Management implications for invertebrate assemblages in the Midwest American agricultural landscape
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Chapter 3

Development of invertebrate assemblages in a recently restored prairie

Based on: Tracy R. Evans, Meredith J. Mahoney, E.D. Cashatt, Bryon W. Cross, Geert R. de Snoo and C.J.M. Musters. Invertebrate communities associated with three early phases of a prairie restoration project. 2016 .*In Press* Great Lakes Entomologist

Abstract

While specific invertebrate groups have been studied in prairie restorations, there are few studies that look at terrestrial invertebrate assemblages. We took the opportunity offered by a restoration project associated with a large-scale housing development in central Illinois to survey invertebrates in three phases of plant restoration that were part of a larger project. This cross-sectional study of invertebrate recovery at two, four and five year's post-restoration showed that there was no overall difference in invertebrate taxa richness and diversity. Overall abundance was greatest in the most recently restored area. Richness, diversity and abundance of six functional groups did not differ. The restoration phases of our study were apparently all characterized by an early pioneer assemblage that did not differ significantly from each other. The conclusion is that all phases are still characterized by pioneer invertebrate assemblages, and that development to more diverse and richer assemblages might take more than five years in prairie restoration projects. The new and unexpected finding was that the reestablishment of invertebrate assemblages was not closely tied to vegetation restoration.

Keywords: invertebrate diversity, prairie restoration, species richness, taxonomic richness, urban watershed protection

Introduction

Illinois was once part of a vast grassland which became known by the French word for grassland, "prairie". Early European settlers soon realized the agricultural potential and converted the rich prairies to croplands. Only a few thousand hectares of the original prairie remains, mostly pioneer cemeteries and linear elements along railroad rights-of-way and highways (Johnson and Anderson, 1986; Walk and Warner, 1999). There is a growing movement to restore prairie, a difficult task considering the lack of scientific documentation of the original ecosystem. Our best records come from descriptions of the vegetation, mammals, and birds during early exploration (Audubon, 1843; Wheeler, 1904).

Historically the focus of prairie restoration projects has been to establish the prairie flora. From an ecological point of view, the traditional focus on vegetation restoration makes sense because of the strong relationship between floral and faunal diversity (Labandeira *et al.*, 1994). The habitat heterogeneity hypothesis predicts invertebrate species richness should be greater with greater structural and vegetation complexity (Nilsson *et al.*, 1988). There are three general layers in the above ground vegetation structure of an established prairie. These include above ground structures that have low growing forbs and grasses, a highly diverse intermediate layer, and later in the season tall perennials. Together these layers provide a diverse microhabitat for invertebrates.

Restorations are planned with careful selection of various seeding mixes and hay spreading from existing prairies, as well as the use of specific management techniques including prescribed fire and mowing (Schramm, 1990; Kindscher and Tieszen, 1998; Dickson and Busby, 2009). However, when a restoration plan succeeeds in establishment of the prairie vegetation it does not automatically mean that the prairie ecosystem is also fully functional. As with plants, many animals and most micro-organisms have limited dispersal capabilities. But since neither animals nor micro-organisms are usually aided by translocations, the recovery of the complete prairie community may take time, if it happens at all (Woodcock *et al.*, 2012a; Woodcock *et al.*, 2012b). This might be especially true when soils are strongly disturbed during the establishment of the restoration. This bares the risk that the prairie under restoration, although having a recovered vegetation, is not functioning well because some functional groups are missing or depending on too few species. Such a prairie could be unstable or have low resilience (Peterson *et al.*, 1998).

Subjective appraisals of restoration projects were characteristic in the early history of restoration ecology. This was partially the result of the feeling of urgency that resulted from the rapid degradation of ecological systems. The pragmatic approach of visually assessing the end product of a restoration continues to be one method of utilizing scarce financial and manpower resources (personal observation). A more rigorous scientific approach includes monitoring fundamental parameters of the restoration and comparison of indigenous species during and after the restoration (Bradshaw, 1993; Ruiz-Jaen and Mitchell Aide, 2005). Post-restoration monitoring ranges from one or two years to a minimum of 15 years for some mine reclamation projects (Craft *et al.*, 2002). Plant and invertebrate diversity and abundance are the most common measures of ecosystem recovery (Ruiz-Jaen and Mitchell Aide, 2005). Invertebrate studies of restored prairie include soil arthropods (Lussenhop, 1976), invertebrate herbivory (Gibson *et al.*, 1990), and invertebrate response to management techniques (Benson *et al.*, 2007). Most studies focus only on one group of organisms (Ruiz-Jaen and Mitchell Aide, 2005). Results of these studies were highly variable (Picaud and Petit, 2007; Wallner *et al.*, 2012).

