites.

The lack of smartweed in restored sites may be due to dispersal limitations or scarcity in the seed bank after sediment removal (Beas *et al*. 2013; O'Connell *et al*. 2013). Current WRP practices generally includes dispersing a wetland seed mixture, which contains smartweed, around the playa edges (Walker, 2017). Additionally, goldenrods are included within WRP upland seed mixtures, however, they do not appear to be establishing in restored sites. Recruitment of seedlings in established vegetation or after disturbance is often low (Turnbull *et al*., 2000). Both upland and wetland plant community restoration practices need to be reevaluated to determine why plant species are not establishing after seeding. Additional practices, such as mycorrhizal fungi inoculation (van der Heijden, 2004), may need to be included in order encourage seedling recruitment.

Restoration of habitat is crucial in providing nesting and food resources for beneficial insects. However, current practices are not providing foraging opportunities throughout the entire growing season due to a lack of late season forbs. Adjusting future vegetation restoration practices in ACEP to incorporate late season food availability can help ensure all necessary habitat requirements are being met, and thus promote pollination.

LITERATURE CITED

Aizen, M. A., & Feinsinger, P. (1994). Habitat fragmentation, native insect pollinators, and feral honey bees in Argentine'Chaco Serrano'. *Ecological applications*, *4*(2), 378—392.

Beas, B. J., Smith, L. M., LaGrange, T. G., & Stutheit, R. (2013). Effects of sediment removal on vegetation communities in Rainwater Basin playa wetlands. *Journal of environmental management*, *128*, 371—379.

Belden, J. B., Hanson, B. R., McMurry, S. T., Smith, L. M., & Haukos, D. A. (2012). Assessment of the effects of farming and conservation programs on pesticide deposition in high plains wetlands. Environmental science & technology, 46(6), 3424-3432.

Biesmeijer, J. C., Roberts, S. P., Reemer, M., Ohlemüller, R., Edwards, M., Peeters, T., ... & Settele, J. (2006). Parallel declines in pollinators and insect-pollinated plants in Britain and the Netherlands. *Science*, *313*(5785), 351—354.

Blacquiere, T., Smagghe, G., Van Gestel, C. A., & Mommaerts, V. (2012). Neonicotinoids in bees: a review on concentrations, side-effects and risk assessment. Ecotoxicology, 21(4), 973-992.

Bonham, C. D. (2013). *Measurements for terrestrial vegetation*. John Wiley & Sons.

Broussard, M. (2012). *Foraging in disturbed areas: a study of sweat bees (Hymenoptera: Halictidae) in Oregon* (Doctoral dissertation). Oregon State University.

Cusser, S., & Goodell, K. (2014). Using a Centrality Index to Determine the Contribution of Restored and Volunteer Plants in the Restoration of Plant-Pollinator Mutualisms on a Reclaimed Strip Mine. *Ecological Restoration*, *32*(2), 179—188.

Danforth, B. N., Eardley, C., Packer, L., Walker, K., Pauly, A., & Randrianambinintsoa, F. J. (2008). Phylogeny of Halictidae with an emphasis on endemic African Halictinae. *Apidologie*, *39*(1), 86—101.

Daniel, D. W., Smith, L. M., & McMurry, S. T. (2015). Land use effects on sedimentation and water storage volume in playas of the rainwater basin of Nebraska. *Land Use Policy*, *42*, 426—431.

Fiedler, A. K., Landis, D. A., & Arduser, M. (2012). Rapid shift in pollinator communities following invasive species removal. *Restoration Ecology*, *20*(5), 593—602.

Free, J. B. (1993). *Insect pollination of crops* (No. Ed. 2). Academic press.

Goulson, D., Hanley, M. E., Darvill, B., Ellis, J. S., & Knight, M. E. (2005). Causes of rarity in bumblebees. *Biological conservation*, *122*(1), 1—8.

Goulson, D., & Darvill, B. (2004). Niche overlap and diet breadth in bumblebees; are rare species more specialized in their choice of flowers? *Apidologie*, *35*(1), 55—63.

Grant, T. A., Flanders-Wanner, B., Shaffer, T. L., Murphy, R. K., & Knutsen, G. A. (2009). An emerging crisis across northern prairie refuges: prevalence of invasive plants and a plan for adaptive management. *Ecological Restoration*, *27*(1), 58—65.

Grosse, R. Re: “Number and ownership of Rainwater Basin wetlands”. Message to Cynthia Park. 13 August 2014. E-mail. Rainwater Basin Joint Ventures.

Hatfield, R. G., & LeBuhn, G. (2007). Patch and landscape factors shape community assemblage of bumble bees, Bombus spp. (Hymenoptera: Apidae), in montane meadows. *Biological Conservation*, *139*(1), 150—158.

Hatfield, R., Jepsen, S., Mader, E., Black, S. H., & Shephard, M. (2012). Conserving Bumble Bees: Guidelines for Creating and Managing Habitat for Americas Declining Pollinators. The Xerces Society for Invertebrate Corporation.

James, R., & Pitts-Singer, T. L. (2008). *Bee pollination in agricultural ecosystems*. Oxford University Press.

Jauker, F., Diekötter, T., Schwarzbach, F., & Wolters, V. (2009). Pollinator dispersal in an agricultural matrix: opposing responses of wild bees and hoverflies to landscape structure and distance from main habitat. *Landscape Ecology*, *24*(4), 547—555.

Jolivet, P. (2004). American Beetles. Vol. 2. Polyphaga: Scarabaeoidea through Curculionidae. *Florida Entomologist*, *87*(3), 422-—422.

Kearns, C. A., Inouye, D. W., & Waser, N. M. (1998). Endangered mutualisms: the conservation of plant-pollinator interactions. *Annual review of ecology and systematics*, *29*(1), 83—112.

Kremen, C., Williams, N. M., & Thorp, R. W. (2002). Crop pollination from native bees at risk from agricultural intensification. *Proceedings of the National Academy of Sciences*, *99*(26), 16812—16816.

Krewenka, K. M., Holzschuh, A., Tscharntke, T., & Dormann, C. F. (2011). Landscape elements as potential barriers and corridors for bees, wasps and parasitoids. Biological Conservation, 144(6), 1816—1825.

Kreyer, D., Oed, A., Walther-Hellwig, K., & Frankl, R. (2004). Are forests potential landscape barriers for foraging bumblebees? Landscape scale experiments with Bombus terrestris agg. and Bombus pascuorum (Hymenoptera, Apidae). *Biological Conservation*, *116*(1), 111—118.

Krochmal, C. (2016). Smartweeds and Knotweeds as Bee Plants. *Bee Cultur*e, *144*: 77—79.

Kual, R.B., Sutherland, D., Rolfsmeier, S. (2006). *The Flora of Nebraska.* Conservation and Survey Division, School of Natural Resources, Institute of Agriculture and Natural Resources. University of Nebraska, Lincoln.

Kuchler, A.W. (1964). Potential natural vegetation of the conterminous United States. New York City, NY, American Geographical Society.

LaGrange, T. (2005). *Guide to Nebraska's wetlands and their conservation needs*. Nebraska Game and Parks Commission.

