Succession of an Iowa sand prairie into an adjoining old-field

Susan Jill Kirt
University of Northern Iowa

SUCCESSION OF AN IOWA SAND PRAIRIE INTO

AN ADJOINING OLD-FIELD

An Abstract of a Thesis

Submitted

in Partial Fulfillment

of the Requirements for the Degree

Master of Science

Susan Jill Kirt

University of Northern Iowa

July 2007

ABSTRACT

Native plant succession studies were conducted in 2000 and 2001 at the Cedar Hills Sand Prairie northwest of Cedar Falls, IA. The study site consisted of a remnant sand prairie with an adjoining old-field that had been undergoing secondary succession since the mid-1970s. Vegetation was sampled over a 100 m transect of the remnant prairie and a 200 m transect of the old-field. The transect was sub-divided into 50 m sub-sites to examine progression of native species into the old-field. To analyze changes in vegetation, the similarity of the sub-sites were compared for percent canopy cover and number of species for the following categories: overall total, natives, native forbs, native grasses, sedges and rushes, non-natives, non-native forbs and non-native grasses. Additional studies examined the seed rain and seed bank.

The old-field vegetation of the sub-site adjacent to the remnant was most similar to the remnant and similarity decreased as distance increased. Between 50 and 150 m north of the remnant, native canopy cover diminished although the number of native species remained similar to the prairie. Apparently, this is a transition zone where native species are becoming established, but remain less prominent. Beyond this point, the vegetation in the most distant sub-site resembled a typical old-field. The number of species dropped 2½ to 3½ times less than the other areas of the study. Non-native species accounted for 98.5% of the canopy cover and the number of species was 2 ½ to 3 times less than the other sites. Additionally, only one native grass was present while four to six native grass species were present in other sub-sites.

Fifty species and 2086 seeds from the seed rain were compared to vegetation surrounding each seed trap to determine species movement. A low percentage of the species and seeds in the seed traps could have originated from the nearby vegetation. Apparently seeds are moving further than expected.

Half the seed bank species were not present in the sampled vegetation, including several native species. Native grasses, common in the vegetation and seed rain, were scarce in the seed bank. Sedges and rushes, scarce in the vegetation and seed rain, were prominent in the seed bank.

Succession is an important field of study to determine what species are moving, where they are moving to and if they are becoming part of the vegetation. Over one quarter of the studies species were not present in the vegetation, signifying potential future changes in the existing vegetation.

Secondary succession of prairie vegetation from the sand prairie remnant into the adjoining old field is proceeding slowly. Twenty-five years after the initiation of succession, the vegetation of the proximal portion of the old-field is similar to that of the adjoining remnant prairie. However, the most distant sample site of the old-field still resembles a typical abandoned agricultural field although intermediate sites are in transition to native prairie.

SUCCESSION OF AN IOWA SAND PRAIRIE INTO AN ADJOINING OLD-FIELD

A Thesis

Submitted

in Partial Fulfillment

of the Requirements for the Degree

Master of Science

Susan Jill Kirt

University of Northern Iowa

July 2007

This Study by: Susan J. Kirt

Entitled: Succession of an Iowa Sand Prairie into an Adjoining Old-Field

has been approved as meeting the thesis requirement for the

Degree of Master of Science

5/3/07	
Date	Dr. Daryl Smith, Chair, Thesis Committee
5-3-07	
Date	Dr. Steve O'Kane, Thesis Committee Member
5-3-07	
Date	Dr. Kurt Pontasch, Thesis Committee Member
6/25/07	
Date	Dr. Susan J. Koch, Dean, Graduate College

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Prairie is "North America's characteristic landscape" (Whitman 1963). The prairie ecosystem covered 15% of North America, approximately 163 million ha and extended in a rough triangle eastward 1,600 km from the Rocky Mountains to northeast Indiana (Samson and Knopf 1994). The westward portion of the prairie extended 3860 km from Edmonton, Alberta to southern Texas (Kuchler 1964).

The North American prairie is sub-divided into three large geographical regions due to differences in rainfall and temperature. These differences are reflected in plant height: shortgrass to the west, mixed grass in the center and tallgrass prairie to the east. The tallgrass prairie region's western border extends from southern Manitoba to central Texas and in the east to central Indiana and covered approximately 68 million ha (Samson and Knopf 1994). Isolated tallgrass prairie communities were once found to the east in northwestern Pennsylvania, Michigan, Kentucky, Tennessee and Ohio (Transeau 1935). Today, less than 3% of the original tallgrass prairie remains in scattered remnants (Smith 1990).

Eighty percent of Iowa was covered by tallgrass prairie, comprising between 12 and 12.5 million ha (Sampson and Knopf 1994, Smith 1998). Today less than 12,000 ha, or 0.1%, of the pre-settlement Iowa prairie remains in scattered remnants (Sampson and Knopf 1994, Smith 1998). Of the remaining remnants many are severely degraded due to overgrazing, neglect and fragmentation (Smith 1990).

Iowa tallgrass prairie types include blacksoil, gravel, hill, wet and sand prairies. Blacksoil prairie was the most common type of prairie in Iowa, however this soil is Grade A farmland and was converted into row crops. It is now the rarest type of prairie in Iowa. As a result, an inordinately high percentage of the remaining remnants in Iowa are on less fertile soils such as sand and gravel that were grazed or hayed though a few were cultivated (Smith 1998).

Due to the large extent of native prairie that was lost, many conservation organizations, agencies and private land owners are currently attempting to restore abandoned farmland back into native prairie. This work is occurring for a variety of reasons including soil conservation, restoring native plant and animal habitat, education, aesthetics and as part of the Conservation Reserve Program (CRP). Farmland usually adjoins remnant prairies and where possible organizations are purchasing and attempting to restore these areas to native prairie to act as a buffer zone for the remnant. For all types of restoration, it is important to understand secondary succession of prairie. This understanding will be useful in successfully reestablishing the plants, animals and microbes that comprise the prairie community. By understanding plant succession land managers will be able to better plan seeding regimes, species composition of seedling mixtures and determine appropriate management practices.

The first generation of American ecologists who helped define the study of succession included Frederic E. Clements, C. E. Bessey and Roscoe Pound in Nebraska and Henry Chandler Cowles in Chicago (Tobey 1982). Clements and Pound studied under Bessey as graduate students and devised quadrat measurement to study variables in their field sites. After graduation Pound left ecology to teach law while Clements devised the "Nebraska Method," which provided a foundation for his theory of succession of prairie ecosystems. Clements believed that the individual species acted together as one large organism and that the initial composition of a community in an area was not important. He believed that vegetation in an area would always arrive at the same climax community, the best arrangement of species for that area regardless of initial composition. Eventually equilibrium is reached in later successional stages with conservative species replacing many of the non-conservative species. These climax communities were stable, and assuming the basic climate remained the same, would persist despite temporary fluctuations in moisture.

Clement's views predominated for several decades in the United States and Great Britain until the Great Drought in the 1930's when several of his ideas began to be questioned (Tobey 1982). The drought demonstrated that while the overall climate in the Midwest stayed the same, prolonged drought caused regression in many of the prairie remnants, devastating much of the prairie Clements had observed.

While Clements was examining Midwestern prairies, Henry Cowles was studying the vegetative succession of the Lake Michigan dune system (Tobey 1982). In 1899, Cowles published his work on the Lake Michigan dunes and began the second school of successional study. According to Cowles vegetation changes in the dunes showed succession was neither direct nor irreversible, both fundamental to Clement's ideas. Instead Cowles believed that each organism functioned on an individualistic level without inter-species cooperation to reach a climax stage.

In 1917, H. A. Gleason developed an alternative to Clements' idea of the community as an organism, termed the "individualistic concept" (Crawley 1997). Unlike Clements who maintained that only one final community was possible in a given area, Gleason believed that the final climax community was not predetermined, but was a result of a sequence of coincidences. Initially widely ignored, the concept began gaining acceptance in the 1950's. Gleason proposed that species respond to the environment on an individual level and chance dictates the final composition of the climax community.

In the mid 1900's John E. Weaver and Paul Sears studied Midwestern prairie succession (Brotherson and Landers 1976). Most prairie succession studies in this period examined the conversion of prairie into forest. It was not until the late 1960s that research began examining old-fields converting back into a prairie.

The current model of succession describes it as a series of communities that develop over time. Each successional stage is recognizable as a distinct community with its own characteristic structure and species composition. These stages may exist for a short time and be quickly replaced by later successional stages, or persist for long periods of time before being replaced.

Secondary succession follows natural disturbances such as bison wallows, anthills and gopher mounds or on abandoned farmland and rights-of-way. It has been shown in remnant prairies that species richness is higher when disturbances such as gopher mounds are present (Tilman 1983, Inouye et al. 1987, Huntly and Inouye 1988, Huntly and Reichman 1994, Wolfe-Bellin and Moloney 2000). Many of the species found in small, disturbed sites have small-seeds, are often short-lived or are clonal species from the vegetation adjoining the open area. Annual species occur more frequently on gopher mounds (Umbanhowar 1992) and as a consequence are more abundant in prairies containing gopher mounds (Inouye et. al. 1987). In addition, perennial grasses decreased in short grass prairies with gopher mounds (Martinsen et al. 1990). The perennial grasses likely decreases because gophers eat grass rhizomes and disturb the soil.

Plant communities are affected by a variety of biotic and abiotic conditions following a disturbance (Schott 1993). Abiotic factors include temperature and moisture and biotic factors include the fauna and seed bank. Cultivation changes the abiotic and biotic conditions originally found at the site. The result is soil compaction along with reduced soil nutrients and organic matter.

Typical old-field succession in the Midwest begins in the first year following a large-scale disturbance (Wochler and Martin 1980, Holt et. al. 1995). The abandoned site is often dominated by a large number of non-native and early successional native species, often annuals, as the seeds of these species are typically present in high numbers in the seed bank. These species often begin to decrease in the vegetation during the second year. In part this is due to their success during the first growing year in which numerous seeds were produced. In the second year, these seeds all start to germinate and the resulting interspecies competition for resources can kill many of the seedlings. As a result, herbaceous perennials begin to dominate during the second year following a disturbance. Non-native and early successional grasses and forbs form colonies through rhizomial expansion. In most areas woody species become established shortly thereafter with seeds from the surrounding area. Eventually most old-fields will become shrubby woodlands and then forests. However, if a native grassland area adjoins the abandoned farmland, cutting and treating stumps with herbicides along with prescribed burns can control woody species encroachment. Short-term annuals and perennials common in the early successional stages are pushed to the margins of the site while longer-lived, more conservative species invade and dominate the central portions.

Native species movement into an old-field is often slow since the further a disturbed area is from the desired source of seed, in this case the prairie remnant, the longer it will take for the native seeds to travel to the area and become established (Wochler and Martin 1980, Holt et. al. 1995). Often seeds travel a short distance, germinate, establish plants and produce seed that moves further into an old-field. Even after native species become established and replace many of the non-native species, non-native and early successional native seeds often persist for long periods of time in the seed bank. Consequently, when there are small, localized disturbances, the species can reestablish themselves even if it has not been present in the vegetation for years.

Seed rain consists of seeds that fall from adult plants or are otherwise dispersed onto the soil (Cheplick 1998). Seeds are dispersed by passive or active methods, with most seeds landing within a few meters of the parent plant. Passive methods include adhesion to animals, wind and water dispersal. Active methods include ingestion by animals and subsequent transport, such as by ants or birds.

Seeds that do not germinate within a short time after falling to the ground become part of the seed bank in the soil. The seeds in the seed bank generally originate from previous and existing vegetation. Seeds present in the soil are part of the transient or persistent seed bank. The transient seed bank consists of seeds that are viable for one growing season. The persistent seed bank consists of seeds that remain viable for two or more growing seasons (Cheplick 1998). The seed bank is a source of new plants for a community following a disturbance.

Seed bank studies began in England in an attempt to estimate the amount of seeds in arable soils (Brenchley 1918). Most early studies examined seed bank germination in pastures and plowed fields (Brenchley and Warrington 1930, Champness and Morris 1948). In the United States, prairie seed bank studies began in the mid 1900s in the short and mid-grass prairies (Lippert and Hopkins 1950). In the tallgrass prairie region the seed banks began to be studied in the early 1980s (Johnson and Anderson 1986, Schott and Hamburg 1997).

Johnson and Anderson (1986) compared the aboveground vegetation in an Illinois blacksoil prairie remnant to the seed bank and found a majority of seeds were present in the top 2 cm of soil. Two studies have examined the seed rain and seed bank in a blacksoil tallgrass prairie and an adjoining old-field (Rabinowitz and Rapp 1980, Schott and Hamburg 1997). In Missouri, Rabinowitz and Rapp (1980) found the seed density was 71% less in the seed bank than in the seed rain. Certain species had a high mortality rate, while others accumulated in the soil. Schott and Hamburg (1997) studied a blacksoil remnant prairie and old-field in Kansas. While there were twice the number of species present in the remnant prairie vegetation, the seed rain in the old-field was twice that of the remnant. In addition, the old-field contained three times more viable seeds in the seed bank than the remnant.

Seed bank research on sand prairies are scarce, with one study by Perez et.al. (1998) on a Nebraska sandhill prairie. The seed bank was dominated by annual forbs, while perennial native grasses and forbs dominated the aboveground vegetation.

Most prairie and old-field succession studies focus on vegetation changes while some examine data for the seed rain. Understanding the relationships between the vegetation, seed rain and seed bank will provide a more complete picture of secondary succession.

An ideal study site to examine secondary succession is a remnant prairie with an adjoining abandoned agricultural field that has not had native seeds spread deliberately by humans. Such a situation exists at the Cedar Hills Sand Prairie. The location of a sand prairie remnant adjacent to an old-field that has not been farmed for 25 years provided an excellent opportunity to study secondary succession.

CHAPTER 2

STUDY SITE

The research was conducted at the Cedar Hills Sand Prairie Preserve which is owned and managed by the Iowa Chapter of The Nature Conservancy. The 36 ha preserve is located at SW 1/4, NW 1/4, Section 19 in Union Township (T 90N, R 14W) 16 km northwest of Cedar Falls in Black Hawk County, on the east side of Butler Road 5.5 km north of Route 20 (Crum 1972, Glenn-Lewin 1980). It consists of a 22 ha old agricultural field to the north and a 14 ha remnant sand prairie to the south. The north and west boundaries of the preserve are bordered by Mark Road and Butler Road. To the east of the prairie is a field, pond, pine plantation and a pasture. An agricultural field, abandoned pasture and a marsh border the preserve to the south.

Cedar Hills Sand Prairie is near the eastern edge of a band of low hills located between Beaver Creek, 3 km to the south, and the west fork of the Cedar River, 4 km to the north (Crum 1972). The elevation is between 274 m and 282 m above sea level (Glenn-Lewin 1980). The preserve is located on an eolian sand ridge (Fouts and Highland 1978) (Figure 1).

The study site at Cedar Hills Sand Prairie (Figures 1 and 2) is located in Sparta loamy fine sand #41 with a slope of 0 to 2 percent (USDA 1978). The flora is classified as xeric upland mixed grass prairie (Crum 1972, USDA 1978). Crum (1972) compiled the first species list consisting of 280 species for the remnant prairie. Freese (1999) recorded a total of 385 species for the remnant and old-field.

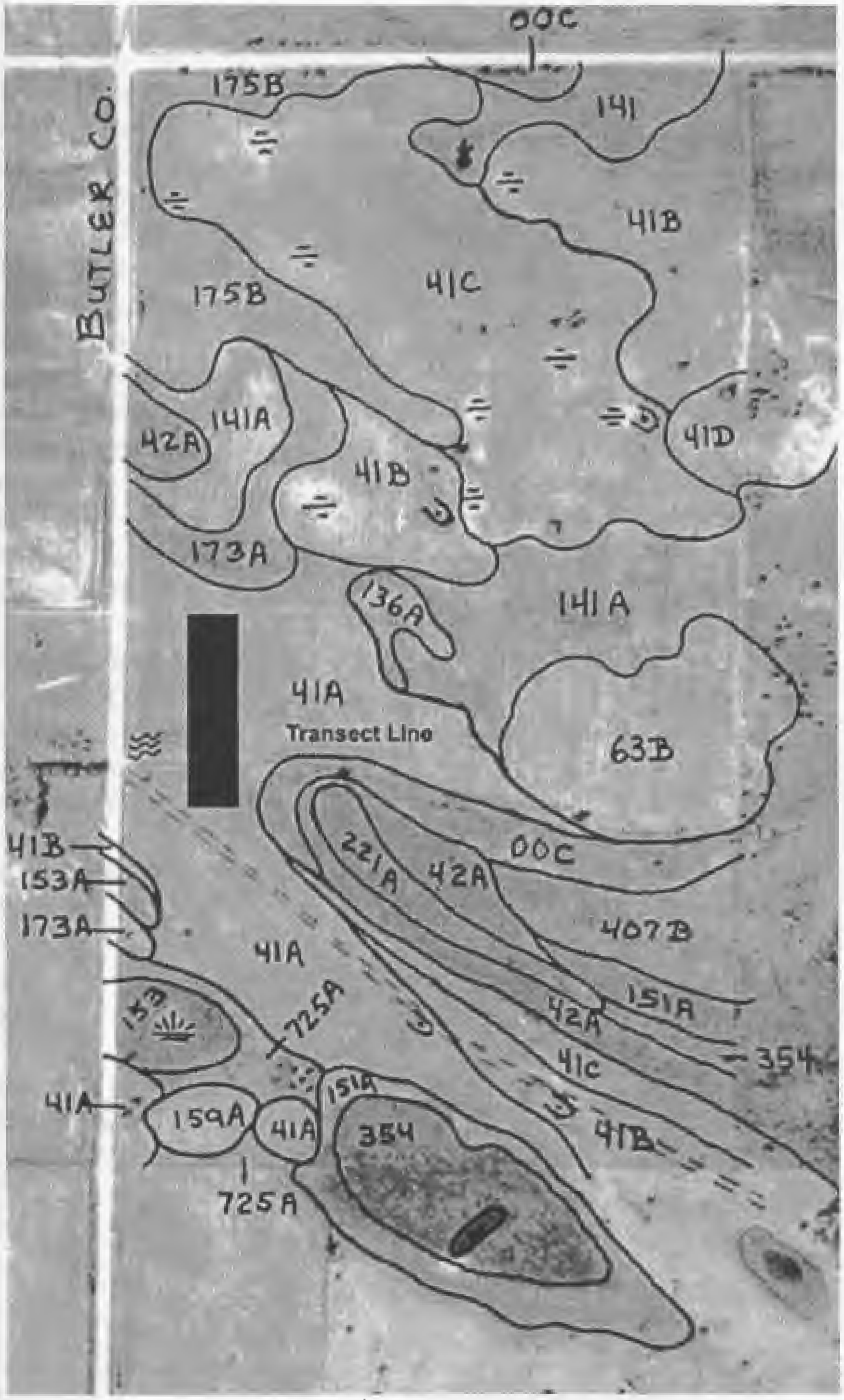

Figure 1: Map of the Cedar Hills Sand Prairie showing the study site, community, and soil types. The black rectangular box encompasses the study site. Soil type and distribution is from the USDA (1978) and was updated in 2003. Arial map obtained from Dr. Daryl Smith (2004). "figure continues"

Figure 1 cont.

00	Maumee loamy sand
41	Sparta fine loamy sand
42	Granby sandy loam
63	Chelsea fine loamy sand
136	Ankeny fine loamy sand
141	Watseka loamy sand
151	Marshan clay loam
153	Shandep loam
159	Finchford loamy sand
173	Hoopeston sandy loam
175	Dickinson fine sandy loam
221	Palms muck
354	Marsh
407	Schley loam, variant
725	Hayfield loam

A slope= 0-2 percent slopes
B slope=2-5 percent slopes
C slope=5-9 percent slopes
D slope=9-14 percent slopes
(354) is depressional

wet spot, depressional
severely eroded
marsh
sand blowout
sand spot
water
parking area
abandoned road bed?

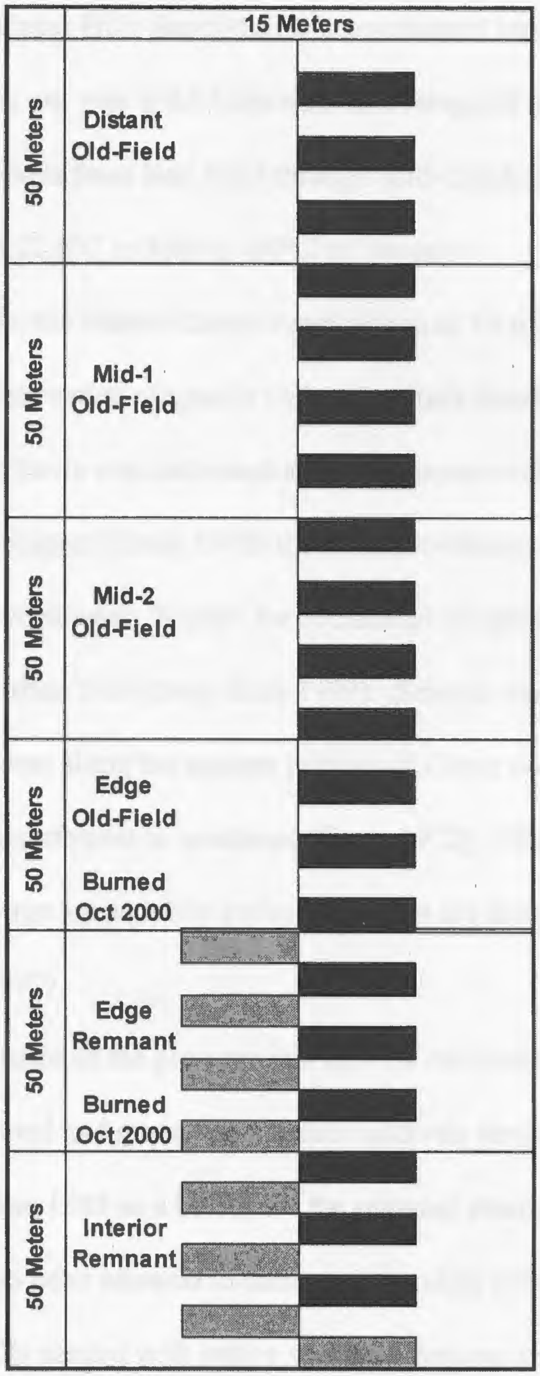

Figure 2: Diagram of the Cedar Hills Sand Prairie transect showing the six, 50 m long sub-sites, the number of plots within each site for 2000 and 2001 and which sub-sites were burned in the fall of 2000. Dark quadrats were sampled in 2000 and 2001 and the light colored quadrats were sampled during 2001.

The climate for Cedar Hills Sand Prairie is continental humid (Willoughby 1995). The average precipitation per year is 84.1 cm with an average of 61.7 cm of snowfall. The active growing season is from late April through mid-October. The average temperature ranges from 22.6°C in July to -10°C in January.

In the early 1980s, the Nature Conservancy acquired 14.6 ha of remnant prairie on the southern third of the preserve, originally called the Mark Sand Prairie. On 18 May 1985, Cedar Hills Sand Prairie was dedicated as a state preserve (Stoll-Slife 1999). According to Mr. H. H. Siepert (Crum 1972) the remnant was occasionally grazed by cattle until 1965 but never plowed. Except for occasional escaped farm animals, the remnant was not grazed after 1965 (Stoll-Slife 1999). Several oval depressions and former blowouts are present along the eastern portion of a long sand ridge that extends across the remnant from northwest to southeast (Crum 1972). The northeast portion of the remnant contains a large swale while pothole marshes are found on the south section of the preserve (Crum 1972).

The north component of the preserve is a 21.6 ha old-field. Various portions of the old-field were cultivated and grazed at different intervals through 1976. The old-field was acquired in September 1985 as a buffer for the remnant prairie. The old-field adjoining the remnant has been allowed to undergo secondary succession back to prairie and has not been manually seeded with native species. Portions of the far north section have been seeded with seed collected from the remnant prairie (Smith, pers. comm.).

In late April 1975, while still under private ownership by the Mark family, the first prescribed burn was conducted on the 14 ha remnant prairie (Glen-Lewin 1980).

Since that time, the preserve has undergone periodic prescribed burns including one in the fall of 1999 when the remnant and old-field study site were burned and in the fall of 2000, when the edge remnant and edge old-field were part of a prescribed burn.