We took an opportunity to study invertebrate abundance, richness and diversity at a project converting land use from agriculture to prairie within a new housing development. Conservation development is an alternative form of housing construction in which homes are located around a central area protected for conservation purposes. An approximately 36 ha prairie restoration followed an initial alteration of hydrology to add meanders, riffles and pools. Water quality was improved and fish abundance increased by 84.6% over the pre-restoration sample (Thomas 2012). Subsequent to the stream restoration, the area was seeded in three phases with prairie forbs and grasses to mimic pre-settlement vegetative conditions.

We were interested in the establishment of invertebrate assemblages after the earth-moving that occurred as part of the stream hydrology portion of the project. Our first hypothesis was that invertebrate abundance, richness and diversity would be positively correlated with the establishment of prairie vegetation.

Methods

Study Area. The study area is located in McLean County in the state of Illinois, USA (40°27'32.97"N, 88°52'36.59"W). This is part of the Grand Prairie Natural Division (Schwegman, 1973). The Grand Prairie was once a vast plain of mostly tallgrass prairie with fertile soils developed from glacial outwash, lakebed sediments and deposited loess. The topography is generally level to rolling. McLean County has a humid continental climate with hot summers and no dry period. The general environment within a 40 km radius is crops. Average temperatures range from 31° C in the summer to -9° C in the winter. Precipitation averages 940 mm per annum (Best Places, 2014).

The study site was part of a housing development near Bloomington, Illinois. The area was formerly row crop agriculture containing the headwaters of Kickapoo Creek. Sections of Kickapoo Creek are classified as a "Biologically Significant Stream" (Thomas 2009) a designation developed by the Illinois Department of Natural Resources (IDNR). Kickapoo Creek is located within the Sangamon River Basin.

Reconstruction of the stream contours was the first part of the project, after which the area surrounding the creek was restored to prairie vegetation. Construction of the restoration (Figures 1-4) and subsequent seeding (Appendix A) occurred in three phases over a four-year period (2008-2012). Phase I construction began in 2008 with the final seeding occurring in the spring of 2009. Phase II construction began in 2009 with final seeding occurring in the spring of 2010. Phase III was constructed in 2011 and had a fall dormant seeding, thus 2012 represented the first growing season of this phase. The construction of each phase involved total disturbance of the site within the phase area. The topsoil layer (A and B horizon) was removed and the new ground contours established in the parent material. Replacement of the A horizon topsoil layer (to provide substrate for seeding) occurred for each phase. B horizon soils were removed from the site. The earthwork resulted in removal of all invertebrate and small mammal populations within a given phase during construction. Additionally, management during 2012 and 2013 included a prescribed burn in Phase I, mowing with hay left in place in phase II and mowing with hay removed in Phase III.

Figure 1. Schematic diagram of the restoration phases: Phase I was constructed and seeded in 2008 but had to be reseeded in spring of 2009. Phase II construction started in 2009 and was finished and the area seeded in spring of 2010. Phase III had a dormant seeding in fall 2011 so the first growing season was spring 2012.

Figure 2. Phase I facing northeast taken July 3, 2013.

Figure 3. Phase II facing northwest taken July 3, 2013.

Figure 4. Phase III facing northwest taken July 3, 2013

Sampling. May 7-14, June 30-July 7, and September 17-24, 2013, invertebrates were sampled by pitfall trapping, sweep netting, and sticky boards. These methods were chosen to sample invertebrates with different modes of locomotion and structural occupation found in a prairie landscape. In each of the three construction phases, there were three transects of six sampling sites. Transects were placed parallel to the creek at 15.8 m average distance (range 7.6-24.1 m) as measured with a GPS (Garmin Oregon 450t). All samples were within the same soil type (Sawmill silty clay loam). Sticky boards and pitfall traps were placed ~10 m apart within each transect and transects were placed 20-40 m apart.

Each sample site had a pitfall and sticky board (Sensor ~ 8 cm x 13 cm Yellow Monitoring Cards, GrowSmart), attached to a flag (~ 6 cm X 9 cm X 76 cm LimeGlo, Forestry Suppliers). Boards were placed with a minimum of ½ the board above the vegetation on to a maximum height of 75 cm. Sticky boards were retrieved two days later and placed in a clear plastic cover for future identification. Pitfall traps were 150 ml plastic cups each with an aperture of 70 mm that were placed in the ground flush with the surface. Each trap was filled with a solution of water and vinegar and a few drops of soap added to break the surface tension of the water. Each pitfall trap was retrieved seven days after placement, strained and placed in a separate clear plastic bag containing 70% alcohol.