Lindsay, D. L., Bailey, P., Lance, R. F., Clifford, M. J., Delph, R., & Cobb, N. S. (2011). Effects of a nonnative, invasive lovegrass on Agave palmeri distribution, abundance, and insect pollinator communities. *Biodiversity and Conservation*, *20*(13), 3251—3266.

Loose, J. L., Drummond, F. A., Stubbs, C., Woods, S., & Hoffmann, S. (2005). Conservation and management of native bees in cranberry. *Maine Agricultural and Forest Experiment Station Technical bulletin*, *191*, 1—27.

Luo, H. R., Smith, L. M., Allen, B. L., & Haukos, D. A. (1997). Effects of sedimentation on playa wetland volume. *Ecological Applications*, *7*(1), 247—252.

Main, A. R., Headley, J. V., Peru, K. M., Michel, N. L., Cessna, A. J., & Morrissey, C. A. (2014). Widespread use and frequent detection of neonicotinoid insecticides in wetlands of Canada's Prairie Pothole Region. PloS one, 9(3).

Michener, C. D. (2000). *The bees of the world* (Vol. 1). Johns Hopkins University press.

Morandin, L. A., Winston, M. L., Abbott, V. A., & Franklin, M. T. (2007). Can pastureland increase wild bee abundance in agriculturally intense areas? Basic and Applied Ecology, 8(2), 117-124.

Moroń, D., Szentgyörgyi, H., Wantuch, M., Celary, W., Westphal, C., Settele, J., & Woyciechowski, M. (2008). Diversity of wild bees in wet meadows: implications for conservation. *Wetlands*, *28*(4), 975—983.

National Research Council. (2007). *Status of pollinators in North America*. National Academies Press.

O'Connell, J. L., Johnson, L. A., Beas, B. J., Smith, L. M., McMurry, S. T., & Haukos, D. A. (2013). Predicting dispersal-limitation in plants: optimizing planting decisions for isolated wetland restoration in agricultural landscapes. *Biological conservation*, *159*, 343—354.

O'Toole, C. (1993). *Diversity of native bees and agroecosystems.* pp. 169—196.

Park, C.N, Overall, L.M., Smith, L.M., LaGrange, T., McMurry, S. (2017). Melittofauna and Other Potential Pollinators in Wetland and Uplands in South Central Nebraska (Insecta: Apoidea). *Zootaxa*, *4242*(2), 255—280.

Parker, F. D., Tepedino, V. J., & Bohart, G. E. (1981). Notes on the biology of a common sunflower bee, Melissodes (Eumelissodes) agilis Cresson. *Journal of the New York Entomological Society*, 43—52.

Potts, S. G., Biesmeijer, J. C., Kremen, C., Neumann, P., Schweiger, O., & Kunin, W. E. (2010). Global pollinator declines: trends, impacts and drivers. *Trends in ecology & evolution*, *25*(6), 345—353.

Schweiger, O., Musche, M., Bailey, D., Billeter, R., Diekötter, T., Hendrickx, F., ... & Dziock, F. (2007). Functional richness of local hoverfly communities (Diptera, Syrphidae) in response to land use across temperate Europe. *Oikos*, *116*(3), 461—472.

Skagen, S., Melcher, K., & Haukos, C. (2008). Reducing sedimentation of depressional wetlands in agricultural landscapes. *Wetlands, 28*(3), 594-604.

Slagle, M. W., & Hendrix, S. D. (2009). Reproduction of *Amorpha canescens* (Fabaceae) and diversity of its bee community in a fragmented landscape. *Oecologia*, *161*(4), 813—823.

Smith, L.M (2003). *Playas of the Great Plains*. Austin, TX, University of Texas Press.

Smith, L. M., & Haukos, D. A. (2002). Floral diversity in relation to playa wetland area and watershed disturbance. *Conservation Biology*, *16*(4), 964—974.

Smith, L. M., Haukos, D. A., McMurry, S. T., LaGrange, T., & Willis, D. (2011). Ecosystem services provided by playas in the High Plains: potential influences of USDA conservation programs. *Ecological Applications*, *21*(sp1).

Steffan-Dewenter, I., & Tscharntke, T. (1999). Effects of habitat isolation on pollinator communities and seed set. *Oecologia*, *121*(3), 432—440.

Stout, J. C., & Morales, C. L. (2009). Ecological impacts of invasive alien species on bees. *Apidologie*, *40*(3), 388—409.

Stutheit, R. G., Gilbert, M. C., Whited, P. W., & Lawrence, K. L. (2004). *A regional guidebook for applying the hydrogeomorphic approach to assessing wetland functions of rainwater basin depressional wetlands in Nebraska*. Corps of Engineers.

Svensson, B., Lagerlöf, J., & Svensson, B. G. (2000). Habitat preferences of nest-seeking bumble bees (Hymenoptera: Apidae) in an agricultural landscape. *Agriculture, Ecosystems & Environment*, *77*(3), 247—255.

Thomas, C. D. (2000). Dispersal and extinction in fragmented landscapes. *Proceedings of the Royal Society of London B: Biological Sciences*, *267*(1439), 139—145.

Tsai, J. S., Venne, L. S., McMurry, S. T., & Smith, L. M. (2007). Influences of land use and wetland characteristics on water loss rates and hydroperiods of playas in the Southern High Plains, USA. *Wetlands*, *27*(3), 683—692.

Turnbull, L. A., Crawley, M. J., & Rees, M. (2000). Are plant populations seed- limited? a review of seed sowing experiments. *Oikos*, 88(2), 225—238.

Walker, N. “Re: WRP Seeding Mixtures”. Message to Cynthia Park. 3 April 2017. E-mail. Natural Resource Conservation Service. Grand Island, NE.

USDA. (2009). Wetland Reserve Program: Final Programmatic Environmental Assessment. Natural Resource Conservation Service.

USDA. (2014). Agricultural Conservation Easement Program. Fact Sheet. Natural Resource Conservation Service.

USDA. (2015). USDA launches new conservation effort to aid monarch butterflies. News Release. Natural Resource Conservation Service. Retrieved 13 March 2017, from <https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/newsroom/releases/?cid=nrcseprd414821>

USFS. (2015). Pollinator-Friendly Best Management Practices for Federal Lands. Fact Sheet. United States Forest Service.

Van den Brink, P. J., & Ter Braak, C. J. (1999). Principal response curves: Analysis of time-dependent multivariate responses of biological community to stress. *Environmental Toxicology and Chemistry*, *18*(2), 138—148.

Van Der Heijden, M. G. (2004). Arbuscular mycorrhizal fungi as support systems for seedling establishment in grassland. Ecology letters, 7(4), 293-303.

Westerkamp, C. (1997). Keel blossoms: bee flowers with adaptations against bees. *Flora*, *192*(2), 125—132.

Westrich, P. (1996). Habitat requirements of central European bees and the problems of partial habitats. In *Linnean Society symposium series* (Vol. 18, pp. 1-16). Academic Press Limited.

Wilmer, P. (2011a). Why pollination is interesting. In: *Pollination and Floral Ecology.* Princeton University Press, Princeton, New Jersey. pp. 3—10.

Wilmer, P. (2011b). Pollination by bees. In: *Pollination and Floral Ecology.* Princeton University Press, Princeton, New Jersey. pp. 378—417.

