ABSTRACT

THE ROLES OF NATURAL AND SEMI-NATURAL HABITAT IN THE PROVISIONING OF BIODIVERSITY AND ECOSYSTEM SERVICES OF BENEFICIAL INSECTS IN AGRICULTURAL LANDSCAPES.

by Jason M. Nelson

As global demands increase for food, livestock, and biofuels, agricultural intensification could further increase the conversion of natural and semi-natural habitats into production. This intensification severely impacts natural plants and crops that rely entirely on pollination and pest control for fruit and seed production. I studied the species richness and composition of insect pollinators and natural enemies in 10 warm-season conservation grasslands. In Chapter 1, I tested richness, species composition, and trait composition (functional diversity) of pollinating bees and predatory beetles against patch area and vegetative composition as well as landscape variables based on surrounding land use and cover. In Chapter 2, I tested richness, species composition, and functional diversity of predatory and parasitoid species against patch and landscape variables. Overall, patch-level processes regulated species richness and composition of pollinators, whereas the surrounding landscape context was more important in the species richness, composition, and functional diversity of predatory and parasitoid insects.

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Chapter 1: Effects of patch and landscape-level variables on the biodiversity of pollinating bees (Hymenoptera: Apoidea) and predatory beetles (Coleoptera) in an agricultural landscape.

Abstract: Conservation of pollinating and natural-enemy insects in agricultural landscapes requires an understanding of how both patch- and landscape-level variables affect the biodiversity of beneficial insects. I investigated the effects of patch- (i.e., area, age, and plant community composition) and landscape-level (i.e., land use / land cover types) factors on the species richness, composition, and functional diversity of bees and predatory beetles. Insect and plant sampling were conducted early and late summer of 2009 in 10 conservation grasslands within a 300 km^2 agricultural landscape of southwestern Ohio. Bee species richness increased with greater patch area during early season and species composition was related to patch area or proportional forb cover, depending on season. Beetle richness increased with a greater proportional amount of semi-natural habitat and intensive agriculture within 370 m of the study patches in early season, and increased with greater amount of semi-natural habitat within 260 m during the second sampling period. Beetle species composition was related to the amount of intensive agriculture within 525 m and 740 m during early and late seasons, respectively. Functional diversity of bees and beetles was based on morphological, ecological, and life-history traits. Bee functional diversity was related to patch area or semi-natural habitat within 130 m radius, depending on season. Functional diversity of beetles was related to the amount of semi-natural area within 1045 m during both sampling periods. The contrasting responses of these two groups of beneficial insects showed that pollinating bees are related to amount of semi-natural habitats within an agricultural landscape, while predatory beetles are related to complementarity of the surrounding agricultural and semi-natural habitats. The results of this study demonstrate that conservation incentives by creating semi-natural habitat and increase landscape heterogeneity of both cultivated and semi-natural areas would benefit the biodiversity conservation of pollinating bees and predatory beetles.

Introduction

Over the past 60 years, agriculture has intensified through the use of high-yielding crops, application of chemical fertilizers and pesticides, irrigation, and mechanization (Matson et al. 1997, Tscharntke et al. 2005a). This intensification has negatively influenced biodiversity of organisms in agricultural environments at local, landscape, and global scales. Increases in crop monocultures, inputs of fertilizers and pesticides, and field sizes are examples of intensification at the local or field scale. Landscape-level intensification includes the loss of forest (hereafter referred to as natural habitat) or conservation warm-season grassland (hereafter referred as semi-natural habitat) and decreases in field margins, filter strips, or grass waterways. From a global perspective, the amount of cultivated land and the intensification of land use have increased across several continents in both temperate and tropical agroecosystems (Chape et al. 2003, Tscharntke et al. 2005a, Tylianakis et al. 2005).

Intensification of agriculture affects both local and landscape characteristics through changing of farming systems from diverse crops in small fields surrounded by natural or semi-natural habitat to large fields with one or two crops types (e.g. corn and soybeans) and little surrounding natural or semi-natural land (Medley et al. 1995, Burel and Baudry 2003). The intensification of cultivated land has negatively affected the richness and abundance of predatory insects (Landis et al. 2000) and pollinators (Klein et al. 2007) in agricultural landscapes. Simplified landscapes dominated by crops and diminished non-crop habitat, negatively affect plants species richness and the resources that plants provide for beneficial insects within agricultural landscapes (Bianchi et al. 2006, Cousins et al. 2007, Tscharntke et al. 2007).

Conservation programs, like the United States Department of Agriculture (USDA) Conservation Reserve Program (CRP), provide monitory incentives to convert marginal cultivated land into semi-natural habitat that would increase wildlife and help prevent topsoil erosion (NCRS 2012). Natural and semi-natural habitats in agricultural landscapes (Vollhardt et al. 2008, Tscharntke et al. 2007) support a greater diversity of pollinating and predatory insects that provide ecosystem services in both semi-natural habitat and cultivated areas (e.g., Holzschuh et al. 2007, Kremen et al. 2007, Winfree et al. 2008). These semi-natural habitats provide resources such as nectar and pollen from a diversity of flowering plants, a variety of prey or hosts, and overwintering and nesting habitat for pollinators and predatory insects (e.g., Wäckers and van Rijn 2005, Tscharntke et al. 2007, Winfree et al. 2008).

Stable and diverse assemblages of plants in natural and semi-natural habitat patches support resident populations of pollinating and predatory insects, by providing the necessary resources (Theis and Tscharntke 1999, Landis et al. 2000, Kremen et al. 2002). Differences in composition of insect species among natural and semi-natural habitat patches lead to shifts in community interactions and increase the functioning and sustainability of ecosystems (Loreau 1998, Loreau 2000). The variety of functional roles that insects serve in crops and the surrounding landscape can be correlated with ecosystem level properties, such as greater productivity in heterogeneous habitats (Tilman 2000, Petchy and Gaston 2006). Mean level of ecosystem functioning is increased when contrasting resources are used by a complementary set of organisms, because different species can occupy dissimilar microhabitats (Tylianakis et al. 2008). Habitat loss and changes in land use / land cover (hereafter referred to as land cover) cause declines in the biodiversity of pollinators and natural enemies, and life history traits of plant dependent organisms which, in turn, decreases mean level of ecosystem functioning (Davies et al 2000).

Using both patch- and landscape-level perspectives to study insect biodiversity in agroecosystems are important because different insect species are affected by processes operating at contrasting scales (Clough et al. 2007, Tscharntke et al. 2007, Marini et al. 2009). A wide array of scales, ranging from adjacent to and a couple of kilometers away the patch, depending on species of study, should be considered for sustaining the biodiversity of insects and the ecological process that they control (Burel and Baudry 2003). Both pollinating and predatory insect assemblages are influenced by the amount and spatial arrangement of permanent landscape elements, such as perennial grasslands, and by the composition of the surrounding landscape (Chust et al. 2000).

In SW Ohio, agricultural landscapes consist of semi-natural habitat, natural forest remnants, and perennial field margins scattered within an agricultural matrix. These non-crop habitats may support larger numbers of natural enemies and pollinating insects than found in cultivated lands (Gardiner et al. 2010, Hendrix et al. 2010). Semi-natural habitats include the marginal lands planted with perennial herbaceous vegetation under agreements with the USDA-CRP or Habitat Enhancement Grants (HEG) from United States Fish and Wildlife Service (USFWS), commonly with matching funds from local land trusts. These grants provide financial and technical subsidies to farmers for planting semi-natural habitats in lieu of crops (NCRS 2012, USFWS 2012). Semi-natural habitats also provide essential ecosystem services including erosion control and wildlife habitat (NCRS 2012), but their roles in supporting beneficial insects are largely unknown (Long et al. 1998, Landis et al. 2000).

Limited data on how patch and landscape factors influence beneficial insects in agricultural landscapes in Midwestern North America preclude accurate assessments of the amount of habitat area, floral resources, or semi-natural habitat in the landscape is needed for biodiverse assemblages of pollinators and predators (Landis et al. 2000, Steffan-Dewenter 2003). Potentially significant factors that could influence the biodiversity of insects, other animals, and plants are patch area, time since planting (age), and plant community composition (i.e., Öckinger and Smith 2006). Similarly, the colonization and persistence of patches by natural predators and pollinators may depend strongly on the amounts and varieties of habitats in the surrounding agricultural landscape (Steffan-Dewenter 2002, Tscharntke et al. 2007).

To evaluate the potential role of semi-natural habitat in maintaining beneficial insects in an agricultural landscape, I studied the richness and composition of pollinating bees and predatory beetles in semi-natural habitats within a 310 km^2 area of SW Ohio in summer 2009. My objectives were to evaluate the role of semi-natural habitat in supporting the biodiversity of bees and beetles within an agricultural landscape. I tested the following hypotheses: i) the species richness and composition of bees and beetles are determined by size, age, and vegetation composition of the patch; and ii) the species richness and composition of bees and beetles are determined by relative amounts of surrounding land cover types (intensive agricultural, natural, and semi-natural habitat); iii) the species trait composition of bees and beetles are determined by both patch-level habitat factors and the surrounding land cover. Stable habitat areas with floral resources are known to be important for bees, especially for small-bodied, solitary bees that are ground nesting and have limited dispersal ability (Steffan-Dewenter et al. 2002). Conversely, the use of complementary resources in crop and non-crop habitats by beetles may be greater for large-bodied, macropterous species (Gutiérrez and Menéndez 1997, Hodek and Michaud 2008). I therefore predicted that the larger, older, grassland patches with greater variation in plant composition would have higher species richness of bees and beetles, and that species composition of bees and beetles would be similar in larger, older, and more heterogeneous patches. Likewise, I predicted that semi-natural habitat with greater amounts of surrounding natural and semi-natural habitats would also support higher bee and beetle richness and differ in species composition from patches surrounded predominantly by crops. Finally, I predict that life-history traits, such as body size and diet breadth in larger and older patches, surrounded by semi-natural habitat, will differ in composition from smaller and younger patches, surrounded predominantly by cultivated land.

Methods

Study Region

My research was focused on 10 semi-natural habitat patches created under either lease agreements with the CRP or from HEG in Butler and Preble Counties of southwestern Ohio (Fig. 1-1). Patches were scattered in a 310 km^2 agricultural landscape, with distances between adjacent patches ranging from 2 to 10 km. In 2009, approximately 51% of Butler County was active cropland, 23% forests, 12% urban, and 11% pasture. In Preble County active cropland was approximately 67%, 17% forest, 8% pasture, and 6% urban (Ohio Department of Development County Profiles 2009).

Study patches ranged in size from 1.2 to 17.8 ha, and were planted in native warm-season grasses and forbs (Table 1-1). Surrounding habitat included cultivated row crop, forests, suburban, hedgerows, pastures, and wetlands (Table 1-2). Time since planting ranged from 1 to 13-yrs, and most areas were cultivated prior to planting perennial grasses and forbs. All patches were planted with a similar mix of grasses and forbs (Appendix 1 and 2), but patches varied in species dominance, diversity, and composition of the established plant community. Dominant grasses included big blue stem (*Andropogon gerardii*), little blue stem (*Schizachyium scoparium*), switchgrass (*Panicum virgatum*), Indian grass (*Sorghastrum nutans*), and side oats grama (*Bouteloua curtipendula*). A variety of forbs were present, including partridge pea (*Cassia fasiculata*), Illinois bundleflower (*Desmanthus illinoensis*), coneflower (*Echinacae purpurea*), and Maximilian sunflower (*Helianthus maximiliani*, Appendix 1 & 2).

Insect Sampling

All patches were sampled during 2-wk periods twice during the summer of 2009: 26 May – 8 June and 27 July – 10 August (hereafter referred to as June and August samples). Five patches were randomly selected to sample during the first week and five during the second week in each of the two sample periods. Random site selection was constrained to include small and large patches in each week of the sampling window. The order of sampling of each site remained the same for both sampling periods.

Combination flight intercept / pan traps, a modification of Duelli et al. (1999), were used to sample aerial insects. Yellow buckets (7.6 L; 29 cm diam. x 21 cm tall) were used to attract pollinators and, to intercept weak flying insects, a pair of perpendicular Lexan™ panes were inserted into the bucket, extending 41 cm vertically from the top of the bucket (Fig. 1-2). Buckets were elevated on platforms 1 m above the ground, which was approximately level with the vegetation during the first sampling period. Water and a few drops of detergent were added, to a depth of 10 cm, to the bucket to cut surface tension.

Pitfall traps, plastic cups (75 mm diam. x 80 mm deep), were used to sample ground-dwelling insect insects. A pit-fall trap was placed 1 m from each flight intercept / pan trap, flush with the ground surface. Ethylene glycol was added to each pitfall trap as a killing agent.

The traps were set in transects through the center axis of the long dimension of each patch. The number of traps in each patch was scaled to the logarithm of the patch area, ranging from 5 traps at the smallest site to 10 traps at the largest site. Trap spacing was 25 m at all sites. Each trap station was marked with a flag to sample the same location later in the summer. In the field, samples were poured through No-see-um netting (Nicamaka™) then washed with 70% ethanol into a Nalgene™ bottle for temporary storage. Pitfall traps were capped and returned to the laboratory.

In the laboratory, bees (Apoidea) were also sorted and identified to genus and morphospecies, with the exception of *Apis* and *Bombus,* which were identified to taxonomic species (Appendix 3 and 4; Heinrich 1979, Michener 2000). Focal families of Coleoptera (predatory beetles, Appendix 5 and 6) were sorted and identified to species (Downie and Arnett 1996, Arnett and Thomas 2001). Some beetles identified were parasitoids (family Meloidae and Ripiphoridae, and subfamily Lebiinae), and hereafter referred to as predatory beetles for simplicity.

Vegetative Cover

Plant sampling was conducted twice during the sampling season (15-17 June and 20-22 August). Vegetative cover was recorded in a pair of 10-m^2 circular quadrants located 3 m from each side of the trap and perpendicular to the transect line. Estimated cover was recorded for each plant species as 0, 1, 5, 10, 25, 50, 75 or 100%. The total number of flowering forb stems was also recorded by species (Table 1-1). Means for flowering stem counts, total cover, and vegetative functional groups of C3 grasses, C4 grasses, and forbs plants were taken across traps for each site (Table 1-1).

Landscape Variables

Digital Orthophoto Quadrangles, (0.15 m resolution for Butler County, 3 m resolution for Preble County) and Geographic Information Systems (ESRI ArcGIS 9.3.1 2009) were used to quantify the size and arrangement of surrounding land-cover types. On-screen digitizing of land cover was implemented within circular windows of eight varying radii (130, 185, 260, 370, 525, 740, 1045, 1480 m), doubling the area sampled with each consecutive radius from the center of the transect within each patch (Fig. 1-1, Marini et al. 2009). Land cover was classified as (1) semi-natural habitat, (2) intensive agriculture, (3) extensive agriculture, (4) forest, (5) low-density residential, (6) high-density residential and (7) water / wetland. Intensive agricultural were characterized by intensively manage row crops of corn, soybean, or barley, whereas extensive agriculture were characterized by hay field or pastures. These spatial scales for analyses ranged from 0.053 (130 m) to 6.8 km^2 (1480 m). These spatial scales were chosen to reflect differential dispersal distances of the insect taxa under investigation (Tscharntke et al. 2007, Marini et al 2009) and to reduce overlap from adjacent habitats (Holland et al. 2004). Within each radius, the Shannon-Weiner diversity of the land-cover types was also calculated. Land cover was ground-checked by site visits to identify land cover that was not clearly interpretable in aerial images.

Functional Diversity

A broad classification of functional groups was developed for bees and beetles based on morphological, ecological, and life-history traits (Petchy and Gaston 2006). Traits to describe functional roles for bees were tongue length (0 = short, 1 = long), body size converted to a categorical variable using the median body size of all bee taxa recorded (< 10.9 mm = 0, > 10.9 mm = 1), nesting location (cavity = 0, ground = 1), and sociality (solitary = 0, social =1) (Michener 2000). Beetles were placed into functional groups based on body size categories using a categorical variable to describe the median of all beetle species recorded (< 5.5 mm = 0, > 5.5 mm =1), diet breadth (specialist = 0, generalist = 1), predator as larva (no = 0, yes = 1), predator as adult (no = 0, yes = 1), diel activity (night = 0, day = 1), and wing type (brachypterous = 0, macropterous = 1) (Arnett and Thomas 2001).

Statistical Analysis

Site-based rarefaction curves of beetles or bees were constructed in the vegan package of R (Oksanen et al. 2011, R Development Core Team 2011) to determine sufficient sampling. Curves were plotted for mean richness estimates for total individuals in the 10 sites in both bee and beetle species with 95% confidence intervals. Chao incidence-based richness estimates were calculated to provide an estimate of species richness in R (Oksanen et al. 2011, R Development Core Team 2011).

The frequency distributions of species richness were first checked for the presence of greater variability in a given data set than expected from Poisson counts (i.e., overdispersion). Statistical models were built for patch-level (n = 10) species richness of both bees and beetles. General linear models with either a Poisson or a quasi-Poisson distribution were tested against several patch (Table 1-1) and landscape variables (Table 1-2). Patch and landscape (proportional of the top three or Shannon diversity measurements of total land cover) models were built separately to limit collinearity, then the top models for patch and landscape were combined. Separate and combined patch and landscape models were constructed for the June and August sampling periods.

The lowest bias-corrected Akaike Information Criteria (AICc), or bias-corrected quasi-Akaike Information Criteria (qAICc, for over-dispersed data) was chosen to be the best fitting statistical models containing both patch and landscape variables. AICc or qAICc was used because ratios between number of samples (n) to the number of parameters (K) were small (n/K < 40; Burnham and Anderson 2001). Models that differed by less than 2 were considered competing. The model residuals were also used to assess model fit. Due to overlapping radii between two of the study sites, statistical analyses were run twice with each site omitted. Overlapping radii during analyses made it so that AICc and qAICc could not be compared between the different data sets; therefore deviances were also considered in describe the best fitting model.

Species composition was analyzed using distance-based redundancy analysis (dbRDA) ordination with Bray-Curtis dissimilarity. Using the dbRDA method is an improvement over other test (i.e., MANOVA) for complex designs because it allows for many rare species, can be based on any distance measure dissimilarity matrix, and gives a reasonable permutational *p*-test (McArdle and Anderson 2001). The best fitting statistical model contained patch or landscape variables that had the lowest AICc, with *p*-values were obtained under random permutation (999 permutations). The top models for patch and landscape models were combined to get the best overall model using the same criteria. Analyses to calculate dissimilarity indices were conducted in the vegan package of the R programming language (Oksanen et al. 2011, R Development Core Team 2011) with user written functions for dbRDA (M. Anderson, personal communication).

Site-by-trait matrices for both bee and beetle species were assembled by multiplying the transposed trait x species matrix by the site x species matrix (McCune and Grace 2002). Functional diversity was analyzed using dbRDA ordination with Euclidean dissimilarity of bee and beetle species trait-by-site matrices and patch or landscape matrices (McArdle and Anderson 2001). The combinations of the patch and landscape variables with the lowest AICc score were chosen to be the best fitting statistical models. *P*-values were obtained under random permutation (999 permutations). The best overall model was chosen using the same criteria after combining the top models for patch and landscape models. In dbRDA models, competing models had a difference in the AICc value less than 2. Analyses to calculate dissimilarity indices were conducted in the vegan package of R (Oksanen et al. 2011, R Development Core Team 2011) with user written functions for dbRDA (M. Anderson, personal communication).

Results

Bee richness and abundance totaled 44 species and 2718 individuals: 49% of the total abundance was during June (1326 individuals, 39 species) and 51% was during August (1391 individuals, 35 species). The mean bee richness per site was 24.0 for the two sampling periods combined, with a minimum site richness of 19 and maximum site richness of 29. The mean bee abundance per site was 272 for the two sampling periods combined, with a minimum site abundance of 142 and a maximum site abundance of 600. The rarefaction curve indicated that sampling of bee richness approached an asymptote (Fig. 1-3) with a Chao incidence-based richness estimate of 47.2.

Long-tongued bees made up 50.0% (95% CI, 34.2 - 65.8%) and 18.4% (16.4 - 20.5%) of species richness and abundance respectively in June, but 48.6% (31.4 - 65.7%) and 65.9% (63.4 - 68.4%) of species richness and abundance in August. Bees that were < 10.9 mm in size made up 44.7% (28.8 - 60.6%) of species richness and 63.3% (60.7 - 65.9%) of species abundance in June, while August sampling of bees showed that 45.7% (28.6 - 62.9%) of species richness and

32.8% (30.3 - 35.2%) abundance were < 10.9 mm in size. Ground-nesting bee species made up 81.6% (68.4 - 92.1%) and 86.3% (84.5 - 88.2%) of the species richness and abundance, respectively, in June, and a slightly lower 77.1% (62.9 - 91.4%) and 79.9% (78.8 – 82.9%) of the species richness and abundance, respectively, in August. In June 81.3% (69.4 - 93.2%) of species richness and 89.4% (87.7 - 91.0%) of species abundance of bees was solitary, whereas in August 85.7% (74.3 - 97.1%) of species richness and 74.3% (72.0 - 76.6%) of species abundance of bees was solitary.

There were a total of 3275 individuals of predatory beetles comprising 138 species. Of the total abundance, 64% was during June (2165 individuals, 115 species) and 36% during August (1111 individuals, 85 species). The mean beetle species per site was 45.0 for the two sampling periods combined, with a minimum site richness of 35 species and a maximum site richness of 66 species. The mean number of individuals of beetles per site was 328 over the two sampling periods combined, with minimum site abundance of 173 individuals and a maximum site abundance if 562 individuals. Many of the species were represented by singletons (28%) and doubletons (17%). The Chao incidence-based richness estimate was 180.9 for beetles and the rarefaction curve continued to rise (Fig. 1-4). About 75% of the estimated species richness was sampled across the 10 sites.

Beetles that were < 5.5 mm in size (median) made up 65.2% (95 CI, 56.5 - 73.9%) of species richness and 72.5% (70.6 - 74.4%) of species abundance in June, while August sampling of beetles showed that 54.1% (43.5 - 64.7%) of species richness and 49.8% (46.8 - 52.7%) abundance were < 5.5 mm in size. During June sampling 45.2% (36.5 - 53.9%) and 18.3% (16.6 - 19.9%) of beetle richness and abundance, respectfully, were classified as general predators, while 52.9% (43.4 - 63.5%) and 38.0% (35.1 - 40.9%) of beetles were classified as generalists during August sampling. In both samples, all beetles were predatory as larvae. In June, 77.4% (69.5 - 85.2%) species richness and 52.1% (50.0 - 54.2%) of species abundance of beetles were predatory as adults, whereas, in August, 75.9% (67.1 - 84.7%) of species richness and 61.9% (59.0 - 64.8%) of species abundance were predatory as adults. Nocturnal beetle species made up 27.6% (19.1 - 35.6%) and 21.2% (19.4 - 22.9%) of the species richness and abundance, respectively, in June and 21.8% (12.9 - 30.9%) and 19.9% (17.6 - 22.2%) of species richness and abundance, respectively, in August. During June sampling 27.0% (21.7 - 38.2%) of species richness and 10.7% (9.4 - 12.0%) of species abundance of beetles had brachyopterous wings, while in August sampling 33.5% (23.5 - 43.5%) of species richness and 31.6% (28.9 - 34.3%) of species abundance of beetles had brachyopterous wings.

Regression Analysis

Poisson regression between bee species richness and patch variables during June showed that the best model was the log semi-natural habitat patch area (Deviance = 4.14, df = 1, 8, *p* = 0.042, Fig. 1-5, Table 1-3). At a landscape level, the best-fitting model for bee richness was the proportion of semi-natural land cover within a 525 m radius; however this relationship was not statistically significant (Deviance = 3.15, df = 1,7, *p* = 0.076). When patch and landscape models were combined, the best overall model contained only log semi-natural habitat patch area (Fig. 1-5). Number of traps in the patch was a competing model (Deviance = 4.26, df = 1, 8, *p* = 0.039, Table 1-3), so greater sampling effort in larger patches may partly explain this effect. Model selection showed that the null model was the best for both patch and landscape level analysis during August sampling for bee species richness.

Total vegetation cover (Deviance = 4.77, df = 1, 8, *p* = 0.029) explained beetle species richness during June sampling. On the landscape scale, the best model for beetle species richness was the proportion intensive agriculture and semi-natural land cover within a 370 m radius (Deviance = 11.75, df = 2,6, *p* = 0.0018, Fig. 1-6, Table 1-3). The explained deviance peaked at the 370 m radius for the combined effect of intensive agriculture and semi-natural land cover (Fig. 1-7). Proportional amount of forest land cover was a competing model (Deviance = 7.71, df = 1,7, *p* = 0.0052), but when combining the best patch and landscape models, the variables of proportional amount of intensive agriculture and semi-natural land cover within 370 m radius was the best model for beetle richness (Fig. 1-6).

During the August sampling period, the best patch variable for predicting beetle species richness was log area of the patch (Dev. = 8.57, df = 1,8, *p* = 0.003). The best landscape-level model showed that proportion of semi-natural grassland within 260 m radius (Dev. = 10.59, df = 1, 7, *p* = 0.0011, Fig. 1-8, Table 1-3) was best predictor of beetle species richness. The explained deviance for the effect of semi-natural grassland was greatest at the 260 m radius (Fig. 1-9). The best model was the landscape model explaining beetle species richness after the patch and landscape model was combined (Fig. 1-8).

Species Composition

Distance-based redundancy analyses (dbRDA) for bee species composition during June sampling showed that 22% of the variation was explained by the log patch area (*p* = 0.015, first ordination axis eigenvalue = 0.2, Fig. 1-10a, Table 1-4). At the landscape level, the proportion of semi-natural area within 130 m radius explained 22% of the variation in bee species composition (*p* = 0.023). When patch and landscape models were combined, the log patch area and the proportion of semi-natural area within 130 m radius were both significant predictors of variation in species composition (p = 0.0069), but after model selection, log patch area yielded the lowest AICc (Fig. 1-10a). Bees associated with larger patches were mostly from the Halictidae family (Genera *Augochlorella*, *Halitcus*, and *Lassioglassum*) species.

During August sampling, dbRDA showed that proportion of forbs in the patch explained 23% of the variation in bee species composition (*p* = 0.0077, first ordination axis eigenvalue = 0.2, Fig. 1-10b, Table 1-4). Landscape-level analyses using dbRDA showed no significant model and no combination of patch and landscape variables gave a significant dbRDA; therefore, the proportions of forbs yield lowest AICc (Fig. 1-10b). Bee species shifted from Apidae (Genera *Apis* and *Bombus*) species in patches with higher proportions of forby herbaceous plants to Halictidae (Genera *Augochlorella*, *Halitcus*, and *Lassioglassum*) in patches with smaller proportions of forbs.

For beetle species composition, dbRDA for patch characteristics showed that C4 grasses explained 16% of the variation during June sampling, but was not statistically significant (*p* = 0.0725). At landscape level dbRDA showed that the proportion intensive agriculture within 525 m radius explained 23% of the variation of beetle species composition (*p* = 0.0096, first ordination axis eigenvalue = 0.3, Fig. 1-11a, Table 1-4). When patch and landscape models were combined only the landscape variable of intensive agriculture gave the lowest AICc (Fig. 1-11a). Beetles species associated with greater proportions of intensive agriculture within 525 m radius were mostly from the Carabidae (*Stenolophus ochropezus* and *Lebia analis*) and Coccinellidae (*Harmonia axyridis*) family, while other Carabidae (*Harplus pensylvanica*) and Cantharidae (*Chaulignathus marginatus and Rhaxonycha carolinus*) species dropped in abundances from patched surrounded by large extents if intensive agriculture within 525 m radius.

In August, C3 grasses explained 17% of the variation of beetle species composition, but this relationship was not significant (*p* = 0.062). At the landscape level, the proportion of intensive agriculture within 1045 m radius explained 22% of the variation in beetle species composition (*p* = 0.036, first ordination axis eigenvalue = 0.3, Fig. 1-11b, Table 1-4). After combining models of patch and landscape variables only the landscape variable of intensive agriculture was retained in the model with the lowest AICc (Fig. 1-11b). Beetles sampled in patches associated with intensive agriculture in the surrounding landscape within 1045 m radius were mostly from the Carabidae (i.e., *Acupalpus tantilus*, *Bembidon affine, Harplus caliginosus*) family.

Functional Diversity

During June sampling period, dbRDA showed that log semi-natural habitat patch area explained 52% of the variation in bee species traits (*p* = 0.0093, first ordination axis eigenvalue = 0.08, Fig. 1-12a, Table 1-5). At a landscape level, the proportion of intensive agriculture and semi-natural grassland at 1045 m explained 79% of the variance (*p* = 0.01). The best-fitting model after combining the patch and landscape models was log semi-natural habitat patch area (Fig 1-12a).

The log number of flowering stems was the best explanatory variable for bee traits for patch variables using dbRDA during August sampling; however this relationship was not significant (*p* = 0.27). On a landscape level, the proportion of semi-natural land cover at 130 m radius had the lowest AICc and explained 32% of the variation in bee species traits (*p* = 0.050, first ordination axis eigenvalue = 0.006, Fig. 1-12b, Table 1-5). Ground nesting, solitary, and smaller bee species (Genera *Augochlorella*, *Halitcus*, and *Lassioglassum*) were found mostly in the larger patched and in patches surrounded by greater proportions of semi-natural habitat the surrounding landscape within 130 m radius in both June and August sampling respectively.