Sweep netting consisted of two 50 m linear sweeps (100 sweeps each) conducted 3 m on both sides of the sampling transects in each of the three construction phases. The sweep net was 38 cm in diameter with muslin netting (Forestry Suppliers). All samples were collected on sunny days between 10:00 and 14:00 with winds below 5.5 m/s as measured on the Beaufort scale. Invertebrates were placed in a "knockdown" jar (containing chloroform soaked cotton) for several minutes and then placed in a separate labeled clear plastic bag containing 70% alcohol.

Invertebrates larger than 2 mm were identified to lowest operational taxonomic unit (OTU) possible, which in most cases was family, using taxonomic keys (Triplehorn and Johnson, 2005) and reference collections housed at the Illinois State Museum Research and Collections Center (ISM RCC) (Oliver and Beattie, 1996). Ten percent of the samples were examined a second time as quality control. An expert was available to assist with difficult identifications. Numbers of arthropods smaller than 2 mm were estimated. The method of locomotion for each OTU was classified as mostly flying or mostly epigeic. The OTU's were categorized by functional guild of detritivores, herbivores, flower visitors, parasites or parasitoids, predators or omnivores.

Data Analysis. Our design was such that we sampled invertebrates repeatedly within each construction phase along three transects at fixed locations using three sampling methods. Our nested design regarded the locations as random locations within transects within phases. We regarded our sampling methods as a random selection of all possible sampling methods and our sampling date as randomly selected from all possible dates. As a result, in most of our analyses, we used a mixed linear model with location, date and method as random effect variables and phase, our treatment, as the fixed effect variable. By applying a mixed effects model, samples can be regarded as independent across space and time (Millar and Anderson, 2004; Lazic, 2010; Winter, 2013). In one instance, we tested whether invertebrate dispersal effected the abundance of the taxa. In that case we regarded the taxa we found as a random selection of all possible taxa and the phases as random selection of all possible phases.

All our models were maximum random effect models, i.e. including the effects on both the intercept and the regression coefficient (Barr *et al.*, 2013). Our dependent variables were abundance, taxonomic richness (TR), i.e., the number of OTUs, and taxonomic diversity (TD), the exponentially transformed Shannon Weaver H', making it Hill numbers of order 1 (Hill, 1973; Jost, 2007). Residuals were checked in all analyses. Normality was visually assessed. Abundance was not normally distributed; therefore, we applied a log transformation. TD was normally distributed. TR was checked with and without log transformation. Results were not significantly different so TR was treated as normally distributed. Capture methods were not merged: abundance and diversity were per sample. The effect of means of locomotion of the invertebrates on abundance w tested with LRT. Data are reported as ± sd.

In all analyses, we applied a Likelihood-Ratio Test (LRT). We performed the statistical analyses using R software 3.1.1 (R Development Core Team (2013). We used lmer () of the package lme4 (Bates 2014), version 1.1-7. The model with the factor of interest is compared to the model without that factor.

Results

In total, there were 105 OTUs sampled from the three restoration phases (Appendix B). There were 26,263 individuals sampled over the three months of the study period. Overall abundance averaged 76.8 ± 347.5 (Table 1). Abundance was greatest in Phase III (142.55 ± 207.7), followed by Phase II (46.62 ± 50.0) and Phase I (41.21 ± 49.8). The influence of phase on abundance was tested with Likelihood Ratio Test and was statistically significant (LRT: Chi Sq=820.78, df=22, *P*=0.0454; n=342. Airborne invertebrates had no difference in abundance than epigeic (LRT: Chi Sq=0.0547, df=1, *P*=0.8151; n=342). Both TR and TD were greatest in July (Table 2).

Table 1. Average taxonomic richness (TR) and diversity (TD) ± sd (range) per sample for Phase I, II, III and overall.

Phase	TR	TD
PI	8.35 ± 4.43 (2-32)	5.14 ± 2.11 (1.21-10.50)
PII	9.04 ± 4.56 (2-34)	5.17 ± 2.35 (1.54-11.68)
PIII	11.23 ± 4.74 (2-26)	5.15 ± 2.24 (1.25-10.70)
Overall	9.5 ± 4.97 (2-34)	5.1 ± 2.2 (1.2-11.7)

Taxonomic richness (TR) in the complete study area averaged 9.5 ± 4.97 (2-34) per sample and was highest in Phase III (Table 1). Phase of restoration on TR was not significant (LRT: Chi Sq=3.956, df=2, *P*=0.1383; n=342). Taxonomic diversity (TD) in the complete study area averaged 5.1 ± 2.1 (1.2-10.50) per sample (Table 1). Phase of restoration on TD was not significant (LRT: Chi Sq=0.3462, df=2, *P*=0.8411; n= 342).