Wilmer, P. (2011c). Generalist flowers and generalist visitors. In: *Pollination and Floral Ecology.* Princeton University Press, Princeton, New Jersey. pp. 288—303.

Zurbuchen, A., Landert, L., Klaiber, J., Müller, A., Hein, S., & Dorn, S. (2010). Maximum foraging ranges in solitary bees: only few individuals have the capability to cover long foraging distances. *Biological Conservation*, *143*(3), 669—676.

TABLES AND FIGURES

Table 4.1: Dates sampled within 2014 and 2015 as they correspond with the sampling period.

2014 Sampling Dates	Period	2015 Sampling Dates
March 31 - April 11	1	April 6 - April 17
April 14 - April 25	2	April 20 - May 1
April 28 - May 9	3	May 4 - May 15
May 12 - May 23	4	May 18 - May 29
May 26 - June 6	5	June 1 - June 12
June 9 - June 20	6	June 15 - June 26
June 23 - July 4	7	June 29 - July 10
July 7 - July 18	8	July 13 - July 24
July 21 - August 1	9	July 27 - August 7
August 4 - August 15	10	August 10 - August 21
August 18 - August 29	11	August 24 - Sept 4
Sept 1 - Sept 12	12	Sept 7 - Sept 18
Sept 15 - Sept 26	13	Sept 21 - Oct 2
Sept 29 - October 10	14	Oct 5 - Oct 16

Figure Legend

Figure 4.1. Canonical Correspondence Analysis of the dominant vegetation in 2014 and 2015 in both uplands and wetlands among different land uses in the Rainwater Basin of Nebraska. WRP is code for restored sites, Ag is code for sites located in crop fields, and Ref is code for reference condition standard.

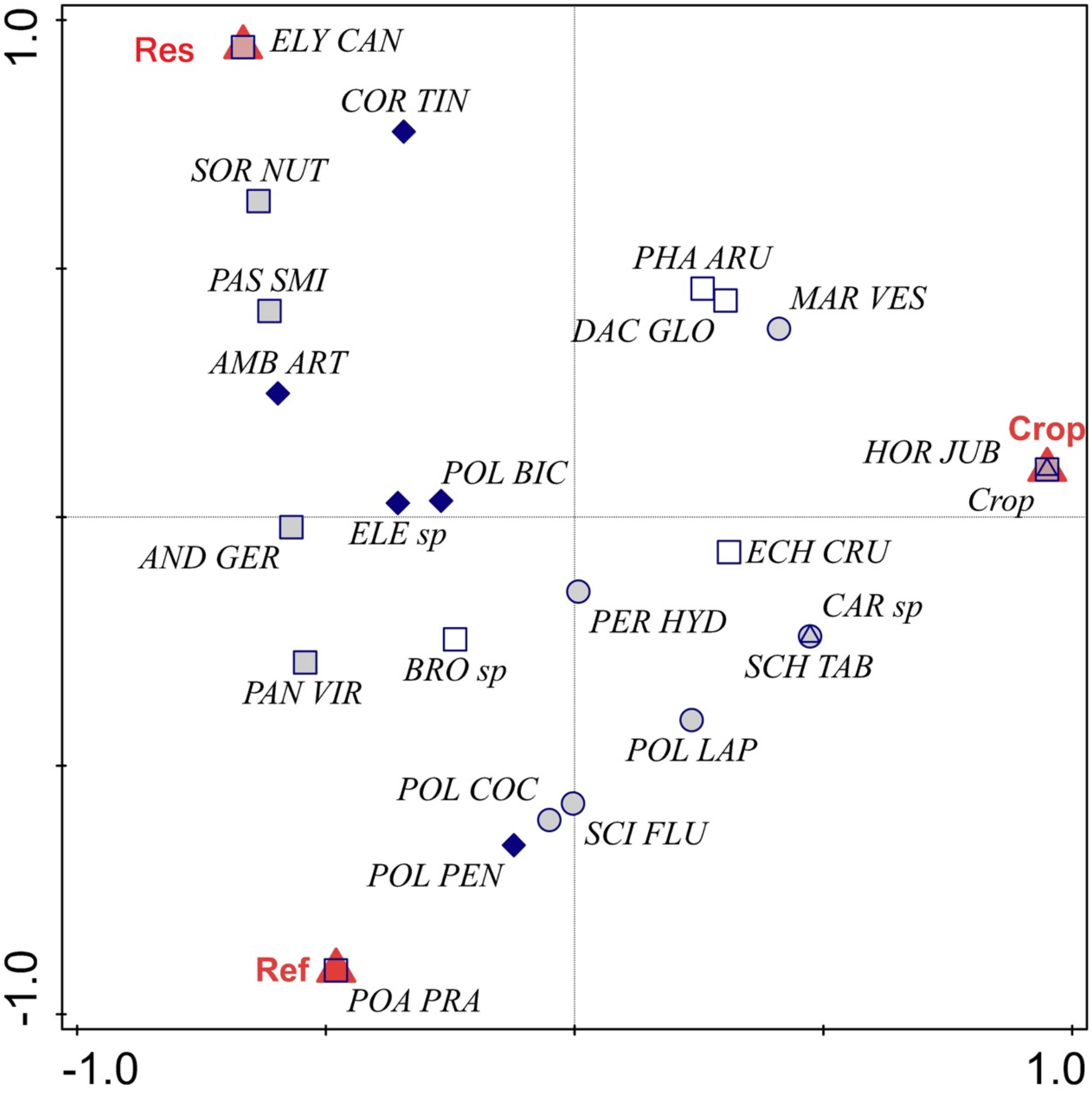
Figure 4.2. Canonical Correspondence Analysis of the dominant forbs in 2014 and 2015 in both uplands and wetlands among different land uses in the Rainwater Basin of Nebraska. WRP is code for restored sites, Ag is code for sites located in crop fields, and Ref is code for reference condition standard. Gray boxes represent perennial species. Black stars represent annual species. Gray circles represent shallow and deep-water perennial species.

Figure 4.3. Principal Response Curve with land use and landscape position combinations as treatments. The species response axis includes the most dominant pollinating insect families collected with insect nets in the Rainwater Basin: the bee families, Apidae and Halictidae, the fly family, Syrphidae, and the beetle family, Cantharidae. Res is code for restored WRP sites. Ag is code for sites located within crop fields. Ref is code for reference condition standard. The baseline for the PRC is restored uplands.

Figure 4.4. Principal Response Curve with the combinations land use and dominant forbs insects were found feeding on as treatments. The species response axis includes the most dominant pollinating insect families collected with insect nets in the Rainwater Basin: the bee families, Apidae and Halictidae, the fly family, Syrphidae, and the beetle family, Cantharidae. Res is code for restored WRP sites. Ag is code for sites located within crop

fields. Ref is code for reference condition. Smart is code for smartweeds. Aster is code for plants within the Asteraceae family. Other is code for all other plants, such as legumes, rose, and vervain. The baseline for the PRC is smartweeds located within reference sites.