White (1978) developed a grading system to assess the natural quality of an area. The scale ranged from a grade of A, a stable or undisturbed area, to a grade of E, an early successional stage. The system considers observed changes in natural diversity, structure, species composition, and successional stability in a community in determining a natural area's grade. Using this scale, study areas in the remnant sand prairie and old-field were assessed and assigned a grade.

CHAPTER 3

METHODS

The vegetation, seed bank and seed rain were studied during 2000 and 2001. The species composition and canopy coverage of the vegetation were sampled in the remnant prairie and old-field study site. Seeds were collected in traps scattered through the study site to sample the seed rain. In the spring and fall of 2000 soil cores were collected to study the seed bank.

Vegetation

During the summer and fall of 2000 and 2001, the remnant and old-field vegetation was sampled along a transect line 302 m in length. Quadrats (2 m by 5 m) were placed every fifteen meters along transect lines. The quadrats were randomly divided into 10 sections (1 m^2) and a 0.1 m^2 area was sampled in each section (Figure 3). Each of the ten 0.1 m^2 areas in each quadrat were added together to total a 1 m^2 sampled area. Each species was identified and their percent cover determined. During 2000, 3 quadrats were sampled in each of the following: interior and edge remnant, edge and distant old-field. Both the mid old-field 1 and mid old-field 2 sub-sites each contained 4 quadrats. In 2001, 4 quadrats were added to the both the interior and edge remnant for a total of 7 in each sub-site in order to increase sample size bringing the number of quadrats in both the remnant and old-field up to 14 apiece. No new quadrats were added in the old-field during 2001. The coordinates were mapped using a GPS unit in the fall of 2005 and are presented in Appendix M. Species lists for the preserve compiled by Crum

(1972) and Freese (1999) served as field guides. Nomenclature follows Gleason and Cronquist (1991), except for the grasses that follow Pohl (1968).

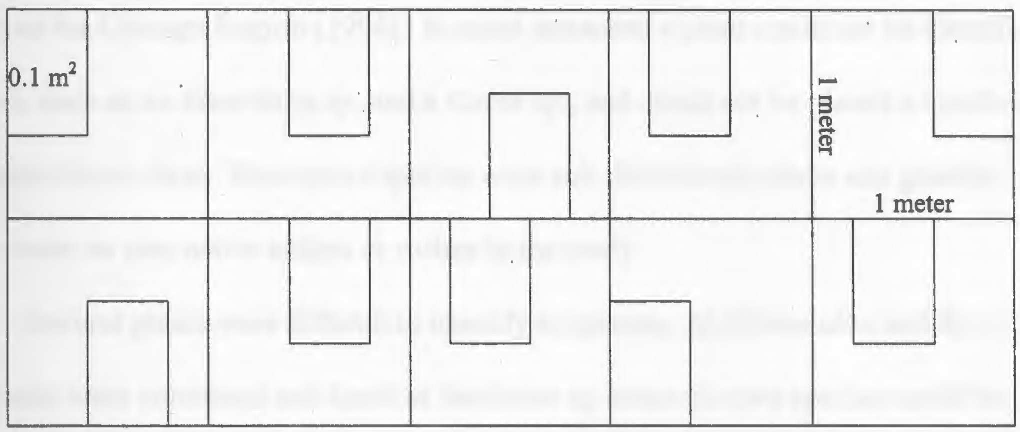

Figure 3: The layout of each two by five m^2 quadrat in the vegetation. Each quadrat was divided into ten, one m^2 sections of which a randomly placed 0.1 m^2 area was sampled.

Within each 0.1 m^2 subsection, the percent of ground covered by the vegetative canopy, gopher mounds and ant hills were recorded. All measurements were visually estimated. Any area of soil not covered by plant material was classified as bare ground. Canopy coverage was estimated for each species and the total cover often exceeded 100% due to species overlap.

The recorded species were divided into several categories to study vegetation changes across the study site. General categories were the total species, total native and total non-native; total grass and total forb species. Native species were divided into native forbs, native grasses and sedges and rushes. In addition, native species were differentiated by coefficient of conservatism classes: early (C: 0-3), mid (C: 4-7) and late

(C: 8-10) successional (Swink and Wilhelm 1994). The native species were split into these three categories depending on its individual coefficient of conservatism number assigned to it on the Iowa species list (unpublished) and based on Swink and Wilhelm's Plants of the Chicago Region (1994). In some instances a plant could not be identified to species, such as an *Eleocharis* sp. and a *Carex* sp., and could not be placed a coefficient of conservatism class. Non-native species were sub-divided into forbs and grasses. There were no non-native sedges or rushes in the study.

Several plants were difficult to identify to species. *Melilotus alba* and *M. officinalis* were combined and listed as *Melilotus* sp. since the two species could be distinguished only while in flower. While the majority of *Dichanthelium* appeared to be *D. oligosanthes* var. *scribnerianum, D. acuminatum* var. *implicatum, D. boreale* and *D. perlongum* are present in the preserve. The genus was recorded as *Dichanthelium* sp. *Rosa arkansana* var. *suffulta* and *R. carolina* were both present and occasionally hybridize; all were recorded as *Rosa* sp. The genus *Solidago* was occasionally recorded as *Solidago* sp., when species identification could not be made. The two most common species were *S. speciosa* and *S. canadensis*; however *S. gigantea, S. missouriensis, S. nemoralis* and *S. rigida* are present in the preserve. Due to the plastic nature of *Ambrosia pilostachya* and *A. artemisiifolia*, the two species were combined for the study and identified as *Ambrosia* sp.

The vegetation was sampled in the mid summer and early fall of 2000 and 2001. Analysis was with a one-way ANOVA followed, when significant ($p \leq 0.05$), by the

Bonferroni Method. Data were occasionally log transformed. There were no significant differences ($p > 0.05$) between the four sampling dates and the data were combined.

To study the vegetative changes across the remnant and old-field in depth, the study site was divided into six, 50 m long sub-sites. The remnant prairie was divided into two sub-sites, the interior (IR) and edge remnant (ER). The old-field was divided in four sub-sites; the edge (EOF), mid-1 (MOF-1), mid-2 (MOF-2) and distant (DOF) old-field.

Seed Bank

Soil samples were collected to determine if differences in the number of seedlings and species that germinated occurred in the seed bank between the remnant and old-field (germinable seed bank). Soil cores were collected in the fall of 2000 from the edge remnant and edge old-field before and after a prescribed burn on 25 October 2000. Analysis was with a one-way ANOVA followed, when significant ($p \leq 0.05$), by the Bonferroni Method.

The soil cores had a diameter of 10.16 cm and a depth of 9 cm. Each soil core had a surface area of 81 cm^2 and a volume of 730 cm^3. Five soil samples were collected at random locations in the edge remnant and five in the edge old-field before and after a controlled burn for a total of 20 soil cores. For the purpose of this study, only the pre-burn samples were used. The data for both the pre-burn and post-burn samples are presented in Appendix F.

The samples were stored in plastic bags, kept moist and cold stratified until 10 January 2001, when the samples were air-dried at room temperature. A 2 mm mesh sieve was used to remove roots, corms and rhizomes to ensure that the germinants originated from the seed bank. The collected soil was spread onto trays over a 4 cm base of sterilized soil and was placed in the University of Northern Iowa greenhouse in order to test the germinable seed bank. Two control trays containing only sterilized soil were interspersed with the seed bank trays to detect any possible contamination. The trays were watered with tap water and kept in ambient light. Germinants that germinated were identified and removed from the trays.

One grass and two herbaceous species could not be identified (Appendix B). Three species, *Ambrosia* sp., *Dichanthelium* sp. and *Melilotus* sp., were identified to genus due to the difficulty of identifying to species level. The genus *Solidago* was not mature enough to identify to species. Testing only the germinable seed bank likely underestimated the seed bank, as some seeds remain dormant. However, additional methods of obtaining seed from the seed bank are difficult and may not provide much additional information (Gross 1990, Thompson and Grime 1979).

Seed Rain

The seed rain was sampled during 2000 and 2001 in the remnant and old-field. The seed trap design was adapted from Schott (1993) and is similar to one used to collect insects (Figure 4). The trap consisted of a 15 cm long and 7.62 cm wide PVC pipe sunk into the ground to a depth of 13 cm. Two cm extended above ground to deter insect entry. A funnel was secured to the top of the PVC pipe with the stem removed to allow seeds to drop into an attached cloth bag. Each soil core had a surface area of 45.6 cm^2.

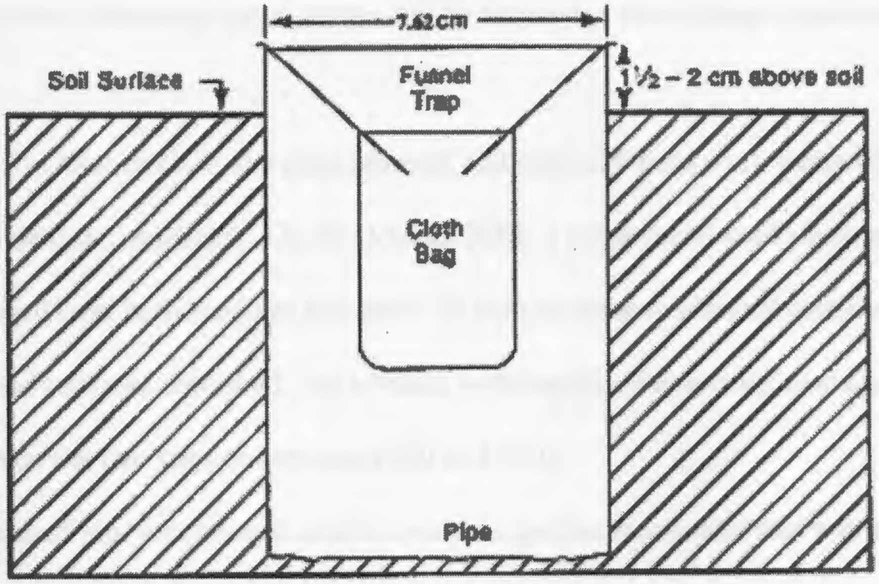

Figure 4: Cross section of the funnel-style seed rain seed trap showing its placement in the ground. Not to scale. Figure modified from Schott (1995).

Permanent seed traps for 2000 and 2001 were placed in the study site in early May and collection of the seed bags began in mid-July. Starting in mid-September the seed bags were collected approximately every two weeks. In both years the seeds were collected on eight different dates until the first snowfall.

The cloth bags containing the seeds were air-dried and stored in plastic bags. These seeds were removed from the bags using forceps and a dissecting scope and identified to species, genus, or family whenever possible. Martin and Barkley (1961), Musil (1963) and other seed manuals were used for identification. The R. H. Runde seed collection and herbarium specimens at The Morton Arboretum herbarium in Lisle, Illinois and the Ada Hayden herbarium and seed laboratory at Iowa State University in Ames, Iowa were also utilized to identify seeds. Sandy Hegna of the Iowa State

University Seed Laboratory (pers. comm. 2002) assisted in identifying a portion of the seeds.

On 25 October 2000, the edge remnant and edge old-field were burned (50 m in the remnant and the old-field). On 20 October 2001, a mechanical seed stripper was used to harvest seed over both remnant sub-sites. In both of these unplanned instances, the potential seed rain was disturbed. As a result, meaningful comparisons could not be made between the two sites or between 2000 and 2001.

The seed rain was instead used to measure species movement that was determined by comparing the trapped seeds to the "local vegetation" reproducing (in fruit or flower) within a 43 cm diameter of the seed traps in the fall of 2000 and 2001. The local vegetation designation was used to determine if seeds present in the seed trap were coming from the surrounding vegetation or if the seeds had to travel to be collected within the seed trap. The local vegetation did not represent the entire community, only the area surrounding each seed trap.

In April 2000, six soil samples were collected in the remnant and the old-field to test for percent organic matter, nitrogen and carbon, calcium and NO3-N. The samples were air dried, stored in plastic bags and analyzed at the Iowa State Soil Laboratory in Ames, Iowa. There were no statistical differences ($p \leq 0.05$) in the carbon, nitrogen or organic matter levels between the remnant and old-field. Statistical analysis was with a one-way ANOVA followed, when significant ($p \leq 0.05$), by the Bonferroni Method.

Information from sampling the vegetation, seed bank and seed rain was used to study the effect of secondary succession in the old-field. Data regarding the coefficient of conservatism, Simpson's conservatism index, percent cover, frequency and importance values were collected (Appendix A).

CHAPTER 4

RESULTS

Remnant and Old-Field Vegetation

Species Richness

Mean species richness was between 20.3 and 25.7 species/m^2 for each sub-site from the IR through the MOF 2 (Table 1). These five sub-sites were typically similar, although the IR contained more species ($p \leq 0.05$) than the MOF 2. There were 8.3 species/m^2 in the DOF, a significant decrease ($p \leq 0.05$) when compared to the other five sub-sites.

The number of native species was highest in the IR and ER, peaking at 23.1 species/m^2 in the ER (Table 1, Figure 5). There were fewer species ($p \leq 0.05$) in the MOF sub-sites (16.4 and 17.4 species/m^2). The DOF contained 5.2 native species/m^2, a significant drop ($p \leq 0.05$) in comparison to the reminder of the study. There were few non-native species/m^2 in the study and the six sub-sites were similar to each other.

The number of early successional species was similar from the IR (8.8 species/m^2) to the MOF 2 (6 species/m^2) (Table 2, Figure 6). With 3.5 species/m^2, the DOF was lower ($p \leq 0.05$) than the IR, ER and EOF and similar to the MOF 1 and 2.

From the IR through the MOF 2, the mean number of mid successional species/m^2 was high and most of the sub-sites similar to each other (Table 2, Figure 6). DOF, with 1.7 species/m^2, was significantly lower ($p \leq 0.05$) than the rest of the study.

The mean number of species/m^2 for the late successional species did not vary greatly across the study area (Table 2). No species were present in the DOF.

Table 1: The mean number of species per m^2 area (± SE) in the vegetation within ten categories for the six sub-sites. Analysis was with a one-way ANOVA followed, when significant ($p \leq 0.05$), by the Bonferroni Method.

	Interior Remnant	Edge Remnant	Edge Old-Field	Mid Old-Field 1	Mid Old-Field 2	Distant Old-Field	P-Value
Total Species	23.5 ± 0.9^{ab}	25.7 ± 1.4^{a}	23.2 ± 1.9^{ab}	21.1 ± 1.3^{ab}	20.3 ± 1.4^{b}	8.3 ± 0.5^{c}	0.000
Total Forb	16.4 ± 0.9^{ab}	18.5 ± 1.2^{a}	14.0 ± 1.3^{ab}	14.0 ± 1.3^{ab}	12.4 ± 1.1^{b}	5.5 ± 0.3^{c}	0.000
Total Grass	6.2 ± 0.2^{a}	6.4 ± 0.2^{a}	5.2 ± 05^{ab}	4.4 ± 0.5^{bc}	5.1 ± 0.4^{ab}	2.8 ± 0.2^{c}	0.000
Total Native	20.4 ± 0.7^{ab}	23.1 ± 1.5^{a}	19.2 ± 1.4^{ab}	17.4 ± 1.2^{b}	16.4 ± 1.5^{b}	5.2 ± 0.5^{c}	0.000
Forb	14.7 ± 0.7^{ab}	17.5 ± 1.2^{a}	12.3 ± 1.0^{b}	12.5 ± 1.2^{b}	11.1 ± 1.1^{b}	4.3 ± 0.3^{c}	0.000
Grass	4.9 ± 0.2^{a}	4.8 ± 0.4^{a}	2.8 ± 0.3^{b}	2.1 ± 0.3^{bc}	2.5 ± 0.4^{b}	0.8 ± 0.2^{c}	0.000
Sedge and Rush	0.8 ± 0.1^{a}	0.8 ± 0.1^{a}	4.0 ± 0.5^{b}	2.8 ± 0.7^{ab}	2.8 ± 0.9^{ab}	0.0 ± 0.0^{a}	0.000
Total Non-Native	3.1 ± 0.3^{a}	2.6 ± 0.4^{a}	4.0 ± 0.5^{a}	3.8 ± 0.3^{a}	3.9 ± 0.2^{a}	3.2 ± 0.3^{a}	0.261
Forb	1.7 ± 0.2^{a}	1.0 ± 0.3^{a}	1.7 ± 0.3^{a}	1.5 ± 0.3^{a}	1.3 ± 0.3^{a}	1.2 ± 0.3^{a}	0.121
Grass	1.4 ± 0.2^{a}	1.6 ± 0.2^{a}	2.3 ± 0.3^{ab}	2.3 ± 0.3^{ab}	2.6 ± 0.2^{b}	2.0 ± 0.0^{ab}	0.000

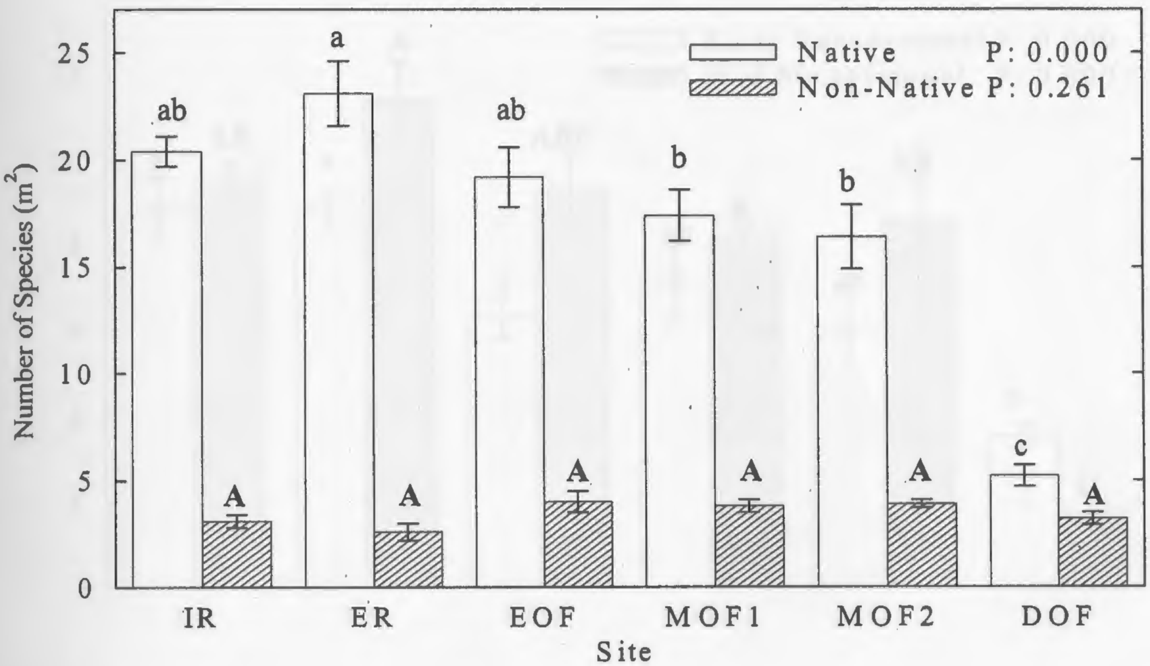

Figure 5: Mean number of native and non-native species/m^2 (± SE) in the vegetation for the six sub-sites. Analysis was with a one-way ANOVA followed, when significant ($p \leq 0.05$), by the Bonferroni Method.

Table 2: The mean number of species per m^2 area (± SE) in the vegetation for the early, mid and late successional species within the six sub-sites. Analysis was with a one-way ANOVA followed, when significant ($p \leq 0.05$), by the Bonferroni Method. Values are compared within each column.

	Early Successional	Mid Successional	Late Successional
Interior Remnant	8.8 ± 0.8^{a}	9.5 ± 0.5^{ab}	1.9 ± 0.9^{ab}
Edge Remnant	8.8 ± 0.4^{a}	11.4 ± 0.9^{a}	2.7 ± 0.5^{b}
Edge Old-Field	6.3 ± 0.5^{a}	9.3 ± 0.8^{abc}	2.3 ± 0.4^{b}
Mid Old-Field-1	7.1 ± 0.9^{ab}	8.1 ± 0.3^{b}	1.8 ± 0.5^{b}
Mid Old-Field-2	6.0 ± 0.9^{ab}	8.6 ± 1.0^{ab}	1.6 ± 0.5^{b}
Distant Old-Field	3.5 ± 0.3^{b}	1.7 ± 0.4^{c}	0.0 ± 0.0^{a}
P-Value	0.000	0.000	0.000

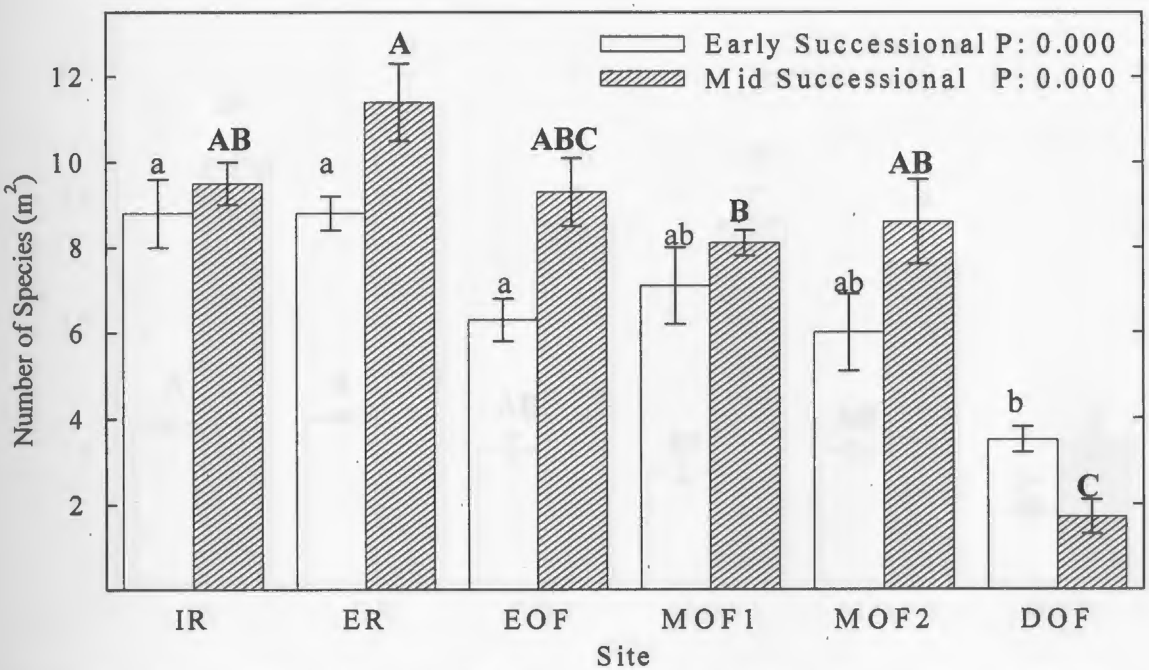

Figure 6: Mean number of early and mid successional native species/m^2 (± SE) in the vegetation for the six sub-sites. Analysis was with a one-way ANOVA followed, when significant ($p \leq 0.05$), by the Bonferroni Method.

The mean number of sedge and rush species in the IR and ER were 0.8 species/m^2 (Table 1). They peaked ($p \leq 0.05$) at 4.0 species/m^2 in the EOF. No sedges or rushes were in the DOF, yet the mean number of species was similar to the IR and ER.

There was little variation in the number of grass species from the IR through the MOF 2 (Table 1, Figure 7). The DOF was lower ($p \leq 0.05$) than all the sub-sites except the MOF 1. With one exception, the number of forb species/m^2 was similar from the IR through the MOF 2. The number of forb species peaked in ER (18.5 species/m^2) which was significantly ($p \leq 0.05$) higher than the MOF 2 (12.4 species/m^2). The mean number of forbs dropped ($p \leq 0.05$) in the DOF where there were 5.5 species/m^2.