Variation in beetle trait composition was not significantly related to any of the patch variables during the June sampling period. At the landscape level dbRDA showed that the proportion of semi-natural land cover at 1045 m radius explained 35% of the variation (*p* = 0.072, first ordination axis eigenvalue = 0.006, Fig. 1-13a, Table 1-5). As in June, none of the patch-level variables was a significant predictor of variation in beetle species traits during the August sampling period. At the landscape-level the proportion of semi-natural land cover at 1045 m radius explained 42% of the variation in beetle species traits (*p* = 0.011, first ordination axis eigenvalue = 0.009, Fig. 1-13b, Table 1-5). During both June and August sampling, larger beetles with macropterous (*Harplus pensylvanica* Carabidae, and *Chaulignathus marginatus and Rhaxonycha carolinus* Cantharidae species) were found in patches surrounded by greater proportions of semi-natural habitat within 1045 m radius.

Discussion

The main objective of this study was to determine how the biodiversity of pollinating bees and predatory beetles in semi-natural habitat are influenced by characteristics of the patch and surrounding land use. Overall, my results showed that patch- level processes regulated the species richness and composition of bees, whereas the surrounding landscape context was more important to the species richness and composition of predatory beetles. I propose that differences between bees and beetle habitat use are that: i) patch-level processes are more important to bees because of variation in resources such of pollen, nectar, and nesting habitat; and that ii) the complementarity of habitat is more important for beetles for in their use of agricultural and semi-natural habitat due to alternative food items or overwintering habitat (Kremen et al. 2004 and 2007, Bianchi et al. 2006, Tscharntke et al. 2007).

Bee diversity, composition, and functional diversity

Many of the pollinating services to native plants and orchards within agricultural landscapes are provided by native bees (Kremen 2002). These services include pollination of native plants and crops (e.g., orchards, cover crops, and flowering native plants) for seed and fruit production (Lonsdorf et al. 2009). Populations of native bees are supported by natural and semi-natural habitats by supplying nectar and pollen resources, as well as nesting habitats (Beismeijer et al. 2006, Kim et al. 2006). Similarly, my results showed that area of semi-natural habitat had a positive effect on species richness of pollinators (Fig. 1-5), and that composition and functional diversity of pollinators differed from large to small semi-natural habitat patch areas (Fig. 1-10a, 1-12a) and larger to small proportions of semi-natural land cover (Fig. 1-12b). Habitat area is key factor for bees that have small body size, ground nesting, and solitary life histories for nesting, and establishment, and influences community structure of bees (Steffan-Dewenter et al. 2002). The richness of ground-nesting bee species has a strong relationship to the amount of habitat and nesting substrate (Cane et al. 2006).

Along with nest-site availability, area of natural and semi-natural habitat is essential for foraging ranges and population viability of bees (Kremen et al. 2007). Foraging distance is critical for bee diversity and composition. Smaller bees have more limited foraging ranges than larger bees (Greenleaf et al. 2007), and foraging ranges of solitary bees are limited when compared with honeybees or bumblebees (Osborne et al. 1999). There is a significant positive relation between species richness and abundance of solitary bees and percentage of semi-natural habitat (Steffan-Dewenter et al. 2002). The majority of the bees that I sampled were ground-nesting, solitary, and smaller in size. My data give further evidence that supports the idea that larger semi-natural patches with abundant floral resources are important for native bees. These data provide strong support that policy incentive for land owners, such as CRP and HEG, to establish semi-natural area provide an important role in the biodiversity conservation of native pollinators.

Positive relationships between habitat area and the amount of species richness extend to other taxonomic groups besides bees (e.g., Connor and McCoy 1979, Gaston and Blackburn 2000, Spengler et al. 2011). Nesting area requirements are positively related with area of habitat for many other organisms including grassland birds (Herkert 1994, Winter and Faaborg 1999), forest birds (Forman et al. 1976, Donovan and Flather 2002), and mammals (Archer et al. 1987, Michalski and Peres 2007). Larger habitat is often required by organisms with limited dispersal ability because larger more vagile organisms can readily disperse between smaller more isolated patches (With and Crist 1995, Drakare et al. 2006, Prugh et al. 2008).

Areas of natural and semi-natural habitat, with abundant forbs and other flowering plants that supply nectar and pollen resources are necessary for maintaining native bee populations (Kremen et al. 2004). During the August sampling, bee richness was not affected by any patch or landscape variable, but composition was significantly affected by the proportion of forbs (Fig. 1-10b). Pollination services require conservation practices that provide sufficient resources for wild pollinators within agricultural landscapes (Ricketts et al. 2008).

Beetle diversity, composition, and functional diversity

Landscape processes have substantial influences on the local diversity and composition of predatory beetles (Holzschuh et al. 2008) and different land cover types may accommodate different predators, depending on their traits (Ribera et al. 2001, Barbaro and van Halder 2005). My results suggest that complementary habitats in semi-natural and agriculture areas may determine the richness and composition of predatory beetles. The competing model of a negative relationship between predatory beetle richness and proportional forest land cover at 370 m radius is just as informative (Table 1-3), but the positive relationship between intensive agriculture at 370 m radius make more ecological sense especially given that sampling was conducted in grasslands rather than closed-canopy forests. Stable resources in semi-natural habitat, such as prey or alternative food items (nectar or pollen), can support a higher biodiversity and more varied composition of predatory beetles as they moved through an agricultural landscape (Landis et al. 2000, Landis et al. 2005, Wäckers and van Rijn 2005). The density of predatory beetle species may also be greatly enhanced by the high productivity of arable crop fields (Tscharntke et al. 2005b). Activity of predatory beetles, such as Carabidae, can be higher in intensively managed agricultural fields where they may feed on pest species (Hajek et al. 2007, Gardiner et al. 2010).

As short-lived habitats, arable agricultural fields are harsh environments for natural enemies to reside, but they can provide seasonally abundant prey items. Many natural enemies can colonize agricultural fields from other natural or semi-natural habitats early in the planting season or after disturbances (Tscharntke et al. 2005b). Both June and August populations of predatory beetles were affected similarly by land cover. Predatory beetle richness was affected by semi-natural habitat and intensive agriculture or by semi-natural habitat alone in June and August sampling periods (Fig. 1-6 & Fig. 1-8); however, the composition of predatory beetles was affected only by intensive agricultural in both the June and August sampling periods (Fig. 1-11). The availability of non-crop habitat in agricultural landscapes allows predatory beetles to disperse and spill-over from semi-natural habitat into cropland, affecting local biodiversity, species composition and pest suppression (Tscharntke et al. 2005a, Bianchi et al. 2006, Tscharntke et al. 2007).

Heterogeneous landscapes with large proportions of semi-natural habitat allows for greater dispersal of vagile predatory beetles across the landscape (Gutiérrez and Menéndez 1997, Hodek and Michaud 2008). The ability of beetles to disperse into arable crop fields from semi-natural habitats is affected by traits (Fig. 1-13). The majority of the beetles I recorded were larger in size with macropterous wing morphology, which allows for greater dispersal ability. Semi-natural habitat that is heterogeneously distributed through agricultural landscapes supports much higher biodiversity of predatory beetles than simplified landscapes (Weibull et al. 2003).

Predatory beetles are one of the dominant insect predators in cultivated fields (Lang et al. 1999, Holland et al. 2005) and the use of semi-natural habitat can be important in different life stages for feeding on prey items or alternative food (Bianchi et al. 2006, Wäckers and van Rijn 2005).

Conclusions and implications for conservation

These data indicate that both local and landscape processes influence the species richness and composition of bees and beetles. The contrasting responses of these two groups of beneficial insects suggest that bee biodiversity is largely driven by the availability of conservational semi-natural habitat patches in an agricultural landscape, while the biodiversity of predatory beetles primarily influenced by broader landscape composition around semi-natural habitat patches, showing complementarity of semi-natural and crop habitats. The size and proportion of semi-natural habitats in an agricultural landscape is critical for the conservation of these insects (e.g., Bianchi et al. 2006, Kremen at al. 2007, Tscharntke et al. 2007). Heterogeneous landscapes comprised of semi-natural habitats with abundant resources and favorable conditions may result in more diverse assemblages of bees and beetles.

These conservation efforts, in turn, could be used to improve the sustainability of crop production by enhancing the biodiversity and ecosystems services of beneficial insects (e.g., Landis et al. 2005, Kremen et al 2007, Tscharntke et al. 2007). Insights from this and other related studies may be especially valuable to local land managers, planners, and extension agents for conservation of pollinators and predators. In the United States, costs of converting cultivated lands to semi-natural habitats could be mitigated through funds provided by CRP (NRCS 2012) and HEG (USFWS 2012). Encouraging farmers to plant native warm-season grassland with a variety of flowering plants, along field margins or in areas that are not used in production, will benefit, not only beneficial insects, but will conserve other animal taxa (e.g., grassland birds and native plants) and other ecosystems processes (e.g., reduction of soil loss and carbon sequestration).

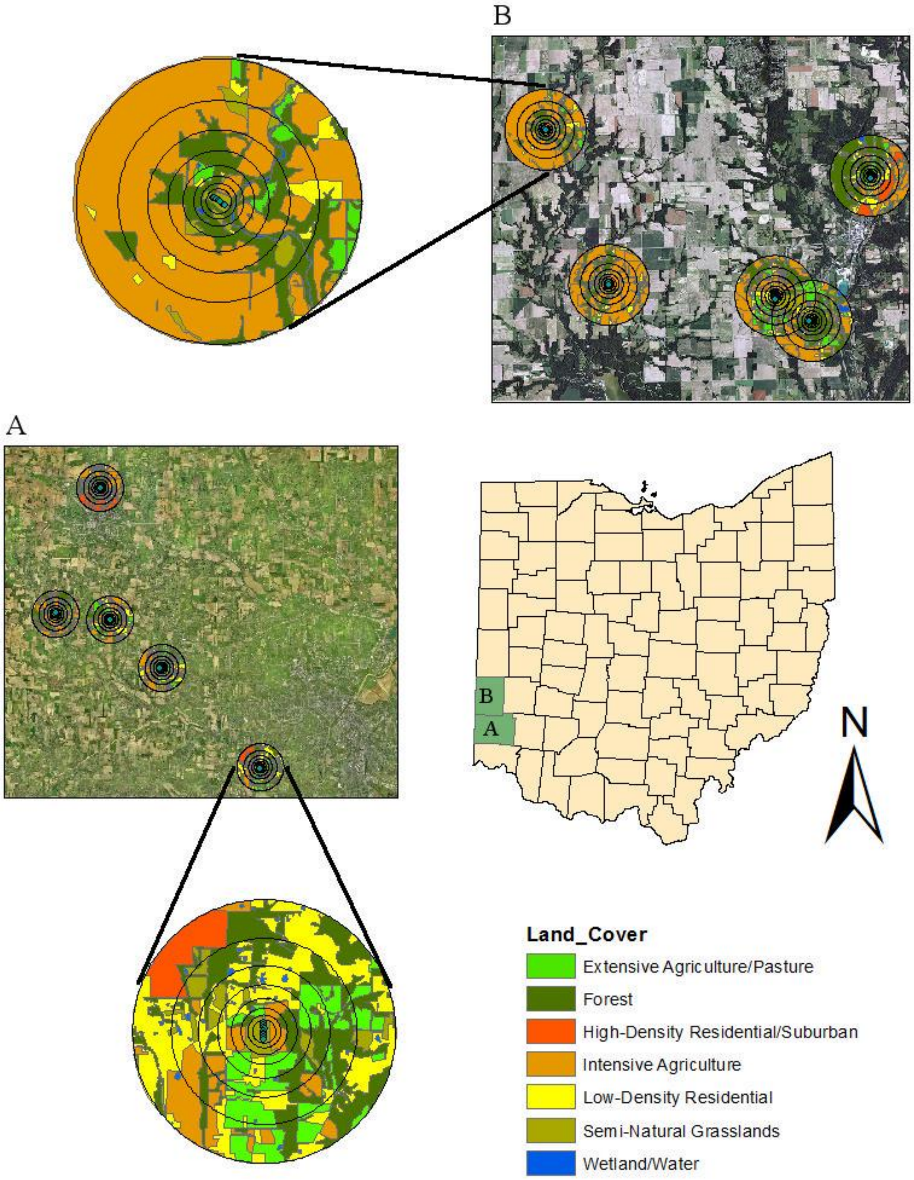

Figure 1-1: Study sites in A.) North Western Butler and B.) South Central Preble counties in SW Ohio. Location of 10 habitat sectors and the distribution of the primary habitat types.

Study sites in A.) North Western Butler and B.) South Central Preble counties in SW Ohio. Location of 10 habitat sectors and the distribution of the primary habitat types.

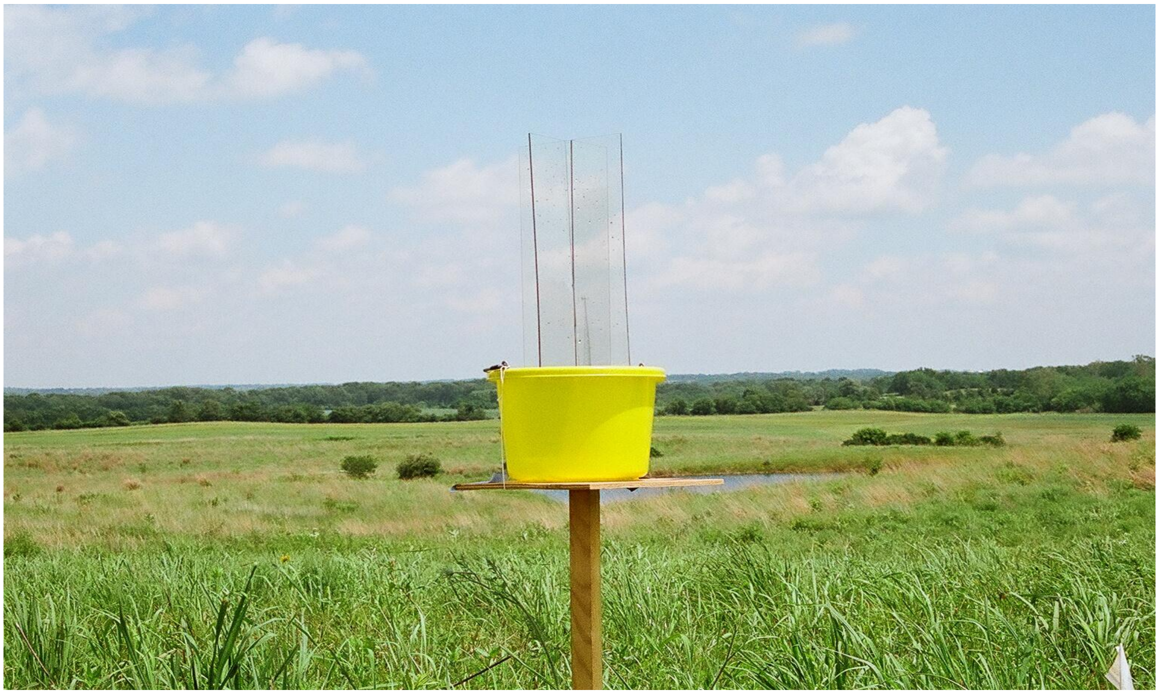

Figure 1-2: Combination of yellow and window trap, with two Lexan™ panes inserted at right angles to intercept insects coming from all directions.

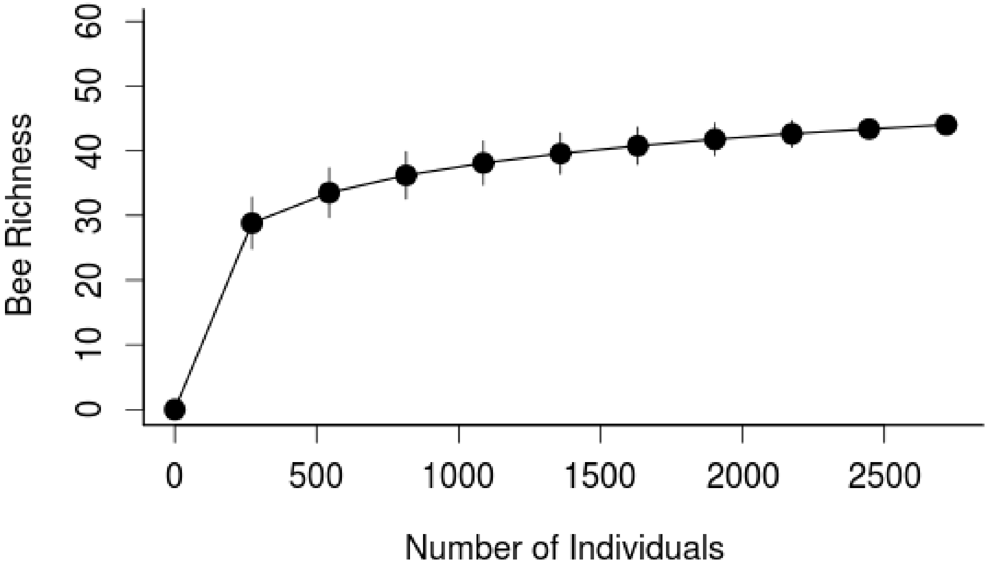

Figure 1-3: Site-based rarefraction curve for bee species richness. Expected species values (solid line) with 95% confidence intervals (vertical lines) are shown in black.

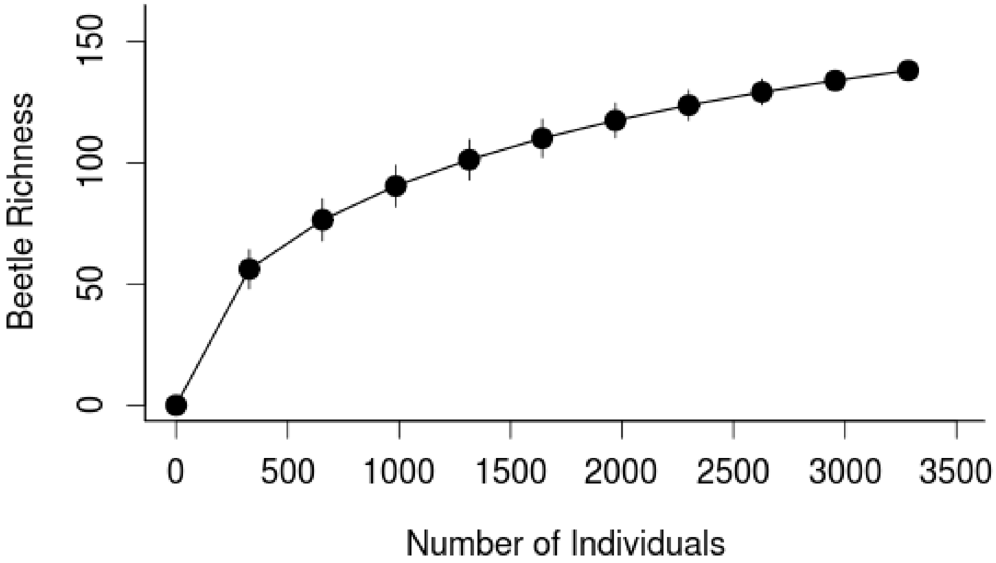

Figure 1-4: Site-based rarefraction curve for beetle species richness. Expected species values (solid line) with 95% confidence intervals (verticle lines) are shown in black.

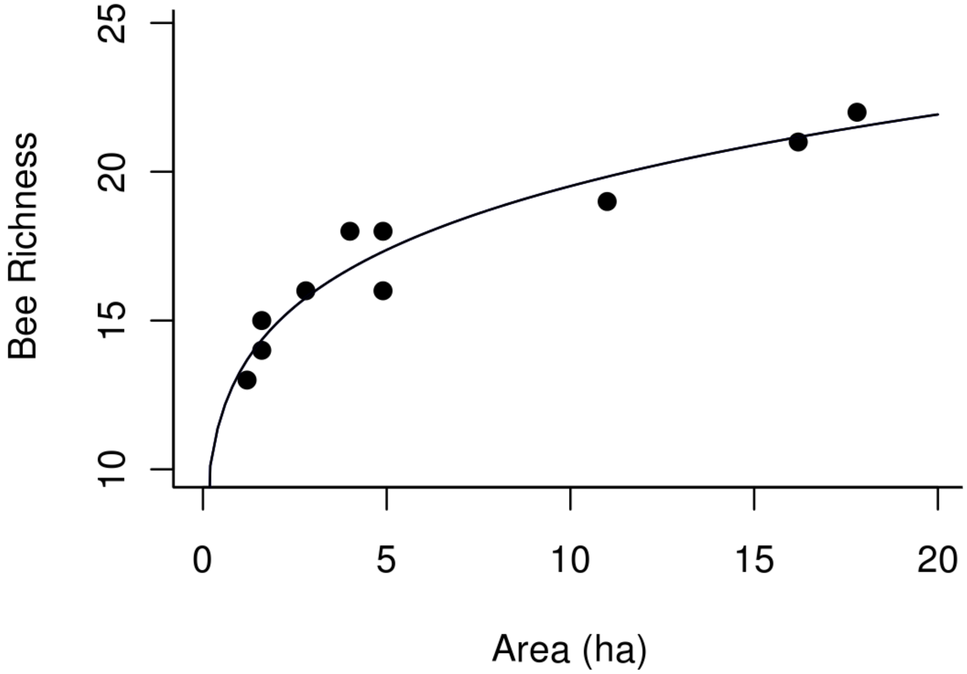

Figure 1-5: Relationship between species richness of bees and habitat area of semi-natural patch. Deviation = 4.14, df = 1, 8, p = 0.042.

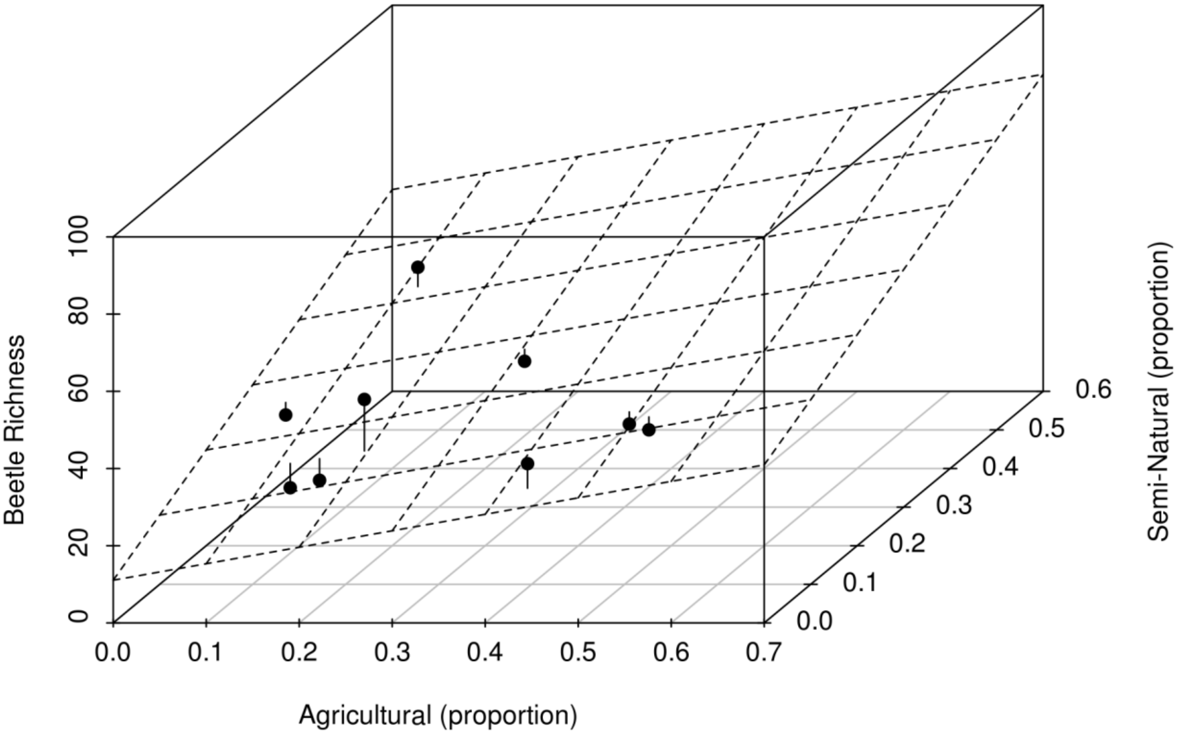

Figure 1-6: The relationship between beetle species richness and the proportions intensive agricultural and semi-natural land cover at the 370 m radius during the June sampling period. Deviance = 11.75, df = 2, 7, p = 0.0018.

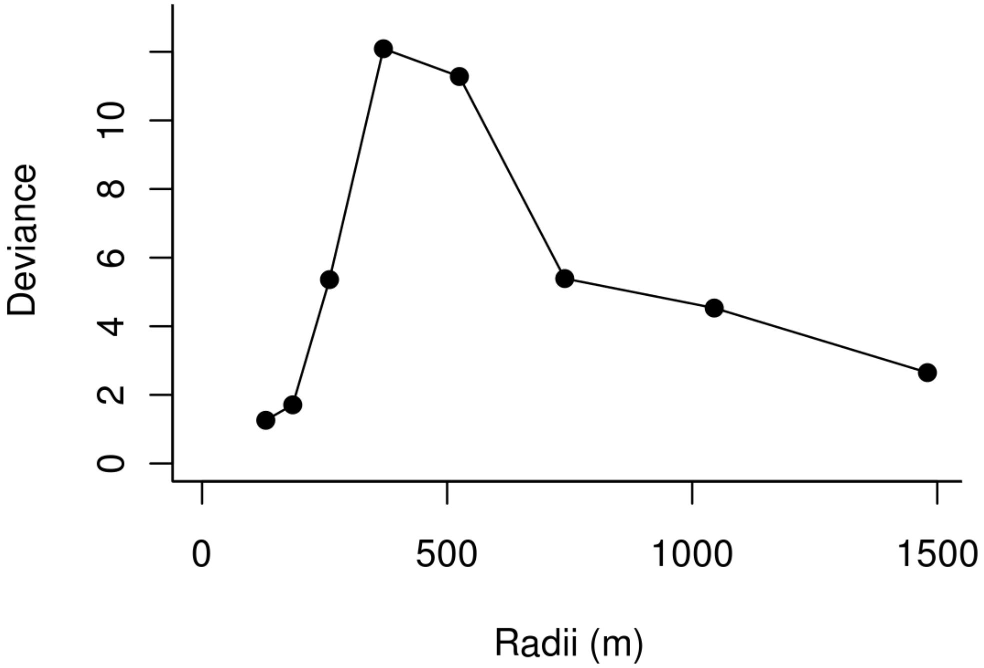

Figure 1-7: Scale-dependent effects of the landscape variables on beetle species richness. Explained deviance of the significant Poisson regression is shown between beetle species richness and the additive model of the proportion of intensive agriculture and semi-natural habitat at 8 scales.