Figure 4.1



1.0
-1.0
-1.0
1.0
Res
ELY CAN
COR TIN
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PAS SMI
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Crop
HOR JUB
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ECH CRU
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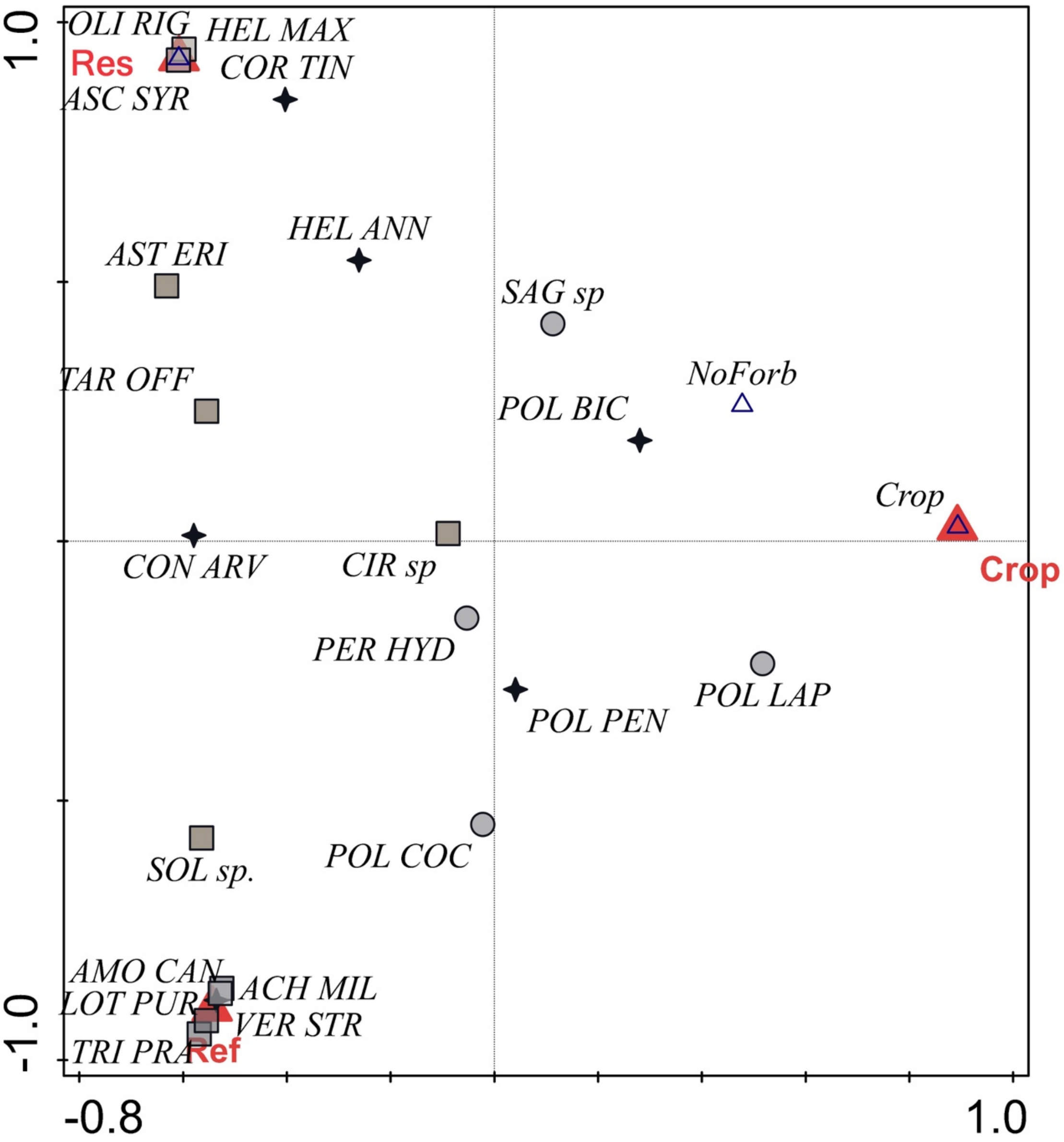
SCH TAB
BRO sp
PAN VIR
POL LAP
POL COC
SCI FLU
POL PEN
Ref
POA PRA