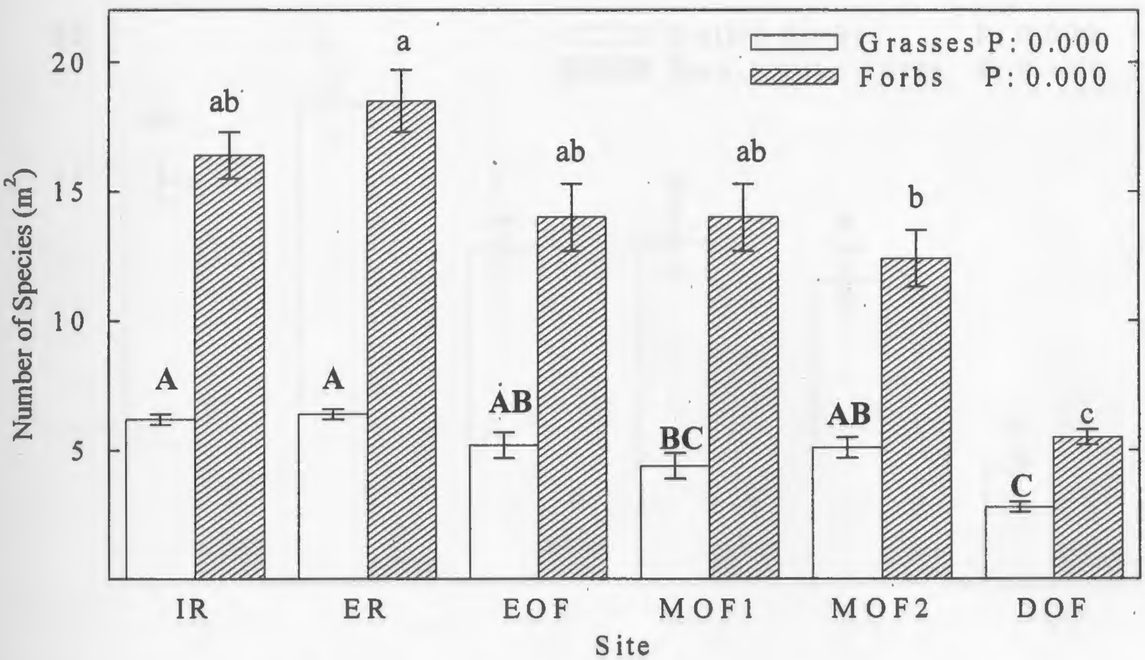

Figure 7: Mean number of grass and forb species/m^2 (± SE) in the vegetation for the six sub-sites. Analysis was with a one-way ANOVA followed, when significant ($p \leq 0.05$), by the Bonferroni Method.

Native forbs were highest in the ER (17.5 species/m^2), though the remnant sub-sites were similar to each other (Table 1, Figure 8). While the IR was similar to the EOF, MOF 1 and 2, the Mean number of native forbs in the ER was higher ($p \leq 0.05$) than the old-field sub-sites. Between the MOF-2 and the DOF, native forbs significantly ($p \leq 0.05$) dropped from 11.1 species/m^2 to 4.3 species/m^2. There were few non-native forb species and they did not vary across the study site.

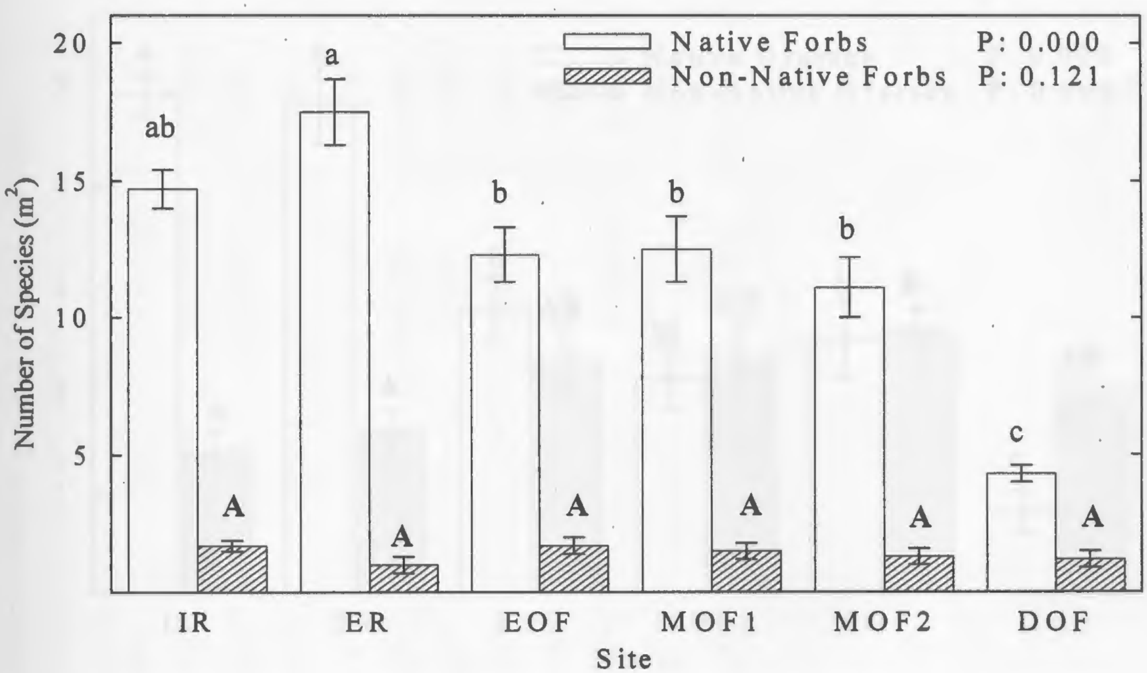

Figure 8: Mean number of native and non-native forb species/m^2 (± SE) in the vegetation for the six sub-sites. Analysis was with a one-way ANOVA followed, when significant ($p \leq 0.05$), by the Bonferroni Method.

Averaging approximately 5.0 species/m^2, there were more ($p \leq 0.05$) native grasses in the IR and ER than in the old-field, whose mean was between 2.1 and 2.8 species/m^2 (Table 1, Figure 9). The mean number of non-native grasses was similar across the study, although the remnant sub-sites had fewer ($p \leq 0.05$) species than the MOF 2.

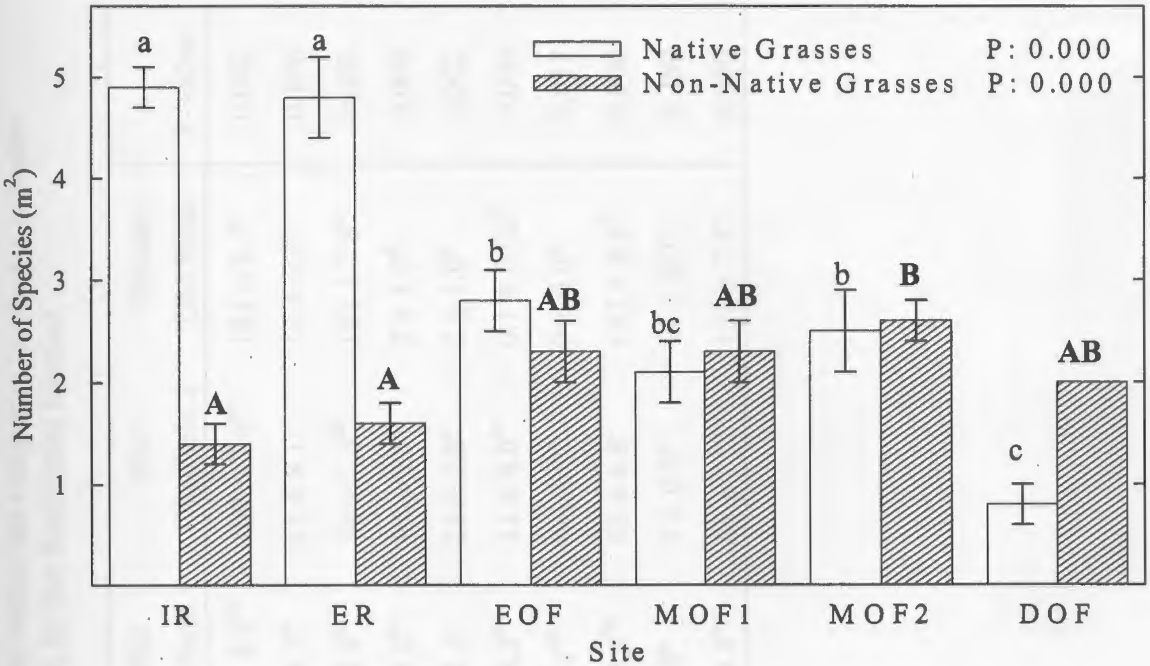

Figure 9: Mean number of native and non-native grass species/m^2 (± SE) in the vegetation for the six sub-sites. Analysis was with a one-way ANOVA followed, when significant ($p \leq 0.05$), by the Bonferroni Method.

Canopy Cover

Excluding the late successional native species, the canopy cover between the IR and ER was the same (Tables 3 and 4). The total species had the lowest cover in the remnant and peaked ($p \leq 0.05$) in the DOF, from 94% in the IR to 134% in the DOF.

The canopy cover of native species was similar between the IR, ER and EOF, ranging from 60% to 71% (Table 3, Figure 10). In the MOF 1 and 2, native cover dropped ($p \leq 0.05$) to 37% and 44%, respectively. Native cover was 2% in the DOF, significantly lower ($p \leq 0.05$) than the other five sub-sites. Conversely, non-native cover was lowest in the IR, ER and EOF and increased ($p \leq 0.05$) across the remaining old-field sub-sites. Non-native cover was four times higher in the DOF than the IR and ER.

Table 3: The mean percent canopy cover per m^2 area (± SE) in the vegetation within ten categories for the six sub-sites. Analysis was with a one-way ANOVA followed, when significant ($p \leq 0.05$), by the Bonferroni Method.

	Interior Remnant	Edge Remnant	Edge Old-Field	Mid Old-Field 1	Mid Old-Field 2	Distant Old-Field	P-Value
Total Species	94 ± 6.0^{a}	102 ± 5.7^{ab}	99 ± 8.6^{ab}	124 ± 4.9^{bc}	109 ± 7.6^{bc}	134 ± 8.5^{c}	0.002
Total Forb	32 ± 3.1^{a}	34 ± 6.3^{a}	35 ± 5.1^{a}	27 ± 4.3^{a}	25 ± 8.1^{a}	13 ± 6.3^{b}	0.156
Total Grass	62 ± 8.3^{a}	65 ± 7.7^{ab}	70 ± 7.9^{ab}	94 ± 4.9^{bc}	74 ± 7.3^{ab}	121 ± 7.8^{c}	0.000
Total Native	60 ± 4.9^{abc}	65 ± 5.4^{ac}	71 ± 8.6^{a}	37 ± 5.0^{bc}	44 ± 5.9^{c}	2 ± 1.0^{d}	0.000
Forb	30 ± 3.4^{a}	33 ± 6.0^{a}	31 ± 6.3^{a}	23 ± 2.4^{a}	24 ± 7.8^{a}	2 ± 1.0^{b}	0.002
Grass	30 ± 4.8^{ab}	30 ± 5.1^{ab}	45 ± 6.0^{a}	12 ± 4.5^{bc}	11 ± 4.0^{bc}	0.1 ± 0.02^{c}	0.000
Sedge and Rush	0.3 ± 0.3^{a}	2 ± 1.0^{ab}	2 ± 0.2^{ab}	3 ± 2.1^{ab}	9 ± 4.0^{b}	0 ± 0.0^{a}	0.017
Total Non-Native	34 ± 6.8^{a}	37 ± 4.7^{a}	28 ± 6.7^{a}	86 ± 5.1^{bc}	65 ± 6.8^{c}	132 ± 9.1^{d}	0.000
Forb	3 ± 0.7^{a}	1 ± 0.6^{a}	4 ± 2.1^{a}	4 ± 2.9^{a}	1 ± 0.5^{a}	11 ± 6.2^{a}	0.269
Grass	32 ± 6.3^{a}	35 ± 4.7^{a}	24 ± 6.7^{a}	90 ± 4.8^{b}	63 ± 7.2^{b}	121 ± 7.8^{c}	0.000

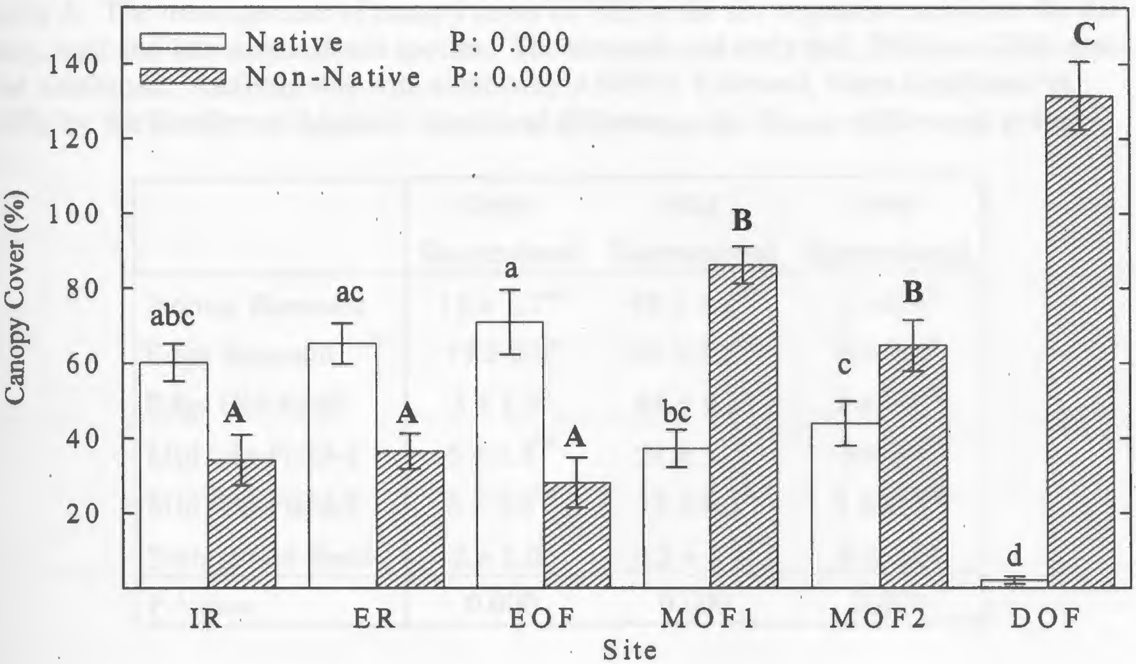

Figure 10: Mean native and non-native percent canopy cover/m^2 (± SE) for the summer and fall, 2000 and 2001 combined vegetation for the six sub-sites. Analysis was with a one-way ANOVA followed, when significant ($p \leq 0.05$), by the Bonferroni Method.

The early successional canopy cover was highest ($p \leq 0.05$) in the ER, which was only similar to the IR (Table 4, Figure 11). The canopy cover in all four old-field sub-sites was similar to each other and was lower ($p \leq 0.05$) than the ER.

Mid successional canopy cover was similar between the IR, ER, MOF 1 and 2, ranging between 29% and 49% (Table 4, Figure 11). The cover spiked in the EOF at 64%. The EOF cover was similar to the IR and ER and significantly higher ($p \leq 0.05$) than the MOF 1 and 2. Canopy cover was lowest ($p \leq 0.05$) in the DOF at 0.2%. The DOF was the only sub-site in which the early successional canopy was higher than the mid successional natives. There was little variation across the study for the late successional cover, despite there being no late successional species in the DOF (Table 4).

Table 4: The mean percent of canopy cover (± SE) in the six vegetative sub-sites for the early, mid and late successional species. The summer and early fall, 2000 and 2001 data was combined. Analysis was with a one-way ANOVA followed, when significant ($p \leq 0.05$), by the Bonferroni Method. Statistical differences are shown within each column.

	Early Successional	Mid Successional	Late Successional
Interior Remnant	11 ± 1.7^{ac}	48 ± 5.1^{ab}	1 ± 0.4^{a}
Edge Remnant	15 ± 3.0^{a}	42 ± 5.5^{ab}	9 ± 2.4^{b}
Edge Old-Field	3 ± 1.0^{b}	64 ± 9.3^{a}	2 ± 0.9^{ab}
Mid Old-Field-1	5 ± 1.3^{bc}	29 ± 5.7^{b}	3 ± 2.1^{a}
Mid Old-Field-2	5 ± 1.2^{bc}	33 ± 6.3^{b}	5 ± 2.8^{ab}
Distant Old-Field	2 ± 1.0^{b}	0.2 ± 0.1^{c}	0 ± 0.0^{a}
P-Value	0.000	0.000	0.000

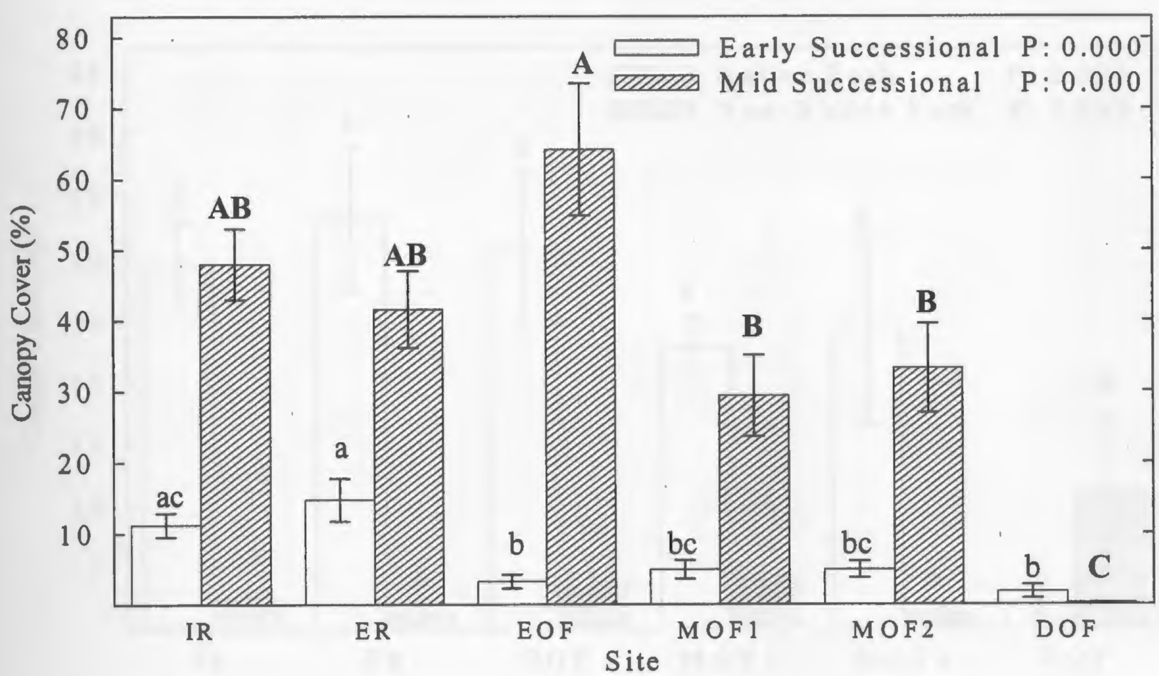

Figure 11: Mean early and mid successional native percent canopy cover/m^2 (± SE) for the summer and fall, 2000 and 2001 combined vegetation for the six sub-sites. Analysis was with a one-way ANOVA followed, when significant ($p \leq 0.05$), by the Bonferroni Method.

Sedge and rush cover was low in the IR, highest in the MOF 2 and non-existent in the DOF (Table 3). Canopy cover was similar between the IR and MOF 1 and between the ER and MOF 2. Cover was higher ($p \leq 0.05$) in the MOF 2 than the IR.

From the IR to the MOF 2, the forb canopy cover was similar, dropping ($p \leq 0.05$) in the DOF (Table 3). The DOF grass canopy cover was 121%, higher ($p \leq 0.05$) than all sub-sites except the MOF 1. Otherwise the grass cover was similar between the sub-sites.

Native forb cover was similar from the IR through the MOF 2 (Table 3, Figure 12) then dropped ($p \leq 0.05$) in the DOF, from 24% to 2%. Non-native forb cover was low and did not vary across the study.

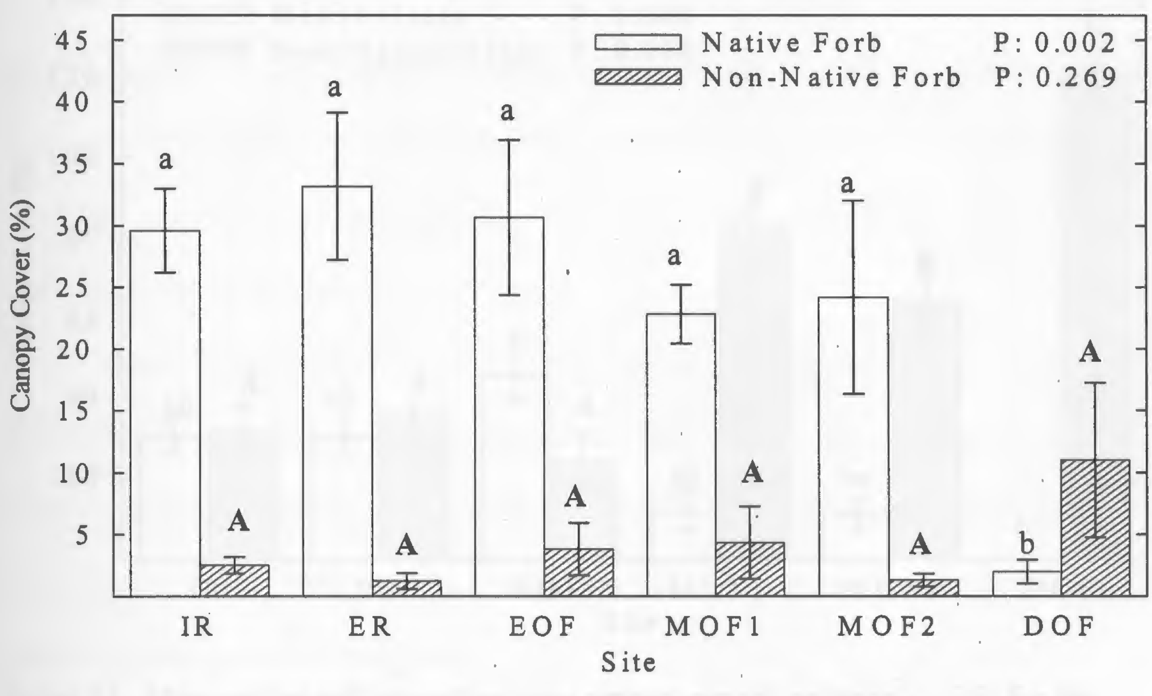

Figure 12: Mean native and non-native forb percent canopy cover/m^2 (± SE) for the summer and fall, 2000 and 2001 combined vegetation for the six sub-sites. Analysis was with a one-way ANOVA followed, when significant ($p \leq 0.05$), by the Bonferroni Method.

The native grass canopy cover was similar in the two remnant sub-sites (30% in both sub-sites) and the EOF, where the cover peaked at 45% (Table 3, Figure 13). The cover in the MOF 1 and 2 (12 and 11%, respectively) was similar to the remnant sub-sites. The native grass cover, at 0.2% in the DOF, was significantly ($p \leq 0.05$) lower than the remnant and EOF, yet similar to the MOF sub-sites. The non-native grass canopy cover was similar between the IR, ER and EOF, ranging from 24% to 35%. The MOF 1 and 2 were similar to each other (82 and 63% respectively) and the cover was higher ($p \leq 0.05$) than the IR, ER and EOF. The highest ($p \leq 0.05$) cover of 121% was in the DOF.

