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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

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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

by

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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

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Insect pollination is an essential ecosystem service, and bees are the principal pollinators of wild and cultivated plants. Habitat management and enhancement are a proven way to encourage wild bee populations, providing them with food and nesting resources. I examined bee diversity and abundance in plots managed by *The Nature Conservancy* near Wood River, NE. The plots were seeded with 2 seed mixes at 2 seeding rates: high diversity mix at the recommended rate, high diversity mix double the recommended rate, Natural Resources Conservation Service (NRCS) conservation planting (CP) 25 mix at one-half the recommended rate, and NRCS CP25 mix at the recommended rate. I measured wild bee abundance and diversity, and established a database of wild bees associated with the plots. I also compared genus richness and abundance among the plots using and aerial net and blue vane traps to collect bees. Significant differences were not observed in genus richness and diversity among the plots; however, plot size and the ability of blue vane traps to draw bees from a long distance may have influenced my results. In 2008, 15 genera and 95 individual bees were

collected using an aerial net and in 2009, 32 genera and 6,103 individual bees were collected using blue vane traps.

I also studied the beneficial insects associated with native Nebraska flora. Seventeen species of native, perennial flora were established in 3 separate plots located in eastern Nebraska. I transplanted four plants of each species in randomized 0.61 m x 0.61 m squares of a 3.05 m x 9.14 m plot. Arthropods were sampled using a modified leaf blower/vacuum. Insects and other arthropods were identified to family and organized into groups of predators, parasites, pollinators, herbivores, and miscellaneous. Associations between plant species and families of beneficial arthropods (predators, parasites, and pollinators) were made. *Pycnanthemum flexuosum* Walter attracted significantly more beneficial arthropod families than 7 other species of plants tested. *Dalea purpurea* Vent and *Liatris punctata* Hook also attracted significantly fewer beneficial arthropod families than 4 other species of plants tested. In total, 31 predator, 11 parasitic, 4 pollinator, 31 herbivore, and 10 miscellaneous families of arthropods were recorded.

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Literature Review

Pollination and Pollinators

Pollination is the transfer of pollen from the anther of one flower to the stigma of the same or another flower (Proctor, Yeo et al. 1996). Abiotic factors such as wind and water and biotic factors such as birds, mammals, and insects, are means by which pollen is transferred. It is estimated that pollen transferred by animal vectors accounts for 90% of the pollination occurring in flowering plants worldwide (Buchmann and Nabhan 1996; Kearns et al. 1998). Insect pollination is an essential ecosystem service, and bees (Hymenoptera: Apoidea) are the principal pollinators of both wild and cultivated plants. Globally, insect pollination is estimated to contribute 67% of the biotic pollination requirements of plants. Plant diversity and pollinator diversity in a community are related (Potts et al. 2003).

Flower visitors range from generalist to specialist, and some of these visitors gather nutrients from the plants without aiding the pollination process (Roubik 1989). Pollinators, most importantly bees, are necessary for plant reproduction, and they are a fundamental part of a food web (Kearns et al. 1998). Bees are the most efficient insect pollinator for most plants because of their branched body hair, foraging behaviors and abilities, and their reliance on floral resources for raising their offspring (Free 1993). Bees transfer pollen from flower to flower and from plant to plant. Their foraging increases pollen movement for cross pollination (James and Pitts-Singer 2008).

Populations of wild pollinators have declined due to factors such as habitat loss and fragmentation (Kearns et al. 1998), intensive agriculture (Klein et al. 2007), introduced species (Goulson 2003), and pesticide use (Kearns et al. 1998). A decline in pollinator populations, especially bees, would be disastrous not only for the insect populations, but for humans as well (Shepherd et al. 2003).

The diversity of plant species, especially forbs, is correlated with the diversity of insects present (Fontaine et al. 2006). The abundance of any one wild insect species can vary greatly from year to year. Consequently, a diversity of species is needed to provide a robust pollinator resource (Kearns et al. 1998). Plants provide resources attractive to pollinators which results in pollen movement. Moving pollen optimizes seed production while the bees gain food resources in the form of pollen and/or nectar. Reduction in plant fitness and populations can be related to the lack of pollinators in an area. Measures of plant fitness that can be affected include lowered or absent seed set, non-viable seed, and inbreeding depression (Reed 2002). Pollination of wildflowers is important to maintain plant diversity as these plants offer food resources for birds and other wildlife. Bees are important to plant communities because they keep them vigorous and able to reproduce (Shepherd et al. 2003).

Honey Bees

Honey bees (*Apis melifera* L.) alone are responsible for pollinating plants that make up approximately 30% of the human diet (McGregor 1976). For U.S. agriculture, the estimated value of crop pollination services provided by honey bees was $14.6 billion in 2000 (Morse and Calderone 2000). Recently, honey bee health issues have resulted in

colony losses and thus reduced their availability for crop pollination (Ellis 2008). The concern for honey bee conservation grew with the detection of tracheal mites in 1984 and varroa mite in 1987 (Anonymous 1987). A dramatic decrease of honey bee colonies, especially wild honey bee colonies was noticed in 1994 (Watanabe 1994). Many national and international organizations were formed to promote pollinator conservation. These groups focused on honey bees initially. With on-going honey bee health problems, the need for pollinator diversity has been apparent, and wild bees (all non- *Apis* bees) have become a major focus for pollinator conservation.

Honey bees are considered one of the most valuable pollinators in agriculture (Kevan 1999). They are polylectic and pollinate many plant species, but it is becoming evident that reliance on them for all pollination may no longer be sufficient. Honey bees are not able to pollinate some flowers due to nectar chemistry, flowering phenology, floral morphology, and body size (Kearns and Inouye 1997). There is also concern that they may compete with wild bees and reduce their populations (Goulson 2003). Wild bees are receiving more attention for their pollination services due to the reduced availability of honey bee colonies (Winfree et al. 2007). It is reported that non-managed wild bees are responsible for an estimated $3.07 billion in pollination each year to crops (Losey and Vaughan 2006). The pollination services provided by wild bees are considered "free" because investments of money and effort are not always necessary to benefit from their services. Unfortunately, these bees are not as well studied as honey bees and little is known about their biology. Wild bees are essential to the diversity of natural habitats, and their abundance can play a key role in crop production (Winfree et al. 2007).

Wild Bee Diversity

Wild bees are diverse in appearance and behavior. They range in color from dull brown and black to brilliant blues and greens, and they vary in length from about a sixteenth of an inch to more than an inch (Shepherd et al. 2003). The most important traits used in identifying bees to family are tongue length, wing venation, and how they transport pollen. There are seven families of bees (Michener 2000).

Wild bees have various foraging strategies. Oligolectic bees forage on only a few plant species and are efficient pollinators of them. Bees that seek out and forage only a few plants do so because their pollen and nectar is highly nutritious and provides a complete diet. Polylectic bees are generalist feeders and forage on many different plant species (Shepherd et al. 2003). Bees that are generalists adapt to a change in plant diversity more readily than specialists. A change in plant community structure can be detrimental for a population of specialist feeders.

Some wild bee females parasitize the nests of others and use the food provisioned by the host to rear her offspring (Shepherd et al. 2003). These bees are referred to as cleptoparasitic bees and are parasites on other solitary bees and bees with lower levels of sociality. About one-quarter of all bee species are parasitic. The egg of cleptoparasitic bees hatches and kills the host egg or larva. The parasitic larva feeds and develops in the host nest and typically emerges as an adult after the unparasitized host offspring (cleptoparasitic bee eggs are laid after the nest is established) (Shepherd et al. 2003).

The majority of wild bees are solitary and a few exhibit different levels of social behavior. Solitary wild bees make up about two-thirds of the bee species. They have minimal social interactions, and males and females only interact to mate (Shepherd et al.

2003). Some solitary wild bees will form aggregations and nest in nearby suitable substrates (James and Pitts-Singer 2008). The next level of sociality is communal nesting which involves two or more females sharing a nest entrance, each has her own group of brood cells within the nest (O'Toole and Raw 1991). Communal nesting females do not cooperate and only tolerate a shared nest entrance. Circumstances such as limited suitable nesting substrate drives some bees to share nest entrances while others always exhibit this behavior.

Quasisocial bees share a communal nest and cooperate in the provisioning of brood cells. This level of sociality is less commonly observed and may be a developmental nesting stage in colonies of bees with higher levels of sociality (O'Toole and Raw 1991). The next levels include subsocial and primitively eusocial behavior where maternal care is exhibited. Subsocial bees are a family group of a female and her offspring. The female will guard her eggs, feed the larvae progressively when they hatch, and will usually die when they become adults (O'Toole and Raw 1991). Primitively eusocial colonies are founded by a single female and have two or more generations that function as workers. Reproductive offspring are then reared and mated females are the only colony members that survive to the next season (James and Pitts-Singer 2008). Eusocial behavior is the highest level of sociality. Characteristics of eusocial bees include cooperative brood care, a division of labor, and overlapping generations (Brady et al. 2006).