Figure 4.2



OLI RIG
HEL MAX
Res
COR TIN
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AST ERI
SAG sp
NoForb
TAR OFF
POL BIC
Crop
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CON ARV
CIR sp
PER HYD
POL LAP
POL PEN
SOL sp.
POL COC
AMO CAN
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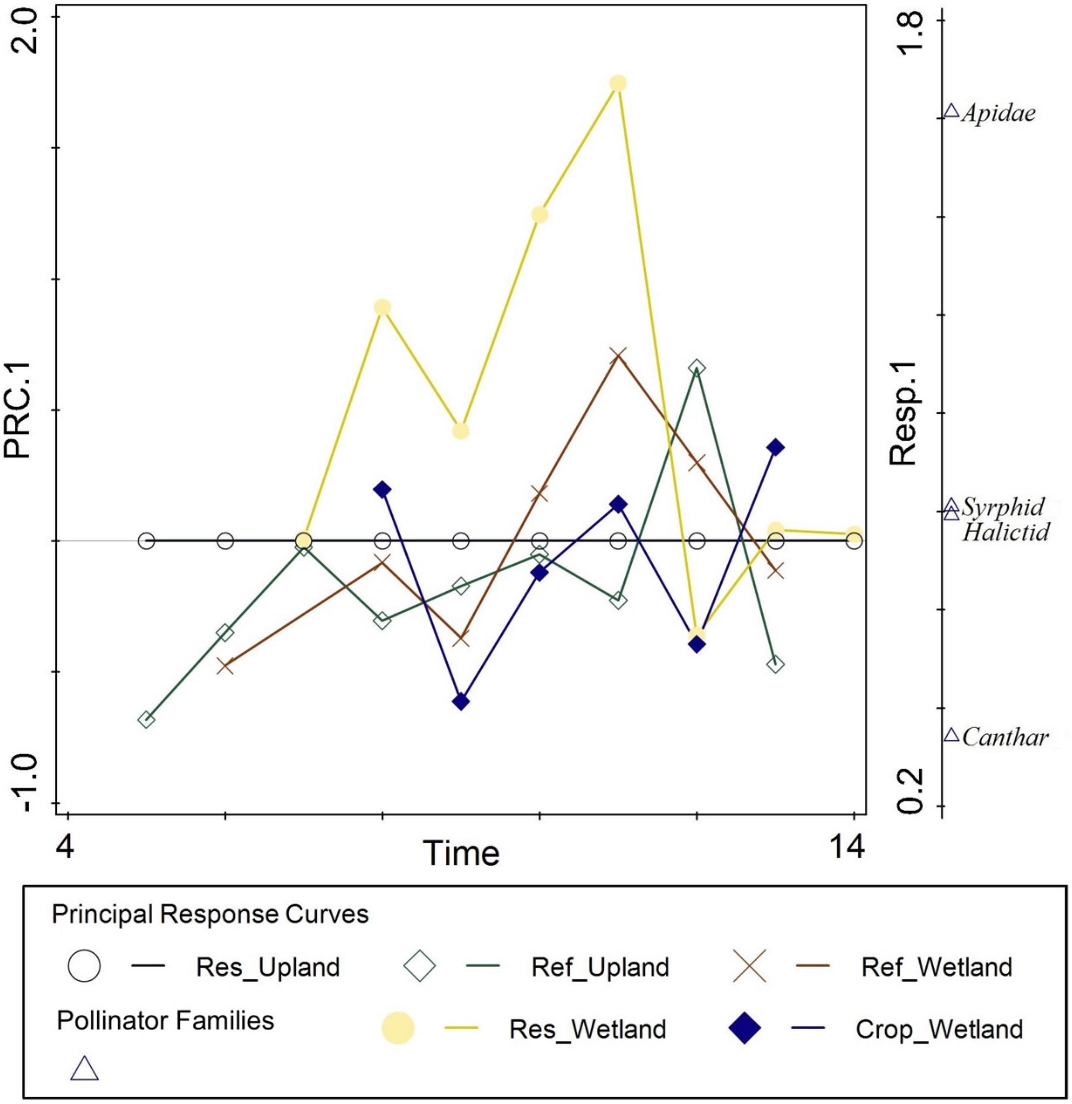
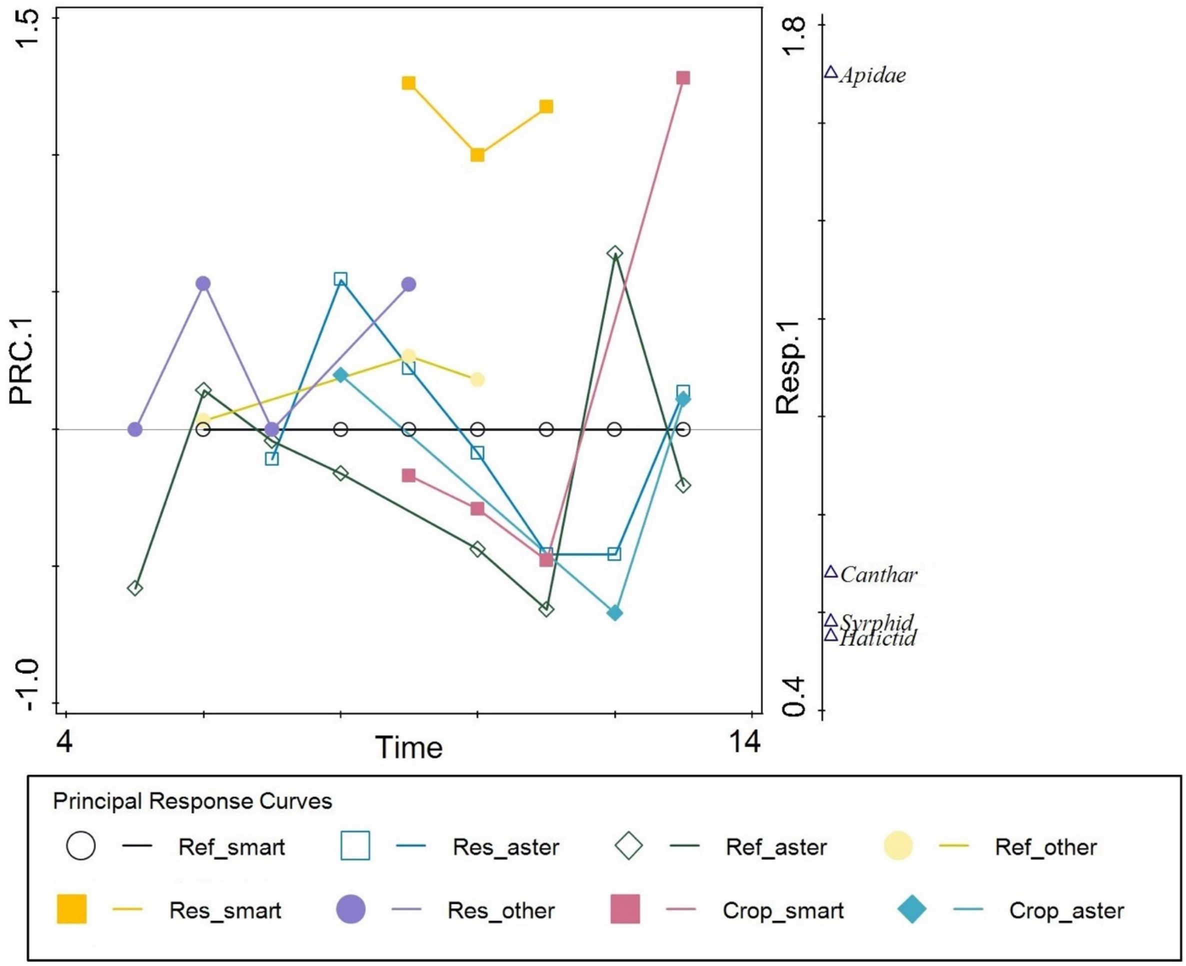
LOT PUR
VER STR
TRI PRA
Ref
1.0
-1.0
-0.8
1.0

Figure 4.3



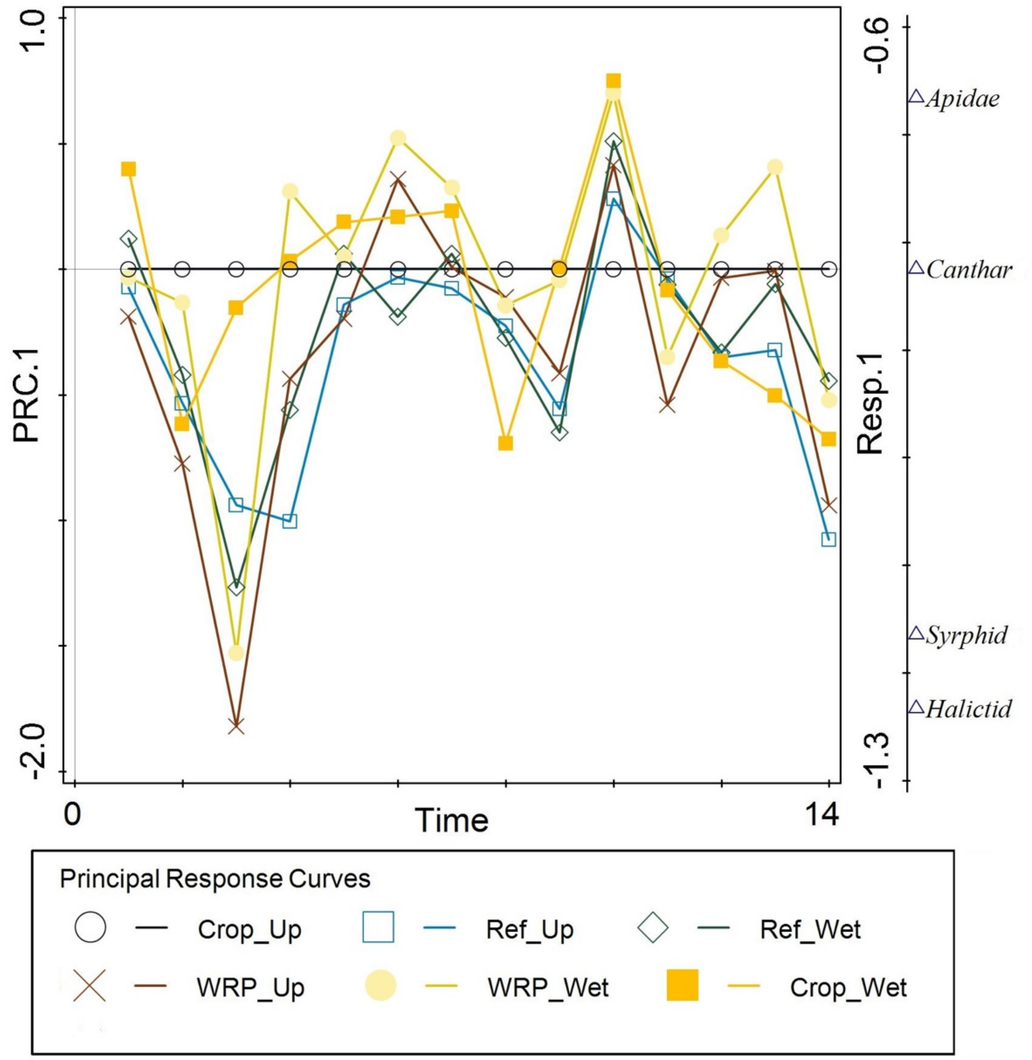
2.0
-1.0
1.8
0.2
PRC.1
Resp.1
Time
4
14
Apidae
Syrphid
Halictid
Canthar
Principal Response Curves
Res_Upland
Ref_Upland
Ref_Wetland
Pollinator Families
Res_Wetland
Crop_Wetland