Table 2. Average taxonomic richness (TR) and diversity (TD) ± sd (range) per sample in each of the sampling periods of May 7, July 7 and September 24.

	TR	TD
May	8.71 ± 3.6 (3-17)	4.69 ± 2.25 (1.28-10.2)
July	11.16 ± 5.93 (3-34)	5.91 ± 2.21 (1.25-11.68)
Sept	8.74 ± 4.74 (2-26)	4.83 ± 2.04 (1.21-10.7)

There was no significant difference in abundance within functional groups between the three phases, but in all groups, abundance was highest in Phase III (Table 3). Detritivores were most abundant (54.38 ± 87.96) followed by omnivores (18.27 ± 70.07), herbivores (12.5 ± 32.44), parasites and parasitoids (6.01 ± 10.72), predators (5.87 ± 8.65) and flower visitors (2.11 ± 5.32). Most abundant taxa were Aranae: Lycosidae (1.5%); Colembola (13.0%); Orthoptera: Acrididae (2.3%) and Gryllidae (2.8%); Hemiptera: Miridae (4.5%) and Cicadellidae (2.4%); Coleoptera: Carabidae (2.8%); Hymenoptera: Braconidae (2.1%) and Formicidae (7.6%); Diptera: Chironomidae (8.2%), Culicidae (5.0%), Mycetophilidae (19.7%), Syrphidae (1.5%) and Muscidae (5.2%). The remaining taxa were either < 1% or unidentified Diptera species (Appendix B).

Table 3. Average abundance ± sd within functional groups of each of the three project phases.

Treatment	PI	PII	PIII	Overall
Detritivores	38.85 ± 45.83	43.75 ± 44.26	80.54 ± 135.06	54.38 ± 87.96
Flower visitors	1.04 ± 2.65	2.57 ± 5.6	2.71 ± 6.73	2.11 ± 5.32
Herbivores	10.26 ± 26.79	9.7 ± 23.45	17.53 ± 43.25	12.5 ± 32.44
Omnivores	8.04 ± 13.86	12.32 ± 15.13	34.44 ± 118.28	18.27 ± 70.07
Parasites and Parasitoids	3.62 ± 5.55	5.18 ± 8.45	9.24 ± 15.09	6.01 ± 10.72
Predators	6.27 ± 9.31	4.28 ± 6.18	7.05 ± 9.83	5.87 ± 8.65

4. Discussion

We expected invertebrate diversity to increase along with plant diversity as the restoration became established with the greatest diversity and richness in Phase I – the oldest phase - and least in Phase III – the youngest phase (Young, 2000). However, we found no significant difference in TR or TD between phases, nor a difference in abundance of functional groups. Visually, Phase I seemed to meet the expected appearance of restored prairie (Fig. 2). As a direct result of vegetation management, Phases II and III had less structure and fewer blooming forbs (Fig. 3 & 4). Subjectively the restored prairie five years' post-construction met visual standard measures of success. Plants had matured and created a diverse vegetative structure. Vegetation management was provided to remove invasive species before they could become fully established and to allow the native grasses and forbs to establish an adequate root system.

Picaud and Petit (2007) suggest a progressive gain of colonizing species over several years, then a plateau and possibly decline in species number. The first species to settle in a new area are likely to be those present in nearby ecosystems. Hendrychova (2008) reported spontaneous succession of plants and animal from neighboring high quality natural areas to often be more species rich and diverse than planned reclamations.

Our study area had the expected populations of highly mobile generalist species. The most abundant species were the Mycetophilidae. Fungus gnats occur around damp decaying vegetation, algae and fungi. In general, they serve a beneficial role as decomposers and convert dead vegetation into nutrients for plant growth. They also serve as pollinators and as a food source for insect predators, reptiles and birds. Chironomidae (midges) and Culicidae (mosquitoes) are also common in wet areas and serve as an important food source in the food chain.

We observed numerous Collembola in each of the three phases. Collembola are wind dispersed in addition to actively migrating and available from the surrounding landscape. They reproduce several times year which allows them to increase abundance in a short time period.