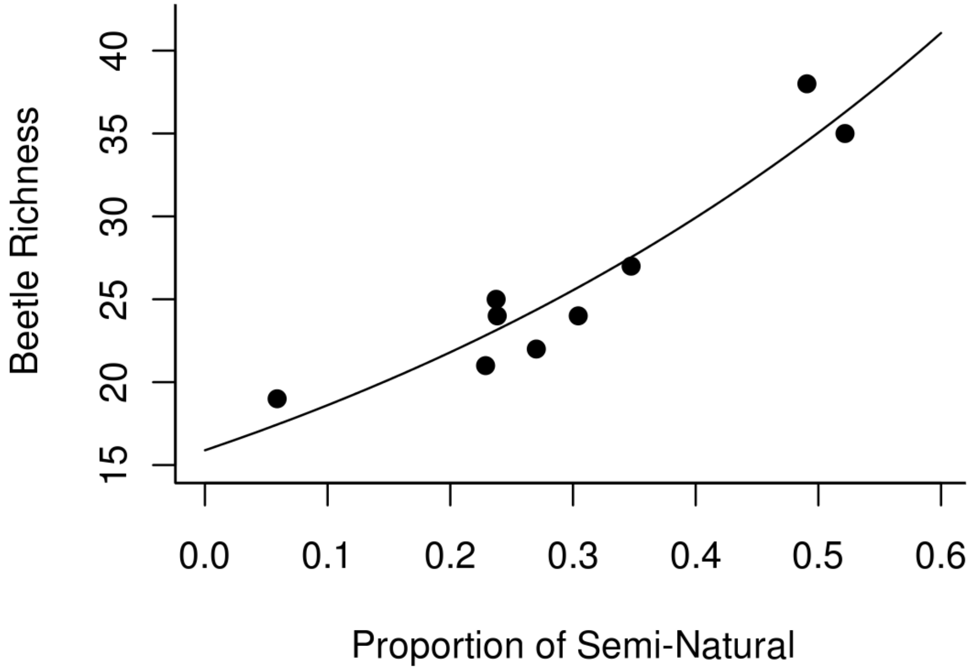

Figure 1-8: The relationship between beetle species richness and proportion of semi-natural habitat at 260 m radius during the August sampling period. Deviance = 10.59, df = 1, 8, p = 0.0011

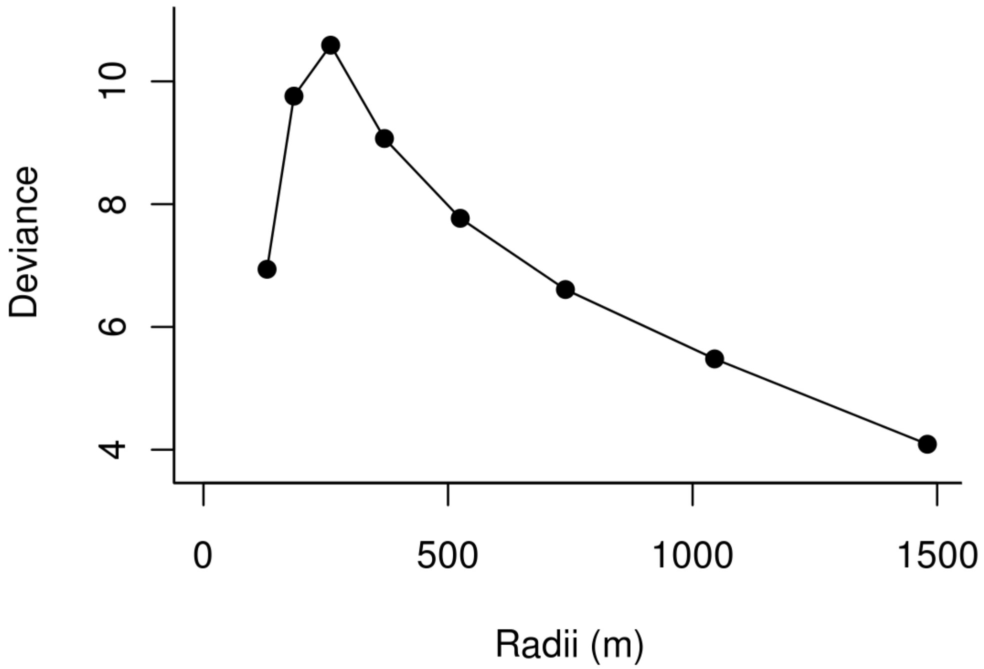

Figure 1-9: Scale-dependent effects of the landscape variables on beetle species richness. Explained deviance of the significant Poisson regression is shown between beetle species richness and semi-natural habitat at 8 scales

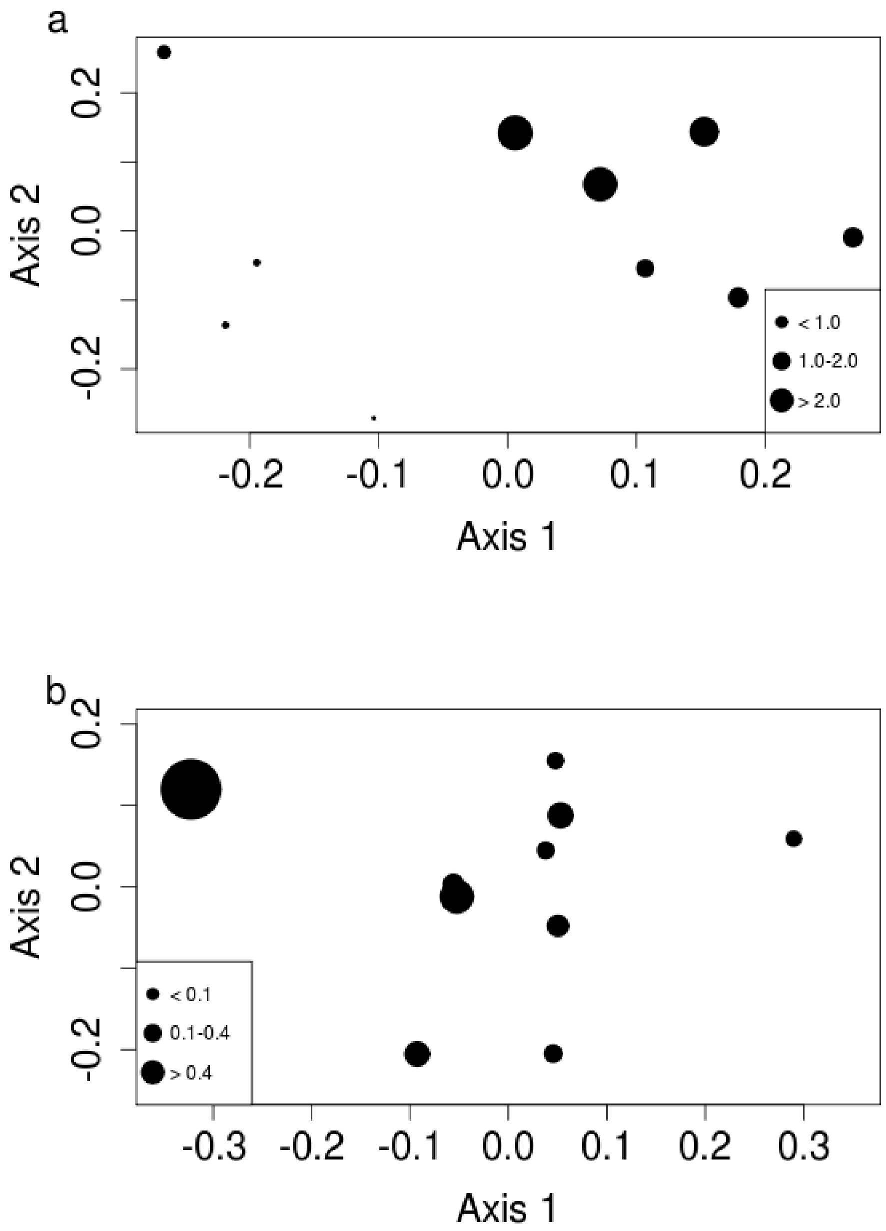

Figure 1-10: Distance-based redundancy analysis (dbRDA) of bee species composition (June sampling panel a, August sampling panel b). Axis 1 is the variable that explains the variation in species composition and Axis 2 is a residual. June variation of bee species composition was explained by semi-natural patch area (point size corresponds to area of patch in ha $r^2 = 0.22$, $p = 0.015$, panel a). August variation of bee species composition was explained by proportion of forbs in the patch (point size corresponds to proportion of forbs $r^2 = 0.23$, $p = 0.0077$, panel b).

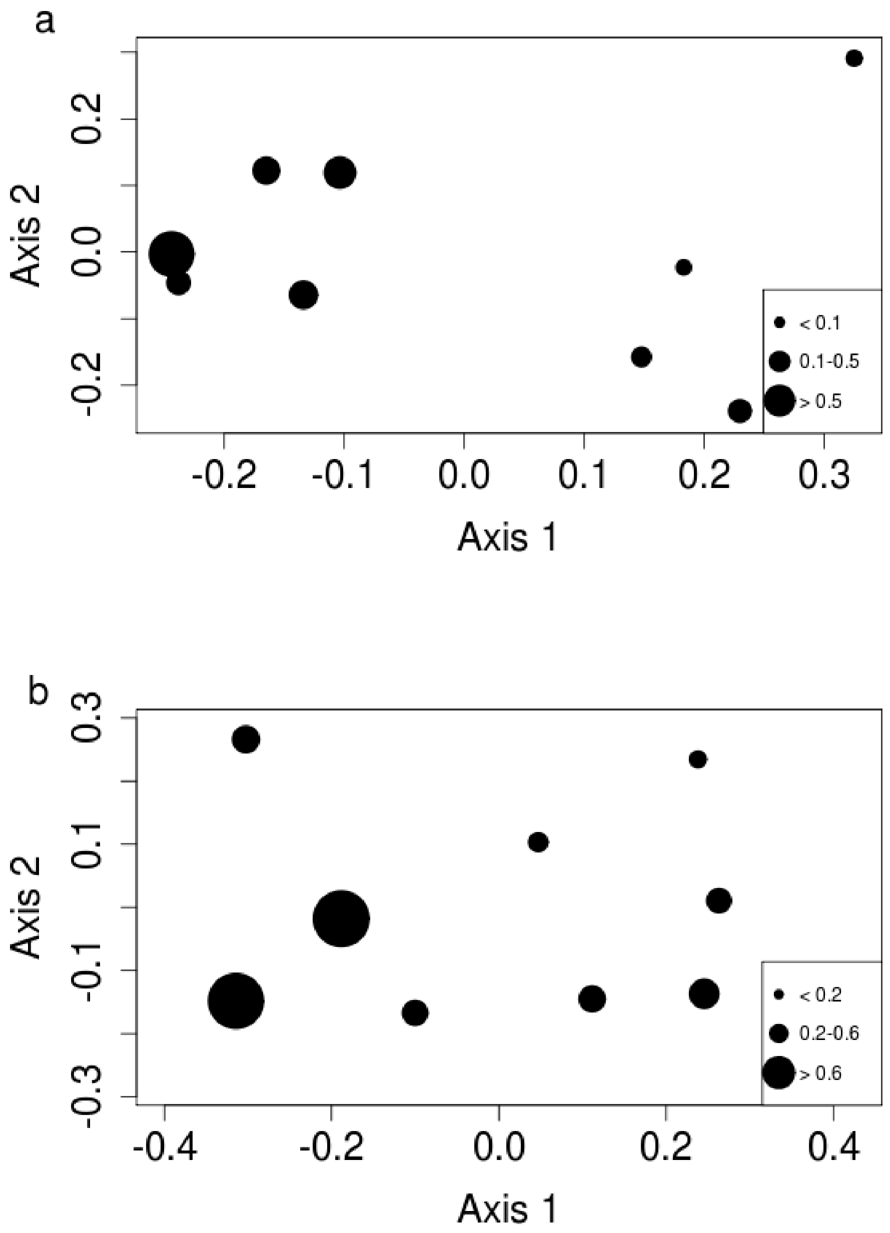

Figure 1-11: Distance-based redundancy analysis (dbRDA) of beetle species composition (June sampling panel a, August sampling panel b). Axis 1 is the variable that explains the variation in species composition and Axis 2 is a residual. June variation of beetle species composition was explained by proportion of intensive agriculture within 525 m radius (point size corresponds to proportion of intensive agriculture $r^2 = 0.23$, $p = 0.0096$, panel a). August variation of beetle species composition was explained by proportion of intensive agriculture within 1045 m radius (point size corresponds to proportion of intensive agriculture $r^2 = 0.22$, $p = 0.036$, panel b).

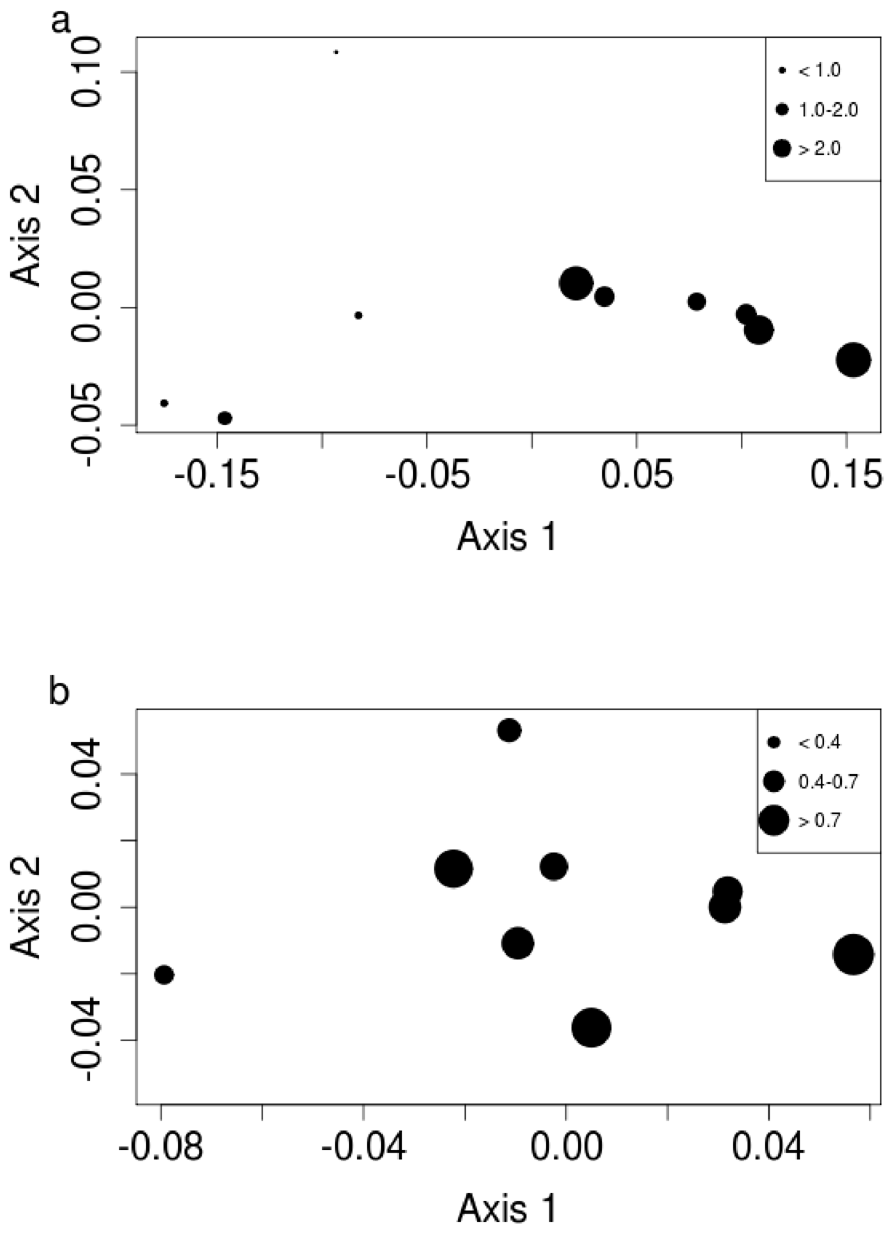

Figure 1-12: Distance-based redundancy analysis (dbRDA) of bee species traits (June sampling panel a, August sampling panel b). Axis 1 is the variable that explains the variation in species composition and Axis 2 is a residual. June variation of bee species composition was explained by semi-natural patch area (point size corresponds to semi-natural patch area $r^2 = 0.52$, $p = 0.0093$, panel a). August variation of bee species composition was explained by proportion of semi-natural habitat within 130 m radius (point size corresponds to proportion of semi-natural habitat $r^2 = 0.32$, $p = 0.050$, panel b).

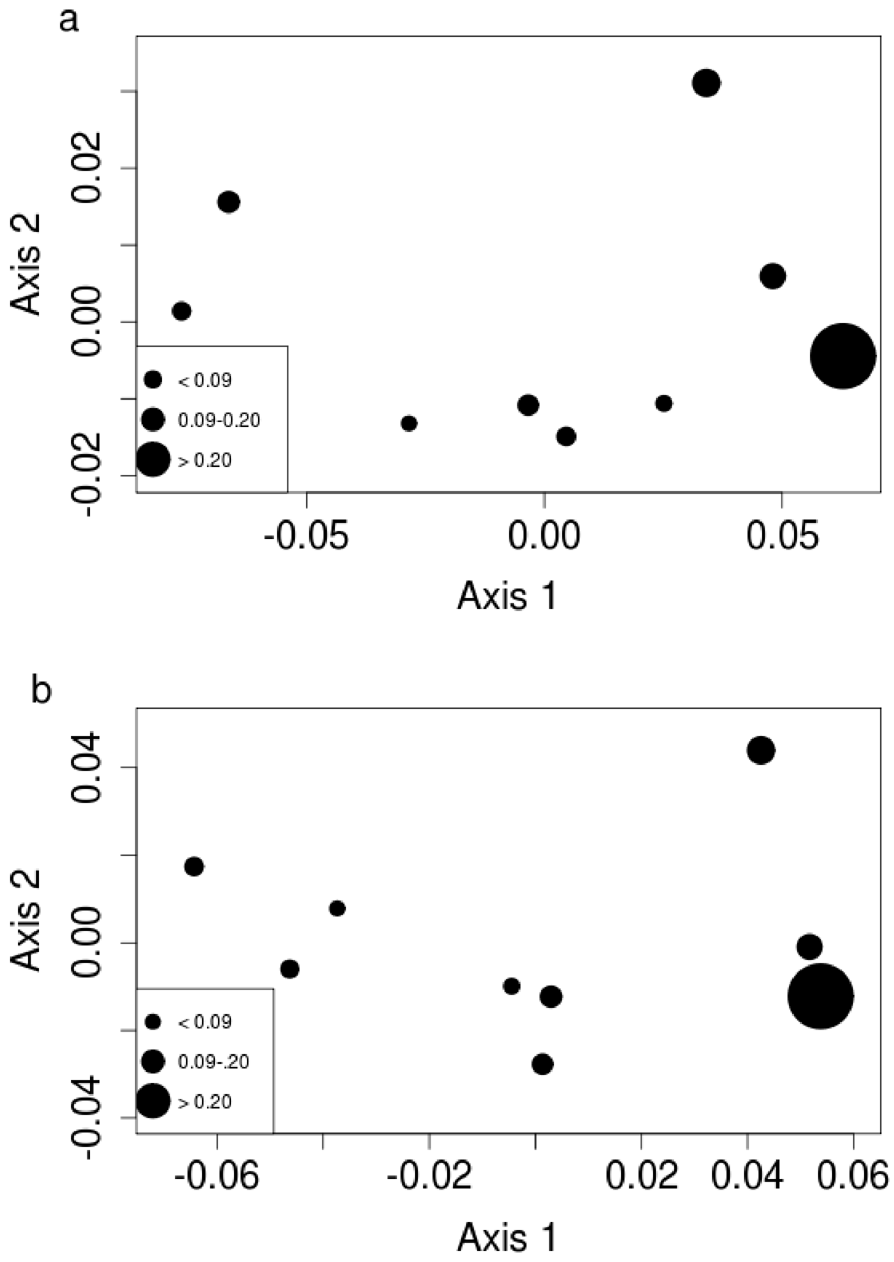

Figure 1-13: Distance-based redundancy analysis (dbRDA) of beetle species traits (June sampling panel a, August sampling panel b). Axis 1 is the variable that explains the variation in species composition and Axis 2 is a residual. The variation of beetle species composition was explained by proportion of semi-natural habitat within 1045 m radius (point size corresponds to proportion of semi-natural habitat $r^2 = 0.35$, $p = 0.072$). The variation of beetle species composition was explained by proportion of semi-natural habitat within 1045 m radius (point size corresponds to proportion of semi-natural habitat $r^2 = 0.42$, $p = 0.011$).

Table 1-1: Patch composition for 10 sites sampled in SW Ohio.

Path Variable	Mean	Minimum	Maximum
a.) June Sampling			
Log Area (Natural log of the patch area in hectares)	1.45	0.18	2.88
Log Age (Natural log of age of patch in years)	1.25	0	2.56
Log Flowers (Natural log of the abundance of flowering stems)	3.89	2.16	5.41
Total Cover (Total proportion of cover by vegetation)	1.12	0.70	1.38
C4 Grass (Proportion of cover by warm-season grasses)	0.45	0.09	0.75
C3 Grass (Proportion of cover by cool-season grasses)	0.4	0	0.20
Forbs (Proportion of herbaceous plants that are not graminiod)	0.45	0.2	0.84
b.) August Sampling			
Log Area (Natural log of the patch area in hectares)	1.45	0.18	2.88
Age (Natural log of age of patch years)	1.25	0	2.56
Log Flowers (Natural log of the abundance of flowering stems)	1.08	0.24	1.69
Total Cover (Total proportion of cover by vegetation)	0.97	0.77	1.06
C4 Grass (Proportion of cover by warm-season grasses)	0.69	0.39	0.92
C3 Grass (Proportion of cover by cool-season grasses)	0.06	0	0.35
Forbs (Proportion of herbaceous plants that are not graminiod)	0.25	0.08	0.72

Table 1-2: Landscape composition for the 10 sites in SW Ohio at 1480 m radius. Habitat proportional data and Shannon-Weiner diversity of land cover / land use based on 8 radii for 10 sites.

Habitat Type	Mean	Min	Max
Intensive agriculture	0.34	0.12	0.68
Extensive Agriculture	0.30	0.19	0.47
Forest	0.08	0.03	0.17
Semi-natural Grassland	0.10	0.01	0.19
Low-Density Residential	0.13	0.03	0.30
High-Density Residential	0.03	0	0.19
Water/Wetland	0.01	0.01	0.03
Shannon-Weiner Diversity Index	1.43	0.98	1.65

Table 1-3: General linear model of the relationship between species richness of beetles and bees to patch or landscape variables.

Response Variable	**Model**	**Effect**	**AICc**	**ΔAICc**	**Deviance**	***p*-value**
Bee richness 1st sampling	traps	positive	52.74	0	4.26	0.039
	log area	positive	52.85	0.11	4.15	0.042
	null	–	54.78	2.04	–	–
Bee richness 2nd sampling	null	–	51.24	0	–	–
	traps	positive	53.46	2.23	1.63	0.20
	log area	positive	53.67	2.43	1.62	0.21
Beetle richness 1st sampling	forest w/in 370 m	negative	70.04	0	7.71	0.0052
	ag + semi-nat w/in 370 m	positive, positive	70.46	0.42	9.72	0.0018
	ag + forest w/in 370 m	positive, negative	74.16	4.11	6.02	0.014
Beetle richness 2nd sampling	semi-nat w/in 260 m	positive	52.95	0	10.59	0.001
	forest + semi-nat w/in 260	positive, positive	57.66	4.71	8.31	0.004

Table 1-4: Distance based redundancy analysis of the relationship between species composition of beetles and bees to patch or landscape variables**.**

Response Variable	**Model**	**AICc**	**ΔAICc**	$\mathbf{r^2}$	***p*-value**
Bee composition 1st sampling	log area	-19.58	0	0.25	0.015
	cover	-19.51	0.06	0.24	0.019
	log flowers	-18.58	0.67	0.16	0.10
Bee composition 2nd sampling	forbs	-23.51	0	0.23	0.0077
	C4 grass	-22.66	0.85	0.16	0.10
	log flowers	-22.62	0.89	0.16	0.11
Beetle composition 1st sampling	agriculture w/in 525 m	-14.05	0	0.23	0.010
	semi-natural w/in 525 m	-12.76	1.28	0.11	0.064
	forest w/in 525 m	12.72	1.33	0.11	0.071
Beetle composition 2nd sampling	agriculture w/in 1045 m	-13.81	0	0.22	0.037
	semi-natural w/in 1045 m	-13.09	0.72	0.15	0.12
	forest w/in 1045	-12.91	0.91	0.13	0.16

Table 1-5: Distance based redundancy analysis of the relationship between species trait composition of beetles and bees to patch or landscape variables.

Response Variable	**Model**	**AICc**	**ΔAICc**	**r^2**	***p*-value**
Bee trait composition 1st sampling	log area	-43.63	0	0.52	0.009
	log area + log flowers	-41.42	2.21	0.62	0.056
	log flowers + log age	-41.35	2.27	0.60	0.061
Bee trait composition 2nd sampling	semi-natural w/in 130 m	-53.21	0	0.32	0.050
	agriculture w/in 130 m	-50.71	2.5	0.10	0.17
	forest w/in 130 m	-50.06	3.15	0.035	0.23
Beetle trait composition 1st sampling	semi-natural w/in 1045 m	-52.57	0	0.34	0.072
	agriculture w/in 1045 m	-50.11	2.46	0.15	0.31
	forest + semi-natural w/in 1045 m	-49.78	2.79	0.48	0.11
Beetle trait composition 2nd sampling	semi-natural w/in 1045 m	-55.96	0	0.42	0.011
	agriculture + semi-nat w/in 1045 m	-55.89	0.06	0.70	0.018
	agriculture w/in 1045 m	-54.60	1.35	0.41	0.014

Chapter 2: Patch and landscape perspectives for the conservation of biodiversity and ecosystem services of natural-enemy insects.

Abstract: Natural-enemy insects play important roles in controlling populations of pest insects in agricultural fields. Understanding how patch- and landscape-level variables affect natural-enemy insects is important for the conservation of biological control within agricultural landscapes. I investigated how patch- and landscape-level variables affected species richness and composition of insect predators (Coleoptera, Hemiptera, and Hymenoptera) and parasitoids (Coleoptera and Hymenoptera). Insects were sampled using combined intercept / pan and pitfall traps in 10 conservation grasslands within a 300 km^2 agricultural landscape spanning two counties of southwestern Ohio. Predatory insect richness in June was affected by the combined proportions of intensive agriculture and semi-natural grassland habitat in the surrounding landscape within 525 m radius, while in August richness was affected by the Shannon-Weiner diversity of land use / land cover within 525 m of focal patches. Species composition of predatory insects was affected by the proportion of semi-natural habitat within 740 m during June, whereas species composition in August was affected by the Shannon-Weiner diversity of the surrounding landscape at the same radius. Parasitoid insect richness in both June and August was affected by the Shannon-Weiner diversity of the surrounding landscape, but within differing radii (525 m and 740 m respectively). Species composition of parasitoid insects was affected by the number flowering stems in the grassland habitat patches during June, but by the Shannon-Weiner diversity of the surrounding land cover types within 740 m during August. In general, predator and parasitoid species are affected at many different scales, from local to landscape, but conservation efforts need to consider the surrounding landscape with floral resources found in semi-natural habitat patches also being important. Heterogeneous landscapes with sufficient floral resources may be best for the long term conservation of natural enemies and the maintaining ecosystem services in agricultural landscapes.

Introduction

Agricultural systems have affected insect biodiversity by changing large parts of terrestrial area to arable crops that are inhospitable to many organisms (Tscharntke et al. 2005a). Through federal agencies, such as the United States Department of Agriculture (USDA) Conservation Reserve Program (CRP, NRCS 2012) and United States Fish and Wildlife Service

(USFWS) Habitat Enhancement Grants (HEG, USFWS 2012), farmers and landowners can receive technical and financial assistance to establish areas of conservation lands as semi-natural grassland habitat (hereafter referred as semi-natural habitat) to address wildlife, soil, water, and related resources concerns. The establishment of conservation lands adds to landscape heterogeneity (Weber et al. 2002). Simplified landscapes, which are dominated by arable crops and diminished non-crop habitats, reduce the exchange of natural enemies between non-crop and crop habitats (Bianchi et al. 2006).

Landscapes with both seasonal crops and more stable natural habitats often support a higher biodiversity than those that are more intensively managed (Theobald and Hobbs 2002, Tscharntke et al. 2007). Stable resources from a diverse assemblage of plants and prey items found in natural (i.e., forest) and semi-natural habitat has been shown to increase survival rate and fecundity of natural enemies (Landis et al. 2000, Steffan-Dewenter 2003, Tscharntke et al. 2007). Heterogeneous landscapes with higher diversity of land use / land cover (hereafter referred as land cover) provide a variety of resources such as over-wintering and refuge in permanent vegetation cover, alternative prey, pollen, and nectar (Landis et al. 2000, Cronin and Reeve 2005, Bianchi et al. 2006.)

Globally, agricultural practices have intensified over the past 60 years through the use of high-yielding crops in monocultures and application of chemical fertilizers. At the same time increases in field size, loss of natural and semi-natural habitat, and decreases in field margins and grass waterways has further intensified agricultural land use (Matson et al. 1997, Tylianakis et al. 2005, Tscharntke et al. 2005a). Local and landscape characteristics have changed in farming systems by implementing these large fields dominated by one or two crops (e.g., corn or soybeans) with diminished non-crop habitats in areas that used to have diverse crops in small fields surrounded by natural and semi-natural habitat (Medley et al. 1995, Burel and Baudry 2003). These practices have severely impacted the abundances and diversity of natural enemies by affecting both local and landscape characteristics (Landis et al. 2000).

An agricultural landscape can vary from areas that are structurally simple, dominated by annual crops, to structurally complex with non-crop habitat such as natural and semi-natural habitat. In heterogeneous landscapes, with crop and non-crop land cover, ecosystem production is increased because organisms can use contrasting resources from complementarity land cover (Tilman 2000, Tscharntke et al. 2007). The degree to which natural enemies can use crop and non-crop habitat can vary depending on resources requirement (Duelli et al 1990). Natural enemies that take advantage of crop habitat for foraging on pest species can also use non-crop habitat as a refuge during disturbances in cropped areas (i.e., planting, tilling, spraying of pesticides and herbicides, and harvesting; Landis et al. 2000, Bianchi et al. 2006). This movement can also be bi-directional, where natural enemies originate in non-crop semi-natural habitat and spillover into crop habitats. Movement of natural enemies, back and forth between crop and non-crop habitats, is dependent on resource need and what resources are provided by each habitat (Tscharntke et al. 2007).

Higher species diversity of natural enemies may occur in heterogeneous agricultural landscapes because highly vagile species move in and out of habitat using resources when they are available (Wissinger 1997, Tscharntke et al. 2007). Populations from adjacent natural and semi-natural habitats provide structural complexity that supports natural enemy populations and could allow for the replacement of a natural enemy species if it is loss from the habitat (Bianchi et al. 2006). Agricultural ecosystems surrounded by more diverse landscapes may reduce pest insects in cultivated fields by enhancing natural enemy diversity (Theis and Tscharntke 1999, Landis et al 2000, Tscharntke et al. 2007). The insurance hypothesis posits that species richness in a diverse landscape could buffer against spatial fluctuations in resource availability by supporting higher species richness in a landscape to insure the function of predation or parasitism (Yachi and Loreau 1999).

Patch-level characteristics of semi-natural habitat, (area, age, and floral resources) and landscape-level characteristics (the amounts and diversity of land cover types in the surrounding landscape) both potentially affect the biodiversity of natural enemies (Tscharntke et al. 2007, Marini et al. 2009). Therefore, it is important to use both patch and landscape perspectives in studying the conservation of natural-enemy insects. In the Midwest, higher biodiversity of natural enemies are supported by natural forest remnants, semi-natural habitat, and perennial field margins in an agricultural landscape (Gardiner et al. 2010, Hendrix et al. 2010). Conservation grasslands in agricultural landscapes, established under agreements by USDA-CRP or USFWS-HEG, commonly with matching funds from local land trusts or conservation organizations, enhance biodiversity through incentives to private landowners.