Figure 4.4


1.5
-1.0
PRC.1
4
Time
14
1.8
0.4
Resp.1
Apidae
Canthar
Syrphid
Halictid
Principal Response Curves
Ref_smart
Res_aster
Ref_aster
Ref_other
Res_smart
Res_other
Crop_smart
Crop_aster

APPENDICES

4.1. Principal Response Curve for dominant pollinator families collected with blue vane traps in the Rainwater Basin region of Nebraska during 2014 and 2015.



4.2. Mesic seed mixture provided by the Natural Resource Conservation Service in Grand Island, NE. Seed mix lists are compiled by the Prairie Plains Resource Institute.

PPRI 2016-2017 Mesic Seed Mix (149 spp.)			
Grasses (20)			**WIS**
Andropogon	gerardii	Big Bluestem	FAC
Calamagrostis	stricta	Northern Reedgrass	FACW
Digitaria	cognata	Fall Witchgrass	SAND
Elymus	canadensis	Canada Wildrye	FACU
Elymus	trachycaulus	Slender Wheatgrass	FACU
Elymus	virginicus	Virginia Wildrye	FAC
Eragrostis	spectabilis	Purple Lovegrass	FACU
Hordeum	jubatum	Foxtail Barley	FACW
Hordeum	pusillum	Little Barley	FACU
Koeleria	macrantha	June Grass	UPL
Panicum	acuminatum	Tapered Rosette Grass	FACW
Panicum	oligosanthes	Scribner's Panicum	FACU
Panicum	virgatum	Switchgrass	FAC
Pascopyrum	smithii	Western Wheatgrass	FACU
Schizachyrium	scoparium	Little Bluestem	FACU
Sorghastrum	nutans	Indiangrass	FACU
Spartina	pectinata	Prairie Cordgrass	FACW
Sphenopholis	obtusata	Prairie Wedgegrass	FACW
Sporobolus	asper	Tall Dropseed	FACU
Tridens	flavus	Purpletop	UPL
Sedges/Rushes (21)			**WIS**
Carex	brachyglossa	Yellowfruit Sedge	FAC
Carex	brevior	Fescue Sedge	FAC
Carex	crawei	Crawe's Sedge	FACW
Carex	cristatella	Crested Sedge	FACW
Carex	gravida	Wetland Gravida	OBL
Carex	gravida	Heavy Sedge	UPL
Carex	laeviconica	Smooth Cone Sedge	OBL
Carex	mesochorea	Midland Sedge	UPL
Carex	molesta	Troublesome Sedge	FAC
Carex	molesta	Troublesome Sedge	FAC
Carex	pellita	Wooly Sedge	OBL
Carex	scoparia	Broom Sedge	FACW
Carex	tribuloides	Blunt Broomsedge	FACW
Carex	vulpinoidea	Fox Sedge	OBL
Fimbristylis	puberula	Hairy Fimbry	OBL
Juncus	dudleyi	Dudley Rush	FACW
Juncus	interior	Interior Rush	FAC

Juncus	tenuis	Tenuis Rush	FAC
Schoenoplectus	pungens	Common Threesquare	OBL
Scirpus	pallidus	Pale Bulrush	OBL
Scirpus	pendulus	Rufous Bulrush	OBL
Legumes (17)			**WIS**
Amorpha	canescens	Leadplant	UPL
Astragalus	canadensis	Canada Milkvetch	FACU
Cassia	chamaecrista	Partridge Pea	FACU
Dalea	candidum	White Prairieclover	UPL
Dalea	leporina	Foxtail Dalea	FACU
Dalea	purpurea	Purple Prairieclover	UPL
Desmanthus	illinoensis	Illinois Bundleflower	FACU
Desmodium	canadense	Canada Tickclover	FAC
Desmodium	canescens	Hoary Tickclover	UPL
Desmodium	illinoense	Illinois Tickclover	UPL
Glycyrrhiza	lepidota	Wild licorice	FACU
Lespedeza	capitata	Roundhead Bushclover	UPL
Lotus	purshianus	Deervetch	FAC
Psoralea	argophylla	Silver-leaf Scurf Pea	UPL
Psoralea	tenuiflora	Wild Alfalfa	UPL
Schrankia	nuttallii	Sensitivebriar	UPL
Strophostyles	leiosperma	Wild Bean	UPL
Composites (46)			**WIS**
Achillea	millefolium	Yarrow	FACU
Arnoglossum	plantagineum	Pale Indian Plantain	FACU
Artemisia	ludoviciana	Sagewort	FACU
Aster	ericoides	Heath Aster	FAC
Aster	novae-angliae	New England Aster	FACW
Aster	prealtus	Blue Willowleaf Aster	FACW
Aster	simplex	Tall White Aster	FACW
Boltonia	asteroides	False Aster	FACW
Brickellia	eupatoroides	False Boneset	UPL
Cirsium	altissimum	Tall Thistle	FAC
Cirsium	flodmanii	Flodman Thistle	FAC
Coreopsis	tinctoria	Plains Correopsis	FAC
Echinacea	angustifolia	Purple Coneflower	UPL
Erigeron	philadelphicus	Marsh Fleabane	FAC
Erigeron	strigosus	Daisy Fleabane	FACW
Eupatorium	altissimum	Tall Joe Pye Weed	FACU
Euthamia	graminifolia	Grassleaf Goldenrod	FACW
Gnaphalium	obtusifolium	Fragrant Cudweed	UPL
Grindelia	squarrosa	Gumweed	FACU