About two-thirds of all solitary bee species nest in the ground. Female solitary bees build their nests and provide food for their offspring alone (James and Pitts-Singer 2008). Nests are generally lined and partitioned with materials such as mud, leaves, plant

resin, and glandular secretions. These linings protect the brood from desiccation, disease, and excess moisture (Shepherd et al. 2003). The female provisions her eggs with a brood ball consisting of a mixture of pollen and nectar. Pollen is a source of protein (16-60%), fats, starches, sugar, phosphates, vitamins, and sterols (James and Pitts-Singer 2008). Nectar is mainly composed of sugar (15-75%) and water, but it also contains amino acids, proteins, organic acids, phosphates, vitamins, and enzymes (James and Pitts-Singer 2008). Nectar is a floral reward and attracts pollinators. The larvae are able to complete their development on the provisions stored by their mother. Solitary bee species have variable development periods, and they typically survive as adults for 1 to 3 weeks. The larvae go through 4 to 5 instars before spinning a cocoon and becoming a prepupa (Shepherd et al. 2003). The time spent as a prepupa and then pupa vary by species. Some wild bees are multivoltine. Other bees may take a year or more between generations. Growth and development are triggered by environmental cues such as day length and winter and spring temperatures so that the adult bees emerge when the flowers they visit are in bloom (James and Pitts-Singer 2008).

Crop Production and Wild Bees

Wild bees play an important role in crop pollination. They efficiently pollinate plants that are not efficiently pollinated by managed pollinators, they enhance pollination by managed pollinators, they can substitute for the pollination services provided by managed pollinators, and they enhance productivity of self-pollinating plants (James and Pitts-Singer 2008). Some wild bees are more efficient pollinators than honey bees of specific crops. Crop plants more efficiently pollinated by wild bees include alfalfa,

blueberries, and cranberries. Bumble bees (*Bombus* spp.) are important blueberry and tomato pollinators because they have the ability to buzz-pollinate. Buzz pollination happens when a bee, such as a bumble bee, lands on the flower and vibrates it's thoracic muscles to release the pollen from the anthers. The flowers of these plants need to be shaken to release pollen from the closed anthers and bumble bees are the only bee species that exhibit the suite of behaviors required for their pollination (Tuell et al. 2009). Bumble bees also play an important role in natural landscapes, because they are able to pollinate certain flowers better than other bees due to their size and long tongue. The alfalfa leafcutter bee (*Megachile rotundata*) and the alkali bee (*Nomia melanderi*) are efficient pollinators of alfalfa. Alfalfa flowers need to be tripped to release the pollen and expose the stigma. When leafcutter or alkali bees visit the flower they release the pressure on the interlocking keel petals which allow the fused reproductive column to snap upward depositing pollen on the bee (Frank 2003). They are efficient pollinators of alfalfa, because they forage from the center of the flower causing it to trip. In contrast, honey bees learn to gather nectar without tripping the flowers by foraging for nectar from the side of the flower (James and Pitts-Singer 2008).

Crop plants bloom for a short window of time. Many wild bees that contribute to pollination require forage sources outside of the crop bloom period (Tuell et al. 2008). Natural landscapes adjacent to crop fields provide floral resources all season and are important to the sustainability of wild bee populations. Creating areas of flowering plants will conserve pollinators and improve crop pollination (Tuell et al. 2008). Areas of floral resources also provide both wild and managed bees a refuge from pesticides that are applied to crops (James and Pitts-Singer 2008). Most wild bees have a smaller foraging

radius than honey bees, and their foraging distances frequently correlate with their body size (Gathmann and Tscharntke 2002). Therefore, it is important that foraging and nesting resources are in close proximity to one another.

Beneficial Insects and Native Flowers

Insect pollinators improve seed set by pollination, beneficial insect predators and parasitoids provide pest suppression and reduce herbivory. Pollination and predation can lead to increased crop yields (Fiedler et al. 2007). One cultural practice used to enhance beneficial insect populations is to provide floral refuges (Bugg 1990). Many beneficial insects use floral resources such as nectar and pollen as their main diet or as an important part of their diet (Landis et al. 2000). The development, reproduction, and survival of beneficial insects can be enhanced with flowering plants (Pontin et al. 2006), and in return, the insects enhance the productivity of many flowering plants. These refuges provide shelter, alternative hosts, and food needed by beneficial insects in harsh, low diversity agroecosystems (Fiedler and Landis 2007).

Annual, non-native plants are often recommended to enhance natural enemy populations; however, recent studies show that native perennial plants attract beneficial arthropods as well as annuals (Fiedler and Landis 2007). There are advantages to establishing perennial native plants. These plants are adapted to the local environment, they add to native biodiversity, and they do not require annual reestablishment costs (Fiedler and Landis 2007). Perennial plants provide a return on investment for years to come (Landis et al. 2000).

Knowledge of pollinators, natural enemies, and other beneficial insects in a landscape is essential for managing habitats to enhance beneficial insect populations. Plants chosen for habitat enhancement should be attractive to important beneficial insects and have accessible floral resources. Understanding the life cycles of important beneficial insects helps to select plants that will be useful to them throughout the season (Pickett and Bugg 1998). The overall goal for using diverse, native perennial plants is to attract beneficial insects that will use the resources for part of their diet and move to the adjacent crops. They may also use it as an overwintering habitat and then move to the adjacent crops (Pickett and Bugg 1998). Beneficial insects use refuge plantings and move into associated crops (Freeman-Long et al. 1998). Diverse plantings aid the movement of beneficial insects between habitats (Landis et al. 2000).

Habitat Management and Enhancement

Providing wild bees and other beneficial arthropods with food and nesting resources through habitat management and enhancement is the best way to support their populations (Shepherd et al. 2003). A key factor is to provision an area with diverse floral resources that bloom over an extended time period. Increasing the diversity of flowering plants has been shown to sustain or increase the diversity of wild bees present (Vaughan and Black 2006a). Strips along edges of crop fields that are planted to flowers provide food resources when the crop is not in bloom (Isaacs and Tuell 2007). Native perennial plants are preferred for resource strips. They are well-adapted to a region's growing conditions and once established require minimal attention (Vaughan and Black

2006b). Using perennial plants with a variety of bloom times creates a more stable habitat and support for a diverse beneficial insect community (Tuell et al. 2008).

A diversity of flowering plants will attract and maintain a higher diversity of wild bees and other beneficial arthropods (Vaughan and Black 2006b). The conservation of existing foraging plants is also important in conserving beneficials. Marginal habitats such as road-sides become important for the conservation of beneficial insect biodiversity in human-impacted environments (Hopwood 2008). Uncultivated areas also provide nesting sites for wild bees. Areas planted with floral resources and natural areas that provide bare ground, dead trees and cavities are ideal habitats for pollinators. Wild bees may nest in the crop fields they help pollinate, but tilling, cultivation, and irrigation practices can kill developing larvae. Providing suitable nesting habitat will promote bee populations and reproduction (James and Pitts-Singer 2008). The abundance of natural habitat in the vicinity of an agricultural site has a significant, positive effect on the pollination services of wild bees (Kremen et al. 2004). Small scale, inexpensive changes in an agricultural system could have effects that pay for themselves in pollination services, less reliance and costs associated with renting honey bees, and benefits to all wildlife (James and Pitts-Singer 2008). However, much remains unknown about creating an artificial nesting site for many bee species (Golick et al. 2006).

Understanding the distribution, abundance, and diversity of wild bees in an area is the first step to providing better habitat and resources for them (James and Pitts-Singer 2008). Little is known about most wild bee species, and efforts to understand their significance in pollinating wild plants are critical to their conservation. Since so little is known about individual species, general strategies are being implemented to support as

many species as possible. Most efforts to conserve and enhance wild bees will benefit many bee species. A negative aspect of using wild bees as pollinators, especially in agricultural systems, is that their populations are variable in space and time (James and Pitts-Singer 2008), and their pollination services may not meet the needs of larger agricultural operations. Reliance on honey bees to pollinate crops and wild plants could be reduced if farmers chose a diversified pollination system that included habitat for wild bees (Kremen et al. 2004).

Blue Vane Traps

Sampling bees for an understanding of pollination services and diversity is a challenge as an accurate measurement of the bee fauna is required. Collection for these studies has involved pan trapping and sweep net sampling. Pan traps are attractive to bees, but if most of the bloom of wild plants is one to several meters above the ground, traps on the ground are less attractive to bees (Stephen and Rao 2007). Stephen and Rao (2005) compared blue and yellow semitransparent vane traps for collecting bees in Oregon. Their results showed that blue vane traps yielded 17.3 bees/trap/day, while yellow vane trap yielded 5.75 bees/trap/day (Stephen and Rao 2005). Vane traps have advantages over other sampling techniques because they are easy to set up and transport, specimens can be released if frequent data collection is used, and the bees can be collected in a near perfect state (Stephen and Rao 2007). In 2007, Stephen and Rao compared the collection efficiency of blue and yellow semitransparent vane traps, sweep net sampling, and vacuum sampling. Their results showed the 94% of all bee species were captured in blue vane traps, 63% of species collected in sweep samples, and 54% of

species collected by each vacuum sampling and yellow vane traps (Stephen and Rao 2007). In proximity to stands of floral resources, blue vane traps can serve as an effective tool for sampling bee diversity.

Objectives and Hypotheses

The objectives of this study were to investigate wild bee diversity and genus richness in 4 different types of seeded plots located in south-central Nebraska and to investigate the attractiveness of selected native Nebraska perennials to beneficial insects and arthropods. The null hypotheses were that seeding treatments of plots did not affect the diversity of wild bees and that the species of native Nebraska flora would not differ in their attractiveness to beneficial insects and arthropods.