To evaluate these potential patch- and landscape-level characteristics, I studied the biodiversity of natural-enemy insects in an agricultural landscape in June and August 2009. My objectives were to evaluate the role of conservation grasslands and the surrounding agricultural landscape in supporting the biodiversity of natural-enemy insects. I tested the following hypotheses: i) the species richness and composition of natural enemies – predatory beetles, true bugs and wasps, and parasitoid beetles and wasps – are determined by size, age, and vegetative composition of the patch; and ii) the relative amounts of surrounding land cover types (intensive agricultural, forest, and semi-natural habitat). Based on previous work in Europe and North America, I predicted that larger, older grassland patches with greater variation in plant composition would have a higher species richness of natural enemies (Landis et al. 2005, Tscharntke et al. 2007). Likewise, I predicted the greater amounts of semi-natural or natural habitat in the surrounding landscape, or greater diversity of land-cover types, would also result in higher richness of natural enemies. I also predicted that species composition would differ among patches in a manner that was consistent with patch area, age, or plant composition, and landscapes with greater amounts of semi-natural and natural habitat or land-cover diversity in the surrounding landscape. A more diverse landscape, with large semi-natural habitat patches and abundant resources are used for survival and fecundity natural-enemy insects (Landis et al. 2005, Wäckers and van Rijn 2005, Tscharntke et al. 2007).

Methods

Study Region

I focused my research in an agricultural landscape covering an area of 310 km^2 in SW Ohio (Fig. 2-1). The study was conducted in 10 semi-natural habitat patches created under lease agreements with USDA-CRP or grants from USFWS-HEG. Semi-natural habitat patches were scattered within both Butler and Preble counties with distances between neighboring patches ranging from 2 to 10 km. In Butler County, approximately 51% of land cover was recorded as active cropland in 2009, forest 23%, urban 12%, and pasture 11%. Approximately 67% of land cover was active cropland in Preble County in 2009, forest 17%, pasture 8%, and Urban 6% (Ohio Department of Development County Profiles 2009).

My study patches ranged in size from 1.2 to 17.8 ha, and time since planting from 1 to 13 years. All grasslands were planted with a similar mix of grasses and forbs (Table 2-1), but they varied in dominance, diversity, and composition of the established plant community (NRCS 2012). Dominant grasses included big blue stem (*Andropogon gerardii*), little blue stem

(*Schizachyium scoparium*), switchgrass (*Panicum virgatum*), Indian grass (*Sorghastrum nutans*), and side oats grama (*Bouteloua curtipendula*). A variety of forbs were present, including partridge pea (*Cassia fasiculata*), Illinois bundleflower (*Desmanthus illinoensis*), coneflower (*Echinacae purpurea*), and Maximilian sunflower (*Helianthus maximiliani*, Appendix 1 and 2). The surrounding landscape within 1480 m radius of the patch included cultivated row crops, forest, suburban, hedgerow, pastures, and wetland (Table 2-2).

Insect Sampling

I sampled insects during a 2-wk period, twice during the summer of 2009: 26 May – 8 June and 27 July – 10 August (hereafter referred to as June and August samples). Sampling of semi-natural habitat patches was chosen randomly and constrained to include small and large patches in each week of the 2-wk sampling window. Five patches were randomly selected to sample during the first week of the 2-wk sampling window, and the other five patches were sampled during the following week. The order of sampling of each patch remained the same for both sampling periods.

To sample aerial insects, I used a combination flight intercept / pan traps, that were modified from the design of Duelli et al. (1999). A pair of perpendicular Lexan™ panes were inserted into a bucket (7.6 L; 29 cm diam. x 21 cm tall) and extended 41 cm vertically from the top of the bucket to intercept weak flying insects (Fig. 2-2). The buckets were placed on platforms that were elevated 1 m above the ground, which was approximately level with the vegetation at the end of the first sampling period. The buckets were filled with water to approximately the depth of 10 cm, with a few drops of detergent to cut surface tension.

Pitfall traps were used to sample ground-dwelling insects (plastic cups 75 mm diam. x 80 mm deep). The pitfall traps were placed 1 m away from the platform and inserted flush to the ground. Ethylene glycol was added to each pitfall trap as a killing agent.

Trapping stations, which included a flight intercept / pan and a pitfall trap, were set along a transect that ran through the center of each patch, parallel to the long edge of each patch. The number of trapping stations was scaled to the log area of each patch, ranging from 5 traps at the smallest site to 10 traps at the largest site. A spacing of 25 m between traps was used at all sites. After 7 days, the liquid from the flight intercept / pan traps was poured through No-see-um netting (Nicamaka™) to capture all insects, and then washed with 70% ethanol into Nalgene™

bottles for temporary storage. Pitfall traps were capped and returned to the laboratory.

In the laboratory, only focal predatory Coleoptera, Hemiptera, and Hymenoptera, and parasitoid Hymenoptera and Coleoptera insects were sorted and separated from other arthropods in the samples. Predatory Coleoptera (Appendix 5 and 6) and Hemiptera (Appendix 7 and 8) were sorted and identified to taxonomic species (Schuh and Slater 1995, Downie and Arnett 1996, Arnett and Thomas 2001, Slater and Baranowski 1978), while the predatory Hymenoptera (Appendix 9 and 10) were identified to family and morphospecies (Goulet and Huber 1993). Hymenopteran parasitoids were all sorted and identified to family and morphospecies (Appendix 9 and 10; Goulet and Huber 1993, Gibson et al. 1997), while parasitoid Coleopteran of Carabidae (Genus Lebia), Meloidae, and Ripiphoridae which were identified to taxonomic species (Appendix 5 and 6; Downie and Arnett 1996, Arnett and Thomas 2001).

Vegetative Cover

Identification of plants was conducted twice during the sampling season (15 – 17 June and 20 – 22 August). I recorded cover of identified plant species in pairs of 10 m^2 circular quadrants located 3 m from each side of the trap, perpendicular to the transect line. Cover was recorded for each plant was recorded as 0, 1, 5, 10, 25, 50, 75, or 100%. The total number of flowering forb stems were also recorded by species (Table 2-2). Means for vegetative functional group were taken across traps for each site (Table 2-2).

Landscape Variables

To quantify the size and arrangement of land-cover types, Digital Orthophoto Quadrangles (DOQ, 0.15 m resolution for Butler County and 3 m resolution for Preble County) were analyzed in a Geographic Information System (ESRI ArcGIS 9.3.1 2009). Land cover types were digitized within windows of eight varying radii (130, 185, 260, 370, 525, 740, 1045, 1480 m) on the DOQ from the central point of each transect. Consecutive radii doubled the area sampled around each patch (Fig. 2-1; Marini et al. 2009). Seven land cover were used to classify the landscape: (1) semi-natural grassland, (2) intensive agriculture, (3) extensive agriculture, (4) forest, (5) low-density residential, (6) high-density residential and (7) water / wetland. Visual characteristics of intensively managed agricultural were row-crops of corn, soybean, or barley, while visual characteristics of extensively managed agriculture were hay field or pasture. Spatial analyses ranged from 0.053 (130 m) to 6.8 km^2 (1480 m), and were chosen to reflect the range of dispersal distances of insect taxa under investigation (Tscharntke et al. 2007, Marini et al 2009) and to reduce overlap from adjacent radii (Holland et al. 2004). Shannon-Weiner diversity of land-cover types in the surrounding landscape was also calculated within each radii. Sites were ground-checked to distinguish between ambiguous land cover from aerial photos.

Statistical Analysis

Sample-based rarefaction curves of predators and parasitoids were constructed in the vegan package of R using sites as sample units (Oksanen et al. 2011, R Development Core Team 2012). Chao incidence-based richness estimated were calculated to provide an estimate of species richness in R (Oksanen et al. 2011, R Development Core Team 2012).

Species richness data were first checked for overdispersion by examining for the presence of greater variability than expected from Poisson counts. Patch-level (n = 10) statistical models were built for species richness for predators and parasitoids. Landscape (Table 2-1) and patch (Table 2-2) variables were tested using general models with either a Poisson or a quasi-Poisson distribution. Separate models were developed for June and August data, and using either patch or landscape variables (Table 2-1 & Table 2-2). The most parsimonious combined patch and landscape model was selected as the best-fitting models for June and August.

The best fitting statistical models for both the patch and landscape model were determined by the lowest bias-corrected Akaike Information Criteria (AICc). AICc or qAICc was used because ratios between number of samples (n) to the number of parameters (K) were small (n/K < 40; Burnham and Anderson 2001). Models that differed by less than 2 were considered competing. Deviance and *p*-values were used in final model selection. The model residuals were also used to assess model fit. Due to overlapping radii between two of the study sites, statistical analyses were run twice with each of the overlapping sites omitted singularly.

Distance-based redundancy analysis (dbRDA) ordination with Bray-Curtis dissimilarity was used to analyze species composition (McArdle and Anderson 2001). Using a dbRDA method is an improvement over other tests (i.e., MANOVA) for complex designs because it allows for many rare species, can be based on any distance dissimilarity matrix, and gives reasonable permutational *p*-test (McArdle and Anderson 2001). Patch or landscape models that had the lowest AICc score was determined to be the best fitting statistical model. Competing models had a difference in the AICc value less than 2. *P*-values were obtained under random permutation (999 permutations) and used in final model selection of competing models. Using the same criteria as above, the top two or three models for patch or landscape models were combined to get the best overall model. Analysis was executed in R (Oksanen et al. 2011, R Development Core Team 2012) with user written functions for dbRDA (M. Anderson, personal communication).

Results

Richness and abundance of predators totaled 171 species and 3380 individuals (Fig. 2-3). Observed richness was 78.9% species of the Chao estimate in June (135 species and 2287 individuals) and 62.6% of the estimated richness in August (107 species and 1093 individuals). In June, 77.8% of all predator species were Coleoptera (105 species), 8.1% Hemiptera (11 species), and 14.1% Hymenoptera (19 species), whereas in August 71.0% of all predators were Coleoptera (76 species), 7.5% Hemiptera (8 species), and 21.5% Hymenoptera (23 species). The mean predator species per site was 53.8 for the two sampling periods, with a minimum richness of 42 species and a maximum richness of 75 species. The mean number of individuals of predators per site was 338.0 over the two sampling periods combined, with a minimum richness of 198 individuals and a maximum richness of 593 individuals. Many of the species were represented by singletons (33%) and doubletons (15%). The Chao incidence-based richness estimate was 241.3 for predators and the rarefaction curve continued to rise (Fig. 2-3).

The combined species richness of parasitoids was 195 species with 1869 individuals (Fig. 2-4). Parasitoid richness and abundance totaled 148 species and 874 individuals (75.9% of species) in June, and 149 species and 995 individuals were collected during August (76.4% of species). Hymenoptera totaled 93.2% (138 species) and Coleoptera totaled 6.6% (10 species) of observed species richness in June, while Hymenoptera accounted for 94.0% (140 species) and Coleoptera only 6.0% (9 species) of species in August. Parasitoid richness per site averaged 61.0 species for the two sampling periods (with a minimum of 42 species and a maximum of 88 species). Parasitoid abundance per site averaged 140.0 for the two sampling periods combined (with a minimum of 86 individuals and a maximum of 247 individuals). Many of the species were represented by singletons (30%) and doubletons (15%). The Chao incidence-based richness estimate was 265.1 for parasitoids and the rarefaction curve continued to rise (Fig. 2-4).

About 74% of the estimated species richness was sampled across the 10 sites.

Regression Analysis

Poisson regression between predator species richness and patch variables during June showed that the best model was the negative correlation with proportion of herbaceous forbs, but this relationship was not significant (Deviance = 3.7678, df = 1, 8, p = 0.052). At a landscape level, the best-fitting model for predator richness included a positive effects of intensive agriculture and semi-natural land cover proportions within a 525 m radius (Deviance = 8.53, df = 2,6, *p* = 0.016, Fig. 2-5a, Table 2-3). The explained deviance peaked at the 370 m radius for the combined effect of intensive agriculture and semi-natural land cover (Fig. 2-5b). After combining the patch and landscape models, the best-fitting model of predator species richness retained the two land-cover variables but dropped the patch-level effects of forb cover (Fig. 2-5a).

In August, the best patch model for predicting predator species richness was a positive effect of log grassland patches area (Deviance = 10.36, df = 1,8, *p* = 0.0013). At a landscape-level, model selection showed that richness of predator species was positively affected by Shannon-Weiner diversity of land cover types within 525 m radius (Deviance = 9.64, df = 1,7, *p* = 0.0019, Fig. 2-6a, Table 2-3). The explained deviance for the effect of Shannon diversity was greatest for the 525 m radius (Fig. 2-6b). The landscape variable had a better fit than the patch variable in explaining predator species richness after patch and landscape models were combined (Fig. 2-6a).

The log semi-natural habitat patch area was the best predictor of parasitoid species richness in June (Deviance = 6.44, df = 1, 8, *p* = 0.011). At the landscape-level, parasitoid species richness was positively related to the Shannon-Weiner diversity of land-cover types within 525 m of the patch (Deviance = 8.58, df = 1,7, *p* = 0.0034, Fig. 2-7a, Table 2-3). The explained deviance for the effect of the land cover diversity was greatest for the 525 radius (Fig. 2-7b). Model selection using multiple regression analysis of the combined effects of patch and landscape variables showed the best model was landscape variable only (Fig. 2-7a).

In August, the best patch-level predictor of parasitoid species richness was again positively related with log semi-natural habitat patch area (Deviance = 15.236, df = 1, 8, $p <$ 0.001). The best landscape-level predictor was Shannon-Weiner diversity of land cover types within 740 m (Deviance = 16.69, df = 1,7, $p < 0.001$, Fig. 2-8a, Table 2-3). The explained deviance by land-cover diversity peaked at the 740 m radius (Fig. 2-8b). When combining the best patch and landscape models, the landscape model was again the best model for parasitoid species richness (Fig. 2-8a).

Species Composition

Distance-based redundancy analyses (dbRDA) for predator species composition in June showed that log number of flowers explained 16% of the variation in composition ($p = 0.046$). At the landscape level, the proportion of semi-natural land cover within 740 m explained 21% of the variation of predator species composition ($p = 0.0027$, first ordination axis eigenvalue = 0.3, Fig. 2-9a, Table 2-4). When patch and landscape models were combined, only the landscape variable of semi-natural land cover gave the lowest AICc (Fig. 2-9a). Predator species associated with greater proportions of semi-natural habitat within 740 m radius are Carabidae (*Harplus pensylvanica*) and Cantharidae (*Chaulignathus marginatus and Rhaxonycha carolinus*) beetle species and certain Pompillidae wasp species.

In August, dbRDA showed that proportion C3 grasses explained 15% of the variation of predator species composition, but this relationship was not significant ($p = 0.0723$). Landscape level analyses using dbRDA showed that the Shannon-Weiner diversity of land cover types within 740 m explained 19% of the variation in predator species composition ($p = 0.045$, first ordination axis eigenvalue = 0.2, Fig. 2-9b, Table 2-4). After combining models of patch and landscape variables, only the landscape variable for the Shannon-Weiner diversity of land cover within 740 m was retained in the model with the lowest AICc (Fig. 2-9b). Predator species associated with a more diverse surrounding landscape within 740 m radius are Cantharidae (*Chaulignathus marginatus and Rhaxonycha carolinus*), Coccinellidae (*Coccinella septempunctata* and *Scymnus americanus*) beetles species, and Reduviidae (*Apiomerus crassipes*) true bug species.

The log number of flowering stems explained 20% of the variation in parasitoid species composition considering patch variables using dbRDA in June ($p = 0.0031$, first ordination axis eigenvalue = 0.4, Fig. 2-10a, Table 2-4). Landscape level analysis using dbRDA showed that the Shannon-Weiner diversity of land cover at 740 m radius explained 22% of the parasitoid species composition variation ($p = 0.016$). When combining the best patch and landscape models, the patch model with flower number was the best model in explained variation in parasitoid species composition (Fig. 2-10a). Parasitoid species associated with higher number of flowering stems in a patch are certain Encyrtidae, Mymaridae, Branconidae, and Scelionidae wasp species, while parasitoid beetles were more associated with lower amounts of flowering stems.

In August, dbRDA for patch characteristics showed that log age of the patch explained 16% of the variation (p = 0.050). The Shannon-Weiner diversity of land cover at 740 m radius explained 20% of the variation in parasitoid species composition considering landscape variables (p = 0.0049, first ordination axis eigenvalue = 0.4, Fig. 2-10b, Table 2-4). After combining the patch and landscape variables, model selection showed that the Shannon-Weiner diversity of land cover within 740 m yielded the lowest AICc (Fig. 2-10b). Parasitoid species associated with a more diverse surrounding landscape within 740 m radius are certain Cerphronidae, Encyrtidae, Mymaridae, Pteromalidae, Trichogrammidae, Ichneumonidae, Branconidae, and Platygasteridae wasp species.

Discussion

The main objective of this study was to determine how the biodiversity, abundance, and species composition of natural-enemy insects in conservation semi-natural habitat patches are influenced by characteristics of the patch and land cover in the surrounding landscape. Patch and landscape effects on local natural-enemy richness and species composition were mostly dependent on the diversity of surrounding land cover, with grassland floral resources abundances also being important (Figs 2-5a, 2-6a, 2-7a, 2-8a, 2-9, and 2-10).

Several other studies support the hypothesis that the diversity of land cover has positive effects on the richness of natural enemies (Tscharntke et al. 2005b). A diverse landscape may consist of suitable habitat for other animals, such as bees (Steffan-Dewenter et al. 2002, Steffan-Dewenter 2003), birds (Pino et al. 2000), reptiles (Ribeiro et. al 2009), and mammals (Harvey et. al 2006). Annual crop systems are subject to higher amounts of disturbance and variation in food or nesting resources. A more diverse landscape that includes natural and semi-natural habitats may support natural-enemy richness and abundance by providing suitable habitat for shelter, overwintering (Hossain et al. 1999, Macfadyen et al. 2009, Roume et al. 2011), and as well as alternative food resources (Wäckers and van Rijn 2005, Isaacs et al. 2009). My results are consistent with the hypothesis that complementary resources found in diverse landscapes support a greater diversity of natural enemies.

In natural and semi-natural habitats, stable resources, such as prey and alternative food items (i.e., nectar and pollen), can support the biodiversity and species composition of natural enemies (Landis et al. 2000, Landis et al. 2005, Wäckers and van Rijn 2005). Many natural enemies spillover at habitat interfaces (Tscharntke et al. 2007) to forage on prey items during seasonal abundant prey items that can be found in ephemeral annual crops (Tscharntke et al. 2005b). Resource use by natural enemies depends on the availability and the requirement of the resources; with greater landscape diversity, the availability of these complementary resources is predicted to increase as well. Thus, along with increasing natural-enemy diversity in the landscape, survival of natural enemies would increase because of a diverse landscape and its associated complementary resources (Steffan-Dewenter 2003). In my study, the surrounding habitat is an important predictor of richness and species composition of natural-enemies insects. The species richness of natural-enemies insects tend to increase with greater diversity in land cover or increasing proportions of complementary habitats of agricultural and semi-natural land cover, but species composition are dependent on both patch and landscape characteristics.

A high species diversity of natural enemies can results in greater biological control of insect pests because of a greater probability that multiple natural-enemy species can feed on the same prey item or have the same host (Ives and Cardinale 2004). The non-additive interaction of multiple enemies could lead to greater pest suppression and higher crop yield that the summed impacts of each enemy species alone (Cardinale et al. 2003). Higher access to crop and non-crop habitats by natural enemies are reliant on a diverse and abundant community of natural-enemies and maintaining a diverse and stable landscape. This heterogeneous landscape allows for greater spillover of natural enemies from non-crop habitat, where they receive resource subsides, into cultivated areas, where they can exploit pest insects (Bianchi et al 2006, Tscharntke et al. 2007). Therefore, this higher species richness insures against ecosystem fluctuations caused by disturbances (i.e., planting, harvesting, and spraying of agrochemicals; Yachi and Loreau 1999). The diverse surrounding landscape in some of the patches in my study may consist partly of other suitable habitat that allows for increase pest control by natural-enemies insects in the landscape and insurance against disturbances.

This insurance is important for cropping systems and the conservation of biological control. Diverse habitats in a landscape may provide suitable habitat depending on the degree which a species is able to use that habitat (Bianchi et al. 2006). Certain resources may be restricted to certain habitats and the amount and availability of these resources may vary spatially (Steffan-Dewenter 2003). Organisms, such as ground beetles (Coleoptera: Carabidae), can make use of intensively managed agricultural fields to forage because seasonal abundant prey (Hajek et al. 2007, Gardiner et al. 2010), but overwinter in edges of natural and semi-natural habitat (i.e., warm-season grasslands and forest) where the organism can be sheltered from harsh conditions (Roume et al. 2011). Likewise, my data show that species richness of predators, the majority of which were beetles, increased with greater proportions of complementary habitats of agricultural and semi-natural habitats or land cover diversity, depending on season. Other organisms, such as parasitoid wasps (Hymenoptera), use flowering plants as a nectar resource in field margins and semi-natural habitat of an agriculture landscape (Bianchi and Wäckers 2008), but use cultivated areas for parasitism of host organisms (Cardinale et al. 2003). Greater similarity in species composition of parasitoid species based on number of flowering stems or landscape diversity, depending on season, and increase parasitoid richness with increase land cover diversity in my data help support the insurance and conservation of biological control.

In conclusion, natural enemies are more sensitive to broad-scale landscape characteristics than local patch-level habitat features, at least for the conservation semi-natural habitat patches in my study. Both predators and parasitoid are reliant on the complementarities of resources found in multiple habitats and are driven mostly by landscape diversity. The proportions of different habitats in an agricultural matrix are critical for the conservation of natural enemies (Landis et al. 2000, Bianchi et al. 2006, Tscharntke et al. 2007).

My results have some important implication for conservation. First, the diversity of land cover types was the most important factor that predicted variation in species richness and compositions of natural enemies. Thus, efforts for conservation of predators and parasitoids depend on land-use practices that support structurally complex landscapes with multiple ecosystems (Landis et. al 2000, Tscharntke et. al 2005a, Tscharntke et. al 2007). Second, flowering herbaceous plants seem to be an important predictor of parasitoid communities. Therefore, conservation of nectar resources in the patches is important for both the fecundity and survival parasitic insects (Bianchi and Wäckers 2008). My study underlines the importance of conservation efforts that could be employed by land owners through policy incentives leading to the establishment of semi-natural habitat, which, in turn, increases populations of natural enemies and wildlife populations while reducing water runoff and sedimentation, and protect groundwater.

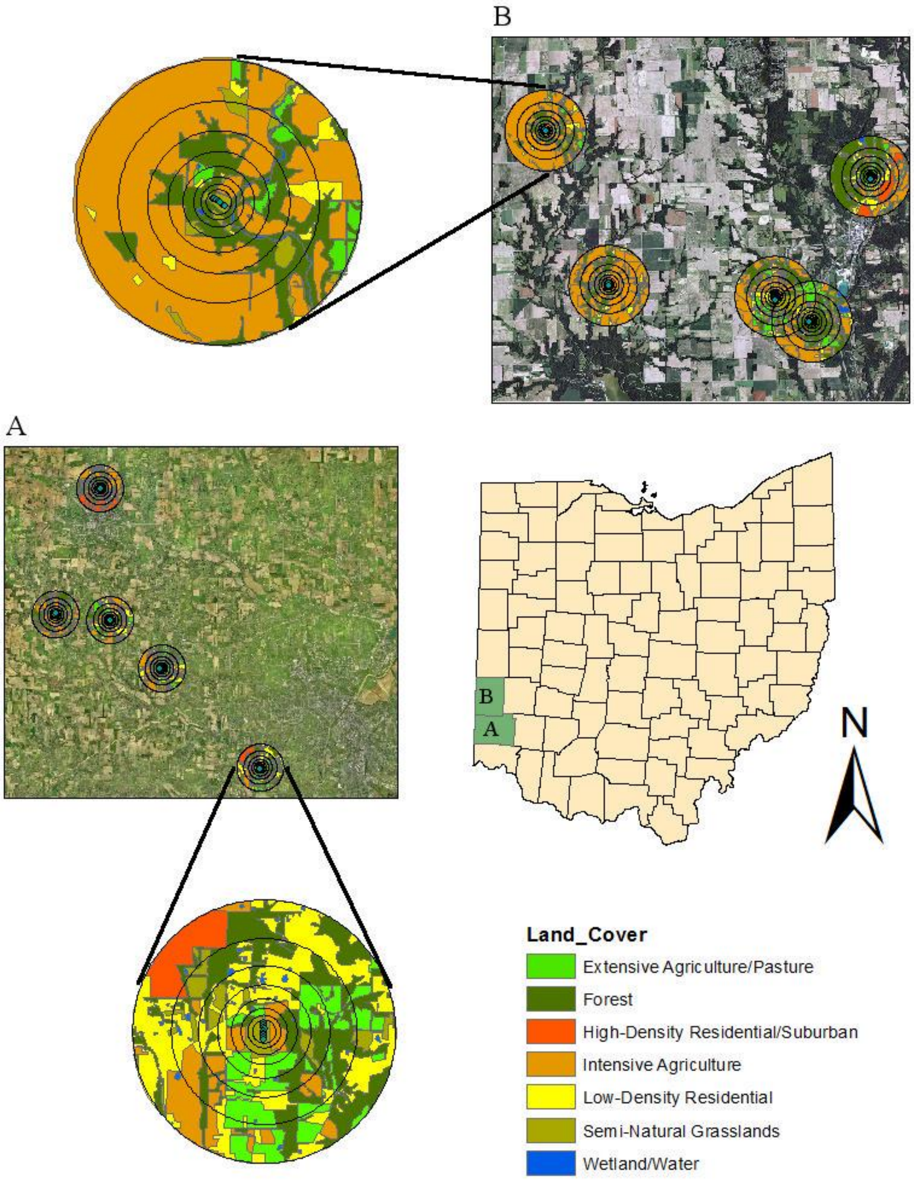

Figure 2-1: Study sites in A.) North Western Butler and B.) South Central Preble counties in SW Ohio. Location of 10 habitat sectors and the distribution of the primary habitat types. Study sites in A.) North Western Butler and B.) South Central Preble counties in SW Ohio. Location of 10 habitat sectors and the distribution of the primary habitat types.

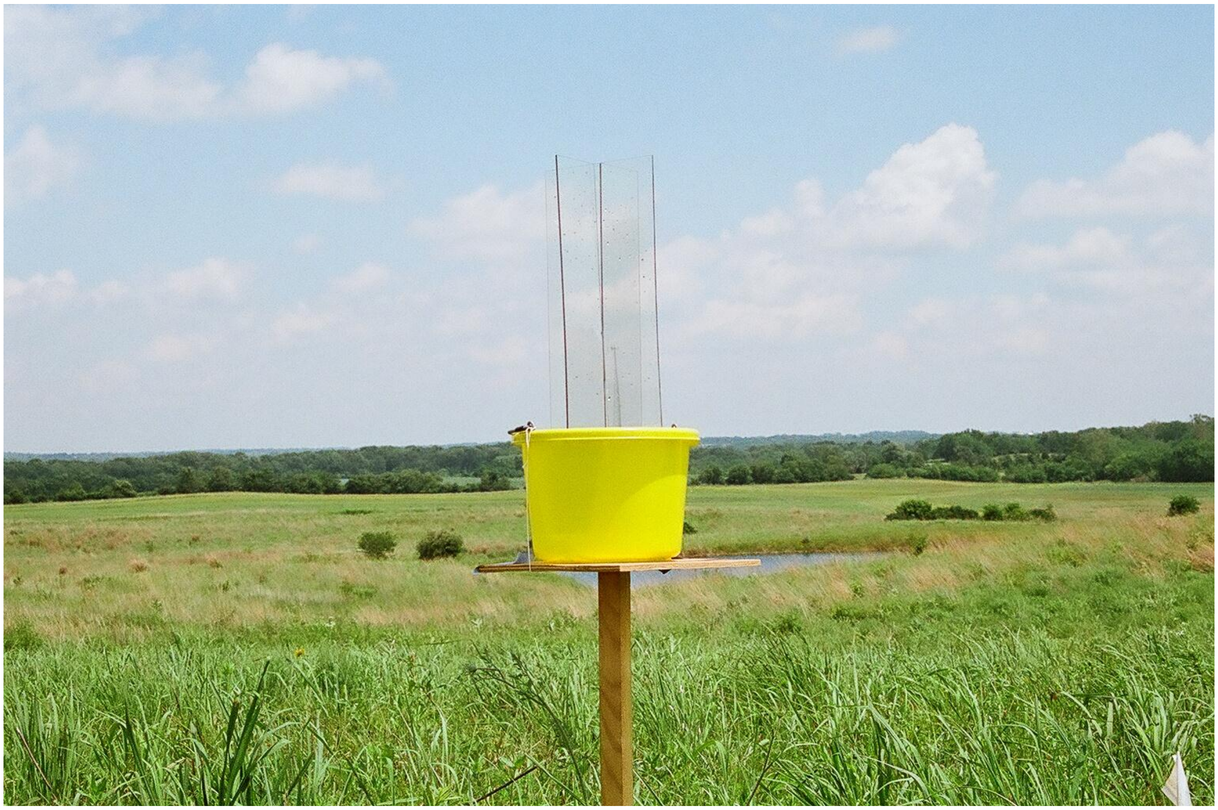

Figure 2-2: Combination flight intercept / pan trap with two Lexan™ panes inserted at right angles to weak-flying intercept insects coming from all directions.