Helenium	autumnale	Sneezeweed	FACW
Helianthus	grosseserratus	Sawtooth Sunflower	FACW
Helianthus	maximilianii	Maximillian Sunflower	UPL
Helianthus	rigidus	Stiff Sunflower	UPL
Helianthus	tuberosus	Jerusalem Artichoke	FAC
Heliopsis	helianthoides	False Sunflower	FACU
Hieracium	longipilum	Longbeard Hawkweed	UPL
Iva	annua	Small Marsh Elder	FAC
Lactuca	canadensis	Canada Lettuce	FACU
Lactuca	ludoviciana	Wild Lettuce	FAC
Liatris	lancifolia	Thickspike Gayfeather	FACW
Liatris	punctata	Dotted Gayfeather	UPL
Prenathes	aspera	Rough Rattlesnake Root	UPL
Ratibida	columnifera	Upright Prairie Coneflower	UPL
Rudbeckia	hirta	Black-eyed Susan	FACU
Rudbeckia	laciniata	Cutleaf Coneflower	FAC
Senecio	plattensis	Prairie Ragwort	FACU
Silphium	integrifolium	Entire-leaf Rosinweed	FACU
Silphium	laciniatum	Compass Plant	UPL
Silphium	perfoliatum	Cup Plant	FAC
Solidago	canadensis	Canada Goldenrod	FACU
Solidago	gigantea	Giant Goldenrod	FACW
Solidago	missouriensis	Missouri Goldenrod	UPL
Solidago	rigida	Stiff Goldenrod	FACU
Solidago	speciosa	Showy Goldenrod	UPL
Vernonia	baldwinii	Western Ironweed	FACW
Vernonia	fasciculata	Ironweed	FAC
Misc. Forbs (45)			**WIS**
Allium	canadense	Canada Garlic (Sets)	FAC
Allium	canadense	Canada Garlic (Seed)	FAC
Anemone	canadensis	Meadow Anemone	FACW
Anemone	cylindrica	Candle Anemone	UPL
Apocynum	cannabinum	Prairie Dogbane	FAC
Asclepias	speciosa	Showy Milkweed	FAC
Asclepias	sullivantii	Sullivant's Milkweed	FAC
Asclepias	syriaca	Common Milkweed	FAC
Asclepias	verticillata	Whorled Milkweed	FACU
Callirhoe	alcaeoides	Pale Poppy Mallow	UPL
Callirhoe	involucrata	Purple Poppy Mallow	UPL
Calylophus	serrulatus	Serrate-leaf Primrose	UPL
Euphorbia	marginata	Snow-On-The-Mountain	FACU
Gaura	parviflora	Velvety Guara	UPL

Gentiana	puberulenta	Downy Gentian	UPL
Linum	sulcatum	grooved Flax	UPL
Lobelia	siphilitica	Blue Cardinal Flower	OBL
Lobelia	spicata	Palespike Lobelia	FAC
Mirabilis	nyctaginea	Wild Four O'clock	UPL
Monarda	fistulosa	Wild Bergamot	FACU
Oenothera	villosa	Common Evening Primrose	FAC
Onosmodium	molle	Marbleseed	FACU
Penstemon	digitalis	Smooth Penstemon	FAC
Penstemon	gracilis	Slender Penstemon	FACU
Penstemon	grandiflorus	Shell-leaf Penstemon	UPL
Physalis	longifolia	Common Ground-cherry	UPL
Plantago	patagonica	Wooly Plantain	UPL
Polygonum	pensylvanicum	Pennsylvania smartweed	FACW
Polytaenia	nuttallii	Prairie Parsley	FACU
Potentilla	arguta	Prairie Cinquefoil	FAC
Potentilla	norvegica	Norwegian Cinquefoil	FACU
Prunella	vulgaris	Self-heal	FACW
Pycnanthemum	virginianum	Mountain Mint	FAC
Rosa	arkansana	Wild Rose	FACU
Rosa	woodsii	Wood's Rose	FACU
Salvia	azurea	Pitcher Sage	UPL
Sisyrinchium	campestre	Prairie Blue-eyed Grass	UPL
Sisyrinchium	montanum	Strict Blue-eyed Grass	FAC
Teucrium	canadense	American Germander	FACW
Thalictrum	dasycarpum	Purple Meadow Rue	FACW
Tradescantia	bracteata	Bracted Spiderwort	FAC
Verbena	hastata	Blue Vervain	FACW
Verbena	stricta	Hoary Vervain	UPL
Verbena	urticifolia	Elm-leaf Verbena	UPL
Symphoricarpos	orbiculatus	Coralberry	FACU

4.3. Wetland seed mixture provided by the Natural Resource Conservation Service in Grand Island, NE. Seed mix lists are compiled by the Prairie Plains Resource Institute.

PPRI 2016-2017 Wetland Seed Mix (139 spp.)			
Grasses (15)			**WIS**
Alopecurus	aequalis	Shortawn Foxtail	OBL
Calamagrostis	canadensis	Bluejoint	OBL
Calamagrostis	stricta	Northern Reedgrass	FACW
Elymus	trachycaulus	Slender Wheatgrass	FACU
Elymus	virginicus	Virginia Wildrye	FAC
Glyceria	grandis	Large Manna Grass	OBL
Glyceria	striata	Manna grass	OBL
Hordeum	jubatum	Foxtail Barley	FACW
Leersia	oryzoides	Rice Cut Grass	OBL
Muhlenbergia	racemosa	Marsh Muhly	FACW
Panicum	acuminatum	Tapered Rosette Grass	FACW
Panicum	oligosanthes	Scribner's Panicum	FACU
Pascopyrum	smithii	Western Wheatgrass	FACU
Spartina	pectinata	Prairie Cordgrass	FACW
Sphenopholis	obtusata	Prairie Wedgegrass	FACW
Sedges/Rushes (34)			**WIS**
Carex	bebbii	Bebb's Sedge	OBL
Carex	brachyglossa	Yellowfruit Sedge	FAC
Carex	brevior	Fescue Sedge	FAC
Carex	crawei	Crawe's Sedge	FACW
Carex	cristatella	Crested Sedge	FACW
Carex	emoryi	Emory's Sedge	OBL
Carex	gravida	Heavy Sedge	UPL
Carex	gravida	Wetland Gravida	OBL
Carex	hystericina	Bottlebrush Sedge	OBL
Carex	interior	Interior Sedge	OBL
Carex	laeviconica	Smooth Cone Sedge	OBL
Carex	molesta	Troublesome Sedge	FAC
Carex	pellita	Wooly Sedge	OBL
Carex	praegracilis	Clustered Field Sedge	FACW
Carex	sartwellii	Sartwell's Sedge	OBL
Carex	scoparia	Broom Sedge	FACW
Carex	stipata	Saw-beak Sedge	OBL
Carex	tribuloides	Blunt Broomsedge	FACW
Carex	vulpinoidea	Fox Sedge	OBL
Eleocharis	palustris	Common Spikerush	OBL
Eleocharis	erythropoda	Bald Spikerush	OBL