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Chapter 2

Bee diversity in plots managed by The Nature Conservancy in south-central Nebraska

Abstract

Habitat management and enhancement are proven ways to encourage native bee populations by providing them with food and nesting resources. I examined the bee diversity and abundance in twenty-four plots managed by *The Nature Conservancy* near Wood River, NE. The plots were seeded with two seed mixes at two seeding rates. I tested the null hypothesis that the seeding treatments would not affect the diversity of bees found in the plots. I measured the wild bee abundance and diversity, and established a data base of wild bees associated with the plots. In 2008, genus richness of bees was recorded for the plots using an aerial net collection method. In 2009, genus richness and abundance were compared among the plots using blue vane traps (SpringStar^{TM}). I did not observe significant differences in bee genus richness and diversity among the plots; however, plot size and the ability of blue vane traps to draw bees from a long distance may have limited my ability to detect differences. There were 15 genera and 95 bees collected total in 2008 and 32 genera and 6,103 bees collected in 2009.

Introduction

Insect pollination is an essential ecosystem service, and bees are the principal pollinators of wild and cultivated plants. Pollinators, most importantly bees, are necessary for plant reproduction, and they are a fundamental part of a food web (Kearns et al. 1998). Wild bees sustain ecosystems by pollinating plants that are consumed by humans, add nitrogen to the soil, and provide food and shelter to wildlife (James and Pitts-Singer 2008).

Providing wild bees with food and nesting resources through habitat management and enhancement is the best way to support their populations (Shepherd et al. 2003). Increasing the diversity of flowering plants has been shown to sustain or increase the diversity of wild bees (Vaughan and Black 2006). Wild bees depend on both nesting and foraging resources in the same or adjacent habitat because the flight range of many wild bees is limited or unknown (Gathmann and Tscarntke 2002). For instance, Gathmann and Tscarntke (2002) found that solitary bees have a foraging range of 150 to 600 m. For many species of wild bees it is difficult to accurately document their foraging range because factors such as resource availability and spatially separated habitats influence how far they move (Gathmann and Tscarntke 2002).

Restoration and conservation efforts should begin with surveys to document the bee taxa present (Tuell et al. 2009). The information gathered from surveys documents known genera or species of wild bees in an area. This base-line information is useful when creating or managing habitats and in measuring the impact of conservation efforts. Intensive bee collections are not available in Nebraska and the distribution of many bees

is relatively unknown for most of the state. In this study wild bee populations were documented and quantified on land managed by *The Nature Conservancy*. The information collected in this project is important for the conservation and improvement of pollinator habitat.

The objective of this study was to examine bee richness and diversity present in the research plots managed by *The Nature Conservancy*. The null hypothesis was that the seeding treatments would not differ in their richness or diversity of bee genera. A expected outcome of this research was to determine which seeding treatment, if any, attracted a larger number and diversity of bees.

Materials and methods

Bees were collected from the Dahm's research plots located south of Wood River, Hall County, Nebraska (40^{o} 44' 40.49" N, 98^{o} 35' 11.03" W). The plots are managed by *The Nature Conservancy*. The plots were seeded in 2006. The site has a total of 24 plots, each 55 m x 55 m (0.75 acres). Four seeding treatments were planted, high diversity mix at the recommended seeding rate (H1), high diversity mix at a double seeding rate (H2), Natural Resources Conservation Service (NRCS) conservation planting (CP) 25 mix at one-half the recommended seeding rate (C1), and NRCS CP25 mix at the recommended seeding rate (C2) (Figure 1 and Appendix A). The CP25 mixture met the standards set by the NRCS Standard #643 for restoration of rare and declining habitat.

The seeding rate was approximately 7.5 pure live seeds (PLS) pounds/ac (27.6 seeds/ft) of grass for C2 plots and 3.8 PLS pounds/ac (13.8 seeds/ft) of grass for C1 plots. The forbs seeding rate for C plots was approximately 2.9 live seeds/ft. C1 and C2 plots

were planted on March 28, 2006 on snow then supplemented on April 4, 2006 to reach the total seed amount needed. 9.75 bulk pounds of mixed seed/plot were planted in C2 plots and 4.9 bulk pounds in C1 plots.

The high diversity plots were planted with a drop seed spreader on March 29, 2006 on mud. H2 plots received additional seed on April 4, 2006 to double the rate. The seeding rate for H1 plots was approximately 2.85 PLS pound/ac of grass and 0.28 PLS pounds/ac of forbs. H2 plots were double this rate. 9.98 pounds of mixed seed/plot were planted in H1 plots and 19.96 pounds in H2 plots. Plots were planted in a "spiral" method with an ATV and John Deere "drop seed spreader." *The Nature Conservancy* harvested all of the seed locally for the high diversity seed mixes as well as the forb seed for the CP mix. The grass seed for the CP mixtures was supplied by Stock Seed Farms, Inc. Management of the plots to encourage the flowering and establishment of forbs included burning in the spring of 2008.

My experimental design was a randomized complete block design (RCBD). The blocking factor was the north-south columns of 4 treatment plots, and the number and diversity of bees collected per seeding treatment were the response variables. Variability in the populations of bees resulted in a low power in the design. I chose an alpha of 0.05 to analyze the data.

Summer 2008

The plots were burned in the spring 2008. Bees were collected using an aerial net and a killing jar charged with ethyl acetate. I spent fifteen minutes in each plot collecting bees observed. Collection periods consisted of 2 days with 3 time periods each (8:00-

10:00am, 1:00-3:00pm, and 5:00-7:00pm) where plots were randomly assigned to each period (Table 1). Samples were collected on June 18 & 19, July 22 & 23, and August 16 & 17. The bees that were collected were placed in a plastic bag and frozen and were later pinned and preserved. Aerial net collection provided a set of genera present in the plots and a reference collection of bees present was made.

Summer 2009

Bees were collected using blue vane traps (SpringStar™ LLC, Woodinville, WA, USA). The trap consisted of a translucent white plastic collecting jar fitted with a fabricated polypropylene screw cap funnel into which two polypropylene cross vanes were inserted (Figure 2). Vane traps were positioned approximately in the center of each plot by wiring them to a PVC pole and placed at the average height of the vegetation. Collections occurred during 10, 2 day periods and samples were collected between 8:00 am-12:00 pm and 12:00 pm-4:00 pm. Blue vane traps were set out at 8:00 am, emptied at 12:00 pm, and emptied and removed from the field at 4:00 pm. The contents of the traps were emptied into gallon sliding-lock plastic bags which were labeled and frozen. Bees were later pinned, preserved, and identified to genus using Guide to the Bees of Eastern Canada (Packer et al. 2007); The Bee Genera of North and Central America (Michener et al. 1994); and Discover Life online (www.discoverlife.org).

Collection dates were May 6 & 7, May 21 & 22, June 1 & 2, June 17 & 18, June 30 & July 1, July 14 & 15, July 29 & 30, August 11 & 12, August 22 & 23, and September 4 & 5. Weather conditions were recorded at approximately 10:00 am and

2:00 pm on each day (Appendix B). Two collecting periods were discarded because weather conditions did not permit sample collection (July 1 & 2 and August 11 & 12).

The Shannon-Wiener Diversity Index value was established for each plot and collecting period in 2009 (Appendix C) in order to compare diversity of bees across the plots. The Shannon-Wiener diversity index value found for each of the 24 plots per time period was analyzed by a repeated measures analysis of variance using SAS 9.2 ($\alpha = 0.05$) (Appendix D). A repeated measures analysis of variance of bee genus richness was conducted for 2008 and 2009 to determine if there were significant differences in bee genus richness among the plot seeding treatments using SAS 9.2 (Table 6 and Table 7).

Collection methods changed in 2009 when I became aware that using translucent colored vane traps was a more objective approach to sampling bees. I wanted to be able to compare the diversity of bees in the same treatments during the same time periods. This would not be feasible to do using an aerial net because all the samples could not be sufficiently sampled in the same time of day. Samples collected in 2008 provided a base-set of the bee genera present in the plots, and samples collected in 2009 were used to test bee diversity in the plots.

Results

There were no significant differences found in bee diversity among seeding treatments over time in 2009 at an $\alpha = 0.05$ ($F = 0.90$ and $P = 0.59$) (Table 2) although a block effect was present ($F = 1.60$ and $P = 0.045$) (Table 3). Based on the data collected, I failed to reject the null hypothesis which stated that the seeding treatments will not differ in their richness or diversity of bee genera. There were no significant differences

in bee genus richness among plot treatments over time in either 2008 (F = 0.95 and P = 0.51) (Table 4) or in 2009 (F = 1.05 and P = 0.41) (Table 5).

In 2008, 15 total genera and 95 individual bees were collected (Table 6). In 2009, there were 32 genera found in the research plots and 6,103 individual bees (Table 7). There were obvious differences in the number of genera and abundance of bees collected over both years. Blue vane traps collected an average of 15.97 bees/trap/day (383.31 bees/day) while aerial net sampling collected an average of 0.68 bees/plot/day (16.33 bees/day). The genus *Nomada* was collected with an aerial net in 2008, but was not collected using blue vane traps in 2009. The genera *Apis, Augochlorella, Ceratina, Dieunomia, Duforea, Eucera, Eumenid, Florilegus, Hoplitis, Hylaeus, Leucospid, Nomia, Osmia, Peponapis, Perdita, Ptilothrix, Sphecodes,* and *Xeromelecta* were collected in 2009, but not in 2008 using an aerial net. *Dialictus* was the most abundant genera collected in 2008 totaling 20 individuals (21 % of bees collected). *Melissodes* was the most abundant genera collected in 2009 totaling 4,764 individuals (78 % of bees collected). The number of bees collected in the traps grew over the season and peaked in August 2009.