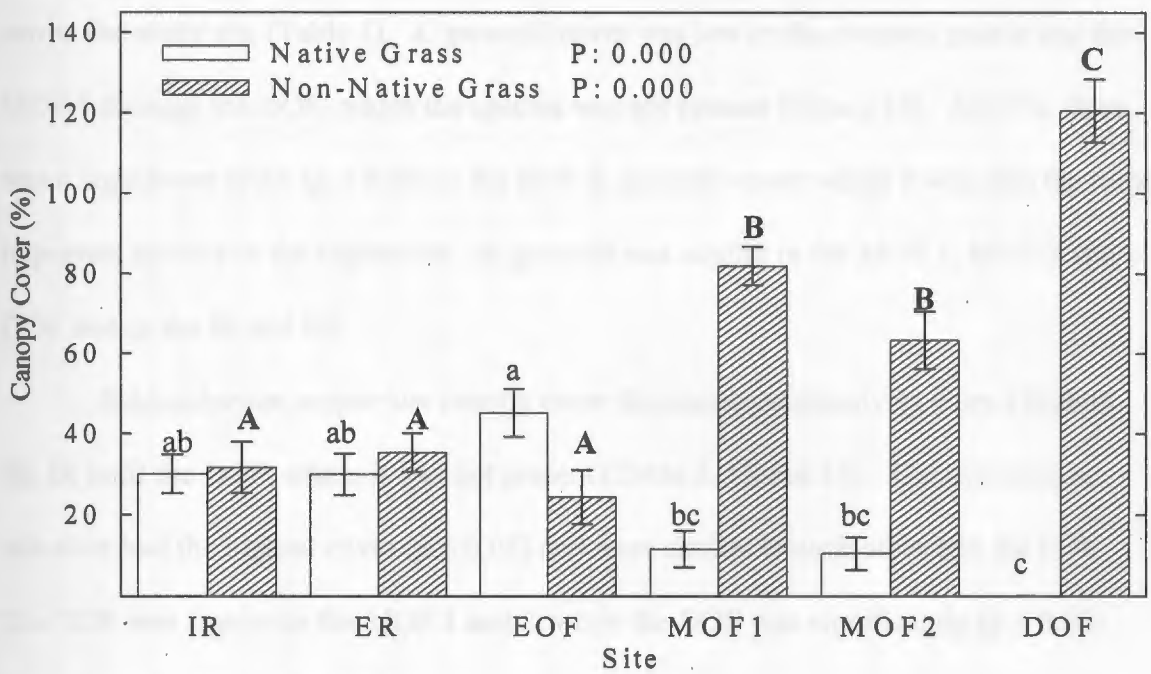

Figure 13: Mean native and non-native grass percent canopy cover/m^2 (± SE) for the summer and fall, 2000 and 2001 combined vegetation for the six sub-sites. Analysis was with a one-way ANOVA followed, when significant ($p \leq 0.05$), by the Bonferroni Method.

Individual Species

Eighteen of the 93 recorded species had an importance value of six or greater in at least one of the six sub-sites (Appendix E). Twelve of the species had significant changes ($p \leq 0.05$) in cover across the study area (Table 5). The twelve species included three native and two non-native grasses, four native and two non-native forbs, and one sedge species. There was no difference across the study for the remaining six species, *Aster ericoides, Euphorbia corollata, Helianthus grosseserratus, Physalis heterophylla, Sorghastrum nutans,* and *Spiraea alba.*

Three native mid-successional grasses, *Andropogon gerardii, Dichanthelium* sp. and *Schizachyrium scoparium* had significant changes ($p \leq 0.05$) in the canopy cover across the study site (Table 5). *A. gerardii* cover was low in the remnant prairie and the MOF 1 through the DOF, where the species was not present (Figure 14). At 23%, there was a significant spike ($p \leq 0.05$) in the EOF *A. gerardii* cover where it was also the most important species in the vegetation. *A. gerardii* was similar in the MOF 1, MOF 2 and DOF and in the IR and ER.

Schizachyrium scoparium canopy cover decreased progressively from a high in the IR until the DOF, where it was not present (Table 5, Figure 14). The two remnant sub-sites had the highest cover ($p \leq 0.05$) and were similar to each other and the EOF. The EOF was similar to the MOF 1 and 2, while the DOF was significantly ($p \leq 0.05$) lower than the rest of the study sites.

Dichanthelium sp. cover was low throughout the study, never covering more than 0.4% of the ground. It was the only native grass present in all six sub-sites.

Table 5: The average percent of canopy cover (± SE) in the six vegetative sub-sites for twelve common species. The mid summer and early fall, 2000 and 2001 sampled quadrats were combined. Statistical differences are presented across the study site using a 95% confidence interval.

	Interior Remnant	Edge Remnant	Edge Old-Field	Mid Old-Field 1	Mid Old-Field 2	Distant Old-Field	P-Value
Achillea millefolium	1.4 ± 0.4^{a}	0.2 ± 0.2^{b}	0.2 ± 0.1^{bc}	0.4 ± 0.1^{bc}	0.2 ± 0.1^{c}	0.1 ± 0.1^{c}	0.000
Ambrosia sp.	0.9 ± 0.3^{a}	0.6 ± 0.2^{ab}	0.5 ± 0.5^{ab}	0.1 ± 0.1^{b}	0.1 ± 0.1^{b}	0.3 ± 0.3^{ab}	0.006
Andropogon gerardii	5.3 ± 1.2^{a}	3.8 ± 1.0^{ab}	22.7 ± 3.5^{d}	1.6 ± 0.7^{bc}	0.5 ± 0.4^{c}	0.0 ± 0.0^{c}	0.000
Bromus inermis	0.02 ± 0.01^{a}	0.6 ± 0.5^{a}	5.3 ± 5.2^{ab}	3.8 ± 1.6^{b}	10.5 ± 2.5^{c}	57.3 ± 6.1^{d}	0.000
Carex conoidea	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	0.4 ± 0.2^{a}	0.7 ± 0.4^{b}	1.9 ± 1.4^{b}	0.0 ± 0.0^{a}	0.012
Dichanthelium sp.	0.3 ± 0.1^{abc}	0.4 ± 0.2^{abc}	0.01 ± 0.0^{ac}	0.6 ± 0.2^{ab}	0.3 ± 0.1^{ab}	0.01 ± 0.0^{c}	0.012
Euthamia graminifolia	0.0 ± 0.0^{a}	0.02 ± 0.02^{a}	0.5 ± 0.1^{b}	2.1 ± 0.4^{c}	1.3 ± 0.3^{d}	0.0 ± 0.0^{a}	0.000
Melilotus sp. 2000	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	1.4 ± 1.3^{a}	0.5 ± 0.3^{a}	0.7 ± 0.2^{a}	19.2 ± 7.0^{b}	0.000
Melilotus sp. 2001	0.0 ± 0.0^{ad}	0.0 ± 0.0^{ad}	6.0 ± 4.0^{bc}	4.6 ± 2.7^{b}	0.2 ± 0.1^{ac}	0.0 ± 0.0^{dc}	0.000
Melilotus sp. 2000+2001	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	2.1 ± 1.3^{ab}	2.6 ± 1.4^{b}	0.5 ± 0.2^{ab}	8.4 ± 3.5^{b}	0.000
Poa pratensis	19.3 ± 3.5^{a}	22.4 ± 2.8^{a}	18.4 ± 3.0^{a}	55.9 ± 4.2^{b}	31.2 ± 5.1^{a}	35.0 ± 5.6^{a}	0.000
Rumex acetosella	1.3 ± 0.4^{a}	1.7 ± 1.0^{a}	0.0 ± 0.0^{b}	0.0 ± 0.0^{b}	0.0 ± 0.0^{b}	0.0 ± 0.0^{b}	0.000
Schizachyrium scoparium	13.2 ± 2.4^{a}	10.5 ± 1.9^{a}	7.3 ± 2.2^{ab}	5.0 ± 1.8^{b}	2.8 ± 1.0^{bc}	0.0 ± 0.0^{c}	0.000
Senecio pauperculus	5.9 ± 1.4^{a}	0.9 ± 0.4^{b}	10.8 ± 2.6^{a}	7.2 ± 1.6^{a}	8.3 ± 3.3^{a}	0.0 ± 0.0^{b}	0.000

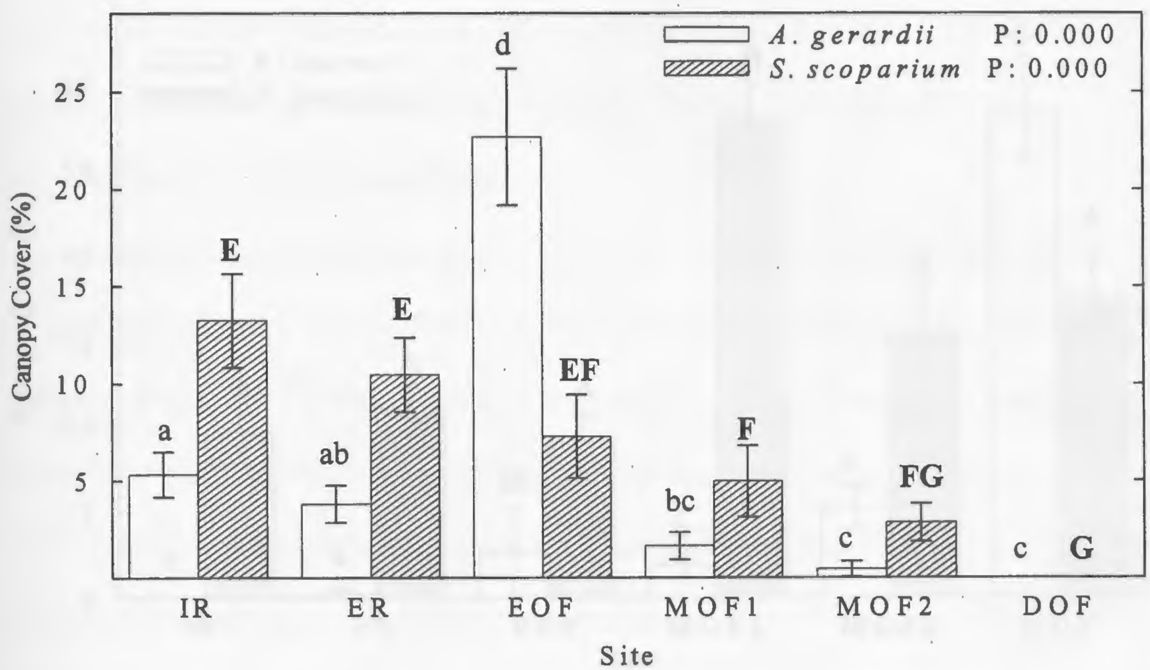

Figure 14: Mean canopy cover/m^2 (± SE) for *Andropogon gerardii* and *Schizachyrium scoparium* in the six vegetative sub-sites. The summer and fall, 2000 and 2001 samples were combined. Analysis was with a one-way ANOVA followed, when significant ($p \leq 0.05$), by the Bonferroni Method.

Bromus inermis and *Poa pratensis* were the only non-native grasses to exhibit significant changes ($p \leq 0.05$) in canopy cover across the study (Table 5, Figure 15). *B. inermis* was almost non-existent in the IR and ER and the cover was similar to that of the EOF. The DOF canopy cover was five times higher in the DOF than in MOF 2, rising from 11 to 57%. There were few significant ($p \leq 0.05$) differences between the six sub-sites for *P. pratensis*. The *P. pratensis* canopy cover was highest in the MOF 1. This was the only sub-site that differed significantly ($p \leq 0.05$) from the other sub-sites.

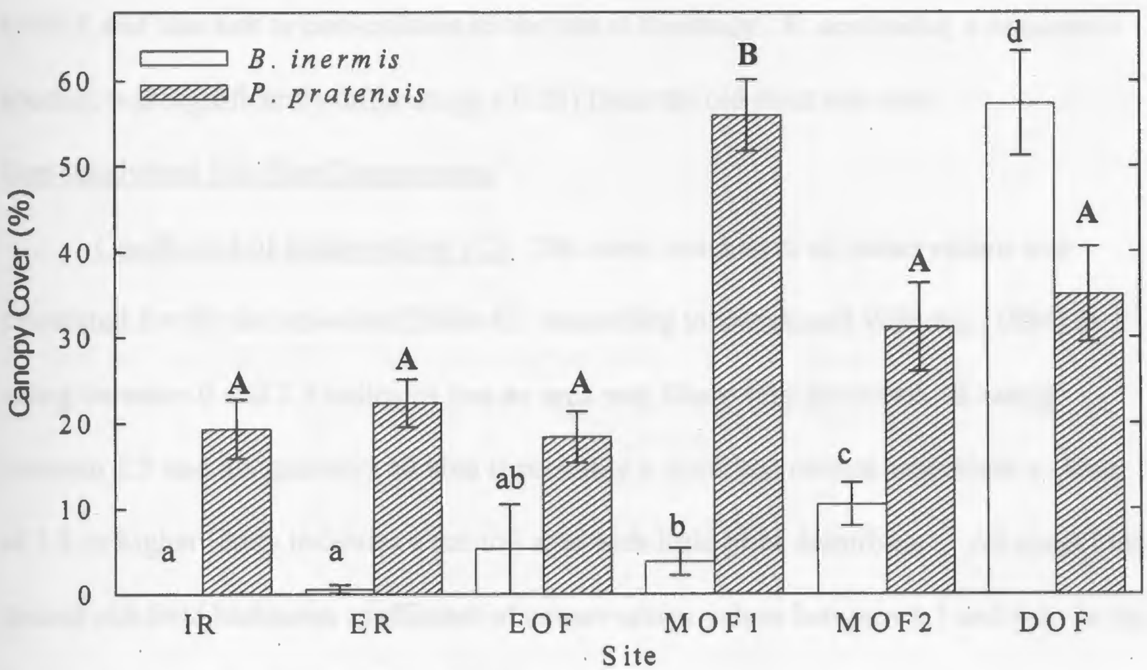

Figure 15: Mean canopy cover/m^2 (± SE) for *Bromus inermis* and *Poa pratensis*. The summer and fall, 2000 and 2001 samples were combined. Analysis was with a one-way ANOVA followed, when significant ($p \leq 0.05$), by the Bonferroni Method.

The MOF 1 and 2 *Carex conoidea* canopy cover differed significantly ($p \leq 0.05$) from the other sub-sites, all of which were similar to one another (Table 5). *C. conoidea* was only present in the EOF, MOF 1 and 2.

Melilotus sp. and *Rumex acetosella* were important non-native forb species that had significant changes ($p \leq 0.05$) in the canopy cover (Table 5). Due to the biennial nature of the *Melilotus* sp., the percent of ground covered varied ($p \leq 0.05$) between 2000 and 2001. In 2000, *Melilotus* sp. was either absent or had a low cover from the IR to the MOF 2 before rising significantly ($p \leq 0.05$) in the DOF. Cover increased from 0.7% in the MOF 2 to 19% in the DOF. During 2001, cover was higher ($p \leq 0.05$) in the EOF and

MOF 1 and was low or non-existent in the rest of the study. *R. acetosella,* a non-native species, was significantly different ($p \leq 0.05$) from the old-field sub-sites.

Non-Analytical Sub-Site Comparisons

Coefficient of conservatism (C). The mean coefficient of conservatism was calculated for the six sub-sites (Table 6). According to Swink and Wilhelm (1994), a rating between 0 and 2.5 indicates that an area was likely very disturbed. A rating between 2.5 and 3.5 indicates an area is probably a disturbed natural area while a rating of 3.5 or higher likely indicates a natural area with little prior disturbance. All except the distant old-field had mean coefficient of conservatism values between 3.5 and 4.2. In the distant old-field the mean dropped to 2.1.

Table 6: The mean coefficient of conservatism values for the six vegetative sub-sites. The mid summer and early fall, 2000 and 2001 sampled quadrats were combined.

	Coefficient of Conservatism
Interior Remnant	4.0
Edge Remnant	3.8
Edge Old-Field	4.1
Mid Old-Field 1	4.2
Mid Old-Field 2	4.1
Distant Old-Field	2.1

Simpson's diversity index. With Simpson's diversity index, the more uniform an area is the closer a value is to zero while the more diverse an area the closer the value is to one. Species diversity was higher in the remnant than in the old-field (0.76 vs. 0.64, respectively) (Table 7). Four of the six sub-sites, the IR and ER, EOF and MOF 2, had high values ranging between 0.71 and 0.77. The MOF 1 and DOF had the lowest species diversity values, 0.57 and 0.55 respectively.

Table 7: Mean Simpson's diversity index (± SE) for the six vegetative sub-sites. The mid summer and early fall, 2000 and 2001 sampled quadrats were combined.

	Simpson's Index
Interior Remnant	0.75 ± 0.02
Edge Remnant	0.77 ± 0.03
Edge Old-Field	0.74 ± 0.02
Mid Old-Field-1	0.58 ± 0.06
Mid Old-Field-2	0.71 ± 0.03
Distant Old-Field	0.55 ± 0.04

<u>Number of species.</u> The IR and ER contained the largest number of species, 56 and 60 respectively (Table 8). From the EOF through the MOF 2 there were between 42 and 48 species. This dropped to 17 species in the DOF. The only major difference between the ER and IR was in the number of late successional species, there were three species in the IR and eight in the ER. There was little variation in the number of species for each category from the EOF to the MOF 2. The sedges and rushes were the only category in which the three mid old-field sub-sites contained more native species than the remnant. The DOF was the most different from the other five sub-sites, although the number of total non-native species and non-native grass species did not vary greatly across the study. The DOF was the only sub-site without any sedges, rushes or late successional native species.

Table 8: Number of species in each of the thirteen categories for the six vegetative sub-sites. The mid summer and early fall, 2000 and 2001 sampled quadrats were combined.

	IR	ER	EOF	MOF1	MOF2	DOF
Total Species	56	60	45	48	42	17
Total Forb	45	50	29	34	29	14
Total Grass	8	9	8	7	7	3
Total Native	47	51	37	40	36	12
Forb	38	44	25	30	26	11
Grass	6	6	4	3	4	1
Sedge and Rush	3	1	8	7	6	0
Early Successional	24	20	14	16	14	9
Mid Successional	19	23	18	19	18	3
Late Successional	3	8	4	4	4	0
Total Non-Native	9	9	8	8	6	5
Forb	7	6	4	4	3	3
Grass	2	3	3	3	3	2

Soil Seed Bank

Site Comparisons

In the test of seeds in the seed bank, 10 soil cores contained 37 species from 910 germinants (Table 9). One hundred thirty germinants from 21 species emerged from the remnant soil cores and 780 germinants from 29 species emerged from the old-field soil cores. The germinants were placed into nine categories: the total, native and non-native species; sedge and rush species; native and non-native forbs and grasses and unknown species.

Table 9: The number of species and germinants from the edge remnant and edge old-field soil cores in nine categories.

	Species		Germinants	
	Remnant	Old-Field	Remnant	Old-Field
Total	21	29	130	780
Native	12	19	54	408
Forb	7	14	20	52
Grass	2	1	2	4
Sedge and Rush	2	4	32	352
Non-Native	7	8	61	308
Forb	5	5	9	34
Grass	2	3	52	274
Unknown	2	2	15	64

There were significantly more ($p \leq 0.05$) total, native, native forb and sedge and rush germinants in the old-field than in the remnant (Table 10). While not always significant, the old-field contained more germinants (actual and mean) than the remnant in all the categories (Table 10).

Table 10: The mean number of germinants/soil core from the edge remnant and edge old-field. Analysis was with a one-way ANOVA followed, when significant ($p \leq 0.05$), by the Bonferroni Method.

	Remnant	Old-Field	P-Value
Total	24 ± 4.8	152 ± 15.6	0.000
Native	11 ± 2.0	82 ± 11.8	0.000
Forb	4 ± 1.4	10 ± 1.6	0.000
Grass	0.4 ± 0.2	1 ± 0.6	0.334
Sedge and Rush	6 ± 1.7	70 ± 10.2	0.000
Non-Native	12 ± 4.1	61 ± 15.7	0.135
Forb	2 ± 0.9	7 ± 1.7	0.000
Grass	10 ± 4.3	55 ± 14.7	0.180

Three species, *Cyperus filiculmis, C. strigosus* and *Poa pratensis* had significantly higher ($p \leq 0.05$) numbers of germinants in the remnant than the old-field (Table 11).

Table 11: The mean number of individual seedlings/soil core in the remnant and old-field seed bank.

	Remnant	Old-Field	P-Value
Cyperus filiculmis	0.0 ± 0.0	1.5 ± 0.6	0.000
Cyperus strigosus	5.6 ± 1.8	74.3 ± 8.6	0.000
Poa pratensis	6.6 ± 1.4	53.6 ± 7.4	0.000

Non-statistical comparisons. There was 6.3 times more germinants in the old-field seed bank than the remnant seed bank. The two main categories in the study were the sedges and rushes and non-native grasses. Of the 910 total germinants, 36% were non-native grasses and 42% were sedges and rushes (Table 12). There was a higher percentage of native and non-native forbs in the remnant samples than the old-field and more of the old-field germinants were composed of sedges and rushes. Within the remaining categories, the ratios appeared to be close between the remnant and old-field.

Table 12: The percent of germinants from the edge remnant and edge old-field cores in nine categories.

	Remnant	Old-Field
Total	100	100
Native	42	52
Forb	15	7
Grass	2	1
Sedge and Rush	25	45
Non-Native	47	39
Forb	7	4
Grass	40	35
Unknown	12	8

Spring 2000 Preliminary Seed Bank

A preliminary seed bank study was conducted in the spring of 2000 using punch cores. From a total of 20 soil cores 25 species germinated, 14 native and 11 non-native (Appendix L). Nine species, *Chenopodium album, Erigeron strigosus, Mollugo verticillata, Oxalis stricta, Poa pratensis, Portulaca oleracea, Potentilla arguta, Setaria faberi* and *Sporobolus heterolepsis*, germinated in both the remnant and old-field samples.

Sixteen species germinated from the remnant soil cores, five native and eleven non-native (Appendix L). There were more total and native species in the old-field and fewer non-native species. While not significant, more seedlings germinated from the remnant than the old-field, 58 vs. 47. Although the remnant contained fewer native species, there were more native seedlings in the old-field, 31 vs. 24.

The three most common species, *P. arguta, P. pratensis* and *R. acetosella,* accounted for 71% of the remnant germinants and 51% of the old-field germinants (Appendix L). *P. arguta* was the only species that accounted for over 10% of the germinants in both the remnant and old-field seed bank.

Seed Rain

It was possible to determine species movement via the 2000 and 2001 seed rain by comparing the 2086 collected seeds to the nearby vegetation (Table 14, Appendix G). Forty-eight species were present in the seed rain; 37 were identified to species, 7 to genus and 4 to family. Seedlings were divided into three categories: wind dispersed, dropped (gravity dispersal) or a combination dispersal method. Over the two-year period, 51 species were identified from the local vegetation. When the local vegetation and the seed rain were combined, there was 73 species, 62 in the remnant and 50 in the old-field.

Table 13: The total number of species and seeds collected in the 2000 and 2001, remnant and old-field seed rain traps.

	Remnant			Old-Field		
	2000	2001	Combined	2000	2001	Combined
Total Species	23	27	38	21	24	34
Total Seeds	532	353	885	637	624	1261

Two major occurrences influenced the seed rain study, a controlled burn on 25 October 2000 in the ER and EOF and a mechanized seed harvest in the remnant prairie on 17 October 2001. Since both occurred in October, there was no effect on the summer or early fall seed rain. However, due to the truncation of the seed rain study in mid-October the data was not statistically analyzed.

In the local vegetation, the remnant prairie seed traps contained over 8 species/m^2 and there were 5.5 species/m^2 in the old-field. Forty-seven percent of the local remnant vegetation had produced seed or was in flower and could have contributed seed to the adjoining seed traps (Appendix J). However, only 10% of the remnant seed rain species could have originated from the local vegetation while the remaining 90% of the species were either not present in the local remnant vegetation or were not reproducing. In the old-field, 50% of the local vegetation produced flowers or seeds while only 12% of the seed rain species could have originated from the local vegetation.

Forty-one percent of the seeds were collected from the remnant and the remaining 59% was collected from the old-field (Table 14). There were 1357 wind dispersed seeds, 359 dropped seed and 372 combination wind/dropped seeds. Only 1/3 (711 seeds) of the collected seeds had the potential to come from the local vegetation. With no local seed source, the remaining 1377 seeds had to have originated outside of the local vegetation.

Table 14: The number and percent of seeds that potentially could have come from the local vegetation and the seeds that must have originated outside of the local vegetation for the entire remnant and old-field seed rain during 2000 and 2001.

	Total Seeds	Potentially From Local Vegetation	Percent	Not From Local Vegetation	Percent
Total Seeds	2086	711	34%	1377	66%
Wind-Dispersed Seeds	1357	434	32%	923	68%
Dropped Seeds	359	71	20%	288	80%
Wind/Dropped Seeds	372	206	55%	166	45%

Gopher Mounds

The mean percent of ground covered by gopher mounds/m^2 was recorded during the fall of 2000 and the summer and fall of 2001. There was no significant difference ($p \leq 0.05$) within each of the sub-sites between the three sampling dates and the data was combined (Table 15). While twice the amount of ground was covered by gopher mounds in the IR, it was similar to the ER. In addition, all four of the old-field sub-sites were similar to each other despite there being no gopher mounds in the EOF. The remnant contained significantly more ($p \leq 0.05$) gopher mounds than the old-field (Figure 16).