Fimbristylis	puberula	Hairy Fimbry	OBL
Juncus	balticus	Baltic Rush	FACW
Juncus	dudleyi	Dudley Rush	FACW
Juncus	interior	Interior Rush	FAC
Juncus	marginatus	Grassleaf Rush	FACW
Juncus	tenuis	Tenuis Rush	FAC
Juncus	torreyi	Torrey's Rush	FACW
Schoenoplectus	acutus	Chairmaker's Rush	OBL
Schoenoplectus	pungens	Common Threesquare	OBL
Scirpus	atrovirens	Dark Green Bulrush	OBL
Scirpus	maritimus	Prairie Bulrush	OBL
Scirpus	pallidus	Pale Bulrush	OBL
Scirpus	pendulus	Rufous Bulrush	OBL
Legumes (6)			**WIS**
Astragalus	canadensis	Canada Milkvetch	FACU
Cassia	chamaecrista	Partridge Pea	FACU
Dalea	leporina	Foxtail Dalea	FACU
Desmanthus	illinoensis	Illinois Bundleflower	FACU
Glycyrrhiza	lepidota	Wild licorice	FACU
Lotus	purshianus	Deervetch	FAC
Composites (32)			**WIS**
Achillea	millefolium	Yarrow	FACU
Aster	ericoides	Heath Aster	FAC
Aster	novae-angliae	New England Aster	FACW
Aster	prealtus	Blue Willowleaf Aster	FACW
Aster	simplex	Tall White Aster	FACW
Bidens	comosa	Threelobe Beggarticks	OBL
Boehmeria	cylindrica	False Nettle	OBL
Boltonia	asteroides	False Aster	FACW
Coreopsis	tinctoria	Plains Correopsis	FAC
Erigeron	philadelphicus	Marsh Fleabane	FAC
Erigeron	strigosus	Daisy Fleabane	FACW
Eupatorium	maculatum	Spotted Joe Pye Weed	OBL
Eupatorium	perfoliatum	Boneset	OBL
Euthamia	graminifolia	Grassleaf Goldenrod	FACW
Grindelia	squarrosa	Gumweed	FACU
Helenium	autumnale	Sneezeweed	FACW
Helenium	autumnale	Sneezeweed (Fertig)	FACW
Helianthus	grosseserratus	Sawtooth Sunflower	FACW
Helianthus	tuberosus	Jerusalem Artichoke	FAC
Iva	annua	Small Marsh Elder	FAC
Lactuca	canadensis	Canada Lettuce	FACU
Lactuca	ludoviciana	Wild Lettuce	FAC

Liatris	lancifolia	Thickspike Gayfeather	FACW
Ratibida	columnifera	Upright Prairie Coneflower	UPL
Rudbeckia	hirta	Black-eyed Susan	FACU
Rudbeckia	laciniata	Cutleaf Coneflower	FAC
Senecio	plattensis	Prairie Ragwort	FACU
Silphium	integrifolium	Entire-leaf Rosinweed	FACU
Silphium	perfoliatum	Cup Plant	FAC
Solidago	canadensis	Canada Goldenrod	FACU
Solidago	gigantea	Giant Goldenrod	FACW
Vernonia	fasciculata	Ironweed	FAC
Misc. Forbs (52)			**WIS**
Agalinis	tenuifolia	Slender False Foxglove	FACW
Alisma	trivale	American Water Plantain	OBL
Allium	canadense	Canada Garlic (Sets)	FAC
Allium	canadense	Canada Garlic (Seed)	FAC
Ammania	coccinea	Tooth Cup	OBL
Anemone	canadensis	Meadow Anemone	FACW
Anemone	cylindrica	Candle Anemone	UPL
Apocynum	cannabinum	Prairie Dogbane	FAC
Asclepias	incarnata	Swamp Milkweed	OBL
Asclepias	speciosa	Showy Milkweed	FAC
Asclepias	sullivantii	Sullivant's Milkweed	FAC
Asclepias	syriaca	Common Milkweed	FAC
Asclepias	verticillata	Whorled Milkweed	FACU
Epilobium	coloratum	Cinnamon Willow Herb	OBL
Gentiana	andrewsii	Bottle Gentian	FAC
Impatiens	capensis	Spotted Touch-me-not	FACW
Lippia	lanceolata	Fog Fruit	OBL
Lobelia	cardinalis	Cardinal Flower	OBL
Lobelia	siphilitica	Blue Cardinal Flower	OBL
Lobelia	spicata	Palespike Lobelia	FAC
Lycopus	americanus	American Bugleweed	OBL
Lycopus	asper	Rough Bugleweed	OBL
Lysimachia	ciliata	Fringed Loosestrife	FACW
Lythrum	alatum	Winged Lythrum	OBL
Mentha	arvensis	Field Mint	FACW
Oenothera	villosa	Common Evening Primrose	FAC
Penstemon	digitalis	Smooth Penstemon	FAC
Penstemon	gracilis	Slender Penstemon	FACU
Penthorum	sedoides	Ditch Stonecrop	OBL
Physalis	longifolia	Common Ground-cherry	UPL
Polygonum	coccineum	Swamp Smartweed	FACW
Polygonum	hydropiperoides	Mild Water Pepper	OBL
Polygonum	lapathifolium	Pale Smartweed	OBL

Polygonum	pensylvanicum	Pennsylvania smartweed	FACW
Polytaenia	nuttallii	Prairie Parsley	FACU
Potentilla	arguta	Prairie Cinquefoil	FAC
Potentilla	norvegica	Norwegian Cinquefoil	FACU
Prunella	vulgaris	Self-heal	FACW
Pycnanthemum	virginianum	Mountain Mint	FAC
Ranunculus	sceleratus	Cursed Crowfoot	OBL
Sagittaria	brevirostra	Shortbeak Arrowhead	OBL
Sagittaria	calycina	Hooded Arrowhead	OBL
Sagittaria	latifolia	Broadleaf Arrowhead	OBL
Scutellaria	galericulata	Marsh Skullcap	OBL
Sisyrinchium	montanum	Strict Blue-eyed Grass	FAC
Teucrium	canadense	American Germander	FACW
Thalictrum	dasycarpum	Purple Meadow Rue	FACW
Tradescantia	bracteata	Bracted Spiderwort	FAC
Tradescantia	occidentale	Western Spiderwort	SAND
Verbena	hastata	Blue Vervain	FACW
Verbena	stricta	Hoary Vervain	UPL
Verbena	urticifolia	Elm-leaf Verbena	UPL

VITA

Cynthia N. Park

Candidate for the Degree of

Master of Science

Thesis: EVALUATING HOW WETLAND PRESENCE AND RESTORATION EFFECTS LANDSCAPE AND RESOURCE USE OF POLLINATOR COMMUNITIES IN AN AGRICULTURAL MATRIX

Major Field: Zoology

Biographical:

Education: Graduated from Edison Preparatory High School, Tulsa, OK, May 2008; Associates of Science degree from Tulsa Community College, Tulsa, OK, December 2010; Bachelor of Science in Natural Resource Ecology and Management from Oklahoma State University, Stillwater, OK, May 2013; completed the requirements for the Master of Science in Zoology at Oklahoma State University, Stillwater, OK, July 2017.

Experience: Graduate Research Assistant, Oklahoma State University, 2014-2017. Graduate Teaching Assistant, Oklahoma State University, Spring 2017: Invertebrate Zoology. Biological Science Technician, Nantucket Conservation Foundation, 2013. Biological Science Technician, Oklahoma State University, 2012-2013. Biological Science Technician, USDA Agricultural Research Station, 2012. Student Temporary Employment Program Biologist, U.S. Fish and Wildlife Service, 2010-2012.