Discussion

This study provided important information about the wild bee diversity and richness in south-central Nebraska; however, we did not find significant differences in the bee diversity among the various plots we sampled. There are possible explanations for no differences in diversity. First, it could be possible that differences do not exist in bee diversity across the plots. The geographic location of all the plots was the same and

the diversity of bees could be consistent over this area. Second, the plots may not have been large or mature enough to show differences in bee diversity. The plots were relatively small when compared to the foraging range of a solitary bee from a nesting site (150 m-600 m). The foraging radius of one bee genus could have overlapped several plots. Bees were able to visit the flowering resources in more than one plot on a foraging trip creating overlap and even bee diversity across the plots. Plots were also relatively young, being planted in 2006, and results could be different when the plants are well established. Finally, the blue vane traps used in 2009 may have attracted bees from across multiple plots. Blue vane traps are highly attractive to wild bees (Stephen and Rao 2005) and with a relatively small plot size, bees could have been attracted from neighboring plots.

Even though the seeding treatments did not differ in bee diversity, there was a block effect across the plots that may have been due to a soil type gradient. The soil gradient could have affected the flowers that established in each plot. Nesting sites are also affected by soil type for many ground nesting bees, and some bees could have preferred soil in one block and not another. Invasive species of plants and "weeds" were also a problem in some of the plots. Flowering weeds can be highly attractive to pollinators creating competition with the seeded plants. CP25 seeding treatments had a lower seeding rate of flowering plants and more invasive weeds. This could have created more plant diversity than intended. Flowering plants diversity and density also create competition for blue vane traps. Bees may be less attracted to blue vane traps because of the abundance of flowers available. The bee diversity and richness in some plots may have been off-set by the availability of bare soil for nesting in lower plant density plots.

Nesting sites would be highly attractive to wild bees and they may have been more abundant in lower plant diversity and density plots due to nest location.

The Shannon-Wiener diversity index was used to establish a value of diversity for each plot during each time period. This index was selected because it was easy to use, calculate, and quantify the data clearly. Disadvantages of using this index were that values did not range greatly which may have lead to no significant differences found in the analysis, and values were greatly influenced by one genus that may have been slightly larger in abundance at different times.

There were 18 genera collected using blue vane traps in 2009 that were not collected with an aerial net in 2008. This difference in genera richness collected is due to methods used. Sampling with an aerial net was time consuming and not many bees were observed while moving through the plot. The advantage of using blue vane traps in 2009 was that all the plots were objectively sampled on each sampling date. There was 1 genus collected in 2008 that was not recorded in 2009. Using both collection techniques shows that in future studies, blue vane traps should be used and aerial net collections should be made to add to the data in attempts to collect more genera present. *Melissodes* was the most abundant genera in 2009. Most *Melissodes* bees were collected in July and August which led to a peak in abundance of bees collected across the season. This also caused diversity index values calculated for plots to be low because of their larger numbers. Bee populations fluctuate from year to year and the results found in this study represent a short period of time relative to what is required for truly understanding wild bee biology. Further studies would provide a more reliable measure of genus richness and abundance.

Table 1. Aerial net collection sampling plot order arranged by time period for 2008.

Day 1

8-10 am	1-3 pm	5-7 pm
13 H2	11 C2	9 C1
19 C1	17 H2	8 H1
22 H1	15 H1	7 C2
24 H2	21 C2	2 C1
18 C2	6 C1	10 H2
12 H1	5 H1	4 C2
16 C1	3 H2	1 H1
14 C2	23 C1	20 H2

Day 2

8-10 am	1-3 pm	5-7 pm
5 H1	18 C2	1 H1
14 C2	23 C1	4 C2
6 C1	20 H2	9 C1
10 H2	8 H1	22 H1
16 C1	19 C1	17 H2
15 H1	7 C2	13 H2
24 H2	12 H1	21 C2
11 C2	3 H2	2 C1

H1 – High diversity mix regular rate
H2 – High diversity mix double rate
C1 – NRCS CP25 mix low rate
C2 – NRCS CP25 mix regular rate

Table 2. Type III tests of fit statistics for the analysis of differences in the Shannon-Wiener diversity index values calculated for each plot treatment using a repeated measures analysis. Samples analyzed were collected in 2009 using blue vane traps in research plots managed by *The Nature Conservancy*. ($\alpha = 0.05$)

Type 3 Tests of Fixed Effects				
Effect	Num df	Den df	F Value	Pr > F
trt	3	24.9	0.01	0.9987
time	7	59.6	25.15	<.0001
trt*time	21	81.7	0.90	0.5901

Table 3. Type III tests of fit statistics for the analysis of differences in bee diversity among blocks using a repeated measures analysis. Samples analyzed were collected in 2009 using blue vane traps in research plots managed by *The Nature Conservancy*. ($\alpha = 0.05$)

Type 3 Tests of Fixed Effects				
Effect	Num df	Den df	F Value	Pr > F
block	5	22.6	4.35	0.0064
time	7	53	33.30	<.0001
block*time	35	74.4	1.60	0.0450

Table 4. Type III tests of fit statistics for the analysis of genus richness differences among treatments over time using a repeated measures analysis for 2008. Samples used in the analysis were collected using an aerial net. ($\alpha = 0.05$)

Type 3 Tests of Fixed Effects				
Effect	Num df	Den df	F Value	Pr > F
trt	3	13.7	1.64	0.2269
time	5	45.7	4.17	<.0001
trt*time	15	60.5	0.95	0.5159

Table 5. Type III tests of fit statistics for the analysis of genus richness differences among treatments over time using a repeated measures analysis for 2009. Samples used in the analysis were collected using blue vane traps. ($\alpha = 0.05$)

Type 3 Tests of Fixed Effects				
Effect	Num df	Den df	F Value	Pr > F
trt	3	22.0	0.76	0.5268
time	7	60.1	18.74	<.0001
trt*time	21	82.0	1.05	0.4136

Table 6. List of bee genera and individual bees found by plot treatment in 2008 that were collected using an aerial net in research plots managed by *The Nature Conservancy*.

C1		***C2***	
Genera	Abundance	Genera	Abundance
Augochloropsis	2	*Bombus*	1
Bombus	4	*Diadasia*	1
Coelioxys	1	*Dialictus*	7
Colletes	3	*Halictus*	4
Diadasia	1	*Megachile*	1
Dialictus	6	*Melissodes*	4
Halictus	7	*Nomada*	1
Megachile	2	*Svastra*	3
Melissodes	7	*Triepeolus*	2
Svastra	4		
Triepeolus	2		
Total		**Total**	
11	**39**	**9**	**24**

H1		***H2***	
Genera	Abundance	Genera	Abundance
Agapostemon	1	*Agapostemon*	3
Bombus	2	*Anthophora*	1
Dialictus	5	*Dialictus*	2
Halictus	4	*Halictus*	1
Lasioglossum	4	*Melissodes*	3
Melissodes	3	*Svastra*	1
Triepeolus	2		
Total		**Total**	
8	**21**	**7**	**11**

Combined Total: 15 Genera & 95 bees

Treatments: H1 – High diversity mix regular rate C1 – NRCS CP25 mix low rate
H2 – High diversity mix double rate C2 – NRCS CP25 mix regular rate

Table 7. List of bee genera and abundance of bees found by plot treatment in 2009 collected using blue vane traps in research plots managed by *The Nature Conservancy*.

C1		***C2***		***H1***		***H2***	
Genera	Abun	Genera	Abun	Genera	Abun	Genera	Abun
Agapostemon	22	*Agapostemon*	14	*Agapostemon*	24	*Agapostemon*	14
Anthophora	3	*Anthophora*	7	*Anthophora*	1	*Anthophora*	2
Augochlorella	13	*Apis*	2	*Apis*	1	*Augochlorella*	9
Bombus	31	*Augochlorella*	20	*Augochlorella*	8	*Augochloropsis*	7
Ceratina	48	*Augochloropsis*	7	*Augochloropsis*	1	*Bombus*	20
Colletes	1	*Bombus*	26	*Bombus*	24	*Ceratina*	24
Diadasia	24	*Ceratina*	62	*Ceratina*	25	*Colletes*	1
Dialictus	59	*Coelioxys*	1	*Diadasia*	12	*Diadasia*	26
Dieunomia	1	*Diadasia*	26	*Dialictus*	62	*Dialictus*	43
Eucera	5	*Dialictus*	87	*Duforea*	1	*Eucera*	2
Florilegus	29	*Eucera*	3	*Eucera*	3	*Florilegus*	5
Halictus	31	*Florilegus*	15	*Eumenid*	1	*Halictus*	21
Hoplitis	14	*Halictus*	32	*Florilegus*	5	*Hoplitis*	8
Hylaeus	11	*Hoplitis*	18	*Halictus*	48	*Hylaeus*	6
Lasioglossum	46	*Hylaeus*	36	*Hoplitis*	9	*Lasioglossum*	25
Megachile	6	*Lasioglossum*	55	*Hylaeus*	11	*Megachile*	3
Melissodes	1456	*Megachile*	7	*Lasioglossum*	30	*Melissodes*	1088
Osmia	1	*Melissodes*	924	*Leucospid*	1	*Svastra*	10
Peponapis	6	*Peponapis*	3	*Megachile*	6	*Triepeolus*	1
Sphecodes	1	*Perdita*	1	*Melissodes*	1296	*Xeromelecta*	1
Svastra	31	*Svastra*	8	*Nomia*	1		
Triepeolus	2	*Triepeolus*	5	*Peponapis*	4		
Xeromelecta	1	*Xeromelecta*	1	*Ptilothrix*	2		
				Sphecodes	2		
				Svastra	10		
				Triepeolus	1		
				Xeromelecta	2		
Total		**Total**		**Total**		**Total**	
23	**1842**	**23**	**1354**	**27**	**1591**	**20**	**1316**