Cicadellidae (leafhoppers) are part of a diverse group of Auchenorryncha, many of which are closely associated with tallgrass prairie. With close to 700 species in Illinois (DeLong, 1948) this taxonomic group has been proposed as an indicator of tallgrass prairie quality (Wallner *et al.*, 2012). They comprised 2.4% of the individuals in our study. Parmenter *et al.* (1991) showed early colonization of beetles and grasshoppers was similar in all stages of restoration. Our study had similar high numbers of carabid beetles and grasshoppers in each of the three phases.

Muscidae were plentiful and play an important role in breaking down dead organic material. There were numerous other Diptera (flies) that were not identified. Mostly these did not fit into the more common families that were identified or were smaller than 2 mm and could not be thoroughly examined on the sticky boards.

Invertebrates that inhabit the area below the surface generally move from undisturbed areas at the edges. Because mobility is limited, the repopulation is generally slow. Our study area showed the heaviest concentration of ants to be in Phase III. Majer (1998) reported the highest number of ant species 6 years after site rehabilitation in a sand quarry in Queensland Australia. It is our belief that the ants were moving from the closest undisturbed area which was cultivated agricultural fields. Areas closest to Phase I were residential areas.

We also expected to find taxa such as Olicochaeta (earthworms), Gastropoda (snails and slugs), Isopods (pillbugs), Coleoptera (beetles), and Lepidoptera (butterflies and moths). There were only six earthworms in all of the pitfall traps in contrast to other studies in which there were often more than this number at each sampling location (Evans *et al. unpublished data*). The same is true for isopods. It would appear that these taxa had not yet penetrated the restoration site. Our results are consistent with those of Hutson (1980) who measured colonization of industrial reclamation sites. Other than Carabid beetles there were few beetle individuals in our samples. Beetle larvae occupy the below ground strata and seemed not to be present. Adults of several species were present and the vegetation was appropriate so complete establishment of reproduction may take more time. Since butterflies are highly dependent on specific plants for reproductive success and they must come from non-agricultural habitats, they too may have been slow to establish reproduction. Our study area was surrounded by agriculture and quite distant from remnant prairies found elsewhere in the county.

It was noted that small mammals were frequently found in identical pitfall traps in other studies in Central Illinois (Evans *et al. unpublished data*). Associated with these samples were numerous carrion beetles. There were only 34 carrion beetles during this entire study and no traps had small mammals. Small mammals, earthworms, and carrion beetles all inhabit the soil, with beetles utilizing burrows created by earthworms and small mammals.

Lack of many of these organisms at the time of this study may indicate the invertebrate assemblage of the prairie is not yet restored. At least the functional group of soil inhabiting species seems missing. This restoration project seems to follow a pattern more closely related to surface mine reclamation rather than to prairie restoration. Removal of soil and reconstruction of geological contours with partial replacement of topsoil provided a novel vegetative substrate. Recovery of soils after mining often requires more than 15 years to achieve values approximating those found in reference sites (Chambers and McComb, 1994; Craft *et al.*, 2002). Soil quality has been proposed as an indicator of sustainable land management (Herrick, 2000). Soil formation is an ongoing process which requires ongoing measurements and increased costs which are seldom fit within the time-frames and budgets of most restoration projects.

Our data indicate that after the extreme disturbance created by topsoil removal and subsequent replacement, establishment of an invertebrate assemblage appropriate to the new vegetation may take time (Schramm, 1990) or not occur at all. The restoration phases of our study (which were only two, four and five years old) are apparently all characterized by early pioneer assemblages that do not differ significantly from each other. The restoration area was farmed for decades prior to the restoration. Species adapted to agricultural row crops can be supposed to have been available to repopulate the restoration. Mobile species are expected to populate the restoration eventually but for epigeic prairie specialist arthropods, this might take a very long time, or they may not reach the restoration site at all due to colonization problems. Our results indicate that a more long-term view is necessary with some prairie restoration projects and that visual inspection may be inadequate to assess complete ecological restoration.

Urban housing development offers an opportunity to create novel ecosystems that are a consequence of our changing environment. Climate change and anthropogenic alteration of species distributions will force human acceptance to conditions as they are, rather than as we would have them (Hobbs *et al.*, 2009). A hybrid system would accept that agricultural inputs have permanently altered the chemical and biotic composition of the soil. It would accept that various pollinators are no longer available to aid the reproduction of both common and rare plants; and that plants once common in a particular place are now out of their climactic tolerance range. Plants are the basis of the ecological food web and thus the succeeding trophic levels are altered along with the vegetation. While we are able to physically restore prairie flora, at least for a time, we may not be aware of or even able to translocate the invertebrate assemblages and soil microorganisms required for sustaining the vegetation and that may not arrive on their own. Hybrid ecosystems may be the best option for sustainability.