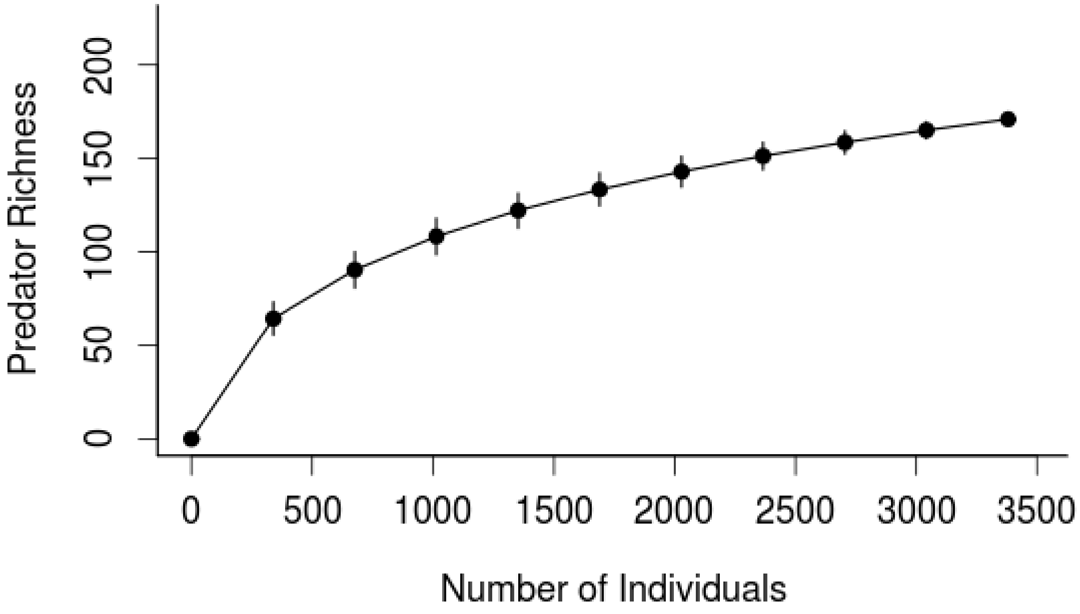

Figure 2-3: Site-based species accumulation curve for predator species richness. Species included predator Coleoptera, Hymenoptera, and Hemiptera. Expected species values (solid line) with 95% confidence intervals (vertical line).

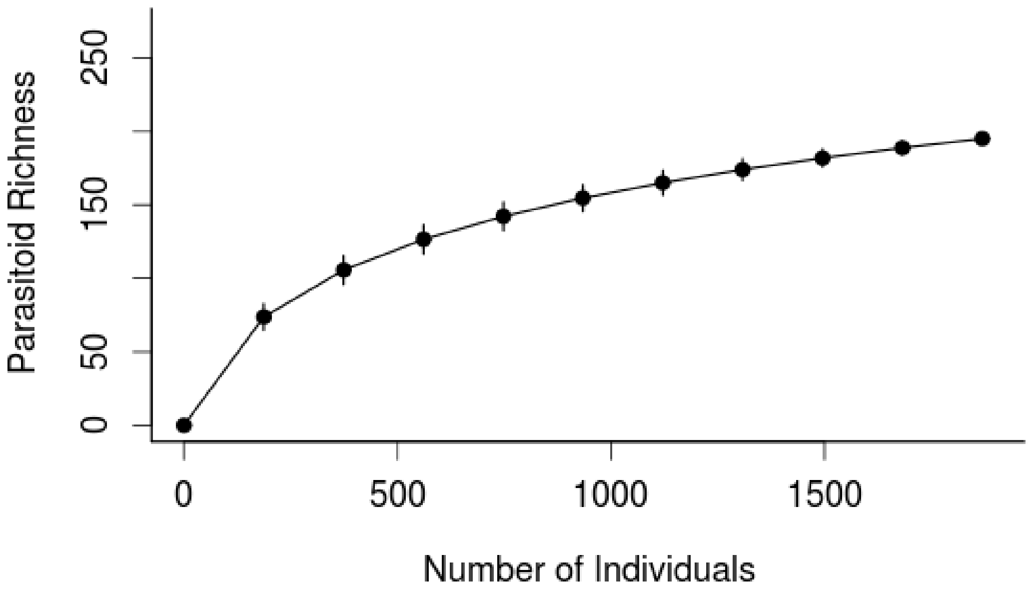

Figure 2-4: Site-based species accumulation curve for parasitoid species richness. Species include parasitoids Coleoptera and Hymenoptera. Expected species values (solid line) with 95% confidence intervals (vertical line).

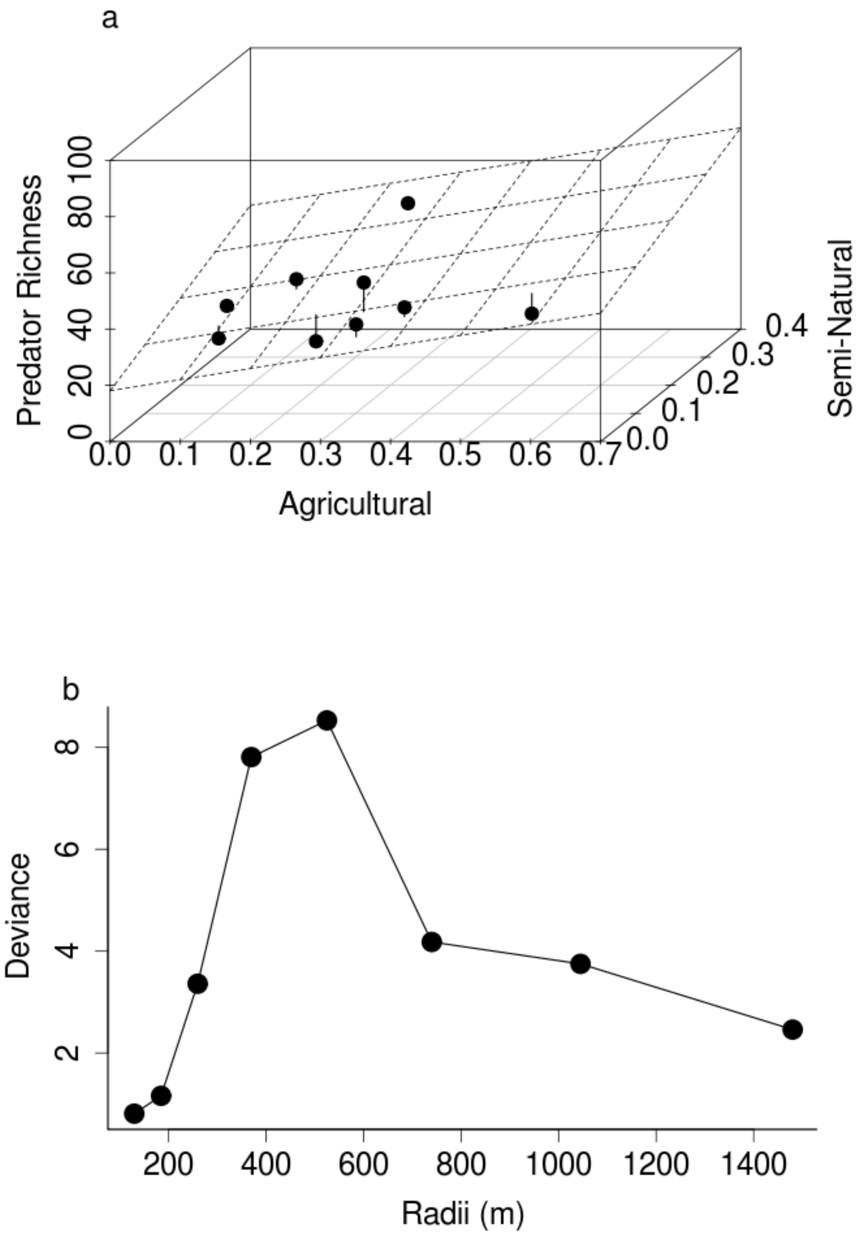

Figure 2-5: The relationship between predator species richness and the proportions intensive agricultural and semi-natural land cover at the 525 m radius during the June sampling period. Deviance = 8.53, d.f. = 2,6, *p* = 0.016 (panel a). Scale-dependent effects of the landscape variables on predator species richness. Explained deviance of the significant Poisson regression is shown between predator species richness and the additive model of the proportion of intensive agriculture and semi-natural habitat at 8 scales (panel b).

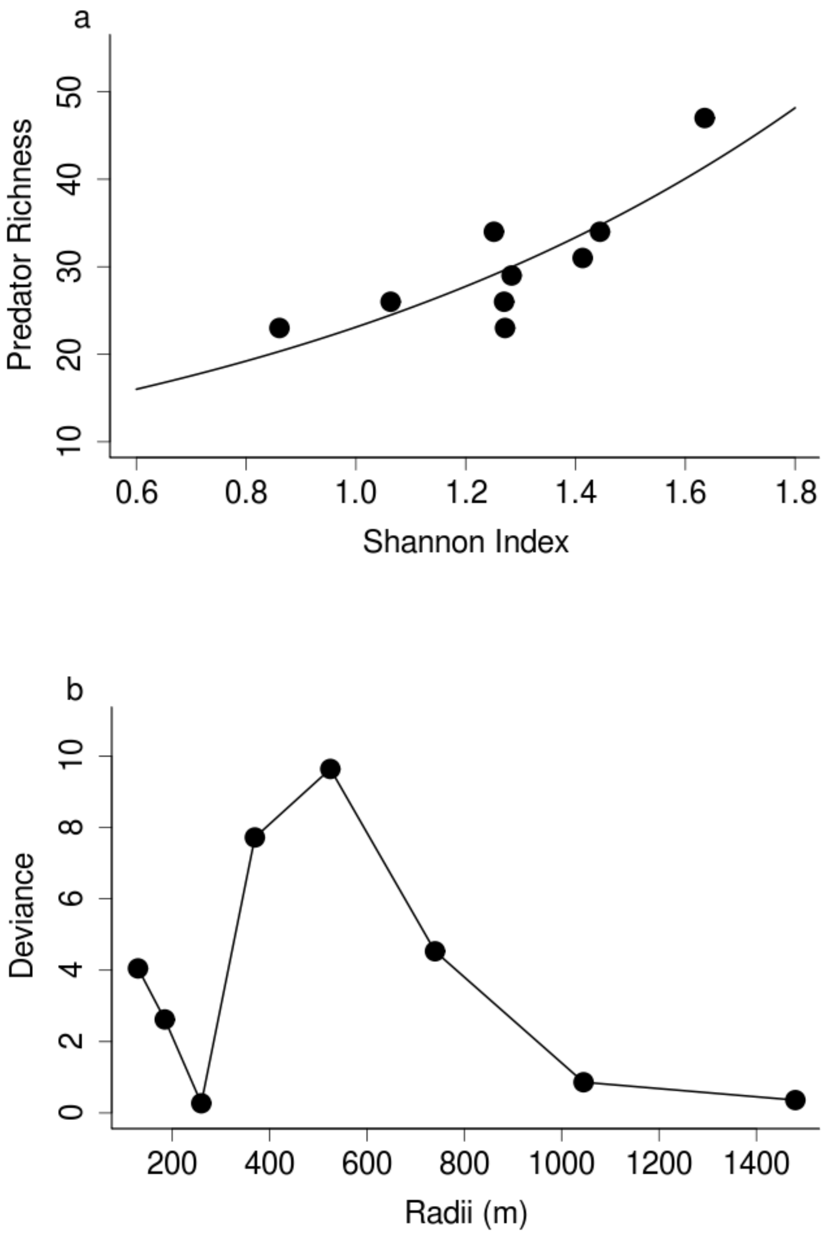

Figure 2-6: The relationship between predator species richness and the Shannon-Weiner diversity land cover at the 525 m radius during the August sampling period. Deviance = 9.64, d.f. = 1,7, *p* = 0.0019 (panel a). Scale-dependent effects of the landscape variables on predator species richness. Explained deviance of the significant Poisson regression is shown between predator species richness and the Shannon-Weiner diversity of land cover at 8 scales (panel b).

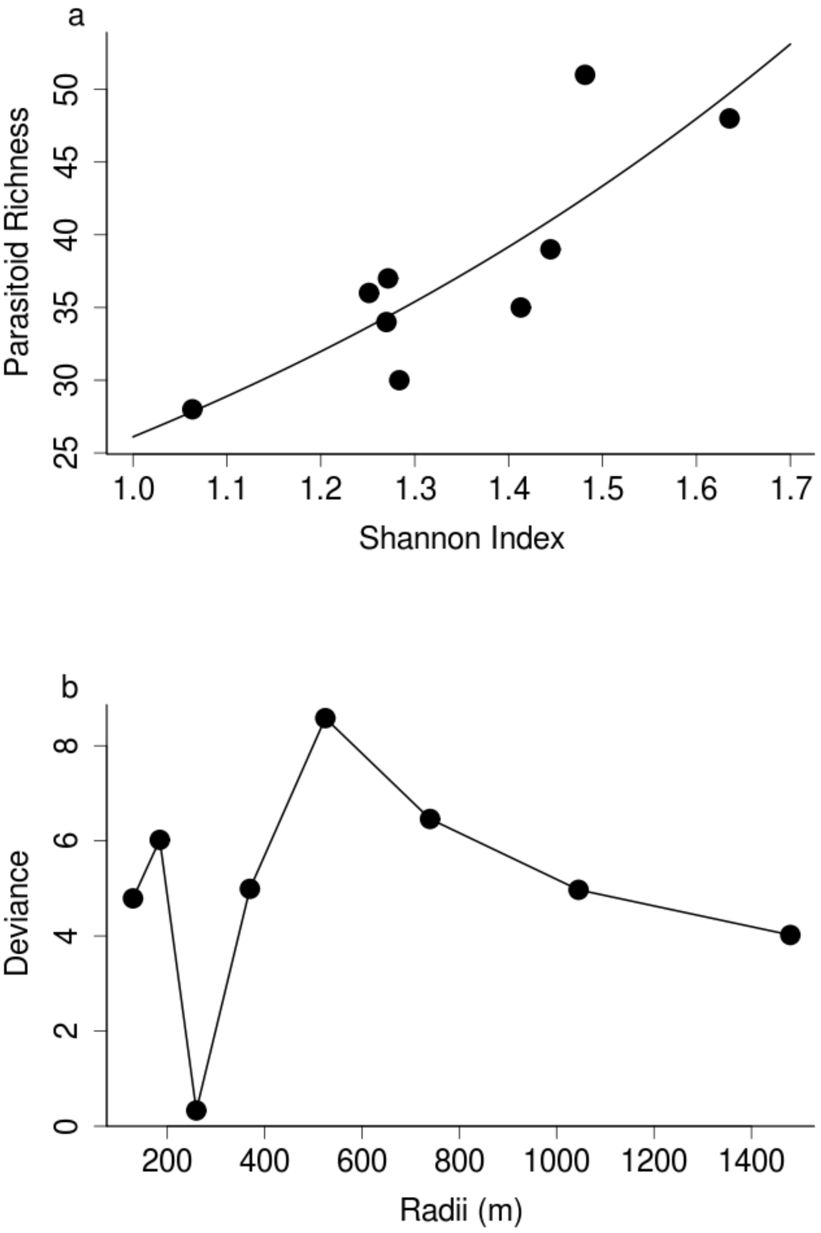

Figure 2-7: The relationship between parasitoid species richness and the Shannon-Weiner diversity land cover at the 525 m radius during the June sampling period. *Deviance = 8.58, d.f. = 1,7, p = 0.0034 (panel a*). Scale-dependent effects of the landscape variables on parasitoid species richness. Explained deviance of the significant Poisson regression is shown between predator species richness and the Shannon-Weiner diversity of land cover at 8 scales (panel b).

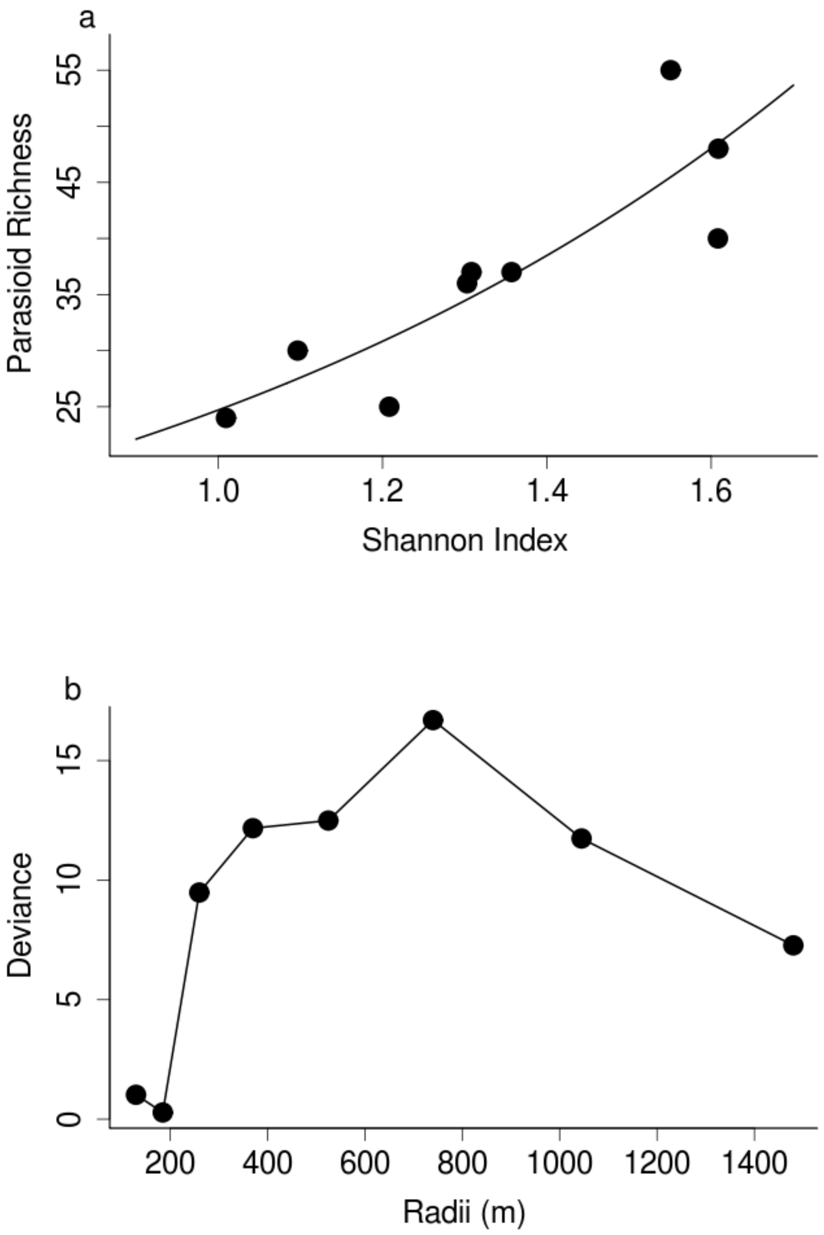

Figure 2-8: The relationship between parasitoid species richness and the Shannon-Weiner diversity land cover at the 740 m radius during the August sampling period. Deviance = 16.692, d.f. = 1,7, $p < 0.001$ (panel a). Scale-dependent effects of the landscape variables on parasitoid species richness. Explained deviance of the significant Poisson regression is shown between parasitoid species richness and the Shannon-Weiner diversity of land cover at 8 scales (panel b).

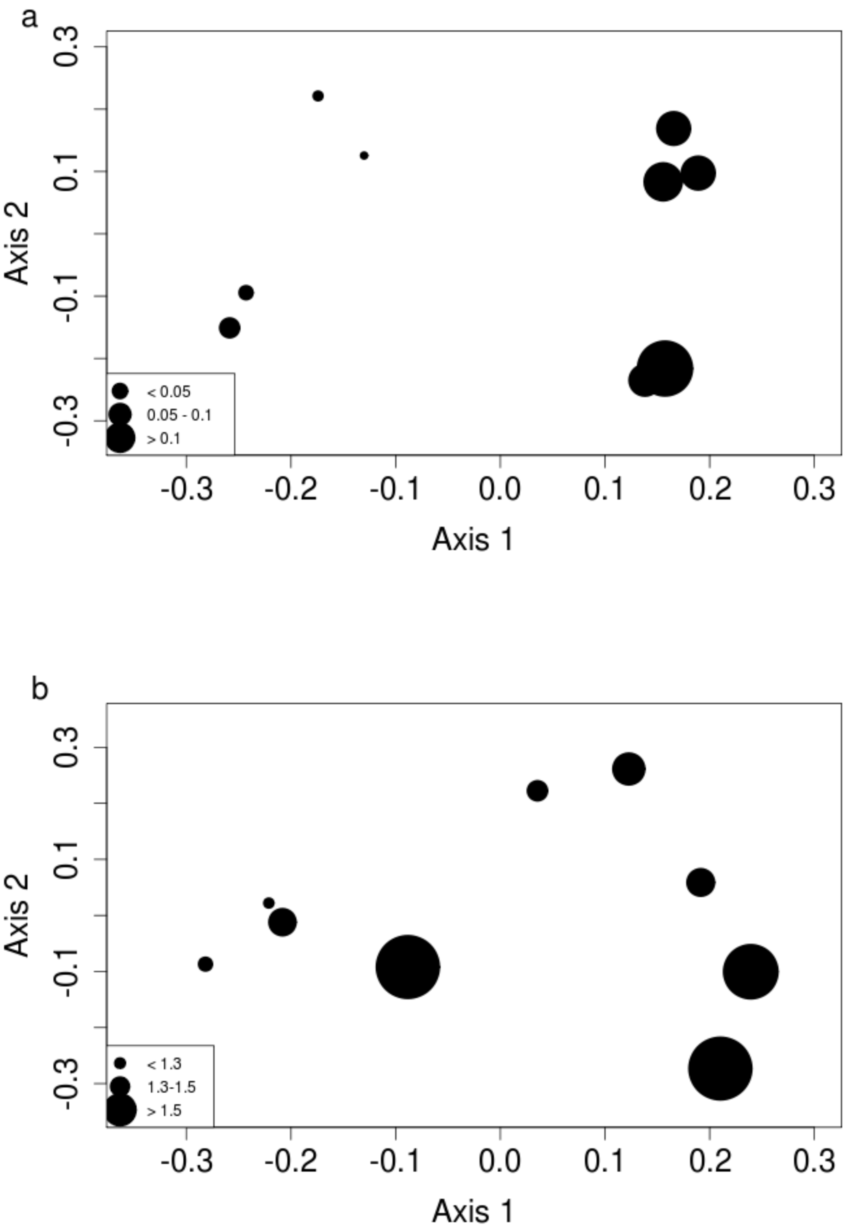

Figure 2-9: Distance-based redundancy analysis (dbRDA) of predator species composition (June sampling panel a, August sampling panel b). Axis 1 is the variable that explains the variation in species composition and Axis 2 is a residual. June variation of predator species composition was explained by semi-natural habitat land cover at 740 m radius (point size corresponds to Shannon-Weiner Diversity Index $r^2 = 0.21$, $p = 0.0027$, panel a). August variation of predator species composition was explained by Shannon-Weiner diversity of land cover at 740 m radius (point size corresponds Shannon-Weiner Diversity Index $r^2 = 0.19$, $p = 0.045$, panel b).

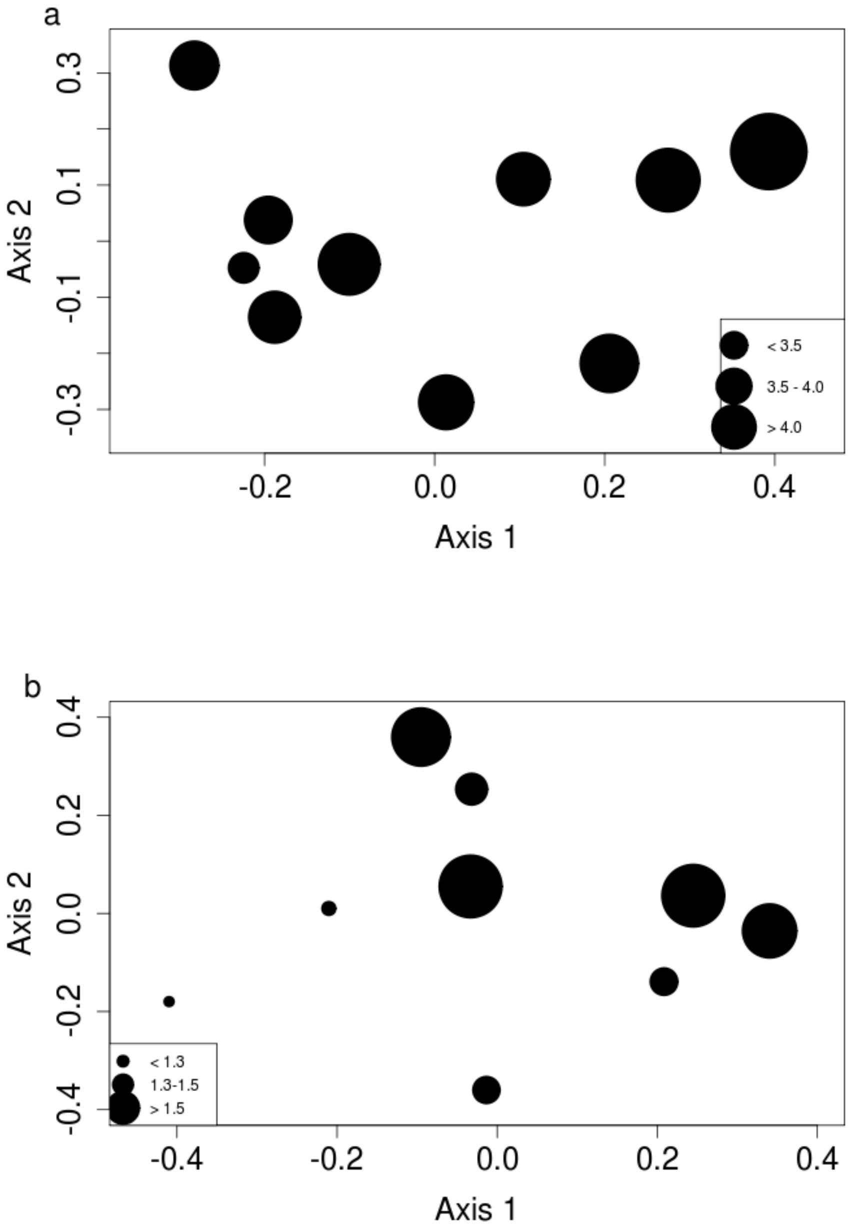

Figure 2-10: Distance-based redundancy analysis (dbRDA) of parasitoid species composition (June sampling panel a, August sampling panel b). Axis 1 is the variable that explains the variation in species composition and Axis 2 is a residual. June variation of parasitoid species composition was explained by log flower abundance (point size corresponds to log flower abundance in ha $r^2 = 0.20$, $p = 0.0031$, panel a). August variation of parasitoid species composition was explained by Shannon-Weiner diversity of land cover at 740 m radius (point size corresponds Shannon-Weiner Diversity Index $r^2 = 0.20$, $p = 0.0049$, panel b).

Table 2-1: Landscape composition for the 10 sites in SW Ohio at 1480 m radius. Habitat proportional data and Shannon-Weiner diversity of land cover / land use based on 8 radii for 10 sites.

Habitat Type	Mean	Min	Max
Intensive Agriculture	0.34	0.12	0.68
Forest	0.30	0.19	0.47
Semi-natural Grassland	0.08	0.03	0.17
Extensive Agriculture	0.10	0.01	0.19
Low-Density Residential	0.13	0.03	0.30
High-Density Residential	0.03	0	0.19
Water / Wetland	0.01	0.01	0.03
Shannon-Weiner Diversity Index	1.43	0.98	1.65

Table 2-2: Patch composition for 10 sites sampled in SW Ohio.

Patch Variable	Mean	Minimum	Maximu
a.) June Sampling			
Log Area (natural log of the patch area in hectares)	1.45	0.18	2.88
Log Age (natural log of age of the patch in years)	1.25	0	2.56
Log Flowers (natural log of the abundance of flowering stems)	3.89	2.16	5.41
Total Cover (total proportional cover of vegetation)	1.12	0.70	1.38
C4 Grasses (proportional cover by warm-season	0.45	0.09	0.75
C3 Grasses (proportional cover by cool-season grasses)	0.04	0	0.20
Forbs (proportional cover by herbaceous plants that are not graminiod)	0.45	0.2	0.84
b.) August Sampling			
Log Area (natural log of the patch area in hectares)	1.45	0.18	2.88
Log Age (natural log of age of the patch in years)	1.25	0	2.56
Log Flowers (natural log of the abundance of flowering stems)	1.08	0.24	1.69
Total Cover (total proportional cover of vegetation)	0.97	0.77	1.06
C4 Grasses (proportional cover by warm-season	0.69	0.39	0.92
C3 Grasses (proportional cover by cool-season grasses)	0.06	0	0.35
Forbs (proportional cover by herbaceous plants that are not graminiod)	0.25	0.08	0.72

Table 2-3: General linear model of the relationship between species richness of predator and parasitoid species to patch or landscape variables.

Response Variable	Model	Effect	AICc	ΔAICc	Deviance	*p*-value
Predator richness 1st sampling	ag + semi-nat w/in 525 m	positive, positive	68.90	0	8.53	0.016
	agriculture w/in 525 m	positive	69.88	0.98	5.76	0.097
	forest w/in 525 m	negative	70.14	1.23	5.50	0.11
	semi-natural w/in 525m	positive	70.18	1.27	5.46	0.12
	agriculture + forest w/in 525 m	positive, negative	72.01	3.10	5.67	0.10
Predator richness 2nd sampling	land cover diversity w/in 525 m	positive	57.37	0	9.64	0.0019
	land cover diversity w/in 370 m	positive	59.29	1.92	7.50	0.0047
	land cover diversity w.in 740 m	positive	62.49	5.11	4.59	0.024
Parasitoid richness 1st sampling	land cover diversity w/in 525 m	positive	59.95	0	8.58	0.0034
	null	–	63.58	3.63	–	–
Parasitoid richness 2nd sampling	land cover diversity w/in 740 m	positive	59.95	0	16.69	< 0.001
	land cover diversity w/in 525 m	positive	64.16	4.20	12.49	<0.001

Table 2-4: Distance based redundancy analysis of the relationship between species composition of predators and parasitoids to patch or landscape variables.