Combined Total: 32 Genera & 6,103 bees

Treatments: H1 – High diversity mix regular rate C1 – NRCS CP25 mix low rate
H2 – High diversity mix double rate C2 – NRCS CP25 mix regular rate

North (treeline and Platte River)

1 H1	2 C1	3 H2	4 C2	5 H1	6 C1
7 C2	8 H1	9 C1	10 H2	11 C2	12 H1
13 H2	14 C2	15 H1	16 C1	17 H2	18 C2
19 C1	20 H2	21 C2	22 H1	23 C1	24 H2

South (gravel road that goes to Denman)

Figure 1. Dahm's research plots managed by *The Nature Conservancy* south of Wood River, NE. Each of the 24 total plots was 55 m long by 55 m wide.

H1 – High diversity regular rate
H2 – High diversity double rate
C1 – CP25 low rate
C2 – CP25 regular rate

Figure 2. Blue vane trap used to collect wild bees in 2009 (SpringStar™).

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Chapter 3

Beneficial arthropods associated with native Nebraska flora

Abstract

Habitat management can provide plant resources for beneficial insects and arthropods that pollinate crops and provide pest suppression. Habitat management is a growing focus of conservation biological control. Some guidelines for enhancing habitat for beneficial arthropods recommend the use of annual, non-native plants. Native perennial plants are likely to provide similar resources and have advantages over annual non-native plants. I compared 17 species in 7 families of native Nebraska perennial plants for their attractiveness to beneficial arthropods. Plant species varied in their attractiveness to beneficial arthropods. In the first year the plant plots were established, and samples were collected during the second year. *Pycnanthemum flexuosum* Walter attracted significantly more beneficial arthropod families than *Allium cernuum* Roth., *Asclepias speciosa* Torr., *Dalea purpurea* Vent., *Salvia azurea* Michx. ex Lam. subsp. *pitcherii* 'Nekan' (Torr. ex Benth.) Epling, *Liatris punctata* Hook., *Lobelia siphilitica* L., and *Penstemon grandiflorus* Nutt. *Dalea purpurea* and *Liatris punctata* attracted significantly fewer beneficial arthropod families than *Aster novae-angliae* L., *Helianthus maximiliani* Schrad., and *Monarda punctata* L. There were a total of 31 predator arthropod families, 11 parasitic arthropod families, and 4 pollinator arthropod families

found. While my study documents arthropod families associated with native flora, further studies need to be performed on the movement of beneficial to nearby crops and on the size, shape and spacing of conservation plots.

Introduction

Beneficial insects (pollinators, predators, and parasitoids) and other arthropods play key roles in many agricultural and natural landscapes. There is an increase in the awareness and use of conservation biological control by employing practices that enhance and protect beneficial insects already present in the landscape (Fiedler and Landis 2007). These practices include conserving or managing habitats to provide resources that enhance beneficial insect survival and efficiency (Dennis and Fry 1992). Beneficial insects often need alternative hosts and non-host food sources to increase their reproduction and lifespan. Nectar and pollen are crucial resources for many beneficial insects (Fiedler and Landis 2007). Enhancing habitat improves the availability of alternative foods, overwintering sites and refuge from environmental factors and pesticides (Landis et al. 2000). Improving habitat by providing shelter and plant diversity has the potential to attract beneficial arthropods as well as increasing their populations (Gurr et al. 2003).

Plant selection is important in habitat management for beneficial insects. Some predators and parasitoids cannot access resources in the deep corollas of some flowers because their mouthparts are not long enough (Jervis et al. 1993). Also, plants need to be selected to provide resources or bloom at the time when they are most needed by the beneficial arthropods one seeks to enhance (Dufour 2000). Some non-native, annual

plants have been recommended for habitat management, because some of them are known to be highly attractive to beneficial insects (Fiedler and Landis 2007). Native perennial plants have potential to work as well as non-indigenous species. Using native perennial plants has several benefits including: (1) they are adapted to the local environment (2) they do not need to be reestablished every year (3) they provide overwintering habitat for beneficial insects (4) they add to native biodiversity and (5) they may be used in restorations. Unlike some non-native species, they will not become invasive or obnoxious plants (Fiedler and Landis 2007). Plants selected should be suitable for the system where they will be established (i.e. garden or agricultural settings) to provide a stable long-term habitat (Long et al. 1998).

The objective of this study was to examine which species of a selected group of native Nebraska flora were most attractive to beneficial insects. The null hypothesis was that the floral species will not differ in their attractiveness to beneficial insects and arthropods. The further goal of this research was to provide a list of native perennial plants to recommend in garden and agricultural settings.

Material and methods

Native Nebraska flora were chosen based on the following criteria: (1) are they native perennials (2) are they adapted to the habitat conditions (i.e. wet, dry, sun, shade) (3) do they represent diverse plant families and (4) are they available locally? Three study sites in eastern Nebraska were used. Two plots were located at the University of Nebraska Agricultural Research and Development Center (UNL-ARDC) near Ithaca, NE

in Saunders, Co. on the forestry and entomology farms. The third plot was located on Prairie Pines Research Site near Lincoln, NE in Lancaster Co.

The plots were transplanted with plants and established in May 2008. There were 68 plants in each plot, represented by 7 families and 17 species of flowers. There were 4 replicates of each plant. The plots were 3.05 m x 9.14 m and one seedling plug was transplanted in the center of a 0.61 m x 0.61 m square (Figure 1). Plants were selected and purchased locally in cooperation with the Bluebird Nursery, Inc., Clarkson, NE. The flowers were assigned to a square in the plot randomly. Plots were watered after the initial transplanting and 2 to 3 times each month to help establish them. Several plants in each plot did not survive the summer of 2008 due to weather conditions, animal herbivores, or other unknown causes and were replanted in early May 2009. All of the *Euphorbia corollata* plants died the first year in all 3 plots and were replaced with *Salvia azurea* subsp. *pitcherii* 'Nekan' in May 2009.

In 2009, samples of the arthropods on the plants were collected using a gas powered leaf vacuum (Homelite® MightyLite). A fine mesh, corn leaf bag was placed around the intake of the vacuum to catch the arthropods. Samples were collected between the hours of 1000 – 1400 CT on sunny days with winds < 15mph. Each plant was vacuumed until all flowers were sampled. Samples were only collected from the plants that had flowers in bloom. Contents of the leaf bags were placed in a quart, sliding lock plastic bag and placed in a freezer until sorted. Arthropods were sorted into families and counted. They were then sorted into predators, parasitoids, pollinators, and herbivores based on the feeding behavior of the majority of the family members. The relative abundance for each family in these groups was also recorded. Insect taxonomic

classifications follows Triplehorn and Johnson (2005). Samples were collected from June – September 2009 only from plants with flowers in bloom. Samples were collected in the forestry farm plot on June 11, June 25, July 7, July 21, August 4, August 18, August 31, and September 18. They were collected in the entomology farm plot on June 10, June 23, July 7, July 21, August 4, August 18, August 31, and September 18. Prairie Pine plot samples were collected on June 9, June 25, July 22, August 5, August 18, August 31, and September 18.

My experimental design was a randomized complete block design (RCBD). The blocking factor was each plot location, and the number of beneficial arthropod families associated with each plant species was the response variable. An analysis of variance of beneficial family richness was conducted on the species of plants across blocks to determine if there were significant differences in beneficial arthropod attractiveness among the plant species using SAS 9.2 (Appendix F). Least squares means were compared to determine significant differences in the attractiveness of the plant species ($\alpha = 0.05$). The total family richness of beneficial arthropod families (predators, parasites, and pollinators) was also found for each plant species within each block (plot) (Appendix E). Bloom periods were observed and recorded for each plant species over the 2009 season (Table 1).

Results

The native perennials examined in the plots showed significant differences in their attractiveness to beneficial arthropods. There were significant differences in the beneficial families associated with each plant ($P < 0.0001$) and there were no significant

differences between blocks ($P = 0.38$) (Table 2). As shown by the least squares means analysis (Table 3), *Pycnanthemum flexuosum* attracted significantly more beneficial arthropod families than *Allium cernuum* ($P = 0.01$), *Asclepias speciosa* ($P = 0.03$), *Dalea purpurea* ($P = 0.001$), *Salvia azurea* subsp. *pitcherii* 'Nekan' ($P = 0.02$), *Liatris punctata* ($P = 0.001$), *Lobelia siphilitica* ($P = 0.04$), and *Penstemon grandiflorus* ($P = 0.01$). *Dalea purpurea* and *Liatris punctata* attracted significantly fewer beneficial arthropod families than *Aster novae-angliae* L. ($P = 0.03$), *Helianthus maximiliani* Schrad. ($P = 0.03$), and *Monarda punctata* L. ($P = 0.02$).