Table 15: The mean amount of ground (m^2) (± SE) disturbed by gopher mounds in the six sub-sites with the fall 2000, summer and fall 2001 samples combined.

Site	Average Percent Of Ground Occupied By Gopher Mounds
Interior Remnant	19.2 ± 3.8^a
Edge Remnant	10.0 ± 2.3^a
Edge Old-Field	0.0 ± 0.0^b
Mid Old-Field 1	3.4 ± 1.4^b
Mid Old-Field 2	1.2 ± 1.7^b
Distant Old-Field	1.2 ± 1.1^b
P-Value	0.000

Figure 16: Photograph of gopher mounds (circled) at Cedar Hills Sand Prairie on 12 December 2004. Twenty-two gopher mounds were visible in the remnant prairie (right side of photo); none were in the old-field (left side of photo).

New Species

Four species, *Carex brevior, C. tribuloides, C. cristatella* and *Silphium perfoliatum,* were identified from the remnant and old-field vegetation were not on the vascular floral checklist (Freese 1999) for the Cedar Hills Sand Prairie (Appendix B). With the exception of *C. brevior*, these species were not present within the sampled quadrats. Two species, *Carex gravida* var. *lynelliana* and *Juncus tenuis* var. *dudleyi,* were listed on the flora checklist by genus and species, but were further identified to variety.

Five species, *Abutilon theophrasti, Amaranthus hybridus, Portulacca oleracea, Setaria viridis* and *Hemicarpha macrantha*, sampled in the preliminary seed bank study were not listed on the Cedar Hill Sand Prairie species checklist (Freese 1999) (Appendixes B and L). There was one new native species for the study site, *H. macrantha*, a late successional sedge identified from viable seed in a DOF soil core.

CHAPTER 5

DISCUSSION

Vegetation

In 1977, an old-field adjoining a remnant sand prairie at the Cedar Hills Sand Prairie (CHSP) started undergoing secondary succession. The assumption that the old-field contained a typical matrix of old-field species at the cessation of the most recent episode of cultivation was verified by Glen-Lewin (1980) who wrote that "there are no adjacent areas (to the prairie) worth obtaining as additions or buffer areas." Twenty-five years later, proximal portions of the old-field vegetation no longer looked like an old-field and had begun to resemble the vegetation of the adjoining remnant prairie.

Twenty-four percent of the species listed for the CHSP (Freese51 1999) were sampled in the 0.45 ha study site vegetation. Seventy-two species were present in the 100 m sample of remnant prairie, 86% of which were native (Appendix B). The adjoining 200 m sample of old-field contained 69 species, of which 80% were native. Fifty percent of the 93 species were located in both the remnant and old-field samples. Of the 48 shared species, 84% were native. Three old-field species are listed on the Iowa Plants of Concern list, *Carex conoidea*, *C. media* and *Juncus greenei* (Natural Resource Commission 2002). There were a high percentage of forbs (native and non-native) in both sites, 80% in the remnant and 75% in the old-field. This is typical of a prairie setting in which a few grasses are dominant, but the majority of species are forbs.

Although the appearance of old-field vegetation had become more like the remnant, 25 years of natural succession in the old-field was not sufficient to replicate the vegetation matrix of the remnant prairie. The species density in nine of thirteen categories (total species, native species, total forbs, total grasses, native forbs, native grasses, early, mid and late successional native species) was greater in the remnant than the old-field (Table 1). Reflecting its agricultural past, the old-field contained a higher density of species in two categories, total non-native species and non-native grass species. Unexpectedly, there was a higher density of native sedges and rushes in the old-field and more early successional natives in the remnant prairie. In addition, the density of non-native forbs was similar between the two sites contrary to predictions that all the non-native groupings would be more prominent in the old-field.

Since all the sedges and rushes in the study are native species, it was assumed that more would be present in the remnant prairie than in the old-field. Instead, there were nine species in the old-field and three in the remnant (Appendix B). Most of the eleven sedges and rushes encountered along the transect typically grow in wetter areas. Many of the same species were present in the swale to the east of the sampled remnant. This nearby swale was the likely source of seed for the sedge and rush species in the study area. Although viable seed of several species of sedges (*Carex vulpinoidea, Cyperus filiculmis*, and *C. strigosus*) were present in both the remnant and old-field seed banks, none of them were present in the sampled vegetation (Appendix B). Apparently factors other than seed movement restricted germination and establishment of these sedges and rushes in the study area.

Although the remnant and old-field were located on the same soil type, the hydrology of the two sites may differ as a result of wind erosion. Water flows laterally underground from the higher elevation in the northern section of the old-field towards the remnant. The old-field has had considerable surface soil erosion, lowering it somewhat below the prairie edge where wind-blown sand accumulated in a ridge along the old fencerow. This small difference in topography may be sufficient to divert some of the underground water flow into the old-field and swale to the east of the study site. Consequently, the sampled remnant may be slightly drier than the sampled old-field. If so, more hydric conditions in the old field would favor sedges and rushes. The vegetative composition to the east is indicative of a wetter area suggesting that water is likely diverted in that direction. Ferns such as *Onoelea sensibilis* and *Thelypteris palustris* as well as *Lobelia siphilitica* and *Spiranthes cernua* were observed in that area, but none were present in the sampled remnant or old-field.

Gopher disturbances open up the root and canopy systems of an established grassland and allow seedlings to germinate. These disturbances especially favor shorter-lived non-native and early successional native species, providing areas where they can maintain a presence within the grassland. According to Armesto and Pickett (1985), these disturbances can increase a site's species diversity. In the remnant prairie, which contained a large number of gopher mounds, there was a wide range of these shorter-lived species. Each of the remnant sub-sites contained more early successional species than any of the old-field sub-sites. In addition there was a higher percentage of early successional cover in the remnant prairie.

A large number of native forbs have moved from the remnant to the old-field. Of the 50 native forbs present in the remnant prairie study area, 66% were also in the old-field, (Appendix B). This is a higher percentage of native forb movement into an old-field during secondary succession than reported for a previous study in the tallgrass prairie region of Kansas (Campbell 1996). In Kansas, 32 of the 70 native forbs (46%) were present in both the remnant and old-field, approximately half the percentage of the CHSP study. There are differences between the Kansas and CHSP studies that could have contributed to this. The CHSP has sandy soil while the Kansas site was a blacksoil prairie. Four native grasses were broadcast seeded in the Kansas old-field, unlike the CHSP where no native seeds were intentionally introduced into the study area. Perhaps the added grasses curtailed forb establishment as the Kansas old-field had been undergoing succession for 35 years, 10 more than the CHSP old-field.

Successional Movement of Native Species into the Old-Field

From south to north, remnant to old-field, the study site was divided into six, 50 m long sections. The remnant prairie was sub-divided into two study sites, interior remnant (IR) and edge remnant (ER), while the old-field was sub-divided into four study sites, edge old-field (EOF), mid old-field 1 (MOF-1), mid old-field 2 (MOF-2) and distant old-field (DOF). A gradual change in species composition occurred in the old-field as distance from the remnant increased. The transition from one sub-site to a neighboring sub-site was gradual, with the exception of the DOF, which was quite different. For example, the ER and EOF closely resembled each other and the EOF and MOF-1 were also very similar. However, there were several major differences between ER and MOF-1. Between 61% and 69% of the species in adjoining sub-sites were common to both sub-sites. The exception was the MOF-2 and DOF, which only shared

31% of their species. Native species were more common closer to the remnant prairie and non-native species were more prominent with increased distance from the remnant. The DOF vegetation differed greatly from the rest of the study sites. Apparently it was still in the early stages of secondary succession.

Remnant prairie. Edges of prairie remnants are subject to invasion by non-native species. If external stresses were placed on the remnant by conditions in the adjoining old-field, the ER would have been more affected than the IR. However, there was little to no edge effect on the remnant prairie due to the proximity of the old-field. The IR and ER were very similar to one another. Sixty-three percent of the remnant prairie species were present in both sub-sites. There were no differences in the species density or canopy cover for any of the aforementioned 13 categories. Their coefficients of conservatism were high as were their species diversities. The similarity of the sites confirms there was no edge effect in the ER. Therefore, the ER was used as the reference section for comparing successional changes occurring across the old-field.

Edge old-field. In the old-field, the vegetative composition of the EOF was most similar to the ER. Twenty-six of the 39 native EOF species were also present in the ER. Quite likely these species originated from the ER. Seven of the eleven EOF native species not present in the ER were sedges or rushes. The seed of these species likely came from the adjoining swale as indicated earlier in the discussion. The extent of succession is reflected in the fact that the average coefficients of conservatism value and species diversity were almost identical between the EOF and the ER. The species density of the ER and EOF for 11 of the 13 categories (total species, native and non-native species, total forbs and grasses, native forbs, non-native forbs and grasses and early, mid and late successional native species) was also similar between the two sub-sites.

Although the EOF vegetative composition has begun to resemble the native prairie, the sub-site has not fully recovered from its agricultural past despite 25 years of secondary succession. Due to evidence of past disturbances, the EOF was assigned a C+ as opposed to an A-/B+ grade for the ER using White's (1978) area grading system. The species density of the native grasses and sedges and rushes differed between the ER and EOF. The species density and number of native grasses were higher in the ER. The species density and number of sedges and rushes were greater in the EOF. Only one native grass, *Koeleria macrantha,* present in the EOF, was not sampled in the remnant transect, although it was present in the remnant prairie just outside of the study area. The presence of viable *Sporobolus heterolepsis* seed in the spring 2000 old-field seed bank raises the possibility that unfavorable conditions for seedling establishment may be responsible for the absence of some native grasses in the EOF vegetation.

As the old-field is still undergoing secondary succession following the cessation of cultivation, it was conjectured that early successional species would be more prevalent in the old-field than in the remnant prairie. Instead, there was almost twice the number of early successional species in the ER (Table 1, Appendix B). The canopy cover of early successional species was also greater in the ER. This was the only factor in which there was a significant difference in canopy cover between the ER and EOF (Table 5). This was likely due to the gopher-induced soil disturbances creating areas in which these species could grow. Despite differences in the canopy cover, the species density of early successional species was similar between the ER and EOF.

The canopy cover of the two primary non-native grasses in the study, *Bromus inermis* and *Poa pratensis*, was similar between the ER and EOF. The two species accounted for less than 25% of the total canopy cover in the remnant and edge old-field sub-sites while occupying 38% to 64% of the canopy cover in the other old-field sub-sites. The reduction of *B. inermis* and *P. pratensis* in the EOF to levels similar to the ER is a good indication of how far succession had progressed in the EOF. Furthermore, *B. inermis* did not flower in the ER or EOF during the study, although it did flower and set seed in the remaining three old-field sub-sites. Evidently succession has progressed to the point that non-native species, such as *B. inermis*, have reduced vegetative and reproductive capabilities due to competition from native species. In the other old-field sub-sites, *B. inermis* began to become more prominent as distance from the remnant increased, appearing with more frequency in the quadrats and exhibiting a higher percent canopy cover. The canopy cover increased dramatically in the distant old-field, where few native species were present.

The species density and canopy cover of *Schizachyrium scoparium* was similar between the EOF and adjoining ER, demonstrating that *S. scoparium* had successfully established itself in the EOF. This native grass exhibited the classical movement of a migrating species in a community undergoing succession. When canopy cover was examined across the sub-sites, cover was highest in the IR and gradually decreased until the DOF, where it was not present. The change was gradual as adjoining sub-sites had a similar amount of cover, while there were significant differences in the cover between more widely separated sub-sites.

Andropogon gerardii was present in all of the ER and EOF samples during the two-year study. However, it was taller and more uniformly dense in the EOF than in any of the other five sub-sites. Its canopy cover was five times that of the ER. In a summary of Michigan sand prairies, Kost (2004) noted that typically *A. gerardii* and other vegetation are often shorter and more scattered in sand prairies than in more nutrient rich sites. An influx of a thick stand of *A. gerardii* similar to that of the EOF was observed at Kalsow Prairie, a remnant blacksoil prairie in Pocahontas County, IA. Kalsow prairie was adjacent to a highly degraded, heavily grazed native pasture that had been fallow for 20 years (Brotherson and Landers 1976). Following cession of grazing, *A. gerardii* quickly established itself in the degraded pasture and formed a wide "front." Vigorous growth of thick stands of *A. gerardii* have been observed in the early stages of prairie reconstructions (Kirt and Smith, pers. comm.). Perhaps some episode occurred early in the succession process that enabled *A. gerardii* to readily establish itself. Over several decades other native species, especially forbs, become established during the reconstruction process and the native grasses decline in extent and stature. Perhaps a similar decline to that witnessed in reconstructed prairies will occur within the EOF as succession proceeds. Additionally, the tall, thick stand of *A. gerardii* can reach heights in excess of two meters at the CHSP and may be blocking the spread of native seed from the remnant prairie into the old-field. *A. gerardii* may also reduce the number of species that germinate in the EOF due to its thick root and rhizome mass and the reduction of light penetration to ground level.

Mid old-fields 1 and 2. The mid old-field sub-sites are located 50 to 150 m north of the remnant prairie. The MOF-1 and MOF-2 sub-sites were very similar to one another with two-thirds of the species in common between both sub-sites. The species density and average canopy cover of both sub-sites were similar to each other for all thirteen categories (total, native and non-native species; sedges and rushes; total native and non-native forbs and grasses; early, mid and late successional native species). Their average coefficients of conservatism values were almost identical. Both sub-sites received a C- grade according to the Natural Quality Grading System (White 1978) indicating that they had begun to recover from previous disturbances. Due to the similarities of the MOF-1 and MOF-2, the two sub-sites were often combined for comparison to the remainder of the studies sub-sites.

By 2000, the vegetation of the MOF sub-sites had begun to revert back into a native vegetation community. Fifty-eight percent of the native MOF species were mid or late successional. The presence of 45 native species demonstrated that over a 25-year period native species were able to successfully invade the old-field to a distance of 150 meters. This is a rate of movement of 6 meters/year into the old-field. Of the 39 species that were in common between the ER and MOF, 33 were native. Lastly, the average coefficient of conservatism was between 3.8 and 4.2 for the three sub-sites.

There were more differences between the sub-sites as distance from the remnant prairie increased. When the average number of species was compared between the EOF, MOF-1 and MOF-2, there was a gradual decrease in the number of species within most of the categories although there were no statistically significant differences between the three sub-sites. The exception was the non-native grasses as there were slightly more species in the MOF-2 than the EOF, although these two sub-sites were similar to each other.

There were more differences in the average number of species between the MOF sub-sites and the ER than between the EOF and the ER in several categories (Table 1). With increased distance from the ER there was a gradual transition in the old-field from one dominated by native vegetation in the EOF to one dominated by non-native vegetation.

There were few differences in canopy cover between the ER, EOF, MOF-1 and MOF-2. The two mid old-field sub-sites had much lower native cover and much higher non-native cover than the EOF. This corresponded with a higher non-native grass cover in the mid old-field sub-sites and a lower mid successional native cover than the EOF. In all other instances, the three old-field sub-sites were similar to one another. Despite a similar number of early successional species between the ER and the three old-field sub-sites, their canopy cover was lower in the old-field. There was a higher canopy cover of total non-native species and non-native grasses and a lower canopy cover of mid successional species in the MOF sub-sites than in the ER. The only difference in the late successional species was between the ER and MOF-1, with the cover higher in the ER. These differences tend to relate to the transitional nature of the MOF-1 and MOF-2 sub-sites.

The MOF 1 and 2 were more similar to the EOF than the ER, confirming the gradual transition in species composition across the old-field, from a later successional state in the EOF to a mid successional state in the MOF sub-sites. All thirteen categories of species density were similar between the EOF and MOF sub-sites. Sixty-five percent of the MOF species were also in the EOF and of the 35 species that were present in both the EF and MOF, 30 were native. The canopy cover for eight of the categories (total species; sedges and rushes; total, native and non-native forbs; total grass; early and late successional native species) was also similar between the three sub-sites. Either both of the MOF sub-sites were similar to the EOF or they were both different. At no time was only one of the MOF sub-sites similar (or different) from the EOF, reinforcing the successional transition of species across the site. The presence of native forbs, which make up the fabric of a native prairie, was especially encouraging in terms of successful colonization of the old-field. Their successful colonization of the MOF demonstrates that native species succession is proceeding well.

The MOF sub-sites were not as successionally advanced as the EOF. Their natural quality grades were a C- when compared to a C+ in the EOF indicating prairie community recovery is less complete in the MOF sub-sites. Additionally, the canopy cover in five of the categories (total native and non-native species; native and non-native grasses and mid successional native species) was different between the MOF and EOF sub-sites. Differences in the three native species categories (total native, native grasses and mid successional native species) were mainly due to *A. gerardii* which peaked in the EOF and formed a wide front across the old-field. The canopy cover for *A. gerardii* dropped from a high in the EOF of 23% to less than 2% in the MOF sub-sites (Table 5). Since *A. gerardii* provided approximately 1/3 of the native canopy cover in the EOF and less than 5% of the native canopy cover in the MOF, the decline in just one species had a major impact on the overall structure of the sub-sites.

For the first time in the successional area, the non-native canopy cover was greater than the native canopy cover. Seventy percent of the EOF canopy cover was due to native species while 30% to 40% of the MOF sub-sites cover was native. This reinforces the argument that the MOF sub-sites represent a transitional zone. While there are a large number of native species (46 species) present in the MOF, they have not yet become well enough established to successfully out-compete the non-native species, especially *B. inermis* and *P. pratensis*.

The main reason for the switch in the native and non-native canopy cover was due to four grasses, two native (*A. gerardii* and *S. scoparium*) and two non-native (*B. inermis* and *P. pratensis*) (Table 5). In both the ER and EOF, *A. gerardii* and *S. scoparium* were the main grasses and helped limit the amount of *B. inermis* and *P. pratensis*. Both species had migrated into the MOF, but *A. gerardii* comprised 5% or less of the canopy, much lower that the EOF where *A. gerardii* cover was 23%. *S. scoparium* canopy cover decreased with distance from the remnant. In the MOF sub-sites the canopy cover was less than 2%. The dense stands of *B. inermis* and *P. pratensis* apparently restrict the areas in which additional native seedlings can become established. Due to the dominance of these two non-native grasses, the MOF visually resembles an old-field. Undoubtedly, over time other native species will join the 46 native species already established in the MOF and eventually displace *B. inermis* and *P. pratensis*.

Distant old-field. The composition of the vegetation in the DOF was considerably different from the other 5 sub-sites, exhibiting an old-field vegetation matrix despite being fallow for 25 years. The vegetation was dominated by biennial and perennial non-native species and early successional native species. While the EOF and MOF contained between 42 and 48 species, there were only 17 species in the DOF. Sixty-five percent of the DOF species were very common, present in all six sub-sites.

The species diversity of the DOF was the lowest of all the sub-sites. The average coefficient of conservatism was 2.1 in the DOF, half that of the MOF. This places the DOF below the cut-off for a potential natural area and in their very disturbed group (Swink and Wilhelm 1994). The DOF received a D grade due to the dominance of non-native species within the sub-site (White 1978). This grade would have been lower except 12 of the 17 species were native, three of which (*Dichanthelium* sp., *Helianthus grosseserratus,* and *Physalis virginiana*) are mid successional native species (Appendix B).

Unlike the other five sub-sites, the DOF contained no native late successional species or sedge or rush species. It is also the only sub-site in which the early successional native canopy cover was greater than the mid successional cover. Native grasses decreased from four in the MOF to one, *Dicanthelium* sp., in the DOF. *Dichanthelium* sp., a mid successional species, is usually restricted to drier prairie sites. Under proper environmental conditions, it can become widespread in that habitat type.

This is likely the reason it is so common at the CHSP. The vegetation in the DOF was dominated by non-native species which accounted for 98.5% of the canopy cover. *B. inermis* and *P. pratensis*, the main non-native species, comprised 70% of the non-native cover. It is not surprising that the DOF resembles an abandoned agricultural field.

The DOF vegetation completes the perspective of the progress of secondary succession in the 150 m adjoining the remnant prairie. Native vegetation had breached the canopy cover of the MOF (60% to 70% non-native cover) but was hardly evident in the DOF where 98.5% of the cover was non-native. Apparently, native succession is just beginning in the DOF. The MOF is probably in an early/mid successional stage. The EOF is in a later mid successional stage moving into a late successional stage. With time, the native species will continue to move further into the old-field and more native species will become established and provide seed for the next sub-site.

<u>Seed Bank</u>

The seed bank is an important component of the successional process. As a repository of viable seeds, the seed bank contains a record of the past, current and future vegetation. Disturbances of the soil and aboveground vegetation create gaps that provide opportunities for seeds in the seed bank to germinate and become established.

Seed bank studies of prairies are rare (Lippert and Hopkins 1950, Rabinowitz 1981, Johnson and Anderson 1986, Perez et. al. 1998). Studies that examine the seed bank of adjoining tallgrass prairies and old-fields are even more uncommon (Archibold 1981, Schott and Hamburg 1997). In a tallgrass blacksoil prairie in Kansas, Schott and Hamburg (1997) found that the contents of the prairie seed bank was three times greater than the old-field and contained more species (23 vs. 19). The opposite occurred at the CHSP where there were approximately five times more seeds in the old-field seed bank than in the remnant. The old-field seed bank also contained more species than the remnant prairie (32 vs. 26). In both studies, the seed bank of the remnant prairie and old-field contained species that were not currently present in the vegetation.

The EOF contained six times more viable seed than the ER (Table 9). The EOF also contained more species than the ER. This adds to the differences between the two sub-sites even after 25-years of succession.

The number of sedge and rush species in the EOF seed bank was twice that of the ER seed bank. This reflects the vegetation composition, where the EOF contained eight species and the ER one. Due to the scarcity of the sedges and rushes in the vegetation, it was not expected that there would be a large number of sedge or rush seeds in the seed bank. However, 25% of the ER seed bank and 45% of the EOF seed bank consisted of sedge and rush germinates (Table 12). It is possible that the sedge and rush seeds originated from plants in the nearby swale and were unable to germinate due to drier site conditions or other limiting factors. Another possibility is that the sedge and rush seeds persist for long periods of time in the soil. Schott and Hamburg (1997) and Rabinowitz and Rapp (1980) showed that *Juncus* sp. seeds accumulate in the seed bank. Longevity of buried seed may be a factor in the CHSP seed bank. Forty percent of the germinates were sedges and rushes and three of their six seed bank species were not in the ER or EOF seed rain.

The opposite trend occurred with the native grasses. While accounting for 30% of the ER vegetation canopy cover and 45% of the EOF vegetation cover only 0.7% of the seed bank was native grasses. The two dominant grasses in the vegetation, *Andropogon gerardii* and *Schizachyrium scoparium*, were not present in the seed bank. This is consistent with other seed bank studies in which there were few or no *A. gerardii* and *S. scoparium* germinates (Rabinowitz 1981, Abrams 1988, Lippert and Hopkins 1950). One reason is the high number of grass seeds that were immature or non-viable when they fell from the parent plant. Sandy Hegna of the Iowa State University Seed Laboratory (pers. comm. 2002) confirmed that many of the seeds collected from the CHSP seed rain were non-viable. Consequently they could not have contributed to the seed bank. Another possibility is that their seeds are only viable for a short period of time in the seed bank. Seed from two other native grass species, *Dicanthelium* sp. and *Sporobolus heterolepsis*, was viable in the soil seed bank. Both of these species also had viable seed in the seed bank studied by Perez et. al. (1998) in the Nebraska Sand Hills.

Seed bank data for fall 2000 suggests that more non-native species were formerly present in the EOF (Appendix B). Five non-native species (*Capsella bursa-pastoris, Nepeta cataria, Hypericum perforatum, Setaria glauca* and *Silene vulgaris*) were present in the EOF seed bank, but not in the EOF vegetation. In a preliminary spring 2000 seed bank study, samples were collected over the entire old-field. Five additional seed bank species (*Abutilon theophrasti, Amaranthus hybridus, Portulacca oleracea, Setaria viridis* and *Hemicarpha macrantha*) were not on the CHSP species list (Freese 1999). All but *H. macrantha* are non-native species. Collectively, 18 seed bank species were not present in the remnant or old-field vegetation transect. Of these 18 species, 11 were non-native. This is a large number of species considering only 0.01 m^3 of soil was collected for seed bank testing. It is likely many more native and non-native species are present in the seed bank, but not in the surrounding vegetation. In an earlier successional stage, conditions may have been more favorable for non-native seedling establishment. Now, these species may be unable to establish within the current flora (Schott and Hamburg 1997). This follows the normal progression of secondary succession where the initial species are gradually out-competed by later successional species.