Response Variable	**Model**	**AICc**	**ΔAICc**	$\mathbf{r^2}$	***p*-value**
Predator composition 1st sampling	semi-natural w/in 740 m	-14.52	0	0.22	0.0027
	agriculture w/in 740 m	-14.42	0.11	0.21	0.010
	forest w/in 740 m	-12.96	1.56	0.07	0.96
	agriculture + semi-natural w/in 740 m	-11.22	3.30	0.34	0.02
Predator composition 2nd sampling	land cover diversity w/in 740 m	-13.61	0	0.19	0.045
	land cover diversity w/in 1045 m	-13.58	0.04	0.18	0.049
	land cover diversity w/in 1480 m	-13.56	0.06	0.18	0.064
	land cover diversity w/in 130 m	-13.40	0.21	0.17	0.099
	land cover diversity w/in 525 m	-13.36	0.26	0.16	0.12
	land cover diversity w/in 370 m	-13.27	0.34	0.15	0.16
	land cover diversity w/in 185 m	-13.15	0.47	0.14	0.28
	land cover diversity w/in 260 m	-12.87	0.74	0.11	0.61
Parasitoid composition 1st sampling	log flowers	-12.90	0	0.20	0.0031
	forbs	-12.89	0.0048	0.19	0.0062
	C4 Grasses	-12.68	0.21	0.18	0.019
	log area	-12.01	0.88	0.12	0.26
	C3 Grasses	-11.90	1.00	0.11	0.46
	cover	-11.85	1.04	0.11	0.45
	log age	-11.85	1.05	0.11	0.67
	forbs + log area	-10.22	2.67	.32	0.0085
Parasitoid composition 2nd sampling	land cover w/in 740 m	-9.64	0	0.19	0.0049

	land cover w/in 1045 m	-9.53	0.11	0.19	0.011
	land cover w/in 1480 m	-9.49	0.15	0.18	0.017
	land cover w/in 525 m	-9.43	0.21	0.18	0.027
	land cover w/in 370 m	-9.24	0.39	0.16	0.11
	land cover w/in 130 m	-9.08	0.56	0.15	0.23
	land cover w/in 185 m	-9.05	0.58	0.14	0.26
	land cover w/in 260 m	-8.44	1.20	0.08	0.95

Chapter 3: Synthesis and Conclusion

Agricultural intensification is known to be a driver of biodiversity of organisms at multiple scales, from local, to landscape, to global (Tscharntke et al. 2005a). My study demonstrates that both local and landscape attributes should be considered in the conservation of beneficial insects. Native bees are important in agricultural landscapes because they provide an ecosystem service of pollination to orchards, cover crops, natural, semi-natural areas (Kremen 2002), which, in turn, is necessary for fruit and seed production (Lonsdorf et al. 2009). Predators and parasitoids are important in agricultural landscapes because they provide an ecosystem service of acting as a natural enemy of insect pests (Landis et al. 2000, Landis et al. 2005).

My study is applicable in other areas of North America as well as other parts of the world. For example, in places such as California and Michigan, vegetable and fruit farms could benefit by establishing land easements for beneficial insect refuges. Agencies, like the United States Department of Agriculture Conservation Reserve Program (NRCS 2012) or the United States Fish and Wildlife Service Habitat Enhancement Grant (FWS 2012) can assist by providing monetary incentives to set aside land as semi-natural habitat. In other parts of the world, for example, where the landscape is heavily influenced with coffee plantations in Brazil, farmers could benefit having field margins or natural habitat (i.e., forest), that can provide resources in nectar, pollen, and other alternative food and prey. These efforts in both North America and the rest of the world, not only can lead to higher yield through conserving the services that these insects provide, but also could reduce topsoil run-off and increase filtering of groundwater and carbon sequestration (NRCS 2012).

Some general findings in my research were that large semi-natural habtat patches had higher species richness of pollinating bees, while more diverse land cover had higher species richness of beetles, predators and parasitoids insects (Table 3-1). Species compositions of bees differ in larger more forby patches compared to smaller less forby patches, while beetle, predators, and parasitoids composition changes across a gradient of with intensive agriculture or semi-natural habitat (Table 3-1). Other more specific findings established that floral resources were important for species composition of parasitoid in late spring, but while the proportion of intensively managed cropland was important for species composition of predatory beetles both in late spring and mid-summer (Table 3-1).

Life-history traits of a complementary set of plant dependent organisms, which determine the functional roles of insects in the ecosystem, are related to ecosystem function (Petchy and Gaston 2006). Native bee pollinators in my study had different trait composition in larger patches then in smaller ones or in greater proportion of semi-natural land cover in the surrounding landscape within 130 m radius compared to smaller proportion of semi-natural habitat (Table 3-1). The majority of bees were small (63.5% of the species abundance during the first sampling period), ground nesting (86.3% and 79.9% of the species abundance during both sampling periods respectively), and solitary (89.4% and 74.3% of the species abundance during both sampling periods respectively). These species decreased in occurrence in smaller patches leading to shifts in both species and trait composition with patch size, and a greater richness in larger patches (Table 3-1). Previous studies have found a positive relationship between pollinating bees richness and semi-natural patch area (Steffan-Dewenter 2003, Kremen et al. 2004), but they did not focus on how similar bees species composition and trait composition are related to habitat patch size and proportion of semi-natural area in the first radius. Bee species traits are mechanisms that help explain the use of habitat size.

Predatory beetles, which accounted for the majority of my natural-enemy insect (97% of the species abundance of all predators) had similar composition in greater proportions of semi-natural land cover within 1045 m radius in both early and late season (Table 3-1). The majority of my predatory beetle was larger (72.5% of species abundance during the first sampling period) and had macropterous wing morphology (89.3% and 68.4% of the species abundance during both sampling periods respectively). Beetles species from non-crop habitat to spill-over into crop habitat, leading to similar species composition in intensively managed agriculture and higher diversity in both intensively managed agriculture and semi-natural habitat.

There are a few possibilities to explain these trends. Ground-nesting, solitary, and smaller bees rely on large area and greater proportions of semi-natural habitat for nesting and foraging, while larger bees are more able to disperse to smaller semi-natural patches that make up lesser of the proportion of the landscape. Natural-enemy insects rely on a heterogeneous landscape, where they are able to use alternative food and prey items in non-crop habitat and spill-over into cropped habitat to exploit pest insects. Therefore, diverse landscape, with ample proportions of semi-natural land cover insures against ecosystem fluctuations caused by disturbances of planting, harvesting, and spraying of agrochemicals.

The positive relationship of diverse landscapes on the richness of various natural-enemy insects has been documented in a few studies (e.g., Steffan-Dewenter 2002, Steffan-Dewenter 2003, Weibull et al. 2003), but my data gives evidence that predatory insects and predatory beetles have complementary habitat use (Fig 1-6 & 2-5a). My data also show similar evidence relating positive relationship between diverse landscapes with predator and parasitoid richness, but unlike Steffan-Dewenter (2002 & 2003) and Weibull et al. (2003) studies, my research covers a wide of predators (Coleoptera, Hemiptera, and Hymenoptera) and parasitoids (Coleoptera and Hymenoptera). My data also show predator species composition shifts in patches with changes in the surrounding landscape diversity, depending on season (Fig. 2-9a & b). Similarly parasitoid species composition is closely related in patches related to the amount of flowering resources and surrounding landscape cover diversity, dependent on season (2-10a & b).

For beetles, a subset of the predators, species traits of size and wing morphology may provide mechanisms into the observed patterns, suggesting that differential movement and dispersal into patches are important to shifts in species composition. Shifts in beetle species composition in a patch is explained by intensively managed agriculture in both sampling periods and similar beetle trait composition in patches is explained by semi-natural land cover in both sampling periods (1-11a & b, 1-13a & b). Larger beetles with macropterous wing morphology in beetles were found in patches surrounded by large proportion of semi-natural habitat, while smaller beetles with brachypterous wing morphology were found in patches surrounded by more intensively managed agriculture.

Based on my finding, because the limitations of number of sites that were sampled (n < 20), it seems greater replication, and sampling from both crop and non-crop areas might be important. Further studies could use a method outlined by Fahrig et al. (2011) using a set of landscapes along a gradient of increasing compositional heterogeneity (cover type richness) as well increasing configurationally heterogeneity (spatial pattern). Future studies should sample both crop and non-crop habitat and focus on increasing heterogeneity in cultivated areas, because heterogeneity in non-cropped area in an agricultural landscape is shown to increase biodiversity (Tscharntke et al. 2005a, Bianchi et al. 2006). The size of the landscape should be constrained to the taxa under investigation (Tscharntke et al. 2007).

Using geographic information systems and aerial photographs, I would begin by digitizing land cover then plotting along the two heterogeneity axes number of crop types and mean field sizes. I would use digital photographs in areas where the compositional heterogeneity of the landscape gradient could be altered by the number of different crops that are grown, and areas where the configurationally heterogeneity of the landscape gradient could be altered by the mean field size of the cropped areas within the landscape. From there, landscapes in a region would be selected from all the landscapes digitized minimize correlation between compositional and configurationally heterogeneity, while trying to maintain the maximum possible range of each axis. Once statistical models are built relating how to manage landscape heterogeneity for conservation efforts, agri-environmental policies can be made to minimize loss of biodiversity.

Table 3-1: Summary table of patch and landscape variables that gave best models for my response variables

Response Variable	Local Variable	Landscape Variable	Conclusion
Bees			
Richness			
June Sampling	Log area	Semi-natural land cover w/in 525 m	Local scale gave best model
August Sampling	Null	Null	Null gave best model
Species Composition			
June Sampling	Log area	Semi-natural land cover w/in 130 m	Local scale gave best model
August Sampling	Proportion forbs	Null	Local scale gave best model
Trait Composition			
June Sampling	Log Area	Combined effect of agriculture and semi-natural land cover w/in 1045 m	Local scale gave best model
August Sampling	Log number flowering stems	Semi-natural land cover w/in 130 m	Landscape scale gave best model
Beetles			
Richness			
June Sampling	Total cover	Combined effect of agriculture and semi-natural land cover w/in 370 m	Landscape scale gave best model
August Sampling	Log area	Semi-natural land cover w/in 260 m	Landscape scale gave best model
Species Composition			
June Sampling	Proportion C4 grasses	Intensive agriculture land cover w/in 525 m	Landscape scale gave best model
August Sampling	Proportion C3 grasses	Intensive agriculture land cover w/in 1045 m	Landscape scale gave best model
Trait Composition			
June Sampling	Null	Semi-natural land cover w/in 1045 m	Landscape scale gave best model

August Sampling	Null	Semi-natural land cover w/in 1045 m	Landscape scale gave best model
Predators			
Richness			
June Sampling	Proportion forbs	Combined effect of agriculture and semi-natural land cover w/in 370 m	Landscape scale gave best model
August Sampling	Log area	Shannon-Weiner land cover diversity w/in 525 m	Landscape scale gave best model
Species Composition			
June Sampling	Log number flowering stems	Semi-natural land cover w/in 740 m	Landscape scale gave best model
August Sampling	Proportion C3 grass	Shannon-Weiner land cover diversity w/in 740 m	Landscape scale gave best model
Parasitoids			
Richness			
June Sampling	Log area	Shannon-Weiner land cover diversity w/in 525 m	Landscape scale gave best model
August Sampling	Log area	Shannon-Weiner land cover diversity w/in 740 m	Landscape scale gave best model
Species Composition			
June Sampling	Log number flowering stems	Shannon-Weiner land cover diversity w/in 740 m	Local scale gave best model
August Sampling	Log age	Shannon-Weiner land cover diversity w/in 740 m	Landscape scale gave best model

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Appendix 1: Plant species proportional cover per m^2 recorded at 10 sites within SW during June 2009. Butler County: Cummins (CU), Gelber (GL), Fitton (F), Geddes (GD), Vaughn (V). Preble County: Bruns (B), Ehrhardt (E), Simth (S), Constanzo (CO), Ketring (K)

Species	**Family**	**CU**	**B**	**E**	**GL**	**S**	**F**	**CO**	**K**	**GD**	**V**	**Mean**
Andropogon gerardii	Poaceae	0.30	0.040	0.53	0.0067	0.0077	0	0.35	0.042	0.096	0.16	0.15
Sorghastrum nutans	Poaceae	0	0.68	0.13	0	0	0	0.24	0.23	0.0033	0	0.13
Erigeron stigosus	Asteraceae	0.028	0	0.11	0.014	0	0.11	0.00065	0.0078	0.053	0.79	0.11
Panicum virgatum	Poaceae	0.40	0	0	0	0.25	0	0.15	0.12	0.072	0	0.10
Solidago canadensis	Asteraceae	0.0018	0.18	0.034	0.0013	0.27	0.0077	0.030	0.12	0.0087	0.046	0.070
Ambrosia artemisiifolia	Asteraceae	0	0	0	0.040	0	0.17	0	0.0067	0.37	0	0.058
Cirsium arvense	Asteraceae	0	0.070	0.016	0.021	0	0.21	0.0032	0.033	0.0011	0	0.035
Rudbeckia hirta	Asteraceae	0.0018	0	0.067	0.035	0.056	0.0043	0.00065	0.0047	0.15	0	0.032
Setaria faberi	Poaceae	0.020	0	0	0.29	0	0	0	0	0	0	0.031
Chamaecrista fasciculata	Fabaceae	0.010	0	0.0022	0.093	0.031	0.018	0.00065	0	0.074	0	0.023
Conyza canadensis	Asteraceae	0.0018	0	0	0.22	0	0	0.0032	0	0.0016	0	0.023
Daucus carota	Apiaceae	0.016	0	0.013	0.038	0	0.076	0.056	0.011	0.0011	0	0.021

Schizachyrium scoparium	Poaceae	0.0064	0	0.0067	0.16	0	0.0011	0	0.00079	0.038	0	0.021
Eupatoriadelphus maculatus	Asteraceae	0.12	0.012	0.0036	0.0080	0	0.30	0	0.0059	0	0	0.018
Bouteloua curtipendula	Poaceae	0.025	0	0.00044	0.045	0.00051	0.086	0.0019	0	0.022	0	0.018
Carex flava	Cyparaceae	0	0	0	0	0.16	0	0	0	0	0	0.016
Unknown Woody A		0	0	0	0	0	0	0	0.15	0	0	0.015
Toxicodendron radicans	Anacardiaceae	0	0	0.011	0	0.13	0	0.00065	0	0	0	0.014
Elymus lanceolatus	Poaceae	0.0027	0	0.00044	0.010	0	0.099	0	0	0.011	0	0.012
Phleum pratense	Poaceae	0	0	0	0	0	0.060	0	0.035	0	0	0.0096
Trifolium pratense	Fabaceae	0	0	0.0031	0.0033	0	0.014	0.072	0.0024	0.00054	0	0.0096
Trifolium repens	Fabaceae	0	0	0	0	0	0	0	0.088	0	0	0.0088
Festuca pratensis	Poaceae	0	0	0	0	0.0026	0.045	0	0.037	0.0027	0	0.0088
Rubus A	Rosaceae	0	0.012	0.0062	0	0	0	0.027	0.0098	0	0	0.0055
Echinochloa crusgalli	Poaceae	0.024	0	0	0	0	0	0.016	0	0	0	0.0040
Cichorium intybus	Asteraceae	0.0036	0	0.013	0	0	0.0033	0.019	0.00039	0	0	0.0037

Solidago lancifolia	Asteraceae	0	0	0.0071	0	0.022	0	0.00065	0.0027	0	0	0.0032
Gleditsia triacanthos	Fabaceae	0	0	0	0	0	0.030	0	0	0	0	0.0030
Ratibidae pinnata	Asteraceae	0	0	0	0	0	0.0011	0	0	0.028	0	0.0029
Desmanthus illinoensis	Fabaceae	0.024	0	0	0	0	0	0	0	0.0028	0	0.0026
Carex stipata	Cyparaceae	0	0	0	0.0040	0.021	0	0	0	0	0	0.0025
Poa A	Poaceae	0	0	0.0044	0	0	0	0	0.018	0.0016	0	0.0024
Populus deltoides	Salicaceae	0	0	0	0	0.021	0	0	0	0	0	0.0021
Diasacus laciniatus	Dipsacaceae	0	0	0	0	0	0.019	0	0	0	0	0.0019
Solidago erecta	Asteraceae	0.0018	0	0.0089	0	0.0015	0	0	0.0063	0	0	0.0019
Halianthus annuus	Asteraceae	0.0036	0	0	0	0	0.011	0	0	0.0027	0	0.0017
Rosa multiflora	Rosaceae	0	0	0	0	0.0031	0	0	0.012	0	0	0.0015
Carex vulpinoidea	Cyparaceae	0.0027	0	0	0	0.010	0	0	0	0.0011	0	0.0014
Koeleria macrantha	Poaceae	0	0	0	0	0	0	0	0.0014	0	0	0.0014
Ipomoea jaegeri	Convolvulaceae	0.0018	0	0.010	0	0	0	0.00065	0	0	0	0.0012
Apocynum androsaemifolium	Apocynaceae	0	0	0	0	0.00052	0	0.0085	0.010	0	0	0.0011

Juniperus polycarpos	Cupressaceae	0	0	0	0	0.0010	0	0	0.0094	0	0	0.0010
Achillea millefolium	Asteraceae	0	0	0	0.0080	0	0	0	0	0.0011	0	0.00091
Melilotus altissimus	Fabaceae	0	0	0.00044	0	0	0.0016	0.0058	0	0.0011	0	0.00090
Vitis A	Vitaceae	0	0	0.0071	0	0	0	0	0	0	0	0.00071
Asclepias purpurascens	Asciepiadaceae	0	0	0.0044	0.00067	0	0	0.0019	0	0	0	0.00071
Elymus canadensis	Poaceae	0	0	0	0.00069	0	0	0	0.0040	0.0022	0	0.00068
Plantago lanceolata	Plantaginaceae	0	0	0.0040	0	0	0	0.00065	0.0020	0	0	0.00065
Danthonia spicata	Poaceae	0	0	0	0	0	0	0	0.0059	0	0	0.00059
Cirsium discolor	Asteraceae	0	0	0	0	0	0.0055	0	0	0	0	0.00055
Fraxinus ameicana	Oleaceae	0	0	0.0053	0	0	0	0	0	0	0	0.00053
Platanus occidentalis	Platanaceae	0	0	0	0	0.0036	0	0	0.00079	0.00054	0	0.00049
Plantago major	Plantaginaceae	0	0	0	0	0	0	0	0.0039	0	0	0.00039
Unknown Woody B		0	0	0	0	0	0	0	0.0031	0	0	0.00031
Taraxacum officinale	Asteraceae	0	0.00075	0	0	0.0010	0	0.00065	0.00039	0	0	0.00028
Glyceria grandis	Poaceae	0	0	0	0	0	0	0	0	0.0027	0	0.00027

Monarda fistulosa	Lamiaceae	0	0	0	0	0.0026	0	0	0	0	0	0.00026
Rumex crispus	Polygonaceae	0	0	0.0013	0	0	0	0.00065	0	0	0	0.00020
Echinaceae purpurea	Asteraceae	0	0	0	0	0.00052	0.0011	0	0	0	0	0.00016
Salix A	Salicaceae	0	0	0	0	0.0015	0	0	0	0	0	0.00015
Helianthus grosseserratus	Asteraceae	0	0.00076	0	0	0	0	0.00065	0	0	0	0.00014
Bidens polylepis	Asteraceae	0	0	0	0	0	0	0.00065	0.00039	0	0	0.00010
Solanum carolinense	Solanaceae	0	0	0	0.00067	0	0	0	0	0	0	0.000067
Acer negundo	Aceraceae	0	0	0	0	0.00053	0	0	0	0	0	0.000052
Rumex obstusifolius	Polygonaceae	0	0	0.00044	0	0	0	0	0	0	0	0.00044
Proportional Cover Density		1.1	1.1	1.1	1.2	1.4	1.1	1.0	1.3	1.1	0.70	1.1
Total Number of Species		20	8	27	20	23	22	26	33	26	3	21

Appenix 2: Plant species proportional cover per m^2 recorded at 10 sites within SW during August 2009. Butler County: Cummins (CU), Gelber (GL), Fitton (F), Geddes (GD), Vaughn (V). Preble County: Bruns (B), Ehrhardt (E), Simth (S), Constanzo (CO), Ketring (K)

Species	**Family**	**CU**	**B**	**E**	**GL**	**S**	**F**	**CO**	**K**	**GD**	**V**	**Mean**
Sorghastrum nutans	Poaceae	0	.043	.70	0	0.0023	0	0.72	0.38	0	0	0.22
Setaria faberi	Poaceae	0.36	0	0.00050	0.70	0.00076	0	0.0013	0.0027	0	0.85	0.18
Schizachyrium scoparium	Poaceae	0.12	0.043	0	0.18	0.43	0.39	0	0	0.32	0.0024	0.15
Solidago canadensis	Asteraceae	0	0.098	0.076	0	0.39	0.071	0.025	0.11	0.019	0	0.079
Andropogon gerardii	Poaceae	0.0020	0.39	0.084	0	0	0	0.059	0.070	0.18	0	0.079
Panicum virgatum	Poaceae	0.44	0	0.0065	0	0.0076	0.0018	0	0.014	0.063	0.0012	0.053
Daucus carota	Apiaceae	0	0	0.0060	0	0	0.44	0.0020	0.080	0	0.0024	0.053
Elymus canadensis	Poaceae	0.0010	0	0	0	0	0.12	0.0020	0	0.33	6.1	0.045
Cirsium arvense	Asteraceae	0	0.022	0.00050	0.0024	0.0030	0.11	0.033	0.080	0.00084	0	0.025
Unknown Woody A		0	0	0	0	0	0	0	0.17	0	0	0.017
Conyza canadensis	Asteraceae	0.0021	0	0	0.14	0	0	0.0013	0	0.0068	0	0.015
Trifolium pratense	Fabaceae	0	0	0.00050	0	0	0.0044	0.077	0	0	0.062	0.014

Eupatoriadelphus maculatus	Asteraceae	0.074	0.0090	0	0.0031	0	0.048	0	0.0027	0	0.0024	0.014
Erigeron stigosus	Asteraceae	0	0	0.12	0	0.0045	0	0.00066	0.0011	0.00084	0.0037	0.013
Carex stipata	Cyparaceae	0	0	0	0	0.091	0	0	0	0.0051	0	0.010
Rudbeckia hirta	Asteraceae	0	0	0.0025	0.0012	0	0	0	0.0027	0.087	0	0.0093
Trifolium repens	Fabaceae	0	0	0	0	0	0	0.082	0	0	0	0.0082
Danthonia spicata	Poaceae	0	0	0	0	0	0.047	0	0	0.019	0	0.0065
Poa A	Poaceae	0	0	0	0	0	0	0	0.061	0.00084	0	0.0062
Chamaecrista fasciculata	Fabaceae	0	0	0	0.048	0.00076	0.00088	0	0	0	0.0018	0.0051
Festuca pratensis	Poaceae	0	0	0	0.046	0	0	0	0	0	0	0.0046
Medicago sativa	Fabaceae	0	0	0	0	0	0	0.037	0	0	0	0.0037
Carex vulpinoidea	Cyparaceae	0	0	0	0	0.022	0.0062	0	0	0.00084	0	0.0030
Populus deltoides	Salicaceae	0	0	0	0	0.027	0	0	0	0	0	0.0027
Rubus A	Rosaceae	0	0.00081	0	0	0.0023	0	0.0033	0.018	0	0	0.0024
Gentiana autumnalis	Gantianaceae	0	0	0	0.00061	0	0.023	0	0	0	0	0.0023
Diasacus laciniatus	Dipsacaceae	0	0	0	0	0	0.016	0	0	0	0	0.0016

Toxicodendron radicans	Anacardiaceae	0	0	0.00050	0	0.012	0	0	0	0	0	0.0013
Rumex crispus	Polygonaceae	0	0	0.0020	0.010	0	0	0	0	0	0	0.0012
Cichorium intybus	Asteraceae	0	0	0.00050	0	0	0	0.0099	0	0	0	0.0010
Platanus occidentalis	Platanaceae	0	0	0.0010	0	0.0083	0	0	0.00050	0	0	0.00099
Gleditsia triacanthos	Fabaceae	0	0	0	0	0	0.0088	0	0	0	0	0.00088
Bouteloua curtipendula	Poaceae	0	0	0.00050	0	0.0045	0.00088	0	0.0016	0	0	0.00075
Elymus lanceolatus	Poaceae	0.0052	0	0	0.0024	0	0	0	0	0	0	0.00075
Halianthus annuus	Asteraceae	0	0	0	0.0012	0	0.0062	0	0	0	0	0.00074
Rosa multiflora	Rosaceae	0	0	0.0050	0	0	0	0	0	0	0	0.00050
Digitaria cognata	Poaceae	0	0	0	0	0	0	0.0040	0	0	0	0.00040
Taraxacum officinale	Asteraceae	0	0	0	0.0031	0	0	0.00066	0	0	0	0.00037
Vitis A	Vitaceae	0	0	0	0.0031	0	0	0	0	0	0	0.00031
Phleum pratense	Poaceae	0	0	0	0	0	0	0	0.0027	0	0	0.00027
Monarda fistulosa	Lamiaceae	0	0	0.0015	0.00061	0	0	0	0	0	0	0.00021
Juniperus polycarpos	Cupressaceae	0	0	0	0	0.00076	0	0	0.0011	0	0	0.00018

Apocynum androsaemifolium	Apocynaceae	0	0	0	0.0016	0	0	0	0	0	0	0.00016
Solidago lancifolia	Asteraceae	0	0	0	0	0.0015	0	0	0	0	0	0.00015
Salix A	Salicaceae	0	0	0	0	0.0015	0	0	0	0	0	0.00015
Oxalis stricta	Oxalidaceae	0	0	0	0.0012	0	0	0	0	0	0	0.00012
Rumex obtusifolius	Polygonaceae	0	0	0.0010	0	0	0	0	0	0	0	0.00010
Plantago lanceolata	Plantaginaceae	0	0	0.0010	0	0	0	0	0	0	0	0.00010
Lactuca virosa	Asteraceae	0	0.00082	0	0	0	0	0	0	0	0	0.000082
Ipomoea jaegeri	Convolvulaceae	0	0	0	0	0	0	0	0	0	0.00061	0.000061
Melilotus altissimus	Fabaceae	0	0	0	0	0	0	0	0	0	0.00061	0.000061
Desmanthus illinoensis	Fabaceae	0	0	0	0	0	0	0	0.00053	0	0	0.000053
Leucanthemum vulgare	Asteraceae	0	0	0	0	0	0	0	0.00053	0	0	0.000053
Solidago erecta	Asteraceae	0	0	0	0	0	0	0	0.00053	0	0	0.000053
Acer negundo	Aceraceae	0	0	0.00050	0	0	0	0	0	0	0	0.000050
Proportional Cover Density		0.97	1.02	1.0	1.1	0.95	0.96	1.02	0.95	1.0	0.77	0.97
Total Number of Species		8	8	20	18	18	16	16	20	13	11	55

Appenix 3: Bee species abundances recorded at 10 sites within SW during June 2009. Butler County: Cummins (CU), Gelber (GL), Fitton (F), Geddes (GD), Vaughn (V). Preble County: Bruns (B), Ehrhardt (E), Simth (S), Constanzo (CO), Ketring (K)

Species	**Family**	**CU**	**B**	**E**	**GL**	**S**	**F**	**CO**	**K**	**GD**	**V**	**Total**
Augochlorella A	Halictidae	1	1	0	0	2	293	46	11	11	57	422
Agapostemon A	Halictidae	13	2	98	7	1	66	11	5	18	16	238
Halictus C	Halictidae	3	7	12	5	2	18	10	10	13	4	84
Apis mellifera	Apidae	0	2	7	1	2	0	8	4	22	6	52
Halictus B	Halictidae	9	4	6	7	0	2	9	8	6	0	51
Lassioglassum E	Halictidae	4	6	5	1	2	2	7	5	7	11	50
Hylaeus A	Colletidae	1	1	11	1	7	6	1	16	4	0	48
Lassioglassum A	Halictidae	1	0	10	4	2	1	16	3	8	1	46
Hylaeus B	Colletidae	3	2	9	2	4	5	1	8	3	0	37
Bombus perplexus	Apidae	0	1	3	1	1	9	10	6	3	3	37
Eucera B	Apidae	0	0	33	0	0	10	0	0	0	0	34
Lassioglassum B	Halictidae	2	0	1	2	0	1	10	3	7	7	33
Hylaeus F	Colletidae	0	2	4	0	2	3	8	4	1	3	27
Bombus impatiens	Apidae	1	0	1	3	1	2	14	0	3	1	26
Eucera C	Apidae	0	0	20	1	0	0	0	0	0	0	21
Halictus A	Halictidae	9	0	0	0	0	1	2	1	2	3	18