There were a total of 31 predator arthropod families, 11 parasitic arthropod families, 4 pollinator arthropod families, and 31 arthropod families classified as herbivores (Table 4). The abundance of individual arthropods found for each organized group was observed to be 718 predators, 166 parasites, 116 pollinators, and 1,881 herbivores. The plant species that attracted the most predator arthropod families were *Pycnanthemum flexuosum* and *Solidago canadensis* L. attracting a total of 20 families each. *Pycnanthemum flexuosum* also attracted the most parasitic and pollinator arthropod families, at 8 and 3 respectively. *Dalea purpurea* and *Liatris punctata* attracted the least total number of beneficial arthropod families, attracting 1 family each, while *Pycnanthemum flexuosum* attracted the greatest number of beneficial arthropod families totaling 31 (Table 3).

Discussion

Floral resources were available from the set of 17 flowers from June through September 2009. Levels of attractiveness differed between the native perennial plants

examined with *Pycnanthemum flexuosum* being significantly more attractive to beneficial arthropods than 7 other species of plants. Also, *Dalea purpurea* and *Liatris punctata* were significantly less attractive to beneficial arthropods than 3 other species of plants. These differences may be due to flower structure and the length of the bloom period.

Fiedler and Landis (2007) found that native perennial plants were as or more attractive to beneficial arthropods as introduced plant species, and that they became more attractive to natural enemies (predators and parasitoids) as they matured. This suggests that native perennial plants have potential to be more attractive to beneficial arthropods than annual plants. The perennial plants tested also offer floral resources over a longer period of time than annual plants.

Using perennial plants in gardens and agricultural systems provides shelter from disturbance for beneficial insects (Fiedler and Landis 2007). Bloom duration is important when selecting plants to include in habitats for beneficial arthropods. A habitat management plan needs to have plants that bloom throughout the season. The plants used in this study included species that flowered in late summer to fall. A majority of the arthropods were collected during these months. Ideally, more species of spring blooming plants should be incorporated to provide more floral resources to support early season arthropod populations.

Native perennial plants can be established in strips along or in crop fields to provide resources and shelter for the beneficial arthropods. This form of conservation management has the potential to increase beneficial arthropod populations by providing food and shelter. Providing habitat may take some land out of crop production resulting in yield reduction. However, the advantage from increased beneficial insect activity and

pest suppression along with the reduction in cost of using fewer pesticides may more than offset a reduction in yield (Landis et al. 2000).

Notably, very few bees were collected in this study. I believe that the gas-powered vacuum disturbed them and many bees took flight as they were observed on the flowers prior to collection. Caution was used to not disturb neighboring plants during sampling and to be aware of the blowing exhaust. However, plants may have been too close to one another, and it was difficult to not disturb neighboring plants while sampling.

Plants did not establish well the first season due to unknown causes and an estimated half of the total plants had to be replaced in 2009. When sampling occurred during the 2009 season, these plants were relatively small and did not have as many blooms as 2 year old plants. Sampling only occurred over one season and this may not have provided a sufficient data to draw conclusions from as populations of insects naturally fluctuate each year and from year to year. This study should be extended to show the attractiveness of the plants over several years.

Further studies also need to be conducted on the efficiency of these plants at attracting beneficial arthropods in an agricultural system. The plots for this study were similar to a garden. I recommend a subset of 10 native Nebraska plants from the flora used in this study to attract beneficial insects in a garden setting. They were determined based on the significance and grouping of the adjusted analysis and are as follows: *Aster navae-angliae, Echinacea angustifolia, Eupatorium purpureum, Helianthus maximiliani, Monarda punctata, Pycnanthemum flexuosum, Ratibida columnifera, Rudbeckia hirta, Solidago canadensis,* and *Vernonia fasciculata*.

Table 1. Native Nebraska flora species established in 3 research plots and their bloom periods.

Scientific Name	Bloom Period[1] May	June	July	Aug	Sept	Oct
Allium cernuum		■	■			
Asclepias speciosa	■	■	■	■		
Aster novae-angliae		■	■	■	■	■
Dalea purpurea		■	■			
Echinacea angustifolia		■	■	■		
Eupatorium purpureum		■	■	■		
**Salvia azurea* subsp. *pitcherii* 'Nekan'			■	■	■	
Helianthus maximiliani			■	■	■	■
Liatris punctata			■	■	■	■
Lobelia siphilitica			■	■	■	
Monarda punctata		■	■	■		
Penstemon grandiflorus		■	■	■		
Pycnanthemum flexuosum			■	■	■	
Ratibida columnifera		■	■	■		
Rudbeckia hirta	■	■	■	■	■	
Solidago canadensis			■	■	■	
Vernonia fasciculata			■	■	■	

* Transplanted in 2009 as a replacement for *Euphorbia corollata*.

[1] Bloom period established from observations in 2009 and literature (USDA & NRCS, PLANTS Database).

Table 2. Analysis of variance of the beneficial families associated with 17 species of native blooming plants in 2009. Samples were collected using a modified leaf vacuum from 3 plots.

Source	DF	Sum of Squares	Mean Square	F	Pr > F
Treatment	16	1110.04	69.38	5.22	<.0001
Block	2	26.63	13.31	1.00	0.3785
Residual	32	425.37	13.29	.	.

Table 3. Native Nebraska flowers and their attractiveness to beneficial arthropods determined by analysis of variance of family richness data collected in 2009.

Scientific Name	Common Name	Total Beneficial Families [1]	*Estimate*
Pycnanthemum flexuosum	Mountain Mint	31	15.67 a[2]
Monarda punctata	Horsemint/Spotted Beebalm	26	12.67 ab
Aster novae-angliae	New England Aster	21	12.33 ab
Helianthus maximiliani	Maximilian sunflower	23	12.33 ab
Rudbeckia hirta	Black-eyed Susan	23	11.33 abc
Vernonia fasciculata	Prairie Ironweed	21	10.33 abc
Solidago canadensis	Canada Goldenrod	24	10.00 abc
Ratibida columnifera	Upright Prairie Coneflower	15	8.67 abc
Eupatorium purpureum	Joe-Pye Weed	13	6.00 abc
Echinacea angustifolia	Coneflower	10	4.67 abc
Lobelia siphilitica	Blue Lobelia	12	4.33 bc
Asclepias speciosa	Showy Milkweed	11	3.67 bc
**Salvia axurea* subsp. *pitcherii* 'Nekan'	Pitcher Sage	7	3.33 bc
Penstemon grandiflorus	Shell-leaf Penstemon	5	2.67 bc
Allium cernuum	Nodding Wild Onion	8	2.67 bc
Dalea purpurea	Purple Prairie Clover	1	0.33 c
Liatris punctata	Blazing star, Gayfeather	1	0.33 c

*Transplanted in May 2009 as a replacement for *Euphorbia corollata*.

[1] Total number of beneficial arthropod families (predators, parasites, and pollinators) recorded to be attracted to each plant species in 2009.

[2] Least squares means estimate of beneficial arthropod families attracted to each plant species in each block listed in a column followed by different letters represent significant differences (analysis of variance, $\alpha = 0.05$, Tukey adjustment for multiple comparisons).

Table 4. Arthropod families collected in 2009 from native Nebraska flora classified by feeding habit of the majority of the members of the family.

Predator	**Parasitic**	**Pollinator**	**Herbivore**	**Misc.**
Anthocoreidae	Braconidae	Apidae	Acridae	Agonoxenidae
Araneidae	Chalcidae	Halictidae	Adeligidae	Bibionidae
Asilidae	Chloropidae	Lycaenidae	Anthiomyidae	Chironomidae
Cantharidae	Chrysidiae	Megachilidae	Aphididae	Drosophilidae
Carabidae	Diapriidae		Berytidae	Entomobryidae
Cloropidae	Evaniidae	**Total = 4**	Buprestidae	Latridiidae
Chrysopidae	Ichneumonidae		Cerambycidae	Otitidae
Clubionidae	Phoridae		Cercopidae	Pyralidae
Coccinellidae	Scoliidae		Chrysomelidae	Stratiomyidae
Doichopodidae	Tachinidae		Cicadellidae	Tipulidae
Empididae	Tiphiidae		Coreidae	
Formicidae			Corimelaenidae	**Total = 10**
Harvestmen	**Total = 11**		Crambidae	
Hemerobiidae			Curculionidae	
Lampyridae			Cydnidae	
Mantidae			Cynipidae	
Nabidae			Dictyopharidae	
Oxyopidae			Geometridae	
Pentatomidae			Gryllidae	
Philodromidae			Lygaeidae	
Phymatidae			Meloidae	
Reduviidae			Membracidae	
Rhagionidae			Miridae	
Salticidae			Mordellidae	
Sciaridae			Noctuidae	
Sphecidae			Piesmatidae	
Syrphidae			Tenthredinidae	
Tetragnathidae			Tephritidae	
Thomisidae			Tettigoniidae	
Theridiidae			Thyreocoridae	
Vespidae			Tortricidae	
Total = 31			**Total = 31**	