Seed Rain

The seed rain was studied to determine the relationship of the movement of seed to the old-field succession. Seed rain is difficult to accurately measure, especially at a community level, for a variety of reasons. These include seed predation by insects, seed traps becoming buried or mature plants interfering with the falling seed (Rabinowitz and Rapp 1980). To ascertain the origin of the seed, the seed rain was compared to the "local vegetation" producing seed or flowering within a 43-cm diameter of each seed trap (the local seed rain). It was anticipated that most of the seeds, especially the heavier seed, would originate from plants close to the seed trap. Seeds from species that produced light, wind-blown seeds could travel further.

The seeds collected from the seed rain traps traveled further than anticipated. Up to 34% of all the trapped seeds could have originated from the near-by vegetation (Appendix L). However, since many of the species present in the local vegetation were also present outside of the quadrat, it is likely that the amount of seed that originated from the local vegetation is less than 34%. Of the 1357 wind-blown seeds, only 32% could have originated from the local vegetation, indicating a high amount of seed movement. Of the 359 trapped heavier seeds, assumed to travel short distances and mainly originate in the local vegetation, only 20% could have originated from the local vegetation. Eighteen of the 50 species collected from the seed rain were not present in either the local vegetation surrounding the seed traps or in the nearby transect. Therefore, they had to originate from other areas of the CHSP preserve. Seed was moving greater distances than expected. Thus seed movement may be less of a limiting factor in succession than expected. This is promising for the movement of native species further into the old-field.

Schizachyrium scoparium is a good example of the seed movement via seed rain at the CHSP. J. E. Weaver (1958, 1965) determined that *S. scoparium* seed had a wind dispersal range from 1.5 to 1.8 meters from the parent plant with winds up to 30 km/hr. Using this value, and assuming that every year there is seedling establishment, plant maturation and viable seed production, over a 25-year period *S. scoparium* would travel a maximum of 32.5 meters into the old-field. However, *S. scoparium* was growing in the vegetation 150 meters north of the remnant prairie. Either other factors are contributing to the movement of *S. scoparium* or Weaver's assumptions need to be revisited.

Comparisons Between the Studies

The vegetation, seed rain and seed bank represent different aspects and time periods at the Cedar Hills Sand Prairie. The vegetation represents the current status of succession. There are two primary ways that species can move, vegetatively or by seed.

Many of the longer-lived plants move short distances through rhizomal growth. Seed rain provides the opportunity for moving longer distances. The spread of native species into the old-field from the remnant prairie was primarily the result of the seed rain. The seed bank is the third component of the study. It contains species that were present within the study site in the past as well as species added by the current vegetation through the seed rain. In addition, the seed bank can provide seed for the future vegetation. Collectively, the three studies form a more complete picture of the CHSP dynamics than just the vegetation alone.

The impact of the seed rain on the vegetation is in part determined by the reproductive strategies of the individual species. Some, such as many sedge, rush and non-native species, have seeds that can persist for long periods of time in the soil. As a result, even if the species no longer exists in the current vegetation their seed remain viable until the proper environmental conditions are met and then germinate. Other species, for example *Andropogon gerardii* and *Schizachyrium scoparium*, have seeds that are transient and persist for short periods of time in the soil. These species rely heavily on the seed rain to become established within a new area. If their seed migrates to a new area and fails to germinate, more seed will have to travel to that area for them to become established when conditions are better for germination.

Many non-native and early successional native species are annuals or short-lived perennials that rely on producing large quantities of seeds that can persist in the soil until conditions are favorable for germination (Schott and Hamburg 1997). Eighty percent of the old-field seed bank species were early successional natives or non-native species, while only 60% of the species in the vegetation of the ER and EOF were non-native or early successional species (Appendix B). One-third of the species identified from the spring and fall seed bank studies were not present in the vegetation or seed rain. Only four of these nineteen species (*Aster laevis, Cyperus filiculmis*, *Hemicarpha macrantha* and *Hypericum majus/mutilum*) were non-native or early successional native species. Many of the seed bank germinants could be successional relics that are no longer able to compete successfully in the successional process. The other possibility is that seeds from several of the species migrated into the sampled area and the proper environmental conditions for germination are not present. For example, the seed of *Setaria faberi* and *Aster lanceolatus*, whose seeds were present in the seed rain and seed bank, but not in the ER or EOF vegetation. Either the existing vegetation or other factors are restricting the establishment of these seedlings. Perhaps they are being out-competed by the other, more mature species in the vegetation.

Despite there being more species in the ER vegetation, it had a smaller seed bank and seed rain than the EOF. This was opposite of a blacksoil remnant prairie and adjoining old-field studied in Kansas (Schott and Hamburg 1997). Interestingly, while there were no differences in the number of non-native species in the vegetation or the seed rain in either site, the old-field seed bank did contain more non-native species. More non-native seeds in the seed bank are common to abandoned crop fields and is another indication of the agricultural history of the old-field. This is despite the similarity of the current above ground vegetation and seed rain to the remnant prairie.

These three different aspects of the plant community provide a more complete understanding of old-field succession. Despite 25 years of succession in the EOF, the imprint of its agricultural past is still evident in the greater number of early successional natives and non-native species in the seed bank.

Summary

The success of succession in the old-field was determined by comparing the vegetation, seed rain and seed bank to what was present in the remnant prairie. The remnant represented the potential community that the old-field could become over time. The remnant prairie is the most likely seed source for the majority of the native species within the old-field, especially the later successional species that would have been adversely affected by the past grazing and sporadic cultivation of the old-field. It is doubtful that the old-field will ever exactly match the current remnant community, especially considering that the prairie is in a constant state of change.

The old-field was last cultivated in 1976 and since then native species have successfully invaded and become established in the old-field to a distance 150 m north of the remnant prairie. The change has been dramatic since the late 1970s. As indicated earlier, Glen-Lewin (1980) felt that adjacent areas to the remnant did not contain any prairie worth acquiring by The Nature Conservancy. By 2001, there were 55 native species in the old-field vegetation and the area adjacent to the remnant "looked like a prairie."

The study of the progression of native species in the old-field was based upon the valid assumption that the native species originated in the remnant prairie. As expected, the edge old-field vegetation was the most similar to the remnant prairie with density and cover of native species the same. Further northward into the old-field the native species density and cover decreased. For example, *Schizachyrium scoparium* declined steadily from a high in the interior remnant to being absent in the distant old-field. On the other hand, *Andropogon gerardii* peaked dramatically in the edge old-field. Apparently *A. gerardii* has the ability to successfully and rapidly colonize a new area following a disturbance. However, unlike *S. scoparium, A. gerardii* has not moved much further than the EOF. Perhaps it will take a major disturbance episode in the old-field for it to occupy more area in the old-field.

The mid old-field sub-sites represent a transitional area between the more successionally advanced prairie community in the EOF and the very early successional community in the DOF. Even though native species had become established to a distance of 150 m north of the remnant, they were scattered in the vegetation and the native canopy cover was less. The two dominant non-native grasses, *Bromus inermis* and *Poa pratensis*, while present in all six sub-sites, had a lower species density, canopy cover and seed production in the remnant sub-sites and the EOF. In the MOF 1 and 2, these species were responsible for a higher percent of non-native canopy cover than native cover. *B. inermis* and *P. pratensis* became quite common in the DOF, responsible for 3/4ths of the canopy cover. These are the species that must be displaced during succession.

After 25 years, the DOF still resembled a typical abandoned agricultural field. The canopy cover was 98.5% non-native, there were no late successional native forb, grass, sedge or rush species in the existing vegetation. The most conservative species in the DOF was *Dichanthelium* sp. with a rating of 5. The vegetation in the DOF was the least affected by succession. There were three mid successional species present in the vegetation, including *Dichanthelium* sp., the only native grass in the sub-site. *Hemicarpha micrantha*, a late successional sedge, was present in the seed bank of the distant old-field. *Carex brachyglossa*, a mid successional sedge, and *Oenothera rhombipetala*, a late successional forb as well as *A. gerardii* and *S. scoparium* were in the DOF seed rain. Obviously, the seed of more successionally advanced species are reaching the DOF but are not becoming established. It is just a matter of time until they become established in the vegetation.

The old-field has undergone succession with the movement of native species from the prairie remnant. As time progresses, more native species should move into the old-field, become established and continue spreading seeds further from the remnant prairie. While this can often be a slow process, it has been shown that the native species are capable of moving and out-competing the non-native species. Perhaps succession in the old-field will be aided by episodic events such as fire or drought. This process will continue until the whole of the study area and beyond resembles the remnant prairie.

As expected, native plant succession had occurred in the old-field following the latest episode of disturbance in 1976. The old-field more resembled the remnant prairie with proximity, yet beyond 150 m north of the remnant, the vegetation was still reminiscent of an abandoned agricultural field. There was also little correlation between the number of species and canopy cover. Both the seed rain and seed bank showed that species movement has and is still occurring at the site and if the proper environmental conditions occur, i.e. fire or drought, there is the potential for an influx of new species in the study area. There were several unexpected results such as the presence of more sedge and rush species in the old-field and more early successional native species in the remnant. In addition, few late successional species were expected to be present in the old-field, yet were growing to distances of 150 m north of the remnant.

During a 25 year period after cultivation ceased, succession has progressed 150-200 m from a sand prairie remnant into an old field. However, much of the more distant successional area still resembles an old field. The 50 meter site most proximal to the remnant is in a mid to late successional state. The most distant 50 meter section is in an early state of succession while the two middle 50 meter sections are in transition from old field vegetation to prairie vegetation.

CHAPTER 6

FURTHER STUDIES AND MANAGEMENT RECOMMENDATIONS

The remnant and old-field vegetation was re-sampled in early September of 2005 and 2006 as a follow-up to this study. Each plot was mapped using a global positioning system (GPS) to enable the relocation of the plots easily (Appendix M). The 2005 data should reflect the effect of a drought on the native and non-native vegetation, and contrast well with the 2006 data when rain fell at more opportune times for plant growth. These permanent plots can be used to study future changes in the vegetation, and assess various management practices such as prescribed burning or mowing.

One of the next steps would be to study the effects of a prescribed burn on the study site. The last time the entire study area was burned was in the fall of 1999. The prescribed burn in 2000 covered the ER and EOF sub-sites. An interesting study would be to determine if reducing the duff, especially in the old-field, would positively impact the native species, especially those that have either decreased in abundance or have disappeared since the fall of 2000 and 2001.

Burning the site, preferably in the spring, could reduce the duff layer, especially in the old-field, and negatively impact some of the non-native species such as *Bromus inermis* (Howard 1996) and *Poa pratensis* (Uchytil 1993). While the duff layer is not a problem in the remnant prairie due to the constant disturbances provided by the gophers, it would be interesting to observe the effects of a burn on the native species. As a mid spring fire promotes flowering and seed set of mature grasses such as *Andropogon gerardii* and *Schizachyrium scoparium*, it would be interesting to observe if establishment of these species is accelerated in the old-field. An additional study would be to determine if native species showed greater flowering following a prescribed burn, since flowering/fruiting data (not presented in this thesis) was collected in 2000, 2001, 2005 and 2006.

While minimal management is important to continue studying succession of native species into the old-field, the site would benefit from minor maintenance in the form of brush removal and prescribed burns. With no management of the study area since 2001, there has been an increase in the woody vegetation in both the sampled remnant and old-field. This could pose a problem in the future if the woody vegetation continues to increase. This is especially true of the area just west of the old-field study site near the parking area where a large colony of *Salix* has become much thicker over the last five years. Controlling the *Salix* population through a variety of methods, such as cutting/mowing, burning and herbicide treatment, should reduce the amount of *Salix* present in the old-field.

The study site is ideal for future successional studies. Aside from minimal management in the form of controlled burning and removal of woody vegetation, such as *Cornus stolonifera*, human contact should be limited to preserve the site for further study. This is especially important due to the scarcity of research on the natural movement of prairie plants into adjoining old-fields, especially in sand prairies.

REFERENCES

Abrams MD. 1988. Effects of burning regime on buried seed banks and canopy coverage in a Kansas tallgrass prairie. The Southwestern Naturalist 33(1): 65-70.

Armesto JJ, Pickett ST. 1985. Experiments on disturbance in old-field plant communities: impact on species richness and abundance. Ecology 66 (1): 230-240.

Archibold OW. 1981. Buried viable propagules in native prairie and edge agricultural sites in central Saskatchewan. Canadian Journal of Botany. 59: 701-706.

Brenchley WE. 1918. Buried weed seeds. Journal of Agricultural Science. 9: 1-31.

Brenchley WE, Warington K. 1930. The weed seed population of arable soil. Numerical estimation of viable seeds and observation on their natural dormancy. The Journal of Ecology 18 (2): 235-272.

Brotherson JD, Landers RQ. 1978. Recovery from severe grazing in an Iowa tall-grass prairie. Fifth Midwest Prairie Conference Proceedings, 1976. p 51-56.

Campbell JA. 1996. A study of the invasion and establishment of native species into a partially restored tallgrass prairie in Northeastern Kansas. [PhD. Thesis] University of Kansas, Manhattan (KS).

Champness SS, Morris K. 1948. The population of buried viable seeds in relation to contrasting pasture and soil types. Journal of Ecology 36: 149-173.

Cheplick GP. 1998. Seed dispersal and seedling establishment in grass populations. Population Biology of Grasses. Cambridge: Cambridge University Press.

Crawley GP. 1997. Plant Ecology. Oxford: Blackwell Science.

Crum GH. 1972. Flora of a sand prairie in Black Hawk County, Iowa. Proceeding of the Iowa Academy of Science 78: 81-87.

Fouts WL, Highland JD. 1978. Soil survey of Black Hawk County, Iowa. USDA Soil Conservation Service, Washington, D.C.

Freese EL. 1999. Cedar Hills Sand Prairie vascular floral checklist. Unpublished.

Glenn-Lewin DC. 1980. Mark Sand Prairie. Department of Botany, Iowa State University. Ames (IA).

Gleason HA, Cronquist A. 1991. Manual of vascular plants of northeastern United States and adjacent Canada. 2nd ed. New York Botanical Garden (NY).

Gross KL. 1990. A comparison of methods for estimating seed numbers in the soil. Journal of Ecology 78: 1079-1093.

Holt RD, Robinson GR, Gaines MS. 1995. Vegetation dynamics in an experimentally fragmented landscape. Ecology 76: 1610-1625.

Howard JL. 1996. Bromus inermis. In: Fire Effects Information System, [Internet]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer) Available from: http://www.fs.fed.us/database/feis/ [Accessed: 2006 September 29]

Huntly N, Inouye R. 1988. Pocket gophers in ecosystems: patterns and mechanisms. Bioscience 38 (11): 786-793.

Huntly N, Reichman O. 1994. Effects of subterranean mammalian herbivores on vegetation. Journal of Mammalogy 75: 852-859.

Inouye RS, Huntly NJ, Tilman D, Tester JR. 1987. Pocket gophers, vegetation and soil nitrogen along a successional sere in east central Minnesota. Oecologia 72: 178-184.

Iowa Species List. Available from: http://www.public.iastate.edu/~herbarium/Cofcons.xls [Accessed: 2007 May 10]

Johnson RG, Anderson RC. 1986. The seed bank of a tallgrass prairie in Illinois. The American Midland Naturalist 123: 123-130.

Kost MK. 2004. Natural community abstract for dry sand prairie. Michigan Natural Features Inventory. Lansing (MI). 9 pp.

Kuchler AW. 1964. Potential natural vegetation of the conterminous United States. American Geographical Society, Special Publication No. 36.

Lippert, Hopkins. 1950. Study viable seeds in various habitats in mixed prairie. Transactions of the Kansas Academy of Science 53: 355-364.

Martin AC., Barkley WD. 1961. Seed Identification Manual. University of California Press, Berkeley (CA).

Martinsen GD, Cushman JH, Whitham TG. 1990. Impact of pocket gopher disturbance in plant species diversity in a shortgrass prairie community. Oecologia 83: 132-138.

Musil AF. 1963. Identification of Crop and Weed Seeds. United States Department of Agriculture, Agricultural Marketing Service, Agriculture Handbook No. 219, Washington, D.C.

Natural Resource Commission. 2002. Chapter 77: Endangered and Threatened Plant and Animal Species. Available from: http://www.iowadnr.com/other/files/chapter77.pdf [Accessed: February 4, 2007]

Perez CJ, Waller SS, Moser LE, Stubbendieck JL, Steuter AA. 1998. Seedbank characteristics of a Nebraska sandhills prairie. Journal of Range Management 51: 55-62.

Pohl RW. 1968. How to know the grasses. Dubuque (IA) Wm. C. Brown Co. Publishers.

Rabinowitz D, Rapp JK. 1980. Seed rain in a North American tall grass prairie. Journal of Applied Ecology 17: 793-802.

Rabinowitz D. 1981. Buried Viable seeds in a North American tall-grass prairie: the resemblance of their abundance and composition to dispersing seeds. Okios 36 (2): 191-195.

Sampson, Knopf. 1994. Prairie conservation in North America. Bioscience 44: 418-421.

Schott GW. 1993. Characterization of a native prairie and old-field succession transition implication for plant species invisibility. [Master of Arts thesis] Department of Systematics and Ecology. University of Kansas (KS).

Schott GW, Hamburg SP. 1997. The seed rain and seed bank of an adjacent native tallgrass prairie and old-field. Canadian Journal of Botany 75: 1-7.

Smith DD. 1998. Iowa prairie: original extent and loss, preservation and recovery attempts. Journal of the Iowa Academy of Science 105: 94-108.

Smith DD. 1990. Tallgrass prairie settlement: prelude to demise of the tallgrass ecosystem. Proceedings of the 12th North American Prairie Conference: 195-199.

Stoll-Slife N. 1999. The effect of prescribed burning on froghoppers, planthopers, and leafhoppers from Cedar Hills Sand Prairie preserve. [Master of Science thesis] University of Northern Iowa Cedar Falls (IA).

Swink F, Wilhelm G. 1994. Plants of the Chicago region, 4th edition. The Indiana Academy of Science.

Thompson K, Grime JP. 1979. Seasonal variation in the seed banks of herbaceous species in ten contrasting habitats. The Journal of Ecology 67 (3): 893-921.

Tilman D. 1983. Plant succession and gopher disturbance along an experimental gradient. Oecologia 60: 1189-1211.

Tobey R. 1982. Saving the prairie: the life cycle of the founding school of American plant ecology, 1895-1955. Berkeley: University of California Press.

Transeau EN. 1935. The prairie peninsula. Ecology 16: 423-437.

Uchytil RJ. 1993. Poa pratensis. In: fire effects information system. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer) Available from: http://www.fs.fed.us/database/feis/ [Accessed 2006 September 29].

Umbanhowar CE. 1992. Reanalysis of the Wisconsin prairie continuum. American Midland Naturalist 127: 268-275.

[USDA] United States Department of Agriculture, Soil Conservation Service. 1978. Soil survey of Black Hawk County, IA. Washington D.C. Fouts WC, Highland JD.

Weaver JE. 1958. Summary and interpretation of underground development in natural grasslands communities. Ecological Monographs 28 (1): 55-78.

Weaver, J. E. 1965. Native vegetation of Nebraska. Lincoln (NE): University of Nebraska Press. 185 p.

White J. 1978. Illinois natural areas inventory technical report; volume 1: survey methods and results. Illinois Natural Areas Inventory. Urbana (IL).

Whitman W. 1963. Specimen Days Volume 1 of Prose Works 1892. Stovall F, editor. New York (NY).

Willoughby CL. 1995. Seasonal composition, productivity, and phenology along a sand prairie slope in northeast Iowa. [Master of Science thesis] University of Northern Iowa. Cedar Falls (IA).

Woehler E, Martin M. 1980. Annual vegetation changes in a reconstructed prairie. Proceedings of the 7th North American Prairie Conference: 98-106.

Wolfe-Bellin KS, Moloney KA. 2000. The effect of gopher mounds and fire on the spatial distribution and demography of a short-lived legume in tallgrass prairie. Canadian Journal of Botany 78: 1299-1308.

APPENDIX A: Methods and Equations

Natural Areas Grading System

Coefficient of Conservatism

Simpson's Diversity Index

Relative Cover

Relative Frequency

Importance Value

Natural Areas Grading System

A grading system used to determine an area's quality incorporates the amount of disturbance in a natural area (White, 1978). The system uses changes in natural diversity, structure, species composition, and amount of successional instability in a community. These values are assigned by visually measuring the site and were determined by Daryl Smith and Susan Kirt in 2003.

The five grades are:

Grade A: Relatively stable or undisturbed communities

Grade B: Late successional or lightly disturbed communities

Grade C: Mid-successional or moderately to heavily disturbed communities

Grade D: Early successional or severely disturbed communities

Grade E: Very early successional or very severely disturbed communities

According to White's (1978) grading system, in 2001 the remnant sand prairie was assigned a A-/B+ grade due to grazing which occurred before 1965. This practice helped introduced non-native species into the remnant prairie. However, the remnant is relatively stable and the species composition does not appear to be rapidly changing. In the old-field, row crop agriculture and grazing have significantly altered the site. Species movement into the old-field from the remnant prairie has helped revert the old-field back into a site dominated by native prairie species.

The edge old-field was assigned a C+ grade. This is due to the original community structure being destroyed by agriculture, changing the species composition. This sub-site is in a mid-successional stage of development, contains many of the same species as the adjoining remnant prairie, including four late successional species (*Carex conoidea, C. meadii, Juncus greenei* and *Rubus fulleri*). The species density and canopy cover of the native and non-native species was similar to the remnant prairie, where native species have out-competed the non-native species.

The mid old-field 1 was assigned a C grade while the mid old-field 2 was a C-. These 2 sub-sites covered half of the sampled old-field and contained a number of mid (C: 4-7) and late (C: 8-10) successional species. However, the native species were more scattered and in these sub-sites the canopy cover shifted from being dominated by native species to being dominated by non-natives. The mid old-field 2 sub-site received a lower grade since there were more differences between it and the remnant prairie than with the mid old-field 1.

The distant old-field received a D grade. Non-native species dominated the area and accounted for 98.5% of the canopy cover. There were two groupings that were notably absent from the distant old-field, the sedges and rushes and late successional native species, both of which were present in the other 5 sub-sites. This sub-site was the most unlike the remnant prairie. However, 12 of the 17 species were native including 4 mid-successional species (*Dichanthelium* sp., *Helianthus grosseserratus, Physalis virginiana* and *Verbena stricta*) which is a fair number of species for an old-field without a nearby native seed source.

<u>Index of Conservatism</u>

Swink and Wilhelm (1994) developed the Coefficient of Conservatism (C) rating for plants in the Chicago region. The values allows comparisons to be made between different sites as well as tracking the quality of an area over time. A C-value is assigned to each native species ranging from 0 to 10 with exotic species not receiving a rating.

A C rating of 0, for example *Achillea millefolium*, is an early successional species and there is no confidence that the plant was collected from a native community. A C rating of 5, for example *Panicum virgatum*, is a mid successional species and suggests the species came from a natural area, though there is little confidence that the area is not degraded. A C rating of 10, for example *Juncus greenei*, is a highly conservative species and has virtually a 100% probability of coming from an intact natural community.

Species have a geographic range and a species common in one area could be rare in another location. The C rating for a species can vary depending on where the species is located. Plant species inventories from different geographic areas, including Iowa, Illinois, the Chicagoland Area, Michigan, Wisconsin, Northern Ohio and the Dakotas have been developed with C values specific to their geographic area. If the area covered by an inventory has a species that is more rare, for example, in the North and more common in the South, an intermediate C value is assigned to the species. C values assigned to each species for this study were taken from the Iowa Species List (Online).

It can be difficult to determine the relationships of non-native species with a natural community. Some non-natives, such as *Poa pratensis,* can occur across a wide range of habitats. Non-native species are considered a disturbance and the impact is measured indirectly. The assumption is the more non-native species in a natural community; the quality of the community is lower which is reflected by a lower C-value.