Further research is needed to learn about the time-scale that is needed for prairie restoration projects on former agricultural lands to create a sustainable and functional prairie ecosystem.

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Appendix A

Seed lists combined from Phase I, II, and III.

Scientific name	**Common name**
Acorus calamus	Sweet Flag
Agastache foeniculum	Hyssop
Alisima subcordatum	Water Plantain
Allium cernuum	Nodding Onion
Allium stellatum	Prairie Onion
Amorpha canescens	Lead Plant
Andropogon gerrardii	Big Blue
Anenome cylindrica	Meadow Anenome
Asclepias incarnata	Swamp Milkweed
Asclepias tuberosa	Butterfly Milkweed
Aster azureus	Sky-blue Aster
Aster ericoides	Heath Aster
Aster novae-angliae	New England Aster
Aster umbellatus	Flat-topped Aster
Baptisia leucantha	White Wild Indigo
Bidens cernua	Nodding Bur-Marigold
Boltonia asteroides	False Aster
Bouteloua curtipendula	Side Oat's Grama
Bromus kalmii	Prairie Brome
Cacalia plantaginea	Indian Plantain
Calamagrostis canadensis	Blue Joint Grass
Caltha palustris	Yellow Marsh-Marigold
Carex bebbii	Bebb's Sedge
Carex bicknelli	Bicknell's Sedge
Carex comosa	Longhair Sedge
Carex cristatella	Crested Sedge
Carex frankii	Frank's Sedge
Carex grayi	Gray's Sedge
Carex hirsutella	Hairy-leaved Sedge
Carex hystricina	Sedge
Carex lacustris	Sedge

Carex laeviconica	Sedge
Carex lupulina	Sedge
Carex lurida	Sedge
Carex scoparia	Broom Sedge
Carex stricta	Tussock Sedge
Carex tribuloides	Bristlebract Sedge
Carex vulpinioidea	Foxtail Sedge
Cassia fasciculata	Partridge Pea
Cassia hebecarpa	Wild Senna
Chelone glabra	White Turtlehead
Coreopsis palmata	Prairie Coreopsis
Dalea purpurea	Purple Prairie Clover
Desmanthus illinoensis	Bundle Flower
Dodectheon meadia	Shooting Star
Echinacea pallida	Pale Coneflower
Echinacea purpurea	Purple Coneflower
Eleocharis obtusa	Spikenard
Elymus canadense	Canada Wild Rye
Elymus hystrix (Hystrix patula)	Bottlebrush Grass
Elymus riparius	Riverbank Rye
Elymus virginiana	Virginia Wild Rye
Eragrostis spectabilis	Love Grass
Eryngium yuccifolium	Rattlesnake Master
Eupatorium maculatum	Joe-pye-weed
Eupatorium perfoliatum	Boneset
Eupatorium purpureum	Sweet Joe-pye-weed
Euphorbia corollata	Flowering Spurge
Eylmus virginicus	Virginia Rye
Filipendula rubra	Queen-of-the-Prairie
Gentiana andrewsii	Bottle Gentian
Gentiana flavida	Cream Gentian
Glyceria striata	Fowl Manna Grass
Helenium autumnale	Sneeze-weed
Heliopsis helianthoides	False Sunflower
Hibiscus laevis	Rose Mallow
Hibiscus moscheutos	Swamp Rose Mallow

Hyericum pyramidatum	St John's Wort
Iris shrevei	Blue Flag / Iris
Juncus dudleyi	Dudley's Rush
Juncus effusus	Soft Rush
Juncus interior	Lake Rush
Juncus tenuis	Path Rush
Juncus torreyi	Torrey's Rush
Justicia americana	American Water-willow
Koeleria macrantha	June Grass
Liatris pychnostachya	Prairie Blazing Star
Liatris spicata	Marsh Blazing Star
Liatris spicata	Prairie Blazing Star
Lobelia cardinalis	Cardinal Flower
Lobelia siphilitica	Great Blue Lobelia
Lythrum alatum	Winged Loosestrife
Mimulus ringens	Monkey Flower
Monarda fistulosa	Bergamot
Panicum virgatum	Switch grass
Parthenium integrifolium	Wild Quinine
Pedicularis canadensis	Wood Betony
Penstemon digitalis	Beardstongue
Penthorum sedoides	Ditch Stonecrop
Phlox maculata	Sweet William
Physostegia angustifolia	Narrow Leafed Obedient Plant
Physostegia virginiana	Obedient Plant
Pontederia cordata	Pickerel Weed
Potentilla arguta	Tall Cinquefoil
Pycnanthemum pilosum	Hairy Mountain Mint
Pycnanthemum virginianum	Mountain Mint
Ratibida pinnata	Yellow Coneflower
Rudbeckia hirta	Black-eyed Susan
Ruellia humilis	Petunia
Sagittaria latifolia	Arrowhead
Schzachyrium scoparium	Little Bluestem
Scirpus cyperinus	Wool-grass
Scutellaria laterifora	Blue Skullcap