Svastra A	Apidae	0	0	7	0	0	2	2	2	0	5	18
Bombus bimaculatus	Apidae	0	0	2	0	10	20	1	2	0	2	10
Bombus pennsylvanicus	Apidae	0	1	1	0	1	2	0	3	2	0	10
Eucera D	Apidae	0	0	9	0	0	0	1	0	0	0	10
Eucera A	Apidae	7	0	1	0	1	0	0	0	0	0	9
Augochlora A	Halictidae	0	1	0	0	0	0	0	0	7	1	9
Lassioglassum C	Halictidae	3	1	2	0	0	0	2	0	0	0	8
Ceratina A	Apidae	0	0	4	2	1	0	0	0	0	0	7
Bombus frigidus	Apidae	0	0	0	2	0	0	0	2	0	0	4
Andrena B	Andrenidae	0	0	0	0	0	1	0	0	3	0	4
Lassioglassum G	Halictidae	0	0	0	0	0	0	0	0	3	0	3
Melissodes B	Apidae	0	0	0	0	1	1	0	0	0	0	2
Lassioglassum F	Halictidae	0	0	1	1	0	0	0	0	0	0	2
Xylocopa A	Apidae	0	0	0	0	0	0	0	0	0	1	1
Svastra B	Apidae	0	0	0	0	0	0	1	0	0	0	1
Sphecode A	Halictidae	0	0	0	0	0	0	0	0	0	1	1
Melissodes A	Apidae	0	0	0	0	0	0	0	1	0	0	1
Hoplitis A	Megachilidae	0	0	0	0	0	0	0	1	0	0	1

Heriades A	Megachilidae	0	0	0	0	0	0	0	1	0	0	1
Bombus melanopygus	Apodae	0	1	0	0	0	0	0	0	0	0	1
Andrena A	Andrenidae	0	0	0	0	0	0	0	1	0	0	1
Total Number of Individuals		57	32	247	40	31	418	159	97	123	122	1326
Total Number of Species		13	14	22	15	16	19	19	21	18	16	39

Appendix 4: Bee species abundances recorded at 10 sites within SW during August 2009. Butler County: Cummins (CU), Gelber (GL), Fitton (F), Geddes (GD), Vaughn (V). Preble County: Bruns (B), Ehrhardt (E), Simth (S), Constanzo (CO), Ketring (K)

Species	**Family**	**CU**	**B**	**E**	**GL**	**S**	**F**	**CO**	**K**	**GD**	**V**	**Total**
Melissodes A	Apidae	86	66	59	63	40	10	58	38	42	17	439
Lassioglassum E	Halictidae	18	2	8	16	4	92	4	11	6	25	186
Bombus impatiens	Apidae	3	6	14	65	9	39	8	3	13	11	171
Apis mellifera	Apidae	5	20	10	37	39	0	11	15	7	9	153
Augochlorella A	Halictidae	1	1	7	6	3	16	9	3	0	10	56
Halictus C	Halictidae	9	1	0	6	5	0	0	7	11	7	46
Augochlora A	Halictidae	0	1	1	13	5	7	9	1	8	0	45
Lassioglassum B	Halictidae	2	1	4	3	3	5	1	5	2	5	31
Svastra A	Apidae	2	6	15	1	0	0	3	1	1	1	30
Hylaeus B	Colletidae	0	0	17	3	2	1	1	1	1	0	26
Hylaeus A	Colletidae	0	1	16	0	1	1	0	3	1	2	25
Bombus pennsylvanicus	Apidae	0	2	3	4	2	2	1	5	1	2	22
Svastra B	Apidae	4	0	11	1	0	0	1	0	0	0	17
Agapostemon A	Halictidae	3	0	8	1	0	0	0	1	1	1	15
Halictus A	Halictidae	5	0	2	0	3	0	0	0	0	3	13
Bombus perplexus	Apidae	0	1	1	2	2	2	1	0	0	1	10

Melissodes B	Apidae	0	0	1	0	0	0	0	3	3	3	10
Ceratina A	Apidae	0	2	0	1	0	1	0	3	1	0	8
Halictus B	Halictidae	0	0	0	2	2	0	0	3	0	0	7
Ptilothrix A	Apidae	3	0	0	0	1	1	0	0	0	1	6
Lassioglassum A	Halictidae	4	0	1	0	0	0	0	0	1	0	6
Lassioglassum C	Halictidae	0	0	1	0	1	1	3	0	0	0	6
Xylocopa B	Apidae	0	0	2	0	2	0	0	0	0	0	4
Andrena B	Andrenidae	0	0	0	0	0	1	0	0	3	0	4
Hylaeus F	Colletidae	0	0	1	0	0	0	0	0	0	2	3
Lassioglassum G	Halictidae	0	0	0	0	0	0	0	2	0	0	2
Heriades A	Megachilidae	0	0	0	0	0	1	0	1	0	0	2
Bombus bimaculatus	Apidae	0	0	1	0	0	0	0	0	0	0	1
Svastra D	Apidae	0	0	0	0	0	0	1	0	0	0	1
Xylocopa A	Apidae	0	0	0	0	0	1	0	0	0	0	1
Lassioglassum F	Halictidae	0	0	0	0	0	1	0	0	0	0	1
Lassioglassum H	Halictidae	0	0	0	0	0	0	1	0	0	0	1
Andrena A	Andrenidae	0	0	0	0	0	0	1	0	0	0	1
Megachile A	Megachilidae	0	1	0	0	0	0	0	0	0	0	1

Megachile B	Megachilidae	0	1	0	0	0	0	0	0	0	0	1
Total Number of Individuals		145	112	183	224	124	182	113	106	102	100	1391
Total Number of Species		13	15	21	16	17	17	16	18	16	16	35

Appendix 5: Beetle species abundances recorded at 10 sites within SW during June 2009. Butler County: Cummins (CU), Gelber (GL), Fitton (F), Geddes (GD), Vaughn (V). Preble County: Bruns (B), Ehrhardt (E), Simth (S), Constanzo (CO), Ketring (K)

Species	**Family**	**CU**	**B**	**E**	**GL**	**S**	**F**	**CO**	**K**	**GD**	**V**	**Total**
Chauliognathus marginatus	Cantharidae	26	40	105	42	16	176	42	23	211	12	704
Stenolophus ochropezus	Carabidae	31	49	40	75	10	2	4	2	2	1	216
Rhaxonycha carolina	Cantharidae	0	5	49	0	2	10	53	83	2	6	210
*Epicauta atrata**	Meloidae	14	6	1	29	0	49	2	19	7	20	147
*Lebia analis**	Carabidae	19	11	33	23	4	5	3	0	0	0	98
Harmonia axyridis	Coccinellidae	5	15	10	16	3	8	0	1	8	3	69
Atheta pennsylvanicus	Staphylinidae	3	18	4	7	7	4	6	3	3	5	60
Melanotus communis	Elateridae	2	7	19	16	7	1	2	3	0	0	57
Harpalus pensylvanicus	Carabidae	2	0	7	2	0	13	4	2	20	1	51
Meronera venustula	Staphylinidae	1	0	15	2	4	2	6	11	0	1	42
Acupalpus partiarius	Carabidae	5	7	12	2	2	1	1	0	0	8	38
Photinus scintillans	Lampyridae	0	4	6	3	2	9	5	5	4	0	38

Lebia atriventris	Carabidae	0	0	0	0	0	26	2	0	0	4	31
Notiobia sayi	Carabidae	7	2	2	10	1	6	0	0	1	0	29
Melanotus sagittarius	Elateridae	2	0	17	2	0	0	1	1	1	1	25
Lobrathium collare	Staphylinidae	2	11	3	0	1	1	3	1	0	0	22
Coccinella septempunctata	Coccinellidae	7	0	3	3	3	2	0	1	2	0	21
Gyrophaena frosti	Staphylinidae	1	2	3	0	2	0	3	3	1	1	16
Diomus terminatus	Coccinellidae	1	0	3	2	2	2	1	1	0	1	13
Poecilus chalcites	Carabidae	0	0	0	0	0	0	0	0	0	13	13
Photuris lucicrescens	Lampyridae	1	6	4	0	1	0	0	0	0	0	12
Stenolophus conjunctus	Carabidae	0	1	4	4	2	0	0	0	0	0	11
Bryoporus rufescens	Staphylinidae	0	1	0	1	1	2	4	0	0	1	10
Melanotus lanei	Elateridae	1	2	7	0	0	0	0	0	0	0	10
Photuris pyralomimus	Lampyridae	0	2	1	1	1	1	0	2	2	0	10
Sepedophilus testaceus	Staphylinidae	2	1	0	0	1	3	1	1	1	0	10

Neobisnius sobrinus	Staphylinidae	2	3	1	0	2	0	0	0	0	0	8
Platydracus maculosus	Staphylinidae	0	2	1	0	1	0	1	3	0	0	8
Rhexius substriatus	Staphylinidae	0	0	2	6	0	0	0	0	0	0	8
Bradycellus rupestris	Carabidae	0	4	2	0	0	0	0	0	0	0	6
Bradycellus tantillus	Carabidae	2	0	0	3	1	0	0	0	0	0	6
Glischrochilus quadrisignatus	Nitidulidae	0	2	2	0	1	0	0	1	0	0	6
Hippodamia parenthesis	Coccinellidae	2	0	0	1	0	0	0	0	1	1	5
Hippodamia variegata	Coccinellidae	0	0	2	0	0	1	1	0	0	1	5
Photinus aquilonius	Lampyridae	0	1	2	0	0	2	0	0	0	0	5
Amphasia sericea	Carabidae	0	1	1	1	0	0	0	1	0	0	4
Anisodactylus sanctaecrucis	Carabidae	1	0	0	0	1	0	0	0	0	2	4
Bembidion affine	Carabidae	0	1	1	1	0	0	1	0	0	0	4
Coproporus ventriculus	Staphylinidae	0	0	0	1	0	0	2	1	0	0	4
Stenolophus rotundicollis	Carabidae	0	2	0	0	2	0	0	0	0	0	4

Acupalpus testaceus	Carabidae	0	0	1	1	0	0	0	0	1	0	3
Anisodactylus dulcicollis	Carabidae	0	0	0	1	0	1	0	0	1	0	3
Bradycellus supplex	Carabidae	0	0	1	0	2	0	0	0	0	0	3
Charhyphus picipennis	Staphylinidae	1	0	0	0	1	0	0	1	0	0	3
Chlaenius aestivus	Carabidae	0	1	0	1	0	0	1	0	0	0	3
Coleomegilla maculata	Coccinellidae	1	0	0	0	1	0	0	0	1	0	3
Glischrochilus fasciatus	Nitidulidae	1	2	0	0	0	0	0	0	0	0	3
*Macrosiagon limbata**	Ripiphoridae	0	0	0	0	0	0	0	2	1	0	3
Notiobia terminata	Carabidae	0	1	2	0	0	0	0	0	0	0	3
Paratachys proximus	Carabidae	0	0	0	0	3	0	0	0	0	0	3
Phyllobaenus humeralis	Cleridae	1	0	0	0	0	1	0	0	0	1	3
Rugilus rufipes	Staphylinidae	0	0	0	0	0	0	1	0	0	2	3
Scarites subterraneus	Carabidae	0	0	0	1	0	1	0	0	1	0	3
Tachyporus nitidulus	Staphylinidae	0	0	2	0	0	1	0	0	0	0	3

Aleochara castaneipennis	Staphylinidae	0	0	1	0	0	1	0	0	0	0	2
Anisodactylus rusticus	Carabidae	0	0	0	0	0	1	0	0	1	0	2
Atholus americanus	Histeridae	0	0	0	0	0	0	2	0	0	0	2
Brachiacantha testudo	Coccinellidae	0	0	0	0	2	0	0	0	0	0	2
Clivina bipustulata	Carabidae	1	0	1	0	0	0	0	0	0	0	2
Cycloneda munda	Coccinellidae	0	0	0	2	0	0	0	0	0	0	2
Diochus schaumi	Staphylinidae	0	0	0	0	0	1	0	1	0	0	2
*Epicauta sericans**	Meloidae	0	0	0	0	0	0	0	0	0	2	2
Falagria dissecta	Staphylinidae	0	0	0	0	0	0	2	0	0	0	2
Gauropterus fulgidus	Staphylinidae	0	0	1	0	1	0	0	0	0	0	2
*Lebia grandis**	Carabidae	0	0	1	0	0	1	0	0	0	0	2
*Lebia viridis**	Carabidae	0	1	0	0	0	0	0	0	1	0	2
Neophyrochroa flabellata	Pyrochroidae	0	0	0	0	0	1	0	1	0	0	2
Ophonus puncticeps	Carabidae	0	0	1	0	0	1	0	0	0	0	2

Oxypoda schaefferi	Staphylinidae	2	0	0	0	0	0	0	0	0	0	2
Oxytelus laqueatus	Staphylinidae	0	1	0	1	0	0	0	0	0	0	2
Philonthus asper	Staphylinidae	0	0	0	0	0	0	1	1	0	0	2
Photinus australis	Lampyridae	0	0	0	0	1	1	0	0	0	0	2
Photuris aureolucens	Lampyridae	0	0	1	0	0	0	0	1	0	0	2
Placopterus thoracicus	Cleridae	1	0	1	0	0	0	0	0	0	0	2
Platydracus praelongus	Staphylinidae	0	0	1	0	0	1	0	0	0	0	2
Stenus alacer	Staphylinidae	1	0	1	0	0	0	0	0	0	0	2
Acupalpus alternans	Carabidae	0	0	1	0	0	0	0	0	0	0	1
Anisodactylus haplomus	Carabidae	0	0	0	0	0	0	0	0	0	1	1
Anotylus insignitus	Staphylinidae	0	0	0	1	0	0	0	0	0	0	1
Astenus discopunctatus	Staphylinidae	0	0	0	0	0	1	0	0	0	0	1
Attalus terminalis	Melyridae	0	0	0	0	0	1	0	0	0	0	1
Bembidion rapidum	Carabidae	0	1	0	0	0	0	0	0	0	0	1

Chauliognathus A	Cantharidae	0	0	0	0	1	0	0	0	0	0	1
Colliurus pensylvanica	Carabidae	1	0	0	0	0	0	0	0	0	0	1
Cryptopleurum subtile	Hydrophilidae	1	0	0	0	0	0	0	0	0	0	1
Cymindis limbata	Carabidae	0	0	0	1	0	0	0	0	0	0	1
Dendroides canadensis	Pyrochroidae	0	0	0	0	0	1	0	0	0	0	1
Drusilla_canaliculata	Staphylinidae	0	0	0	0	1	0	0	0	0	0	1
Elaphropus vivax	Carabidae	0	0	0	0	1	0	0	0	0	0	1
*Epicauta cinerea**	Meloidae	1	0	0	0	0	0	0	0	0	0	1
*Epicauta pennsylvanica**	Meloidae	0	0	0	1	0	0	0	0	0	0	1
Falagria sulcata	Staphylinidae	0	0	1	0	0	0	0	0	0	0	1
Geomysaprinus moniliatus	Histeridae	0	0	0	1	0	0	0	0	0	0	1
Gyrophaena vitrina	Staphylinidae	0	0	0	0	0	1	0	0	0	0	1
Harpalus caliginosus	Carabidae	0	0	0	0	0	0	0	0	1	0	1
Homalota plana	Carabidae	0	0	0	0	0	0	1	0	0	0	1

Hyperaspis undulata	Coccinellidae	0	0	0	0	1	0	0	0	0	0	1
Margarinotus lecontei	Histeridae	0	0	0	0	1	0	0	0	0	0	1
Microweisea misella	Coccinellidae	0	0	0	0	0	1	0	0	0	0	1
Paratachys oblitus	Carabidae	0	1	0	0	0	0	0	0	0	0	1
Pediacus depressus	Cucujidae	0	0	1	0	0	0	0	0	0	0	1
Pediacus fuscus	Cucujidae	0	0	1	0	0	0	0	0	0	0	1
Podabrus A	Cantharidae	0	0	0	1	0	0	0	0	0	0	1
Poecilus lucublandus	Carabidae	0	0	0	0	1	0	0	0	0	0	1
Pterostichus atratus	Carabidae	0	0	1	0	0	0	0	0	0	0	1
Pyractomena ecostata	Lampyridae	0	0	1	0	0	0	0	0	0	0	1
*Ripiphorus luteipennis**	Ripiphoridae	0	0	0	0	1	0	0	0	0	0	1
Stenolophus comma	Carabidae	0	1	0	0	0	0	0	0	0	0	1
Stenolophus fulginosus	Carabidae	0	0	0	1	0	0	0	0	0	0	1
Stenolophus lecontei	Carabidae	0	1	0	0	0	0	0	0	0	0	1

Tachyporus elegans	Staphylinidae	0	0	0	0	1	0	0	0	0	0	1
Tropisternus collaris	Hydrophilidae	1	0	0	0	0	0	0	0	0	0	1
Tropisternus lateralis	Hydrophilidae	1	0	0	0	0	0	0	0	0	0	1
Trypherus latipennis	Cantharidae	0	0	0	0	1	0	0	0	0	0	1
Zuphium americanum	Carabidae	1	0	0	0	0	0	0	0	0	0	1
Total Number of Individuals		154	216	383	266	100	343	155	175	273	100	2165
Total Number of Species		37	36	50	36	42	39	28	27	22	23	115

*Parasitoid otherwise Predator

Appendix 6: Beetle species abundances recorded at 10 sites within SW during August 2009. Butler County: Cummins (CU), Gelber (GL), Fitton (F), Geddes (GD), Vaughn (V). Preble County: Bruns (B), Ehrhardt (E), Simth (S), Constanzo (CO), Ketring (K)

Species	**Family**	**CU**	**B**	**E**	**GL**	**S**	**F**	**CO**	**K**	**GD**	**V**	**Total**
Atheta pennsylvanica	Staphylinidae	8	10	14	10	28	9	13	35	7	31	165
*Epicauta pennsylvanica**	Meloidae	0	0	0	0	0	12	0	0	118	21	151
*Epicauta atrata**	Meloidae	26	2	0	14	0	46	1	18	13	14	134
Meronera venustula	Staphylinidae	5	5	23	10	6	9	6	12	2	1	79
Harpalus pensylvanicus	Carabidae	10	4	2	13	3	2	1	10	15	3	63
Photinus scintillans	Lampyridae	0	13	27	4	12	1	2	3	0	0	62
Rhaxonycha carolinus	Cantharidae	0	6	27	0	0	1	0	3	0	1	38
Harmonia axyridis	Coccinellidae	2	3	3	8	2	5	3	4	3	3	36
Stenolophus ochropezus	Carabidae	2	1	6	2	0	10	2	2	2	4	31
Phyllobaenus humeralis	Cleridae	0	0	1	0	0	16	0	0	0	8	25
Euspilotus assimilis	Histeridae	0	0	0	0	0	17	0	4	0	1	22
*Macrosiagon limbata**	Ripiphoridae	0	3	0	10	7	0	0	0	1	1	22
Notiobia sayi	Carabidae	0	1	3	15	0	1	0	2	0	0	22
*Lebia analis**	Carabidae	1	4	0	0	1	6	2	4	1	0	19
Hemicrepidius bilobatus	Elateridae	0	0	17	0	0	0	0	1	0	0	18

Sepedophilus testaceus	Staphylinidae	2	0	0	0	0	2	2	2	2	5	15
Scymnus americanus	Coccinellidae	1	0	8	0	0	1	0	0	0	3	13
Lobrathium collare	Staphylinidae	1	1	3	4	1	0	1	0	0	0	11
Bryoporus rufescens	Staphylinidae	2	1	2	0	1	1	0	0	1	1	9
Neobisnius sobrinus	Staphylinidae	1	1	0	0	0	5	1	1	0	0	9
Coproporus ventriculus	Staphylinidae	0	0	0	0	0	2	2	1	2	1	8
Diomus terminatus	Coccinellidae	1	1	1	0	0	1	2	0	1	1	8
Chauliognathus marginatus	Cantharidae	0	0	6	1	0	0	0	0	0	0	7
Coccinella septempunctata	Coccinellidae	0	1	1	0	1	1	0	1	0	2	7
Gyrophaena frosti	Staphylinidae	0	0	1	0	0	3	2	1	0	0	7
Rhexius substriatus	Staphylinidae	1	0	0	0	1	0	1	0	0	4	7
Glischrochilus quadrisignatus	Nitidulidae	0	1	3	0	1	0	0	0	1	0	6
Poecilus chalcites	Carabidae	3	0	0	1	0	0	0	0	0	2	6
Cypha ziegleri	Staphylinidae	1	0	1	1	1	0	0	1	0	0	5
Hippodamia parenthesis	Coccinellidae	0	1	0	1	0	2	0	0	0	1	5
*Lebia atriventris**	Carabidae	0	0	0	0	0	3	0	1	1	0	5
Falagria dissecta	Staphylinidae	0	0	0	1	1	0	2	0	0	0	4

Hemicrepidius hemipodus	Elateridae	0	0	1	0	2	0	0	0	1	0	4
Photinus aquilonius	Lampyridae	0	1	2	0	1	0	0	0	0	0	4
Platydracus maculosus	Staphylinidae	0	0	1	0	0	0	1	2	0	0	4
Coleomegilla maculata	Coccinellidae	0	0	0	0	0	0	0	0	0	3	3
Cordalia obscura	Staphylinidae	0	0	1	0	1	0	0	0	1	0	3
Harpalus caliginosus	Carabidae	0	0	0	0	0	1	0	0	2	0	3
Hippodamia variegata	Coccinellidae	0	0	0	0	0	2	0	1	0	0	3
*Lebia grandis**	Carabidae	0	0	2	0	0	1	0	0	0	0	3
Oxytelus laqueatus	Staphylinidae	0	0	0	0	0	2	0	1	0	0	3
Photinus australis	Lampyridae	0	0	2	0	1	0	0	0	0	0	3
Photuris lucicrescens	Lampyridae	0	1	1	0	1	0	0	0	0	0	3
Silis percomis	Cantharidae	1	0	0	0	0	2	0	0	0	0	3
Bembidion affine	Carabidae	1	0	0	0	0	1	0	0	0	0	2
Bradycellus tantillus	Carabidae	0	0	0	0	0	0	1	1	0	0	2
Cycloneda munda	Coccinellidae	0	0	0	0	0	0	0	0	1	1	2
Ditemnus freemani	Cantharidae	1	0	1	0	0	0	0	0	0	0	2
Glischrochilus fasciatus	Nitidulidae	0	1	1	0	0	0	0	0	0	0	2

Hesperus baltimorensis	Staphylinidae	0	0	0	0	1	1	0	0	0	0	2
Leptotrachelus dorsalis	Carabidae	0	0	2	0	0	0	0	0	0	0	2
Melanotus communis	Elateridae	0	0	0	1	0	0	0	1	0	0	2
Nephus intrusus	Coccinellidae	0	0	0	0	0	1	0	0	1	0	2
Philonthus caucasicus	Staphylinidae	0	0	0	1	0	1	0	0	0	0	2
Photinus pyralis	Lampyridae	0	0	2	0	0	0	0	0	0	0	2
Poecilus lucublandus	Carabidae	0	0	0	0	1	1	0	0	0	0	2
Stenolophus rotundicollis	Carabidae	0	0	0	0	0	0	0	0	1	1	2
Acupalpus tantillus	Carabidae	1	0	0	0	0	0	0	0	0	0	1
Agonum punctiforme	Carabidae	1	0	0	0	0	0	0	0	0	0	1
Aleochara castaneipennis	Staphylinidae	0	0	0	0	1	0	0	0	0	0	1
Astenus discopunctatus	Staphylinidae	0	0	0	0	0	1	0	0	0	0	1
Brachiacantha testudo	Coccinellidae	0	0	0	0	1	0	0	0	0	0	1
Chlaenius_aestivus	Carabidae	0	0	0	0	1	0	0	0	0	0	1
Collops quadrimaculatus	Cleridae	0	0	0	0	0	0	0	1	0	0	1
Creophilus maxillosus	Staphylinidae	0	0	0	0	1	0	0	0	0	0	1
Dendroides canadensis	Pyrochroidae	0	0	0	0	0	1	0	0	0	0	1

Dicaelus dilatatus	Carabidae	0	0	1	0	0	0	0	0	0	0	1
Diestota A	Staphylinidae	0	0	0	0	0	0	0	1	0	0	1
*Epicauta cinerea**	Meloidae	0	0	0	0	0	0	0	0	1	0	1
*Epicautao ccidentalis**	Meloidae	0	0	0	0	0	0	0	0	0	1	1
*Epicauta strigosa**	Meloidae	0	0	0	0	0	0	0	1	0	0	1
Geomysaprinus moniliatus	Histeridae	0	0	0	1	0	0	0	0	0	0	1
Gyrophaena vitrin[§]a	Staphylinidae	0	0	1	0	0	0	0	0	0	0	1
Halocoryza A	Carabidae	0	0	0	0	0	1	0	0	0	0	1
Hemicrepidius memnonius	Elateridae	0	0	0	0	0	1	0	0	0	0	1
Homalota plana	Staphylinidae	0	0	1	0	0	0	0	0	0	0	1
Leptacinus intermedius	Staphylinidae	0	0	0	0	0	0	0	0	1	0	1
Margarinotus lecontei	Histeridae	0	0	1	0	0	0	0	0	0	0	1
Melanotus A	Elateridae	0	0	0	1	0	0	0	0	0	0	1
Oosternum costatum	Hydrophilidae	0	0	1	0	0	0	0	0	0	0	1
Philonthus asper	Staphylinidae	0	0	0	0	0	0	1	0	0	0	1
Scarites subterraneus	Carabidae	0	0	0	0	0	1	0	0	0	0	1
Stenus alacer	Staphylinidae	1	0	0	0	0	0	0	0	0	0	1

Tachinus corticinus	Staphylinidae	0	0	0	0	0	0	0	0	1	0	1
Total Number of Individuals		73	62	170	99	78	174	46	115	180	114	1111
Total Number of Species		22	21	35	19	25	38	19	27	24	24	85

*Parasitoid otherwise Predator

Appendix 7: Hemiptera species abundances recorded at 10 sites within SW during June 2009. Butler County: Cummins (CU), Gelber (GL), Fitton (F), Geddes (GD), Vaughn (V). Preble County: Bruns (B), Ehrhardt (E), Simth (S), Constanzo (CO), Ketring (K)

Species	**Family**	**CU**	**B**	**E**	**GL**	**S**	**F**	**CO**	**K**	**GD**	**V**	**Total**
Orius insidiosus	Anthocoridae	17	8	21	27	7	90	23	16	63	61	333
Nabis capsiformis	Nabidae	4	0	5	3	0	4	0	0	0	2	13
Narvesus carolinensis	Reduviidae	1	0	3	3	0	4	0	0	0	2	13
Apiomerus crassipes	Reduviidae	0	0	0	0	0	0	1	4	2	1	8
Lycotocoris campestris	Anthocoridae	0	0	1	0	0	0	0	0	0	0	1
Oncerotrachelus acuminatus	Reduviidae	0	1	0	0	0	0	0	0	0	0	1
Phylus coryli	Meridae	0	0	0	0	1	0	0	0	0	0	1
Podisus maculiventris	Pentatomidae	0	0	0	0	0	0	0	0	1	0	1
Pselliopus barberi	Reduviidae	0	0	0	0	0	0	0	0	1	0	1
Sinea complexa	Reduviidae	1	0	0	0	0	0	0	0	0	0	1
Systelloderes biceps	Enicocephalomorpha	0	1	0	0	0	0	0	0	0	0	1
Total Number of Individuals		23	10	30	30	9	94	25	20	67	66	374
Total Number of Species		4	3	4	2	3	2	3	2	4	4	11

Appendix 8: Hemiptera species abundances recorded at 10 sites within SW during August 2009. Butler County: Cummins (CU), Gelber (GL), Fitton (F), Geddes (GD), Vaughn (V). Preble County: Bruns (B), Ehrhardt (E), Simth (S), Constanzo (CO), Ketring (K)

Species	**Family**	**CU**	**B**	**E**	**GL**	**S**	**F**	**CO**	**K**	**GD**	**V**	**Total**
Orius insidiosus	Anthocoridae	4	2	13	8	23	11	3	8	41	29	142
Systelloderes biceps	Enicocephalomorpha	1	0	0	0	0	0	2	2	0	0	5
Nabis capsiformis	Nabidae	0	0	0	0	0	1	1	0	1	1	4
Apiomerus crassipes	Reduviidae	0	1	0	0	0	0	0	1	0	1	3
Micracanthia humilis	Pentatomidae	0	0	0	0	0	0	0	1	0	1	2
Podisus maculiventris	Salididae	0	0	0	0	0	1	0	0	0	1	2
Geocoris A	Geocoridae	0	0	0	1	0	0	0	0	0	0	1
Zelus tetracanthus	Reduviidae	0	0	0	0	0	1	0	0	0	0	1
Total Number of Individuals		5	3	13	9	23	14	6	12	42	33	160
Total Number of Species		2	2	1	2	1	4	3	4	2	5	8

Appendix 9: Hymenoptera species abundances recorded at 10 sites within SW during June 2009. Butler County: Cummins (CU), Gelber (GL), Fitton (F), Geddes (GD), Vaughn (V). Preble County: Bruns (B), Ehrhardt (E), Simth (S), Constanzo (CO), Ketring (K)

Species	**Family**	**CU**	**B**	**E**	**GL**	**S**	**F**	**CO**	**K**	**GD**	**V**	**Total**
Encyrtidae A	Encyrtidae	5	0	2	20	4	25	4	1	0	1	62
Cerphronidae G	Cerphronidae	1	4	6	3	1	3	4	5	3	0	30
Mymaridae A	Mymaridae	2	2	6	1	4	2	2	2	2	1	24
Cerphronidae A	Cerphronidae	3	1	4	1	5	1	1	2	1	1	20
Scelionidae V	Scelionidae	2	0	2	6	0	2	0	4	1	2	19
Cerphronidae_C	Cerphronidae	4	0	6	1	0	2	3	0	1	0	17
Mymaridae D	Mymaridae	2	1	5	1	0	2	1	2	1	1	16
Encyrtidae B	Encyrtidae	0	0	11	0	1	0	0	0	1	1	14
Mymaridae C	Mymaridae	1	2	3	0	1	3	1	3	0	0	14
Figitidae B	Figitidae	1	1	3	0	1	0	2	5	0	0	13
Scelionidae A	Scelionidae	0	0	2	1	1	2	1	2	0	4	13
Scelionidae B	Scelionidae	3	0	2	2	1	3	0	1	1	0	13
Scelionidae R	Scelionidae	5	1	2	1	0	0	1	1	0	1	12
Diapriidae C	Diapriidae	1	0	2	1	0	3	2	0	0	0	9
Figitidae A	Figitidae	1	0	2	1	0	5	0	0	0	0	9