Overall, the Iowa species list provided a good framework for splitting up the native species. Those that were termed early succession had C-values between 0 and 3 and these species are often present in both remnant and old-field settings. The mid successional species, C-values between 4 and 7, contained most of the species often encountered in a remnant prairie and that are often not located in an abandoned field. Late successional species were classified as those with C-values between 8 and 10. These species tend to be more rare in Iowa and typically have narrower niche requirements. As with the mid successional species these plants are often not present in abandoned agricultural land. Non-native species are considered those that originated from outside of Iowa, mostly from Eurasia.

Several issues concerning coefficient values should be kept in mind. First, species lists deals with the individual species in today's framework and is not a reflection of pre-European settlement. As such, a plant that is rare in today's landscape and has a high C-value might have been very common in pre-settlement Iowa, often due to habitat fragmentation and destruction. The list also covers the entire state, from the wetter eastern portions to the drier western portions. Due to this species that are common out west can be rare in the east and would receive a middle number. In addition, the study area at Cedar Hills Sand Prairie is a dry site and will contain species that are rare in the state of Iowa but that could be common in sand, gravel or hill prairies. The most notable species in the study area is *Dichanthelium* sp. which has a C-value of 5. However, this plant is common throughout all the dry areas of the preserve, whether remnant or old-field. As such, in the dry prairie context this species would likely be reclassified as an early successional species (was classified as mid successional for the study). Lastly, several non-native species are so common in today's landscape that they are a part of nearly every ecosystem, for example, *Bromus inermis* and *Poa pratensis*. As such, the mere presence of these species is likely not an indicator that the area is degraded, and instead how dominant these species are might be a better indicator of site health. Despite the aforementioned caveats, the general grouping appeared to work well in the context of measuring native species invasion from the remnant prairie north into the old-field.

The mean coefficient of conservatism ($\bar{C}$) is calculated by taking the sum of the C values for each native species and dividing by the total number of native species present (N). One problem with this measurement is that it only takes into account the number of species present at a site and does not take into account species abundance. However, according to Swink and Wilhelm (1994) restored areas and abandoned fields often do not have a high $\bar{C}$ value.

<u>Simpson's Diversity Index</u>

Simpson's Diversity Index is used to measure diversity in each of the treatments using canopy coverage. The index's range is from 0 to almost 1; the diversity is higher as 1 is approached. Simpson's Diversity Index represents the probability of picking two individual plants at random and having them be the same species (index approaches 0) or different species (index approaches 1).

$$1\text{-}D = 1 - \sum (P_i)^2$$

Where (1-D)= Simpson's Diversity Index

P_i= proportion of individuals of species i in the community (n_i/N)

N= the total coverage of the plot

n_i= the cover of the individual species

Relative Cover, Frequency and Importance Value (IV)

The frequency of a species is dependent on the shape and size of the plots used. In large plots it is more likely to find most of the species while in small plots the same species may be rarely encountered. The frequency (F) is the chance of finding a specific species within a sample:

$$F_i = j_i/k$$

Where F_i= frequency of species i

j_i= the number of samples in which species i occurred in

k= the total number of samples taken

Relative frequency (Rf) was used for many of the analyses, as the total coverage for each of the plots did not equal 100. This is due to the overlap of species that can cause the total coverage to be greater than 100 or the present of bare ground, such as gopher mounds, in which case the coverage would be less than 100. The relative frequency equals the coverage in all of the plots to 100.

$$Rf = f_i/\sum f$$

Where f_i= the frequency of a given species

$\sum f$= the sum of frequency for all species

The coverage (C) is a projection of the proportion of the ground occupied from the aerial parts of a plant, such as leaves. The coverage of a species is determined by:

$Ci = ai/A$

Where ai= the total foliage area covered by a species

A= the total area sampled

The relative coverage (RCi) for species i is the coverage for the species (Ci) as a proportion of the total coverage (TC). Where $\sum C$: the sum of the coverage for all the species.

$Rci = Ci/TC$: $Ci/\sum C$

The importance value (IV) is the sum of the two above relative measures for species i. The value can range from 0 to 2 (or 0% to 200%). The importance value provides an estimate of the relative importance of a species in the community.

$IVi = Rfi + RCi$

REFERENCES

Iowa Species List. Unpublished. [cited: 2007, May 10]. Available from: http://www.public.iastate.edu/~herbarium/Cofcons.xls

Swink F, Wilhelm G. 1994. Plants of the Chicago region, 4th edition. The Indiana Academy of Science.

White J. 1978. Illinois natural areas inventory technical report; volume 1: survey methods and results. Illinois Natural Areas Inventory. Urbana (IL).

APPENDIX B

Location of species in the vegetation, seed rain and seed bank during the 2000 and 2001 sampling period. The vegetation is presented as the interior (IR) and edge remnant (ER) and the old-field as the edge (EOF), mid-1 (MOF1), mid-2 (MOF2) and distant (DOF) old-field. The 2000 and 2001 seed rain was combined and divided into the remnant (R) and old-field (F). The fall 2000 seed bank was divided into the pre-burn and post-burn, remnant and old-field seed bank. The preliminary spring 2000 seed bank species were shown for the remnant and old-field.

			Vegetation						Seed Rain		Fall Seed Bank				Spring	
			Remnant		Old-Field						Pre-Burn		Post-Burn		Seed Bank	
Type	C	SPECIES	IR	ER	EOF	MOF1	MOF2	DOF	R	F	R	F	R	F	R	F
NNF	*	Abutilon theophrasti	-	-	-	-	-	-	-	-	-	-	-	-	1	-
NF	0	Achillea millefolium	1	1	1	1	1	1	1	1	1	1	1	1	1	-
NF	4	Agalinis tenuifolia	-	-	1	1	1	-	-	-	-	-	-	-	-	-
NNG	*	Agrostis gigantea	-	1	1	1	1	-	-	-	-	1	-	-	-	-
NG	4	Agrostis hyemalis	-	-	-	-	-	-	1	1	-	-	-	-	-	-
NNF	*	Amaranthus hybridus	-	-	-	-	-	-	-	-	-	-	-	-	1	-
NF	2	Ambrosia sp.	1	1	1	1	1	1	1	1	1	1	1	1	-	-
NF	0	Ambrosia trifida	1	-	-	-	-	-	-	-	-	-	-	-	-	-
NF	8	Amorpha canescens	-	1	-	1	-	-	-	-	-	-	-	-	-	-
NG	4	Andropogon gerardii	1	1	1	1	1	-	1	1	-	-	-	-	-	-
NF	2	Anemone canadensis	1	1	-	1	1	-	1	-	-	-	-	-	-	-
NF	7	Anemone cylindrica	1	1	-	1	1	-	-	-	-	-	-	-	-	-
NF	2	Antennaria neglecta	1	1	-	-	-	-	-	-	-	-	-	-	-	-
NF	2	Artemisia ludoviciana	1	1	-	1	-	-	-	-	-	-	-	-	-	-
NF	0	Asclepias syriaca	1	-	-	1	-	-	-	-	-	-	-	-	-	-
NF	0	Asclepias verticillata	1	1	-	-	-	-	-	-	-	-	-	-	-	-
NF	7	Aster azureus	-	1	1	1	-	-	-	1	-	-	-	-	-	-
NF	3	Aster ericoides	1	1	1	1	1	-	1	1	-	-	-	-	-	-
NF	7	Aster laevis	-	-	-	-	-	-	-	-	-	1	-	-	-	-
NF	4	Aster lanceolatus	-	-	-	-	-	-	-	1	-	1	-	-	-	-
NF	0	Aster pilosus	-	-	-	-	-	-	1	1	-	-	-	-	-	-
NF	?	ASTERACEAE	-	-	-	-	-	-	1	-	-	-	-	-	-	-
NNG	*	Bromus inermis	1	1	1	1	1	1	-	1	-	-	-	1	-	-
NF	0	Calystegia sepium	-	-	-	-	1	1	-	-	-	-	-	-	-	-
NNF	*	Cannabis sativa	-	-	-	-	-	-	-	-	1	-	-	-	-	-
NNF	*	Capsella bursa-pastoris	-	-	-	-	-	-	-	-	-	1	1	1	-	-
SR	6	Carex brachyglossa	-	-	1	1	1	-	-	1	-	-	-	-	-	-
SR	4	Carex brevior	-	-	1	1	1	-	-	-	-	-	-	-	-	-

			Vegetation						Seed Rain		Fall Seed Bank				Spring	
			Remnant		Old-Field						Pre-Burn		Post-Burn		Seed Bank	
Type	C	SPECIES	IR	ER	EOF	MOF1	MOF2	DOF	R	F	R	F	R	F	R	F
SR	10	Carex conoidea	-	-	1	1	1	-	-	-	-	-	-	-	-	-
SR	9	Carex meadii	1	1	1	1	1	-	-	-	-	-	-	-	-	-
SR	5	Carex scoparia	-	-	-	1	1	-	-	1	-	-	-	-	-	-
SR	?	Carex sp.	-	-	-	-	-	-	1	1	-	-	-	-	-	1
SR	3	Carex vulpinoidea	-	-	-	-	-	-	-	-	-	1	-	-	-	-
NNF	*	Chenopodium album	-	-	-	-	-	-	-	-	-	-	-	-	1	1
NF	1	Cirsium discolor	1	1	1	1	1	1	-	1	-	-	-	-	-	-
NF	7	Coreopsis palmata	1	-	-	-	-	-	-	-	-	-	-	-	-	-
SR	?	CYPERACEAE	-	-	-	-	-	-	1	-	-	-	-	-	-	-
SR	0	Cyperus esculentus	-	-	1	-	-	-	-	-	-	1	-	1	-	-
SR	8	Cyperus filiculmis	-	-	-	-	-	-	-	-	-	1	-	-	-	-
SR	2	Cyperus strigosus	-	-	-	-	-	-	-	-	1	1	-	1	-	1
NF	7	Delphinium virescens	1	1	-	-	-	-	-	-	1	1	-	-	-	-
NF	6	Desmodium canadense	-	-	1	-	-	-	-	-	-	-	-	-	-	-
NF	?	Desmodium sp.	-	-	-	-	-	-	1	1	-	-	-	-	-	-
NG	5	Dichanthelium sp.	1	1	1	1	1	1	1	1	1	1	-	-	-	-
SR	?	Eleocharis sp.	-	-	1	1	-	-	-	-	-	-	-	-	-	-
NF	0	Equisetum arvense	1	1	1	-	-	-	-	-	-	-	-	-	-	-
NF	2	Erigeron strigosus	-	-	-	1	1	-	-	-	-	1	-	-	1	1
NF	6	Eupatorium purpureum	-	-	-	-	-	-	1	-	-	-	-	-	-	-
NF	3	Euphorbia corollata	1	1	1	1	1	1	1	1	-	1	-	1	-	-
NF	5	Euthamia graminifolia	-	1	1	1	1	-	1	1	-	1	-	-	-	-
NF	3	Fragaria virginiana	1	1	1	1	1	-	-	-	-	-	-	-	-	-
NF	?	Galium sp.	-	-	-	-	-	-	-	1	-	-	-	-	-	-
NF	9	Gentiana puberulenta	-	1	-	-	-	-	-	-	-	-	-	-	-	-
?	?	Grass	-	-	-	-	-	-	-	-	1	-	-	-	-	-
NF	2	Hedeoma hispidum	-	-	-	-	-	-	1	1	-	-	-	-	-	-
NF	0	Helianthus annuus	-	-	-	1	-	-	-	-	-	-	-	-	-	-

			Vegetation						Seed Rain		Fall Seed Bank				Spring Seed Bank	
			Remnant		Old-Field						Pre-Burn		Post-Burn			
Type	C	SPECIES	IR	ER	EOF	MOF1	MOF2	DOF	R	F	R	F	R	F	R	F
NF	4	Helianthus grosseserratus	1	1	1	1	1	1	-	-	-	-	-	-	-	-
SR	8	Hemicarpha micrantha	-	-	-	-	-	-	-	-	-	-	-	-	-	1
NF	7	Hypericum majus/mutilum	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NNF	*	Hypericum perforatum	-	-	-	-	-	-	-	-	-	1	-	-	-	1
SR	10	Juncus greenei	-	-	1	1	1	-	-	-	1	-	-	1	-	-
SR	0	Juncus tenuis var. tenuis	1	-	-	-	-	-	-	-	-	-	1	1	-	-
NG	7	Koeleria macrantha	-	-	1	-	-	-	-	-	-	-	-	-	-	-
NF	1	Lactuca canadensis	-	-	-	-	-	-	1	1	-	-	-	-	-	-
NF	3	Lespedeza capitata	1	1	1	1	1	1	1	-	-	-	-	-	-	-
NF	8	Liatris aspera	-	1	-	-	-	-	-	-	-	-	-	-	-	-
NF	7	Lithospermum canescens	1	1	-	-	-	-	-	-	-	-	-	-	-	-
NF	4	Lycopus americanus	1	1	1	1	1	-	-	-	-	-	-	-	-	-
NF	4	Lysimachia ciliata	-	-	-	-	1	-	-	-	-	-	-	-	-	-
NNF	*	Medicago lupulina	-	-	1	-	-	-	-	-	-	-	-	-	1	-
NNF	*	Melilotus sp.	1	1	1	1	1	1	-	1	1	1	1	1	-	-
NNF	*	Mollugo verticillata	-	-	-	-	-	-	-	-	-	-	-	-	1	1
NF	2	Monarda fistulosa	-	1	-	1	-	-	1	1	-	-	-	-	-	1
NNF	*	Nepeta cataria	-	-	-	-	-	-	-	-	-	1	1	1	-	-
NF	0	Oenothera biennis	1	-	-	-	-	-	1	1	-	-	-	-	-	1
NF	8	Oenothera rhombipetala	-	-	-	-	-	-	1	1	-	-	-	-	-	-
NF	0	Oxalis stricta	1	1	1	1	1	-	1	1	-	-	-	-	1	1
NNG	*	Panicum miliaceum	-	-	-	-	-	-	1	-	-	-	-	-	-	-
NG	5	Panicum virgatum	1	1	-	-	-	-	1	1	-	-	-	-	-	1
NG	4	Paspalum setaceum	1	-	-	-	-	-	-	1	-	-	-	-	-	-
NNF	*	Phlem pratense	-	-	1	1	-	-	-	-	-	-	-	-	-	-
NF	2	Physalis heterophylla	1	1	-	-	1	1	-	-	-	-	-	-	-	-
NF	4	Physalis virginiana	1	1	-	-	1	1	-	-	-	-	-	-	-	-
?	?	Plant 1	-	-	-	-	-	-	-	-	1	1	-	-	-	-

			Vegetation						Seed Rain		Fall Seed Bank				Spring	
			Remnant		Old-Field						Pre-Burn		Post-Burn		Seed Bank	
Type	C	SPECIES	IR	ER	EOF	MOF1	MOF2	DOF	R	F	R	F	R	F	R	F
?	?	Plant A	-	-	-	-	-	-	-	-	-	1	1	1	-	-
NF	0	Plantago rugelii	1	-	-	-	-	-	-	-	-	-	-	-	-	-
NNG	*	Poa pratensis	1	1	1	1	1	1	1	1	1	1	1	1	1	1
?	?	POACEAE	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NNF	*	Polygonum persicaria	-	-	-	-	-	-	1	-	-	-	-	-	-	-
NNF	*	Portulaca oleracea	-	-	-	-	-	-	-	-	-	-	-	-	1	1
NF	8	Potentilla arguta	1	1	-	-	-	-	1	1	1	1	-	-	1	1
NF	2	Potentilla norvegica	1	1	-	-	-	-	1	-	1	1	1	1	-	1
NNF	*	Potentilla recta	1	-	-	1	-	-	-	-	-	-	-	-	-	-
NF	3	Potentilla simplex	-	1	1	1	-	-	-	-	-	-	-	-	-	-
NNF	*	Prunella vulgaris	-	-	1	-	-	-	-	-	-	-	-	-	-	-
NF	6	Pycnanthemum tenuifolium	1	1	-	1	-	-	-	-	-	-	-	-	-	-
NF	4	Rosa sp.	1	1	-	-	-	-	-	-	-	-	-	-	-	-
NF	?	ROSACEAE 1	-	-	-	-	-	-	-	1	-	-	-	-	-	-
NF	?	ROSACEAE 2	-	-	-	-	-	-	1	-	-	-	-	-	-	-
NF	2	Rubus allegheniensis	1	1	1	-	-	-	-	-	-	-	-	-	-	-
NF	9	Rubus fulleri	1	1	1	-	1	-	-	-	-	-	-	-	-	-
NF	2	Rudbeckia hirta	-	-	1	-	-	-	-	-	1	1	1	1	-	-
NNF	*	Rumex acetosella	1	1	-	-	-	-	1	1	1	-	1	-	1	-
NNF	*	Rumex crispus	1	1	-	1	1	-	-	-	-	-	-	-	-	-
NG	5	Schizachyrium scoparium	1	1	1	1	1	-	1	1	-	-	-	-	-	-
SR	4	Scirpus cyperinus	-	-	1	-	-	-	1	1	-	-	-	-	-	-
SR	?	Scirpus sp.	1	-	-	-	-	-	-	1	-	-	-	-	-	-
NF	5	Senecio pauperculus	1	1	1	1	1	-	1	1	1	1	-	1	-	-
NNG	*	Setaria faberi	-	-	-	-	-	-	1	-	-	-	-	-	-	1
NNG	*	Setaria glauca	-	-	-	-	-	-	-	-	1	1	1	-	1	1
NNG	*	Setaria viridis	-	-	-	-	-	-	-	-	-	-	-	-	1	-
NNF	*	Silene pratensis	-	-	-	-	-	1	-	-	-	-	-	-	-	-

			Vegetation						Seed Rain		Fall Seed Bank				Spring	
			Remnant		Old-Field						Pre-Burn		Post-Burn		Seed Bank	
Type	C	SPECIES	IR	ER	EOF	MOF1	MOF2	DOF	R	F	R	F	R	F	R	F
NNF	*	Silene vulgaris	-	-	-	-	-	-	-	-	-	1	-	-	-	-
NF	4	Sisyrinchium campestre	1	-	-	1	1	-	-	-	-	-	-	-	-	-
NF	5	Smilacina stellata	-	1	-	-	-	-	-	-	-	-	-	-	-	-
NF	0	Solidago canadensis	1	1	1	1	1	1	-	-	-	-	-	-	-	-
NF	?	Solidago sp.	1	1	1	1	1	-	-	-	-	1	-	-	-	-
NF	7	Solidago speciosa	1	1	1	1	1	-	-	-	-	-	-	-	-	-
NG	4	Sorghastrum nutans	1	1	1	-	1	-	1	-	-	-	-	-	-	-
NF	5	Spiraea alba	-	1	1	1	1	-	-	-	-	-	-	-	-	-
NG	9	Sporobolus heterolepis	-	1	-	-	-	-	1	-	1	-	-	-	1	1
NG	6	Stipa spartea	1	1	-	-	-	-	-	-	-	-	-	-	-	-
NNF	*	Taraxacum officinale	1	1	-	-	-	-	-	-	1	-	-	-	-	-
NF	4	Tradescantia ohiensis	-	1	-	-	-	-	-	-	-	-	-	-	-	-
NNF	*	Tragopogon dubius	1	1	-	-	-	-	-	-	-	-	-	-	-	-
NNF	*	Trifolium pratense	1	1	-	1	1	-	-	-	-	-	-	-	1	-
NNF	*	Trifolium repens	-	-	1	-	-	-	-	-	-	-	-	-	-	-
?	?	Unknown	-	-	-	-	-	-	-	-	-	-	-	-	-	-
?	?	Unknown (Aster sp.)	-	-	-	-	-	-	-	1	-	-	-	-	-	-
?	?	Unknown (broken)	-	-	-	-	-	-	1	-	-	-	-	-	-	-
NNF	*	Verbascum thapsus	-	-	-	-	-	1	-	1	1	-	1	-	-	-
NF	3	Verbena hastata	1	1	-	1	1	-	-	-	-	1	1	1	-	-
NF	1	Verbena stricta	1	-	-	-	-	1	1	-	-	-	1	-	-	1
NF	5	Veronicastrum virginicum	-	1	-	-	-	-	-	-	-	-	-	-	-	-
NF	8	Viola pedatifida	-	1	-	-	-	-	-	-	-	-	-	-	-	-
NF	7	Viola sagittata	-	1	1	1	-	-	-	-	-	-	-	-	-	-
B	3	Zanthoxylum americanum	-	-	-	-	-	-	-	-	1	-	1	-	-	-

APPENDIX C

The 25 most common species with an average frequency of 50% or higher in the sampled remnant and/or old-field vegetation.

Classification	Type	Species	Remnant	Old-Field
E	NF	Achillea millefolium spp lanulosa	100	82
E	NF	Ambrosia sp.	100	43
M	NG	Andropogon gerardii	100	46
M	NF	Anemone cylindrica	65	7
E	NF	Artemisia ludoviciana	80	7
E	NF	Aster ericoides	20	61
*	NNG	Bromus inermis	45	86
M	SR	Carex brevior	-	50
L	SR	Carex meadii	70	39
M	NG	Dichanthelium sp.	90	71
E	NF	Equisetum arvense	70	18
E	NF	Euphorbia corollata	90	71
M	NF	Helianthus grosseserratus	50	75
L	SR	Juncus greenei	-	50
E	NF	Lespedeza capitata	30	61
*	NNF	Melilotus sp.	10	86
E	NF	Oxalis stricta	55	18
*	NNG	Poa pratensis	100	100
M	NF	Rosa sp.	65	-
*	NNF	Rumex acetosella	85	-
M	NG	Schizachyrium scoparium	100	64
M	NF	Senecio pauperculus	95	36
M	NF	Solidago speciosa	40	54
M	NG	Sorghastrum nutans	85	21
M	NG	Stipa spartea	50	-

E Early Successional Native
M Mid Successional Native
L Late Successional Native
* Non-Native
NF Native Forb
NNF Non-Native Forb
NG Native Grass
NNG Non-Native Grass
SR Sedges and Rushes

APPENDIX D

Relative cover, frequency, and importance value (IV) for the remnant (R) and old-field (F) vegetation.