Silene regia	Royal Catchfly
Silphium integrifolium	Rosinweed
Silphium laciniatum	Compass Plant
Silphium perfoliatum	Cup-plant
Silphium terebinthinaceum	Prairie Dock
Sisyrinchium angustifolium	Narrowleaf Blue-eyed Grass
Solidago rigida	Rigid Goldenrod
Solidago speciosa	Showy Goldenrod
Sorghastrum nutans	Indian Grass
Spartina pectinata	Cord Grass
Sporobolis asper	Rough Dropseed
Sporobolus heterolepsis	Northern Dropseed
Teucrium canadense	Germander
Tradescantia ohiensis	Ohio Spiderwort
Tridens flavus	Purpletop
Verbena hastata	Blue Vervain
Verbena stricta	Hoary Vervain
Vernonia fasciculata	Ironweed
Veronicastrum virginicum	Culver's Root
Viola pedatifida	Prairie Violet
Zizia aurea	Golden Alexanders

Appendix B

Abundance of Operational Taxonomic Units (OTU) in each of the three phases of restoration. Guild associations are detritivores (D), flower visitors (F), herbivores (H), not feeding as adults (NA), omnivores (O), parasites and parasitoids (PA), and predators (PR).

Taxa	Phase I	Phase II	Phase III	Guild
Class Oligochaeta: Earthworms	4	2	0	D
Class Gastropoda				
Snails	6	1	0	H
Slugs	46	64	47	H
Order Araneae: Spiders				
Araneidae: Orb Weavers	4	0	0	PR
Acanthepeira stellate: Starbellied Orbweavers	0	0	1	PR
Tetragnathidae: Long-jawed Orb Weavers	4	10	1	PR
Linyphiidae: Sheet Web Spiders	91	36	39	PR
Pisauridae: Nursery-Web Spiders	0	0	2	PR
Lycosidae: Wolf Spiders	101	87	201	PR
Gnaphosidae: Parson Spiders	19	9	21	PR
Thomisidae: Crab Spiders	2	3	12	PR
Salticidae: Jumping Spiders	4	4	3	PR
Spider hatchlings	40	0	0	PR
Order Opiliones: Harvestmen	0	2	11	PR
Order Acari: Ticks	4	1	2	PA
Order Isopoda: Isopods				
Armadillidiidae: Common Pillbugs	21	5	2	O
Order Diplopoda: Millipedes	1	2	3	D
Order Chilopoda: Centipedes	0	4	14	PR
Order Collembola: Springtails	611	861	1934	D
Order Odonata: Damselflies				
Coenagrionidae: Damselflies	5	21	9	PR
Order Orthoptera				
Acrididae: Grasshoppers	109	311	197	H

Taxa	Phase I	Phase II	Phase III	Guild
Gryllidae: Crickets	180	41	504	H
Order Plecoptera: Stoneflies	0	0	1	NA
Order Hemiptera: True Bugs				
Miridae: Plant Bugs	292	199	697	H
Nabidae: Damsel Bugs	0	0	1	PR
Anthocoridae: Minute Pirate Bugs	3	20	43	PR
Reduviidae: Assassin Bugs	6	32	27	PR
Lygaeidae: Seed Bugs	2	1	1	H
Geocoridae: Big-Eyed Bugs	0	1	0	PR
Largidae: Plant Bugs	58	78	8	H
Alydidae: Broad-headed Bugs	2	0	0	H
Scutelleridae: Shield-Backed Bugs	0	0	4	H
Rhopalidae: Scentless Plant Bugs	1	0	0	H
Cydnidae: Burrower Bugs	0	0	1	H
Pentatomidae: Stink Bugs	1	7	0	H
Cicadidae: Cicadas	0	1	0	H
Membracidae: Treehoppers	1	2	0	H
Cicadellidae: Leafhoppers	276	171	184	H
Fulgoroidea: Planthopper	28	12	18	H
Aphidae: Aphids	42	76	123	H
Order Thysanoptera: Thrips	1	0	0	H
Order Coleoptera: Beetles				
Cicindelidae: Tiger Beetles	0	0	1	PR
Carabidae: Ground Beetles	218	178	331	PR
Histeridae: Hister Beetles	3	4	2	PR
Silphidae: Carrion Beetles	32	0	2	D
Scaphidiidae: Shining Fungus Beetles	2	4	7	D
Trogidae: Trox Beetles	11	4	4	D
Scarabaeidae: Scarab Beetles	80	9	9	H
Popillia japonica: Japanese Beetle	1	0	0	H
Elateridae: Click Beetles	12	16	15	H
Cantharidae: Soldier Beetles	7	5	2	PR
Cleridae: Checkered Beetles	108	44	36	PR