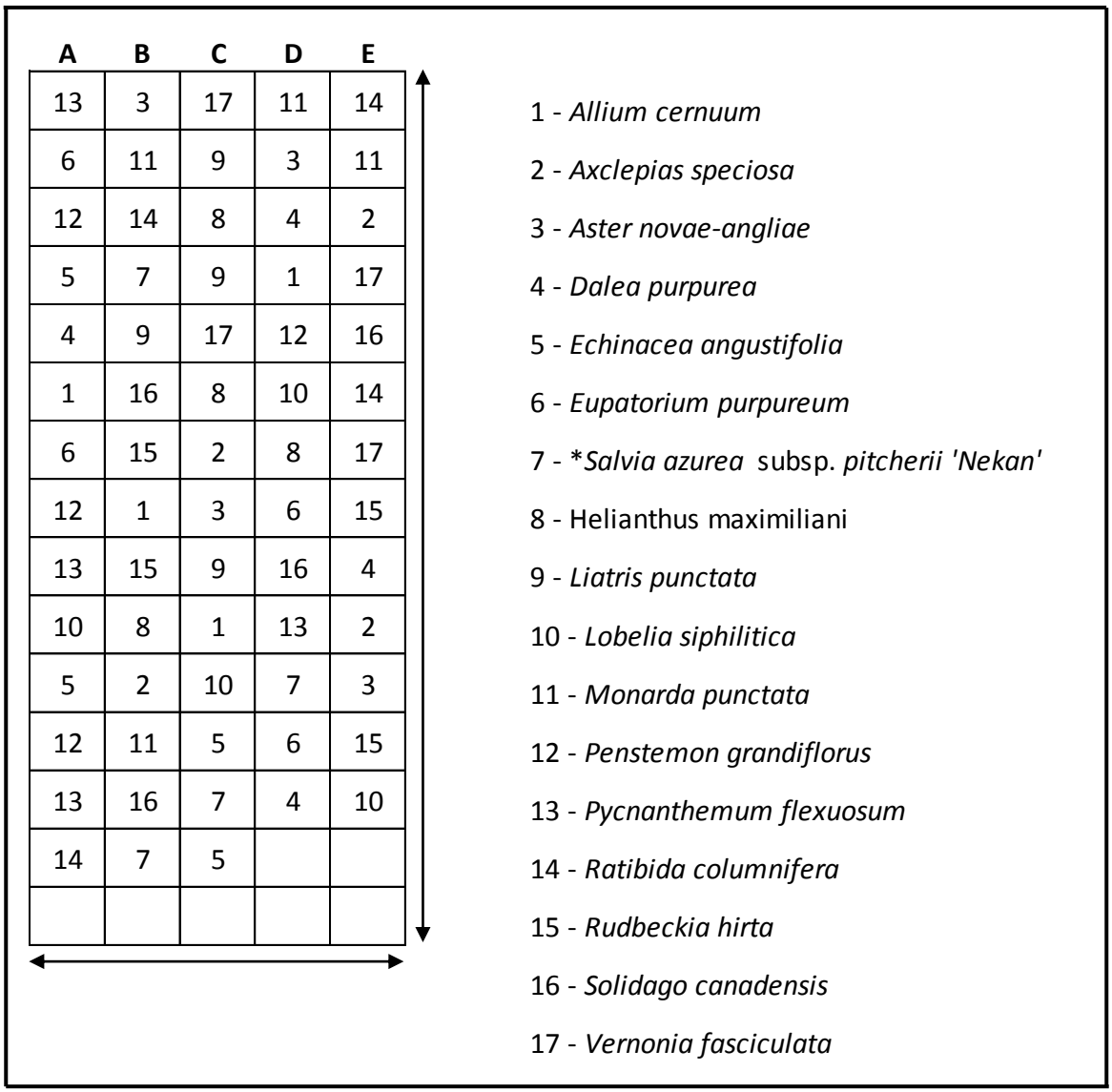

Figure 1. Native floral plot design and associated numbers to the plants. 3 plots with 17 total species and 4 plants of each species in each plot. Plots were 3.05 m wide x 9.14 m long.

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Appendix A. List of plants seeded in The Nature Conservancy's Dahm's research plots.

C – Treatment Plots

Forbs	**Grasses**
Amorpha canescens	*Andropogon gerardii*
Astragalus candensis	*Bouteloua curtipendula*
Dalea purpurea	*Elymus canadensis*
Desmanthus illinoensis	*Elymus smithii*
Liatris punctata	*Elymus virginicus*
Ratibida comumnifera	*Panicum virgatun*
Solidago missouriensis	*Schizachyrium scoparium*
	Sorghastrum nutans

H – Treatment Plots

Forbs	**Grasses**
Achillea lanulosa	*Andropogon gerardii*
Allium canadensis	*Bouteloua curtipendula*
Amorpha canescens	*Calamagrostis inexpansa*
Anemone canadensis	*Digitaria congnata*
Artemisia ludoviciana	*Elymus canadensis*
Asclepias speciosa	*Elymus trachycaulus*
Asclepias syriaca	*Elymus virginicus*
Asclepias verticillata	*Eragrostis spectabilis*
Aster ericoides	*Eragrostis trichodes*
Aster novae-angliae	*Hesperostipa comata*
Aster simplex	*Hesperostipa spartea*
Astragalus canadensis	*Panicum virgatum*
Brickellia eupaoroides	*Spartina pectinata*
Callirhoe involucrate	*Sporobolus compositus*
Calylophus serrulata	*Sporobolus cryptandrus*
Carex brevior	*Sorghastrum nutans*
Carex eliocharis	*Tridens flavus*
Carex gravida	
Crepis runcinata	
Cyperus lupulinus	

Appendix A.2. List of plants seeded in The Nature Conservancy's Dahm's research plots.

H – Treatment Plots

Forbs

Cyperus schweinitzii
Dalea candidum
Dalea purpurea
Delphinium carolinense
Desmanthus illinoensis
Desmodium illinoense
Eliocharis elliptica
Eupatorium altissimum
Eustoma grandiflorum
Euthamia graminifolia
Gaura parviflora
Geum canadenvse
Geum vernum
Glycyrrhiza lepidota
Helianthus grosse-serratus
Helianthus laetiflorus
Helianthus maximilliani
Helianthus petiolaris
Helianthus petiolaris
Helianthus tuberosa
Heliopsis helianthoides
Heterotheca villosa
Juncus dudleyi
Lespedeza capitata
Liatris lancifolia
Liatris punctata
Liatris squarrosa
Lithospermum caroliniense
Lithospermum incisum
Lotus unifoliolatus
Mirabilis nyctaginea
Monarda fistulosa

Appendix A.3. List of plants seeded in The Nature Conservancy's Dahm's research plots.

H – Treatment Plots

Forbs

Oenothera biennis
Oenothera rhombipetala
Onosmodium molle
Penstemon digitalis
Penstemon gracilis
Penstemon grandiflorus
Plantago patagonica
Potentilla norvegica
Prunella vulgaris
Pycnanthemum virginianum
Ratibida columnifera
Rosa arkansana
Rudbeckia hirta
Schrankia nuttallii
Senecio plattensis
Senecio plattensis
Silphium speciosum
Sisyrinchium campestre
Solidago gigantea
Solidago missouriensis
Solidago rigida
Teucrium canadense
Tradescantia bracteata
Tradescantia occidentale
Verbena hastata
Verbena stricta
Vernonia fasciculata

Appendix B.
Weather Data for Bee Diversity Study (Weather Channel, www.weather.com)

Date	Weather Conditions
5-6-10 AM	NA
5-6-10 PM	NA
5-7-10 AM	NA
5-7-10 PM	NA
5-21-10 AM	70F, partly cloudy, Hum 57%, Wind 8mph NNE
5-21-10 PM	71F, partly cloudy, Hum 47%, Wind approx 20 mph gusting to 32 mph
5-22-10 AM	66F, sunny, Hum 54%, Wind 6 mph SE
5-22-10 PM	81F, partly cloudy, Hum 34%, Wind 16 mph S
6-1-10 AM	72F, mostly cloudy, Hum 60%, Wind 5mph E
6-1-10 PM	79F, mostly cloudy, Hum 54%, Wind 7mph ENE
6-2-10 AM	Rained out
6-2-10 PM	Rained out – still too wet
6-17-10 AM	80F, mostly sunny, Hum 56%, Wind 9 mph N
6-17-10 PM	88F, sunny, Hum 43%, Wind 17 mph
6-18-10 AM	75F, sunny, Hum 67%, Wind 5 mph SE
6-18-10 PM	82F, partly cloudy, Hum 58%, Wind 4 mph
6-30-10 AM	73F, sunny, Hum 56%, Wind 8mph NE
6-30-10 PM	78F, sunny, Hum 59%, Wind 14 mph NE
7-1-10 AM	71F, sunny, Hum 60%, Wind 5 mph SE
7-1-10 PM	80F, sunny, Hum 47%, Wind 6 mph SSE
7-14-10 AM	72F, sunny, Hum 83%, Wind 11 mph S
7-14-10 PM	83F, partly cloudy, Hum 64%, Wind 8 mph SSW
7-15-10 AM	71F, sunny, Hum 55%, Wind 13 mph NNE
7-15-10 PM	80F, sunny, Hum 46%, Wind 7 mph NNE
7-29-10 AM	66F, mostly cloudy, Hum 69%, Wind 10 mph SSW
7-29-10 PM	Rained out
7-30-10 AM	62F, sunny, Hum 63%, Wind 11 mph NNW
7-30-10 PM	72F, sunny, Hum 38%, Wind 11 mph NNW
8-11-10 AM	79F, sunny, Hum 60%, Wind 11 mph SSW
8-11-10 PM	87F, sunny, Hum 43%, Wind 8 mph SSW
8-12-10 AM	Rained out
8-12-10 PM	Rained out
8-22-10 AM	67F, sunny, Hum 60%, Wind 13 mph SSW
8-22-10 PM	77F, sunny, Hum 46%, Wind 12 mph S
8-23-10 AM	72F, mostly sunny, Hum 57%, Wind 17 mph SSW
8-23-10 PM	79F, sunny, Hum 52%, Wind 18mph SSE
9-4-10 AM	Too Cool!
9-4-10 PM	71F, mostly cloudy, Hum 61%, Wind 10 mph ESE
9-5-10 AM	61F, mostly cloudy, Hum 92%, Wind 5 mph S
9-5-10 PM	73F, mostly cloudy, Hum 67%, Wind 12 mph SSE