Mymaridae E	Mymaridae	0	8	0	0	0	0	1	0	0	0	9
Pteromalidae A	Pteromalidae	0	0	0	0	0	5	0	0	2	2	9
Mymaridae J	Mymaridae	0	0	1	0	0	3	0	2	1	1	8
Diapriidae B	Diapriidae	2	0	1	0	2	0	0	1	0	1	7
Scelionidae C	Scelionidae	1	1	3	0	1	0	1	0	0	0	7
Tiphiidae A[§]	Tiphiidae	0	0	1	1	2	0	2	0	1	0	7
Branconidae C	Branconidae	0	0	2	0	0	1	0	1	1	1	6
Cerphronidae H	Cerphronidae	0	1	2	0	0	0	0	2	1	0	6
Platygasteridae F	Platygasteridae	1	1	2	0	1	0	1	0	0	0	6
Pteromalidae G	Pteromalidae	1	1	2	0	1	0	1	0	0	0	6
Crabronidae A[§]	Crabronidae	0	0	0	0	1	0	0	2	2	0	5
Diapriidae D	Diapriidae	0	0	1	0	0	2	0	1	1	0	5
Mymaridae H	Mymaridae	0	0	2	0	0	0	1	1	0	1	5
Mymaridae K	Mymaridae	0	0	0	0	0	1	2	1	1	0	5
Platygasteridae A	Platygasteridae	1	0	0	2	0	0	1	0	1	0	5
Pompilidae E[§]	Pompilidae	0	1	0	0	0	2	1	1	0	0	5
Pteromalidae K	Pteromalidae	0	0	0	0	0	0	2	3	0	0	5

Scelionidae F	Scelionidae	0	1	1	1	0	0	0	1	0	1	5
Scelionidae P	Scelionidae	1	0	0	0	1	1	1	0	1	0	5
Vespidae C[§]	Vespidae	0	4	0	0	1	0	0	0	0	0	5
Branconidae A	Branconidae	1	0	0	0	0	1	1	1	0	0	4
Branconidae B	Branconidae	1	0	0	0	2	0	0	1	0	0	4
Cerphronidae B	Cerphronidae	0	0	1	0	0	1	2	0	0	0	4
Diapriidae E	Diapriidae	0	0	0	0	0	1	0	0	3	0	4
Figitidae C	Figitidae	2	0	0	0	0	0	0	2	0	0	4
Mymaridae L	Mymaridae	0	0	0	0	0	1	0	0	2	1	4
Platygasteridae D	Platygasteridae	1	1	0	0	0	0	1	1	0	0	4
Pteromalidae H	Pteromalidae	0	0	1	2	0	1	0	0	0	0	4
Pteromalidae J	Pteromalidae	0	0	0	2	0	0	1	0	0	1	4
Scelionidae T	Scelionidae	1	1	0	1	0	1	0	0	0	0	4
Trichogrammatidae A	Trichogrammatidae	1	0	1	0	0	0	1	1	0	0	4
Bethylidae C	Bethylidae	0	0	0	0	1	0	1	1	0	0	3
Branconidae E	Branconidae	1	0	1	1	0	0	0	0	0	0	3
Branconidae H	Branconidae	0	0	0	0	2	0	0	0	0	1	3

Cerphronidae D	Cerphronidae	0	0	0	0	0	2	0	0	0	1	3
Cerphronidae L	Cerphronidae	0	0	2	0	0	1	0	0	0	0	3
Diapriidae A	Diapriidae	0	2	0	1	0	0	0	0	0	0	3
Diapriidae F	Diapriidae	2	0	0	0	0	0	0	0	1	0	3
Encyrtidae G	Encyrtidae	0	0	1	0	0	0	1	0	0	1	3
Ichneumonidae C	Ichneumonidae	0	0	2	0	1	0	0	0	0	0	3
Ichneumonidae E	Ichneumonidae	0	0	0	1	1	0	0	1	0	0	3
Mymaridae B	Mymaridae	0	0	3	0	0	0	0	0	0	0	3
Platygasteridae B	Platygasteridae	0	0	0	1	0	1	0	0	0	1	3
Pteromalidae M	Pteromalidae	0	0	0	0	1	1	0	1	0	0	3
Pteromalidae Q	Pteromalidae	0	1	0	0	0	2	0	0	0	0	3
Scelionidae E	Scelionidae	0	0	0	0	0	0	0	2	0	1	3
Scelionidae J	Scelionidae	0	0	0	0	0	1	0	1	1	0	3
Scelionidae S	Scelionidae	0	0	0	0	0	1	0	0	0	2	3
Trichogrammatidae B	Trichogrammatidae	0	0	0	1	1	0	1	0	0	0	3
Bethylidae A	Bethylidae	0	0	1	0	0	0	0	0	1	0	2
Branconidae F	Branconidae	0	1	0	0	1	0	0	0	0	0	2

Branconidae L	Branconidae	0	0	0	0	0	2	0	0	0	0	2
Branconidae M	Branconidae	1	1	0	0	0	0	0	0	0	0	2
Branconidae N	Branconidae	0	0	0	0	0	0	0	1	0	1	2
Branconidae Q	Branconidae	0	0	0	0	0	0	0	0	0	2	2
Eurtomidae C	Eurtomidae	0	0	0	0	0	0	0	0	1	1	2
Ichneumonidae G	Ichneumonidae	0	0	0	0	1	0	0	0	0	1	2
Ichneumonidae H	Ichneumonidae	0	0	0	0	0	1	0	0	0	1	2
Mymaridae F	Mymaridae	0	0	0	0	0	0	1	1	0	0	2
Pompilidae A[§]	Pompilidae	2	0	0	0	0	0	0	0	0	0	2
Pompilidae B[§]	Pompilidae	0	0	0	0	0	0	1	1	0	0	2
Pompilidae F[§]	Pompilidae	0	0	0	0	0	0	1	0	0	1	2
Pteromalidae B	Pteromalidae	0	0	0	0	1	0	0	0	0	1	2
Pteromalidae E	Pteromalidae	0	0	0	1	0	1	0	0	0	0	2
Pteromalidae I	Pteromalidae	0	0	0	1	0	1	0	0	0	0	2
Pteromalidae N	Pteromalidae	0	0	0	0	0	2	0	0	0	0	2
Pteromalidae P	Pteromalidae	0	0	0	0	1	0	0	0	1	0	2
Pteromalidae Z	Pteromalidae	0	0	1	0	1	0	0	0	0	0	2

Scelionidae G	Scelionidae	0	0	0	0	0	0	0	0	1	1	2
Scelionidae M	Scelionidae	0	0	1	0	0	1	0	0	0	0	2
Trichogrammatidae C	Trichogrammatidae	1	0	0	0	0	1	0	0	0	0	2
Vespidae B[§]	Vespidae	0	0	0	1	0	0	0	1	0	0	2
Vespidae_D[§]	Vespidae	0	0	0	1	1	0	0	0	0	0	2
Branconidae CC	Branconidae	0	0	0	0	0	1	0	0	0	0	1
Branconidae D	Branconidae	0	0	0	0	1	0	0	0	0	0	1
Branconidae DD	Branconidae	0	0	1	0	0	0	0	0	0	0	1
Branconidae G	Branconidae	0	0	0	1	0	0	0	0	0	0	1
Branconidae J	Branconidae	0	0	0	0	1	0	0	0	0	0	1
Branconidae K	Branconidae	0	0	0	0	0	0	0	1	0	0	1
Branconidae O	Branconidae	1	0	0	0	0	0	0	0	0	0	1
Branconidae R	Branconidae	0	1	0	0	0	0	0	0	0	0	1
Branconidae S	Branconidae	0	0	1	0	0	0	0	0	0	0	1
Branconidae Y	Branconidae	0	0	0	0	0	0	0	1	0	0	1
Branconidae Z	Branconidae	0	0	0	0	0	0	0	0	0	1	1
Cerphronidae E	Cerphronidae	0	0	0	0	0	0	1	0	0	0	1

Cerphronidae I	Cerphronidae	0	0	0	0	0	0	0	1	0	0	1
Cerphronidae K	Cerphronidae	0	0	1	0	0	0	0	0	0	0	1
Crabronidae B[§]	Crabronidae	0	0	0	0	0	0	1	0	0	0	1
Crabronidae C[§]	Crabronidae	0	0	0	0	0	0	1	0	0	0	1
Crabronidae D[§]	Crabronidae	0	0	0	0	0	1	0	0	0	0	1
Crabronidae E[§]	Crabronidae	0	0	0	1	0	0	0	0	0	0	1
Crabronidae F[§]	Crabronidae	1	0	0	0	0	0	0	0	0	0	1
Diapriidae G	Diapriidae	0	0	0	0	1	0	0	0	0	0	1
Encyrtidae C	Encyrtidae	0	0	0	0	0	0	0	1	0	0	1
Encyrtidae D	Encyrtidae	0	0	1	0	0	0	0	0	0	0	1
Encyrtidae E	Encyrtidae	0	0	0	1	0	0	0	0	0	0	1
Encyrtidae F	Encyrtidae	0	1	0	0	0	0	0	0	0	0	1
Eurtomidae A	Eurtomidae	0	1	0	0	0	0	0	0	0	0	1
Eurtomidae B	Eurtomidae	0	0	0	0	0	1	0	0	0	0	1
Figitidae D	Figitidae	0	1	0	0	0	0	0	0	0	0	1
Ichneumonidae A	Ichneumonidae	1	0	0	0	0	0	0	0	0	0	1
Ichneumonidae B	Ichneumonidae	0	0	1	0	0	0	0	0	0	0	1

Ichneumonidae D	Ichneumonidae	0	0	1	0	0	0	0	0	0	0	1
Ichneumonidae F	Ichneumonidae	0	0	0	1	0	0	0	0	0	0	1
Ichneumonidae J	Ichneumonidae	0	0	0	0	0	0	0	0	0	1	1
Ichneumonidae K	Ichneumonidae	0	0	0	0	0	1	0	0	0	0	1
Ichneumonidae L	Ichneumonidae	0	0	0	0	0	0	1	0	0	0	1
Ichneumonidae M	Ichneumonidae	0	0	0	0	0	0	1	0	0	0	1
Ichneumonidae N	Ichneumonidae	0	0	0	0	0	0	0	1	0	0	1
Megaspilidae A	Megaspilidae	0	0	0	1	0	0	0	0	0	0	1
Platygasteridae C	Platygasteridae	0	0	1	0	0	0	0	0	0	0	1
Platygasteridae E	Platygasteridae	0	0	0	0	1	0	0	0	0	0	1
Platygasteridae G	Platygasteridae	0	0	0	0	0	0	0	0	1	0	1
Platygasteridae H	Platygasteridae	0	0	0	0	0	1	0	0	0	0	1
Platygasteridae I	Platygasteridae	0	0	0	0	0	0	1	0	0	0	1
Pompilidae C§	Pompilidae	0	0	0	0	0	0	0	0	1	0	1
Pompilidae D§	Pompilidae	0	0	0	0	0	1	0	0	0	0	1
Pompilidae G§	Pompilidae	1	0	0	0	0	0	0	0	0	0	1
Proctotrupidae A	Proctotrupidae	0	1	0	0	0	0	0	0	0	0	1

Proctotrupidae B	Proctotrupidae	0	1	0	0	0	0	0	0	0	0	1
Proctotrupidae C	Proctotrupidae	0	0	0	0	1	0	0	0	0	0	1
Pteromalidae C	Pteromalidae	1	0	0	0	0	0	0	0	0	0	1
Pteromalidae D	Pteromalidae	1	0	0	0	0	0	0	0	0	0	1
Pteromalidae L	Pteromalidae	0	0	0	0	0	0	1	0	0	0	1
Pteromalidae O	Pteromalidae	0	0	0	0	0	1	0	0	0	0	1
Pteromalidae R	Pteromalidae	0	0	0	0	1	0	0	0	0	0	1
Pteromalidae T	Pteromalidae	0	0	0	0	0	1	0	0	0	0	1
Pteromalidae V	Pteromalidae	0	0	0	0	0	0	0	0	0	1	1
Pteromalidae W	Pteromalidae	0	0	0	1	0	0	0	0	0	0	1
Pteromalidae X	Pteromalidae	0	0	0	0	1	0	0	0	0	0	1
Scelionidae H	Scelionidae	1	0	0	0	0	0	0	0	0	0	1
Scelionidae K	Scelionidae	0	0	1	0	0	0	0	0	0	0	1
Scelionidae L	Scelionidae	0	0	1	0	0	0	0	0	0	0	1
Sphecidae A[§]	Sphecidae	0	0	0	0	0	0	1	0	0	0	1
Tiphiidae B[§]	Tiphiidae	0	0	0	0	0	0	0	0	1	0	1
Tiphiidae C[§]	Tiphiidae	0	0	0	1	0	0	0	0	0	0	1

Toryidae A	Toryidae	0	0	1	0	0	0	0	0	0	0	1
Trichogrammatidae D	Trichogrammatidae	0	0	1	0	0	0	0	0	0	0	1
Vespidae A§	Vespidae	0	0	0	0	0	0	1	0	0	0	1
Vespidae E§	Vespidae	0	0	0	0	1	0	0	0	0	0	1
Total Number of Individuals		59	43	102	64	52	100	57	65	37	40	619
Total Number of Species		37	27	48	34	38	47	42	41	29	33	155

§Predator otherwise Parasitoid

Appendix 10: Hymenoptera species abundances recorded at 10 sites within SW during August 2009. Butler County: Cummins (CU), Gelber (GL), Fitton (F), Geddes (GD), Vaughn (V). Preble County: Bruns (B), Ehrhardt (E), Simth (S), Constanzo (CO), Ketring (K)

Species	**Family**	**CU**	**B**	**E**	**GL**	**S**	**F**	**CO**	**K**	**GD**	**V**	**Total**
Pompilidae E[§]	Pompilidae	0	20	21	4	10	0	1	7	1	1	65
Encyrtidae A	Encyrtidae	2	0	0	10	0	32	0	0	0	1	45
Pteromalidae A	Pteromalidae	0	0	7	1	4	0	0	1	11	1	25
Platygasteridae C	Platygasteridae	0	1	2	1	1	0	3	10	1	0	19
Scelionidae R	Scelionidae	2	2	6	1	2	0	2	0	3	1	19
Mymaridae B	Mymaridae	2	0	1	3	1	1	0	5	2	3	18
Scelionidae B	Scelionidae	2	0	10	0	5	0	0	0	0	1	18
Mymaridae I	Mymaridae	0	2	3	0	1	2	2	2	1	4	17
Tiphiidae B[§]	Tiphiidae	0	0	1	2	0	1	1	11	0	0	17
Trichogrammatidae A	Trichogrammatidae	1	0	1	0	0	4	1	5	0	5	17
Cerphronidae G	Cerphronidae	2	3	0	2	1	2	0	3	1	1	15
Mymaridae A	Mymaridae	0	3	3	0	0	3	2	4	0	0	15
Platygasteridae I	Platygasteridae	0	3	0	1	0	0	3	8	0	0	15
Mymaridae K	Mymaridae	0	0	5	1	0	4	0	1	1	2	14
Vespidae C[§]	Vespidae	0	1	2	0	2	2	0	5	1	1	14

Cerphronidae A	Cerphronidae	0	1	2	1	1	0	0	5	1	1	12
Diapriidae C	Diapriidae	3	0	2	0	0	4	0	2	0	1	12
Scelionidae C	Scelionidae	0	0	2	1	0	0	0	0	4	5	12
Vespidae F[§]	Vespidae	0	0	2	0	0	0	4	1	4	1	12
Tiphiidae A[§]	Tiphiidae	0	0	0	1	0	0	4	0	4	1	10
Vespidae J[§]	Vespidae	0	2	3	0	2	0	2	1	0	0	10
Platygasteridae F	Platygasteridae	2	0	1	0	1	3	0	1	0	1	9
Tiphiidae E[§]	Tiphiidae	1	0	0	0	1	3	1	0	1	2	9
Trichogrammatidae B	Trichogrammatidae	0	0	0	1	0	3	0	0	3	2	9
Vespidae G[§]	Vespidae	0	0	0	1	3	1	0	3	0	1	9
Bethylidae C	Bethylidae	0	0	0	0	1	1	0	1	0	5	8
Diapriidae E	Diapriidae	1	0	0	0	1	1	0	1	0	4	8
Figitidae C	Figitidae	2	0	1	0	0	0	2	2	1	0	8
Platygasteridae A	Platygasteridae	1	1	1	0	0	2	1	1	0	1	8
Scelionidae F	Scelionidae	0	0	0	1	0	3	0	0	3	1	8
Scelionidae V	Scelionidae	0	0	2	2	0	1	0	1	1	1	8
Tiphiidae G[§]	Tiphiidae	0	0	0	1	0	1	0	1	1	4	8

Bethylidae B	Bethylidae	0	0	0	0	0	0	0	0	0	7	7
Cerphronidae C	Cerphronidae	1	0	2	0	0	0	0	2	1	1	7
Diapriidae B	Diapriidae	0	0	3	1	0	0	0	3	0	0	7
Platygasteridae B	Platygasteridae	1	0	0	0	1	2	0	0	1	2	7
Pteromalidae E	Pteromalidae	1	1	2	0	3	0	0	0	0	0	7
Crabronidae A[§]	Crabronidae	0	0	0	3	2	1	0	0	0	0	6
Diapriidae D	Diapriidae	0	2	2	1	0	0	0	1	0	0	6
Mymaridae F	Mymaridae	0	1	0	1	0	0	0	4	0	0	6
Pompilidae F[§]	Pompilidae	0	0	1	1	1	1	0	2	0	0	6
Scelionidae A	Scelionidae	1	0	3	0	0	0	0	0	0	2	6
Scelionidae M	Scelionidae	1	0	1	0	0	3	0	0	0	1	6
Cerphronidae B	Cerphronidae	0	0	0	1	0	3	0	0	0	1	5
Eurtomidae B	Eurtomidae	0	0	4	0	0	1	0	0	0	0	5
Mymaridae H	Mymaridae	1	0	2	0	0	0	1	1	0	0	5
Platygasteridae D	Platygasteridae	1	0	1	0	1	1	0	0	1	0	5
Scelionidae E	Scelionidae	1	0	1	0	1	0	0	2	0	0	5
Tiphiidae F[§]	Tiphiidae	3	0	0	0	0	0	0	1	1	0	5

Vespidae I[§]	Vespidae	0	1	0	0	1	0	0	1	2	0	5
Branconidae B	Branconidae	0	0	2	0	0	2	0	0	0	0	4
Branconidae M	Branconidae	0	0	1	0	0	3	0	0	0	0	4
Cerphronidae L	Cerphronidae	0	0	2	0	0	0	0	2	0	0	4
Crabronidae B[§]	Crabronidae	0	0	3	0	0	1	0	0	0	0	4
Figitidae B	Figitidae	1	1	0	0	0	0	0	0	1	1	4
Mymaridae D	Mymaridae	0	0	0	0	0	2	0	0	0	2	4
Pompilidae A	Pompilidae	2	0	0	0	0	1	0	0	0	1	4
Pteromalidae F	Pteromalidae	1	0	1	0	1	0	0	0	1	0	4
Pteromalidae I	Pteromalidae	0	0	0	1	1	1	1	0	0	0	4
Pteromalidae P	Pteromalidae	0	0	0	0	0	0	4	0	0	0	4
Scelionidae L	Scelionidae	0	0	1	0	0	1	1	0	0	1	4
Tiphiidae D[§]	Tiphiidae	0	0	0	0	0	0	1	2	0	1	4
Bethylidae A	Bethylidae	2	1	0	0	0	0	0	0	0	0	3
Branconidae D	Branconidae	0	0	1	1	1	0	0	0	0	0	3
Cerphronidae D	Cerphronidae	0	1	2	0	0	0	0	0	0	0	3
Cerphronidae E	Cerphronidae	0	0	1	0	0	0	0	1	0	1	3

Cerphronidae H	Cerphronidae	1	1	0	0	0	0	0	1	0	0	3
Crabronidae F§	Crabronidae	0	0	0	0	0	2	0	0	1	0	3
Encyrtidae B	Encyrtidae	0	0	0	0	0	0	0	0	3	0	3
Encyrtidae G	Encyrtidae	0	0	1	0	0	2	0	0	0	0	3
Figitidae D	Figitidae	1	0	1	0	0	0	1	0	0	0	3
Mymaridae C	Mymaridae	0	0	0	0	0	0	0	0	2	1	3
Mymaridae E	Mymaridae	0	2	0	0	0	0	1	0	0	0	3
Pompilidae H	Pompilidae	0	0	0	1	0	0	0	0	0	2	3
Pteromalidae H	Pteromalidae	0	0	0	1	1	0	0	0	0	1	3
Pteromalidae K	Pteromalidae	0	0	0	0	1	1	0	1	0	0	3
Scelionidae G	Scelionidae	0	0	0	0	0	1	0	0	0	2	3
Scelionidae O	Scelionidae	0	0	0	0	0	0	0	0	1	2	3
Scelionidae T	Scelionidae	0	0	0	0	0	0	0	0	1	2	3
Sphecidae B§	Sphecidae	0	0	0	1	0	0	0	0	2	0	3
Sphecidae C§	Sphecidae	0	0	0	2	1	0	0	0	0	0	3
Tiphiidae H§	Tiphiidae	2	0	0	0	0	0	0	0	0	1	3
Branconidae BB	Branconidae	0	0	0	0	1	0	0	0	0	1	2

Branconidae CC	Branconidae	0	0	0	0	0	0	0	1	0	1	2
Branconidae G	Branconidae	0	0	1	0	0	1	0	0	0	0	2
Branconidae I	Branconidae	0	0	1	0	0	0	1	0	0	0	2
Branconidae K	Branconidae	0	0	1	1	0	0	0	0	0	0	2
Branconidae L	Branconidae	0	0	1	0	0	0	1	0	0	0	2
Branconidae O	Branconidae	0	0	1	0	0	0	1	0	0	0	2
Branconidae P	Branconidae	0	1	0	0	0	1	0	0	0	0	2
Cerphronidae I	Cerphronidae	1	0	1	0	0	0	0	0	0	0	2
Cerphronidae J	Cerphronidae	0	0	0	0	1	0	1	0	0	0	2
Chysididae A	Chysididae	0	0	0	2	0	0	0	0	0	0	2
Crabronidae C[§]	Crabronidae	0	0	0	0	0	1	0	0	1	0	2
Crabronidae H[§]	Crabronidae	0	0	0	0	0	2	0	0	0	0	2
Encyrtidae H	Encyrtidae	0	0	0	0	0	0	0	0	1	1	2
Eulophidae A	Eulophidae	0	0	0	0	0	1	0	0	1	0	2
Eurtomidae D	Eurtomidae	0	0	2	0	0	0	0	0	0	0	2
Figitidae A	Figitidae	1	0	1	0	0	0	0	0	0	0	2
Ichneumonidae I	Ichneumonidae	0	0	0	1	0	1	0	0	0	0	2

Ichneumonidae P	Ichneumonidae	0	0	0	0	0	0	0	0	0	2	2
Mymaridae G	Mymaridae	0	0	0	0	0	0	0	1	0	1	2
Mymaridae L	Mymaridae	0	0	0	0	0	0	0	1	0	1	2
Pteromalidae M	Pteromalidae	0	0	2	0	0	0	0	0	0	0	2
Pteromalidae S	Pteromalidae	0	0	1	0	0	0	0	1	0	0	2
Scelionidae D	Scelionidae	0	0	0	0	0	0	0	1	1	0	2
Scelionidae N	Scelionidae	1	0	0	0	0	0	0	1	0	0	2
Scelionidae P	Scelionidae	0	1	0	1	0	0	0	0	0	0	2
Scelionidae U	Scelionidae	2	0	0	0	0	0	0	0	0	0	2
Sphecidae A[§]	Sphecidae	0	0	0	0	0	0	0	0	2	0	2
Tiphiidae C[§]	Tiphiidae	0	0	0	1	0	0	0	1	0	0	2
Bethylidae D	Bethylidae	0	0	0	2	0	0	0	0	0	0	1
Bethylidae E	Bethylidae	1	0	0	0	0	0	0	0	0	0	1
Branconidae A	Branconidae	1	0	0	0	0	0	0	0	0	0	1
Branconidae AA	Branconidae	0	0	1	0	0	0	0	0	0	0	1
Branconidae C	Branconidae	0	0	0	0	0	0	0	0	0	1	1
Branconidae EE	Branconidae	0	0	1	0	0	0	0	0	0	0	1

Branconidae F	Branconidae	0	0	1	0	0	0	0	0	0	0	1
Branconidae H	Branconidae	0	0	0	1	0	0	0	0	0	0	1
Branconidae N	Branconidae	0	0	1	0	0	0	0	0	0	0	1
Branconidae T	Branconidae	0	0	0	0	1	0	0	0	0	0	1
Branconidae U	Branconidae	0	0	1	0	0	0	0	0	0	0	1
Branconidae V	Branconidae	0	0	0	0	0	0	0	0	1	0	1
Branconidae W	Branconidae	0	0	1	0	0	0	0	0	0	0	1
Branconidae X	Branconidae	0	0	1	0	0	0	0	0	0	0	1
Cerphronidae F	Cerphronidae	0	0	0	0	0	0	0	1	0	0	1
Chrysididae B	Chrysididae	0	0	0	0	1	0	0	0	0	0	1
Crabronidae G§	Crabronidae	0	0	0	0	1	0	0	0	0	0	1
Crabronidae I§	Crabronidae	0	0	0	0	0	0	0	0	1	0	1
Diapriidae A	Diapriidae	0	0	0	1	0	0	0	0	0	0	1
Diapriidae F	Diapriidae	0	0	0	0	0	0	0	0	0	1	1
Diapriidae G	Diapriidae	0	0	0	0	0	0	1	0	0	0	1
Eurtomidae E	Eurtomidae	0	0	1	0	0	0	0	0	0	0	1
Ichneumonidae C	Ichneumonidae	0	0	1	0	0	0	0	0	0	0	1

Ichneumonidae D	Ichneumonidae	0	1	0	0	0	0	0	0	0	0	1
Ichneumonidae H	Ichneumonidae	0	0	1	0	0	0	0	0	0	0	1
Ichneumonidae J	Ichneumonidae	0	0	0	0	0	0	0	0	0	1	1
Ichneumonidae O	Ichneumonidae	0	0	0	1	0	0	0	0	0	0	1
Ichneumonidae Q	Ichneumonidae	0	0	0	0	0	0	0	0	0	1	1
Ichneumonidae R	Ichneumonidae	0	0	1	0	0	0	0	0	0	0	1
Megaspilidae B	Megaspilidae	1	0	0	0	0	0	0	0	0	0	1
Mymaridae J	Mymaridae	0	1	0	0	0	0	0	0	0	0	1
Platygasteridae E	Platygasteridae	0	1	0	0	0	0	0	0	0	0	1
Pompilidae B[§]	Pompilidae	0	1	0	0	0	0	0	0	0	0	1
Pteromalidae J	Pteromalidae	0	0	0	0	0	0	0	1	0	0	1
Pteromalidae L	Pteromalidae	1	0	0	0	0	0	0	0	0	0	1
Pteromalidae N	Pteromalidae	0	0	0	0	1	0	0	0	0	0	1
Pteromalidae Q	Pteromalidae	0	0	0	0	0	0	0	1	0	0	1
Pteromalidae R	Pteromalidae	0	0	1	0	0	0	0	0	0	0	1
Pteromalidae U	Pteromalidae	0	0	0	0	0	0	0	0	0	1	1
Pteromalidae X	Pteromalidae	0	0	0	0	1	0	0	0	0	0	1

Pteromalidae Y	Pteromalidae	0	0	0	0	0	0	0	1	0	0	1
Scelionidae H	Scelionidae	0	0	0	0	0	0	0	1	0	0	1
Scelionidae I	Scelionidae	0	0	0	1	0	0	0	0	0	0	1
Scelionidae K	Scelionidae	0	0	0	1	0	0	0	0	0	0	1
Scelionidae Q	Scelionidae	0	0	0	0	0	0	0	0	0	1	1
Scelionidae W	Scelionidae	0	0	0	0	1	0	0	0	0	0	1
Scelionidae X	Scelionidae	0	0	0	0	0	0	0	0	1	0	1
Sphecidae D§	Sphecidae	0	0	0	0	1	0	0	0	0	0	1
Sphecidea E§	Sphecidea	0	1	0	0	0	0	0	0	0	0	1
Trichogrammatidae C	Trichogrammatidae	0	0	0	0	0	0	0	1	0	0	1
Trichogrammatidae E	Trichogrammatidae	0	0	1	0	0	0	0	0	0	0	1
Vesipdae H§	Vesipdae	0	0	0	0	0	1	0	0	0	0	1
Total Number of Individuals		51	57	141	63	62	111	44	119	72	97	817
Total Number of Species		36	27	66	41	38	45	26	51	40	57	163

§Predator otherwise Parasitoid