Taxa	Phase I	Phase II	Phase III	Guild
Erotylidae: Pleasing Fungus Beetles	0	1	3	D
Byturidae: Fruitworm Beetles	0	0	1	H
Coccinellidae: Lady Beetles	6	2	6	PR
Hippodamia parenthesis: Parenthesis Beetles	3	4	6	PR
Mordellidae: Tumbling Flower Beetles	15	19	16	F
Meloidae: Blister Beetles	1	7	7	H
Cerambycidae: Long-horned Beetles	0	1	1	H
Chrysomelidae: Leaf Beetles	42	31	26	H
Microhopala vittata: Goldenrod leaf miner	1	0	0	H
Curculionidae: Weevils	38	50	106	H
Coleoptera larva ssp	18	5	17	H
Order Neuroptera: Antlions, Lacewings	10	2	2	PR
Order Hymenoptera: Wasps, Bees, Ants				
Symphyta: Sawfly ssp	15	10	12	H
Ichneumonidae: Ichneumon Wasps	6	15	11	PA
Braconidae: Parasitic Wasps	229	144	178	PA
Chrysididae : Cuckoo Wasps	4	9	23	PA
Sphecidae: Thread-Waisted Wasps	6	6	8	F
Halictidae: Sweat Bees	8	16	7	F
Andrenidae: Mining Bees	5	23	54	F
Apidae: Honey Bees	6	14	42	F
Bombus pensylvanicus: Bumble Bee	0	1	4	F
Mutillidae: Velvet Ants	1	0	0	PA
Pompilidae: Spider Wasps	0	1	1	F
Vespidae: Hornets, Wasps	2	14	22	F
Dolichovespula maculate: Bald faced hornet	6	5	21	F
Formicidae: Ants	122	74	1799	O
Lepidopetera: Butterflies and Moths				
Micro-lepidoptera[1]	8	15	8	F
Hesperiidae: Skippers	1	1	1	F
Pieridae: Sulphers	2	7	7	F
Pieris rapae: Cabbage Butterfly	0	1	0	F
Geometridae: Geometer Moths	1	0	0	F

Taxa	Phase I	Phase II	Phase III	Guild
Noctuidae: Owlet Moths	0	3	3	F
Lepidoptera larva ssp	9	34	29	H
Order Diptera: Flies				
Tipulidae: Crane Flies	5	5	4	F
Chironomidae: Midges	412	422	1318	NA
Culicidae: Mosquitoes	147	381	774	PA
Mycetophilidae: Fungus Gnats	167	103	4863	D
Stratiomyidae: Soldier Flies	0	2	0	F
Rhagionidae: Snipe Flies	1	0	0	PR
Tabanidae: Horse Flies, Deer Flies	0	1	0	PA
Asilidae: Robber Flies	1	0	1	PR
Bombyliidae: Bee Flies	0	2	0	F
Dolichopodidae: Long-legged Flies	57	1	10	PR
Phoridae: Hump-backed Flies	4	25	22	O
Syrphidae: Flower Flies	61	185	144	F
Calliphoridae: Blow Flies	26	3	5	D
Tachinidae: Tachinid Flies	0	0	4	PA
Muscidae: House Flies	224	291	842	O
Ulidiidae: Picture-winged Flies	19	20	30	F
Diptera ssp	543	1012	1249	O
Diptera larva ssp	2	3	7	O

[1] Small Lepidoptera of the Super Families Gelechioidea, Pyraloidea, Tiniodea, Gracillarioidea, Incurvarioidea, and Families Tortricidae and Pterophoridae.

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