Appendix C. Shannon-Wiener diversity index values for each plot by time period in 2009.

Block	Trt	Plot	t1	t2	t3	t4	t5	t6	t7	t8
1	1	1	0.0000	1.7815	1.7329	0.0000	0.2146	1.1693	0.1495	0.0000
5	1	5	0.6931	1.6716	0.5623	1.3863	0.5004	0.5141	0.5910	0.4095
2	1	8	0.6931	1.8286	1.6679	1.0397	0.6931	0.5927	0.3782	0.0000
6	1	12	0.6931	1.3209	0.0000	0.0000	0.5004	0.3735	0.4989	0.3488
3	1	15	1.1218	1.8342	0.0114	0.0000	0.5661	0.7550	0.3557	0.0000
4	1	22	0.6931	1.3317	0.0000	1.0549	0.9557	0.5433	0.0965	0.7743
3	2	3	0.6931	1.7290	0.6931	1.0986	0.9503	0.2449	0.5433	0.0000
4	2	10	0.0000	1.3863	1.0397	0.6829	0.6931	0.5586	0.2464	0.4487
1	2	13	1.0790	1.7354	1.9062	0.0000	0.9369	0.7858	0.2929	0.0000
5	2	17	0.0000	1.7329	2.1458	1.0986	0.7550	0.1269	0.2019	0.0000
2	2	20	1.0549	1.3897	1.0397	0.0000	0.6365	0.2911	0.3616	0.0000
6	2	24	0.0000	1.0397	0.6931	0.6931	1.6675	0.5073	0.2916	0.1788
2	3	2	1.0397	0.6931	1.3863	0.0000	0.6931	0.7992	0.4549	0.0000
6	3	6	0.0000	0.0000	0.0000	0.7550	0.5010	0.8105	0.3821	0.1541
3	3	9	0.6931	1.0416	0.8676	1.2425	0.8676	0.4726	0.9081	0.1425
4	3	16	0.6837	1.7287	0.4101	0.9557	0.3046	0.2053	0.6339	0.3307
1	3	19	0.9503	1.9339	1.0397	1.4271	1.1668	0.4645	0.3737	0.3676
5	3	23	1.0986	1.9355	0.8676	1.2799	0.8953	0.4129	0.0616	0.0034
4	4	4	1.0986	1.0397	1.3863	0.0000	0.8856	0.2839	0.5187	0.1500
1	4	7	0.6931	1.8479	0.0000	0.0000	0.6837	0.8523	0.2320	0.7494
5	4	11	0.6931	1.8352	0.0000	0.6365	0.6365	0.3867	0.3782	0.1217
2	4	14	0.7963	1.7588	1.4751	1.3863	0.9180	0.8540	0.6577	0.0000
6	4	18	0.0000	1.0609	0.0000	0.0000	0.8487	0.7420	0.2449	0.0000
3	4	21	0.6837	1.8691	1.0986	1.3322	0.7083	0.8945	0.3861	0.1358

Treatments: (1) H1 – High diversity mix regular rate
(2) H2 – High diversity mix double rate
(3) C1 – NRCS CP25 mix low rate
(4) C2 – NRCS CP25 mix regular rate

Appendix D. Bee diversity index values 2009 SAS 9.2 code used.

```
data beesindex;
input blck trt t1 t2 t3 t4 t5 t6 t7 t8;
cards;
1     1  0.0000  1.7815  1.7329  0.0000  0.2146  1.1693  0.1495  0.0000
5     1  0.6931  1.6716  0.5623  1.3863  0.5004  0.5141  0.5910  0.4095
2     1  0.6931  1.8286  1.6679  1.0397  0.6931  0.5927  0.3782  0.0000
6     1  0.6931  1.3209  0.0000  0.0000  0.5004  0.3735  0.4989  0.3488
3     1  1.1218  1.8342  1.0114  0.0000  0.5661  0.7550  0.3557  0.0000
4     1  0.6931  1.3317  0.0000  1.0549  0.9557  0.5433  0.0965  0.7743
3     2  0.6931  1.7290  0.6931  1.0986  0.9503  0.2449  0.5433  0.0000
4     2  0.0000  1.3863  1.0397  0.6829  0.6931  0.5586  0.2464  0.4487
1     2  1.0790  1.7354  1.9062  0.0000  0.9369  0.7858  0.2929  0.0000
5     2  0.0000  1.7329  2.1458  1.0986  0.7550  0.1269  0.2019  0.0000
2     2  1.0549  1.3897  1.0397  0.0000  0.6365  0.2911  0.3616  0.0000
6     2  0.0000  1.0397  0.6931  0.6931  1.6675  0.5073  0.2916  0.1788
2     3  1.0397  0.6931  1.3863  0.0000  0.6931  0.7992  0.4549  0.0000
6     3  0.0000  0.0000  0.0000  0.7550  0.5010  0.8105  0.3821  0.1541
3     3  0.6931  1.0416  0.8676  1.2425  0.8676  0.4726  0.9081  0.1425
4     3  0.6837  1.7287  0.4101  0.9557  0.3046  0.2053  0.6339  0.3307
1     3  0.9503  0.9339  1.0397  1.4271  1.1667  0.4645  0.3737  0.3676
5     3  1.0986  1.8355  0.8676  1.2799  0.8953  0.4129  0.0616  0.0034
4     4  1.0986  1.0397  1.3863  0.0000  0.8856  0.2839  0.5187  0.1500
1     4  0.6931  1.8479  0.0000  0.0000  0.6837  0.8523  0.2320  0.7494
5     4  0.6931  1.8352  0.0000  0.6365  0.6365  0.3867  0.3782  0.1217
2     4  0.7963  1.7588  1.4751  1.3863  0.9180  0.8540  0.6577  0.0000
6     4  0.0000  1.0609  0.0000  0.0000  0.8487  0.7420  0.2449  0.0000
3     4  0.6837  1.8691  1.0986  1.3322  0.7083  0.8945  0.3861  0.1358
;
data newbees;
set beesindex;
time=1; div=t1; output;
time=2; div=t2; output;
time=3; div=t3; output;
time=4; div=t4; output;
time=5; div=t5; output;
time=6; div=t6; output;
time=7; div=t7; output;
time=8; div=t8; output;
keep blck trt time div;
run;
proc mixed;
class blck trt time;
model div=trt time trt*time/ddfm=kr;
random blck;
repeated/subject=blck*trt type=csh;
lsmeans trt/diff;
run;
```

Appendix E. Beneficial arthropod family richness for each plant species (trt) in each plot: Forestry (block 1), Prairie Pines (block 2), and Entomology (block 3) collected in 2009.

Block 1		Block 2		Block 3	
Trt	**Richness**	**Trt**	**Richness**	**Trt**	**Richness**
1	8	1	0	1	0
2	4	2	3	2	4
3	12	3	8	3	17
4	0	4	0	4	1
5	8	5	4	5	2
6	0	6	8	6	10
7	5	7	5	7	0
8	12	8	13	8	12
9	1	9	0	9	0
10	2	10	6	10	5
11	15	11	9	11	14
12	2	12	5	12	1
13	10	13	19	13	18
14	7	14	9	14	10
15	12	15	14	15	8
16	1	16	15	16	14
17	5	17	13	17	13

Appendix F. Beneficial arthropod richness SAS 9.2 code used

```
data beneficialrichess;
input trt @;
do block=1 to 3;
input richness @;
output;
end;
datalines;
1	8	0	0
2	4	3	4
3	12	8	17
4	0	0	1
5	8	4	2
6	0	8	10
7	5	5	0
8	12	13	12
9	1	0	0
10	2	6	5
11	15	9	14
12	2	5	1
13	10	19	18
14	7	9	10
15	12	14	8
16	1	15	14
17	5	13	13
;
proc glimmix;
class trt block;
model richness=trt block;
lsmeans trt/diff adjust=tukey lines;
output out=comp resid=resid pred=pred;
run;
```