	Relative Cover				Relative Frequency				Importance Value			
	2000	2001	2000	2001	2000	2001	2000	2001	2000	2001	2000	2001
	R	R	F	F	R	R	F	F	R	R	F	F
Achillea millefolium	2.2	1.9	0.5	0.2	3.9	4	4.7	4.1	6.1	5.9	5.2	4.3
Agalinis tenuifolia	-	-	0	0	-	-	0.8	1.1	-	-	0.8	1.1
Agrostis gigantea	-	0	0.1	0.1	-	0.3	2.3	1.5	-	0.3	2.4	1.6
Ambrosia sp.	0.8	1.7	0.4	0.6	3.9	4	1.6	3	4.7	5.7	2	3.6
Ambrosia trifida	0.2	-	-	-	0.7	-	-	-	0.9	-	-	-
Amorpha canescens	0	0	-	0	0.7	0.3	-	0.4	0.7	0.3	-	0.4
Andropogon gerardii	7.2	8.3	7	9.1	3.9	4	2.7	2.2	11.1	12.3	9.7	11.3
Anemone canadensis	1.2	1.2	0		2.6	1.1	1.2	-	3.8	2.3	1.2	-
Anemone cylindrica	2.3	0.9	-	0	2.6	2.6	-	0.7	4.9	3.5	-	0.8
Antennaria neglecta	-	1	-	-	-	0.6	-	-	-	1.6	-	-
Artemisia ludoviciana	0.6	0.7	0	0.4	2.6	3.4	0.4	0.4	3.2	4.1	0.4	0.8
Asclepias syriaca	0	-	-	0	0.7	-	-	0.4	0.7	-	-	0.4
Asclepias verticillata	0.1	0	-	-	1.3	0.6	-	-	1.4	0.6	-	-
Aster azureus	0.5	0.6	0.4	-	2	1.1	1.2	-	2.5	1.7	1.6	-
Aster ericoides	0	0.1	1	0.4	1.3	0.6	3.1	3.3	1.3	0.7	4.1	3.7
Aster sp.	-	-	-	0	-	-	-	0.4	-	-	-	0.4
Bromus inermis	0	0.8	13.4	22.3	0.7	2.3	4.3	4.8	0.7	3.1	17.7	27.1
Calystegia sepium	-	-	0	-	-	-	0.8	-	-	-	0.8	-
Carex brachyglossa	-	-	0.5	0	-	-	2.3	0.7	-	-	2.9	0.7
Carex brevior	-	-	1.5	0	-	-	3.1	2.2	-	-	4.6	2.2
Carex conoidea	-	-	0.4	2.3	-	-	1.2	3.3	-	-	1.5	5.6
Carex meadii	0.5	1.2	17.5	0	2.6	2.8	3.5	0.7	3.1	4	21	0.7
Carex scoparia	-	-	0.2	0	-	-	0.8	0.7	-	-	1	0.8
Cirsium discolor	0.2	0.6	0.1	0.1	1.3	1.4	0.8	1.5	1.6	2.1	0.8	1.6
Coreopsis palmata	-	0.6	-	-	-	0.6	-	-	-	1.2	-	-
Cyperus esculentus	-	-	0	-	-	-	0.8	-	-	-	0.8	-
Delphinium virescens	-	0	-	-	-	0.6	-	-	-	0.6	-	-
Desmodium canadense	-	-	-	0	-	-	-	0.4	-	-	-	-
Dichanthelium sp.	0.6	0.6	0.4	0.4	3.3	3.7	3.1	4.4	3.9	4.3	3.5	-
Eleocharis sp.	-	-	-	0	-	-	-	0.7	-	-	-	-
Equisetum arvense	0.1	0	0	0.1	2	3.1	0.8	1.1	2.1	3.2	0.8	-
Erigeron strigosus	-	-	0	0.1	-	-	0.4	1.1	-	-	0.4	-
Euphorbia corollata	0.8	0.6	0.2	0.2	3.3	3.7	3.5	4.1	4.1	4.3	3.7	-

	Relative Cover				Relative Frequency				Importance Value			
	2000	2001	2000	2001	2000	2001	2000	2001	2000	2001	2000	2001
	R	R	F	F	R	R	F	F	R	R	F	F
Euthamia graminifolia	0.1	-	2.0	1.4	0.7	-	4.3	4.1	0.7	-	6.3	-
Fragaria virginiana	0.2	1.1	0.3	0.5	0.7	2.3	1.6	2.2	0.9	3.3	1.9	-
Gentiana puberulenta	-	0.0	-	-	-	0.3	-	-	-	0.3	-	-
Helianthus annuus	-	-	0.0	-	-	-	1.2	-	-	-	1.2	-
Helianthus grosseserratus	0.0	0.6	0.7	0.9	0.7	2.6	3.5	4.4	0.7	3.2	4.2	5.3
Juncus greenei	-	-	0.5	0.1	-	-	2.0	3.3	-	-	2.5	3.4
Koeleria macrantha	-	-	-	0.0	-	-	-	0.4	-	-	-	0.4
Lespedeza capitata	0.1	0.1	0.3	0.3	1.3	1.1	3.5	3.0	1.4	1.2	3.8	3.2
Liatris aspera	0.1	-	-	-	0.7	-	-	-	0.8	-	-	-
Lithospermum canescens	0.4	0.0	-	-	3.3	0.9	-	-	3.6	0.9	-	-
Lycopus americanus	0.0	0.0	0.0	0.1	0.7	0.9	1.2	1.5	0.7	0.9	1.2	1.6
Lysimachia ciliata	-	-	-	0.0	-	-	-	0.4	-	-	-	0.4
Medicago lupulina	-	-	-	0.0	-	-	-	0.4	-	-	-	0.4
Melilotus sp.	-	0.0	4.1	3.4	-	0.6	5.1	4.1	-	0.6	9.1	7.4
Monarda fistulosa	0.2	0.2	0.0	-	1.3	0.6	0.4	-	1.5	0.7	0.4	-
Oenothera biennis	0.0	-	-	-	0.7	-	-	-	0.7	-	-	-
Oxalis stricta	0.0	0.0	0.0	0.0	1.3	2.6	0.8	1.1	1.3	2.6	0.8	1.1
Panicum virgatum	0.2	-	-	-	2.0	-	-	0.4	2.2	-	-	0.4
Paspalum setaceum	-	0.0	-	-	-	0.3	-	-	-	0.3	-	-
Phlem pratense	-	-	0.4	-	-	-	1.2	-	-	-	1.5	-
Physalis heterophylla	0.6	0.1	0.0	0.0	3.3	0.9	0.4	1.1	3.8	0.9	0.4	1.1
Physalis virginiana	-	0.1	0.0	0.0	-	2.6	0.4	0.7	-	2.7	0.4	0.7
Plantago rugelii	0.9	-	-	-	1.3	-	-	-	2.2	-	-	-
Poa pratensis	32.2	31.9	46.6	38.6	3.9	4.0	5.5	5.2	36.2	35.9	52.0	43.7
Potentilla arguta	0.0	0.9	-	-	0.7	2.3	-	-	0.7	3.2	-	-
Potentilla norvegica	0.3	-	-	-	1.3	-	-	-	1.6	-	-	-
Potentilla recta	-	0.0	0.0	-	-	0.3	0.4	0.0	-	0.3	0.4	0.0
Potentilla simplex	-	0.2	-	0.4	-	1.1	-	1.5	-	1.4	-	1.9
Prunella vulgaris	-	-	0.0	0.0	-	-	0.4	0.4	-	-	0.4	0.4
Pycnanthemum tenuifolium	0.4	0.8	0.0	-	0.7	0.9	0.4	-	1.0	1.7	0.4	-
Rosa sp.	1.3	0.9	-	-	2.6	2.0	-	-	4.0	2.9	-	-
Rubus allegheniensis	1.2	2.3		0.2	0.7	1.1		0.4	1.8	3.4		0.6
Rubus fulleri	6.0	0.4	0.4	-	2.6	0.3	1.2	-	8.6	0.7	1.6	-

	Relative Cover				Relative Frequency				Importance Value			
	2000 R	2001 R	2000 F	2001 F	2000 R	2001 R	2000 F	2001 F	2000 R	2001 R	2000 F	2001 F
Rudbeckia hirta	-	-	-	0.0	-	-	-	0.4	-	-	-	0.4
Rumex acetosella	0.7	3.8	-	-	2.6	4.3	-	-	3.3	8.0	-	-
Rumex crispus	-	0.2	-	0.1	-	0.9	-	0.7	-	1.0	-	0.9
Schizachyrium scoparium	21.8	19.4	6.4	4.7	3.9	4.0	3.9	3.0	25.8	23.4	10.3	7.7
Scirpus cyperinus	-	-	0.0	-	-	-	0.4	-	-	-	0.4	-
Sedge sp.	-	0.0	-	-	-	0.6	-	-	-	0.6	-	-
Senecio pauperculus	8.0	6.5	8.5	8.8	3.9	3.7	3.9	3.7	11.9	10.2	12.4	12.5
Silene pratensis	-	-	-	0.0	-	-	-	0.7	-	-	-	0.7
Sisyrinchium campestre	-	0.7	-	0.0	-	0.9	-	0.7	-	1.6	-	0.7
Smilacina stellata	0.1	0.0	-	-	0.7	0.3	-	-	0.7	0.3	-	-
Solidago canadensis	1.1	0.7	0.3	0.2	0.7	1.4	3.5	1.5	1.8	2.2	3.8	1.7
Solidago sp.	-	0.3	0.1	0.8	-	1.1	1.6	1.9	-	1.4	1.7	2.6
Solidago speciosa	0.7	0.9	1.3	0.4	2.0	1.4	4.7	1.1	2.7	2.3	6.0	1.5
Sorghastrum nutans	2.0	1.6	0.2	2.0	3.9	3.1	1.6	0.7	5.9	4.8	1.8	2.8
Spiraea alba	3.0	2.7	0.1	0.5	1.3	0.6	1.6	2.2	4.3	3.2	1.7	2.8
Sporobolus heterolepis	0.4	1.6	-	-	1.3	0.6	-	-	1.7	2.2	-	-
Stipa spartea	0.4	0.3	-	-	2.6	1.7	-	-	3.0	2.0	-	-
Taraxacum officinale	0.0	0.0	-	-	0.7	0.6	-	-	0.7	0.6	-	-
Tradescantia ohiensis	0.0	0.0	-	-	0.7	0.3	-	-	0.7	0.3	-	-
Tragopogon dubius	0.0	0.0	-	-	0.7	0.6	-	-	0.7	0.6	-	-
Trifolium pratense	0.0	0.0	0.0	0.1	0.7	0.6	0.4	0.7	0.7	0.6	0.4	0.8
Trifolium repens	-	-	0.0	-	-	-	0.4	-	-	-	0.4	-
Unknown	0.1	0.0	0.0	0.1	1.3	0.3	0.8	1.9	1.4	0.3	0.8	1.9
Verbascum thapsus	-	-	0.2	0.1	-	-	0.4	0.4	-	-	0.6	0.4
Verbena hastata	0.0	0.0	0.1	0.0	1.3	0.9	0.4	1.5	1.3	0.9	0.4	1.5
Verbena stricta	-	0.1	-	0.0	-	0.6	-	0.4	-	0.7	-	0.4
Veronicastrum virginicum	0.3	0.4	-	-	2.0	1.1	-	-	2.3	1.5	-	-
Viola pedatifida	-	0.1	-	-	-	0.3	-	-	-	0.4	-	-
Viola sagittata	-	0.0	-	0.1	-	1.1	-	0.7	-	1.2	-	0.8

APPENDIX E

Importance values for the 18 most common species in the vegetation. At least one sub-site has a value of 6.0 or above in the remnant and old-field, with the exception of *Carex conoidea*, the most dominant sedge species.

SPECIES	Total Remnant	Total Field	Distant Remnant	Edge Remnant	Edge Old-Field	Mid Old-Field-1	Mid Old-Field-2	Distant Old-Field
Achillea millefolium	6.0	4.8	6.8	5.3	4.6	5.2	4.2	6.0
Ambrosia sp.	5.4	2.8	6.0	4.8	3.7	1.4	2.2	6.6
Andropogon gerardii	12.1	9.5	13.9	10.4	38.3	4.1	2.0	-
Aster ericoides	0.9	3.9	0.4	1.3	1.6	5.2	12.5	-
Bromus inermis	2.4	24.3	1.7	3.0	2.2	10.2	24.4	66.4
Carex conoidea	-	3.6	-	-	3.5	3.4	7.1	-
Dichanthelium sp.	4.2	4.2	4.7	3.8	1.4	4.8	4.5	9.9
Euphorbia corollata	4.3	4.0	4.9	3.7	2.1	5.0	2.1	8.0
Euthamia graminifolia	0.2	5.8	-	0.4	5.1	7.6	7.0	-
Helianthus grosserseratus	2.4	4.8	1.5	3.2	3.2	4.9	6.4	6.0
Melilotus sp.	0.4	8.4	0.4	0.4	8.0	8.1	4.7	13.5
Physalis heterophylla	1.8	0.8	1.5	2.1	-	-	0.6	6.0
Poa pratensis	37.1	48.1	36.7	37.5	27.4	65.3	32.9	47.4
Rumex acetosella	5.0	-	6.6	3.5	-	-	-	-
Schizachyrium scoparium	24.4	8.7	27.6	21.4	14.3	10.3	9.8	-
Senecio pauperculus	10.1	12.3	15.2	5.4	20.7	13.2	12.3	-
Sorghastrum nutans	5.1	2.2	5.1	5.2	1.9	-	8.1	-
Spiraea alba	3.7	2.1	-	7.1	1.6	1.8	4.7	-

APPENDIX F

Species and number of seedlings that emerged from the pre-burn and post-burn edge remnant and edge old-field seed bank.

C	Class	Species	Remnant Pre-Burn	Remnant Post-Burn	Old-Field Pre-Burn	Old-Field Post-Burn
0	NF	Achillea millefolium	3	6	2	2
*	NNG	Agrostis gigantea	-	-	5	-
2	NF	Ambrosia sp.	2	1	3	6
4	NF	Aster laevis	-	-	3	-
4	NF	Aster lanceolatus	-	-	1	-
*	NNG	Bromus inermis	-	-	-	15
*	NNF	Cannabis sativa	2	-	-	-
*	NNF	Capsella bursa-pastoris	-	1	1	21
3	SR	Carex vulpinoidea	-	-	1	-
0	SR	Cyperus esculentus	-	1	4	80
8	SR	Cyperus filiculmis	-	-	6	1
2	SR	Cyperus strigosus	28	-	341	1
?	UK	Dead	10	-	19	-
5	NG	Dichanthelium sp.	1	-	4	-
2	NF	Erigeron strigosus	-	-	1	15
3	NF	Euphorbia corollata	-	-	11	-
5	NF	Euthamia graminifolia	-	-	2	-
?	UK	Grass	1	-	-	-
*	NNF	Hypericum perforatum	-	-	21	-
10	SR	Juncus greenei	4	-	-	1
0	SR	Juncus tenuis var. tenuis	-	10	-	12
*	NNF	Melilotus sp.	1	2	2	2
*	NNF	Nepeta cataria	-	3	6	3
?	UK	Plant 1	4	-	37	-
?	UK	Plant 2	-	-	8	-
?	UK	Plant A	-	3	-	5
*	NNG	Poa pratensis	33	23	268	86
8	NF	Potentilla arguta	1	-	1	-
2	NF	Potentilla norvegica	1	3	15	8
2	NF	Rudbeckia hirta	4	9	5	4
*	NNF	Rumex acetosella	2	2	-	-
5	NF	Senecio pauperculus	8	-	6	5

C	Class	Species	Remnant Pre-Burn	Remnant Post-Burn	Old-Field Pre-Burn	Old-Field Post-Burn
*	NNG	Setaria glauca	19	1	1	-
*	NNF	Silene vulgaris	-	-	4	-
?	NF	Solidago sp.	-	-	1	-
9	NG	Sporobolus heterolepsis	1	-	-	-
*	NNF	Taraxacum officinale	1	-	-	-
*	NNF	Verbascum thapsus	3	2	-	-
3	NF	Verbena hastata	-	-	1	-
5	NF	Verbena stricta	-	1	-	-
3	B	Zanthoxylum americanum	1	1	-	-

APPENDIX G

Species and number of seeds collected by date from the 2000 and 2001 remnant and old-field seed rain.

Table G1: Species and number of seeds collected by date from the 2000 remnant seed rain.

	1-Jul	16-Jul	27-Aug	9-Sep	24-Sep	14-Oct	25-Oct	17-Nov	Total
Ambrosia sp.	-	-	-	3	11	2	-	-	16
Andropogon gerardii	1	-	-	4	14	68	6	7	100
Anemone canadensis	-	-	4	10	2	-	-	-	16
Aster ericoides	-	-	-	-	-	1	-	-	1
Aster lanceolatus	-	-	-	-	-	2	17	-	19
Aster pilosus	-	-	-	-	-	-	12	-	12
Broken seed	-	-	-	-	-	2	-	2	4
Dichanthelium sp.	-	-	1	-	-	-	-	-	1
Euphorbia corollata	-	-	-	2	-	-	-	-	2
Euthamia graminifolia	-	-	-	-	-	1	-	-	1
Monarda fistulosa	-	-	-	4	-	3	-	-	7
Oenothera biennis	-	-	-	-	-	4	-	-	4
Oenothera rhombipetala	-	-	-	-	-	5	2	-	6
Oxalis stricta	-	2	-	-	-	-	-	-	2
Panicum virgatum	-	1	-	-	-	-	-	-	1
Potentilla arguta	-	-	-	4	-	4	-	-	8
ROSACEAE 2	-	1	-	-	-	-	-	-	1
Rumex acetosella	-	5	1	1	-	-	-	-	7
Schizachyrium scoparium	-	-	-	40	52	24	31	17	164
Scirpus cyperinus	-	-	-	1	-	-	-	-	1
Senecio pauperculus	-	-	-	-	-	32	26	-	58
Setaria faberi	-	1	-	14	1	-	-	-	16
Sorghastrum nutans	-	-	-	1	4	6	-	-	11
Verbena stricta	-	-	-	-	6	2	-	-	8
Total	1	10	6	84	90	156	94	27	466

* A controlled burn impacted 5 traps during the November 14 and December 8 sampling.

Table G2: Species and number of seeds collected by date from the 2000 old-field seed rain.

	1-Jul	16-Jul	27-Aug	9-Sep	24-Sep	14-Oct	25-Oct	17-Nov	Total
Achillea millefolium	-	-	-	-	1	-	1	-	2
Agrostis hyemalis	-	-	-	-	-	1	1	-	2
Andropogon gerardii	-	1	-	2	11	8	8	-	30
Aster azureus	-	-	-	-	4	-	-	-	4
Aster lanceolatus	-	-	5	1	-	6	25	44	81
Aster pilosus	-	-	-	-	1	-	-	-	1
Carex brachyglossa	-	13	-	-	3	-	-	-	16
Carex scoparia	-	3	-	-	-	-	-	-	3
Cirsium discolor	-	-	-	3	1	-	-	-	4
Dichanthelium sp.	-	-	-	-	-	-	-	1	1
Euphorbia corollata	-	-	2	-	-	-	-	-	2
Euthamia graminifolia	-	-	-	14	108	26	5	-	153
Galium sp.	-	-	1	-	-	-	-	-	1
Melilotus sp.	-	-	9	3	-	-	-	-	12
Oenothera biennis	-	-	-	-	-	34	-	-	34
Oenothera rhombipetala	1	-	-	7	15	2	12	17	54
Oxalis stricta	-	1	-	-	-	-	-	-	206
Panicum virgatum	-	-	3	8	1	1	-	-	1
Paspalum setaceum	-	1	3	8	1	1	-	-	14
Poa pratensis	5	2	-	-	-	-	-	-	7
Rumex acetosella	-	-	-	1	-	-	-	-	1
Schizachyrium scoparium	-	-	-	4	6	3	1	-	14
Total	6	21	23	51	152	82	53	62	643

* A controlled burn impacted 3 traps during the November 14 and December 8 sampling.

Table G3: Species and number of seeds collected by date from the 2001 remnant seed rain.

	10-Jul	1-Sep	15-Sep	30-Sep	17-Oct	1-Nov	15-Nov	30-Nov	Total
Achillea millefolium	-	-	5	3	6				14
Agrostis hyemalis	-	-	-	-	1				1
Ambrosia sp.	-	-	2	-	4		NO SEED		6
Andropogon gerardii	-	-	-	39	10		COLLECTED		49
Anemone canadensis	-	2	-	5	26				33
Aster ericoides	-	-	-	-	1				1
Aster pilosus	-	-	-	-	4				4
ASTERACEAE	-	-	-	3	-				3
Carex sp.	-	12	-	-	-				12
CYPERACEAE	-	-	-	2	-				2
Cyperus esculentus	1	-	-	-	-				1
Desmodium sp.	-	1	-	-	-				1
Dichanthelium sp.	1	8	2	-	-				11
Eupatorium maculatum	-	-	-	-	1				1
Hedeoma hispidum	2	-	-	-	-				2
Lactuca canadensis	-	-	1	-	-				1
Lespedeza capitata	-	-	-	-	2				2
Poa pratensis	11	17	1	-	1				30
Polygonum persicaria	-	3	-	-	-				3
Potentilla arguta	-	7	13	-	6				26
Potentilla norvegica	1	-	-	-	-				1
Rumex acetosella	1	3	-	-	1				5
Schizachyrium scoparium	-	-	5	19	110				134
Setaria faberi	-	-	-	-	2				2
Sorghastrum nutans	-	-	2	-	-				2
Sporobolus heterolepis	-	-	-	-	1				1
Verbena stricta	-	-	-	-	5				5
Total	17	53	31	71	181				353

* No seed collected on November 1, 15 and 30 due to a mechanical seed harvest.

Table G4: Species and number of seeds collected by date from the 2001 old-field seed rain.

	10-Jul	1-Sep	15-Sep	30-Sep	17-Oct	1-Nov	15-Nov	30-Nov	Total
Achillea millefolium	-	-	1	-	-	-	-	-	1
Ambrosia sp.	-	-	1	-	3	-	-	3	7
Andropogon gerardii	-	-	2	5	56	17	2	10	92
Aster ericoides	-	-	-	-	-	3	-	-	3
Aster lanceolatus	-	-	-	-	2	-	-	-	2
Aster sp. immature	-	-	-	-	-	11	-	-	11
Bromus inermis	-	8	1	-	8	2	-	-	19
Carex sp.	-	8	-	-	-	-	-	-	8
Desmodium sp.	-	1	-	-	-	-	-	-	1
Dichanthelium sp.	1	4	2	-	-	-	-	-	7
Euthamia graminifolia	-	-	-	-	2	-	-	-	2
Galium sp.	-	-	-	1	-	-	-	-	1
Lactuca canadensis	-	-	1	-	-	-	-	-	1
Melilotus sp.	-	1	-	1	-	-	-	-	2
Oenothera biennis	-	-	-	-	2	-	-	-	2
Oxalis stricta	3	-	-	-	1	-	-	-	4
Paspalum setaceum	-	4	2	7	3	-	-	-	16
Poa pratensis	87	15	1	-	2	-	-	-	105
Potentilla agruta	-	1	-	3	-	-	-	-	4
ROSACEAE 1	-	-	-	-	2	-	-	-	2
Schizacharium scoparium	-	1	-	15	148	61	12	6	243
Scirpus cyperinus	-	-	-	1	-	-	-	-	1
Scirpus sp.	-	1	-	-	-	-	-	-	1
Senecio pauperculus	88	-	-	-	-	-	-	-	88
Verbascum thapsus	-	-	-	1	-	-	-	-	1
Total	179	44	11	34	229	94	14	19	624

APPENDIX H

The coefficient of conservatism (C) values, species, the number of collected seeds and the percent of the sampled remnant and old-field seed rain occupied by each species.

C	Species	Number of Seeds				Percent of Seed Rain			
		Remnant		Old-Field		Remnant		Old-Field	
		2000	2001	2000	2001	2000	2001	2000	2001
0	Achillea millefolium	-	14	2	1	-	4	0.3	0.2
*	Agrostis hyemalis	-	1	2	-	-	0.3	0.3	-
2	Ambrosia sp.	16	6	-	7	3	1.7	-	1.1
4	Andropogon gerardii	100	49	30	92	18.8	13.9	4.7	14.7
2	Anemone canadensis	16	33	-	-	3	9.3	-	-
3	Aster ericoides	1	1	-	3	0.2	0.3	-	0.5
4	Aster lanceolatus	19	-	81	2	4.7	-	13.3	0.3
0	Aster pilosus	12	4	1	-	2.3	1.1	0.2	-
?	Aster sp. immature	-	-	-	11	-	-	-	1.8
?	ASTERACEAE	-	3	-	-	-	0.8	-	-
?	Broken seed	4	-	-	-	0.8	-	-	-
*	Bromus inermis	-	-	-	19	-	-	-	3
6	Carex brachyglossa	-	-	16	-	-	-	2.5	-
5	Carex scoparia	-	-	3	-	-	-	0.5	-
?	Carex sp.	-	12	-	8	-	3.4	-	1.3
1	Cirsium discolor	-	-	4	-	-	-	0.6	-
?	CYPERACEAE	-	2	-	-	-	0.6	-	-
0	Cyperus esculentus	-	1	-	-	-	0.3	-	-
?	Desmodium sp.	-	1	-	1	-	0.3	-	0.2
5	Dichanthelium sp.	1	11	1	7	0.2	3.1	0.2	1.1
6	Eupatorium maculatum	-	1	-	-	-	0.3	-	-
3	Euphorbia corollata	2	-	2	-	0.4	-	0.3	-
5	Euthamia graminifolia	1	-	153	2	0.2	-	22.4	0.3
?	Galium sp.	-	-	1	1	-	-	0.2	0.2
2	Hedeoma hispidum	-	2	-	-	-	0.6	-	-
1	Lactuca canadensis	-	1	-	1	-	0.3	-	0.2
3	Lespedeza capitata	-	2	-	-	-	0.6	-	-
*	Melilotus sp.	-	-	12	2	-	-	1.9	0.3
2	Monarda fistulosa	7	-	-	-	1.3	-	-	-
0	Oenothera biennis	4	-	34	2	0.8	-	5.3	0.3
8	Oenothera rhombipetala	6	-	54	-	1.1	-	8.5	-
0	Oxalis stricta	2	-	206	4	0.4	-	32.5	0.6
5	Panicum virgatum	1	-	1	-	0.2	-	2.2	-

C	Species	Number of Seeds				Percent of Seed Rain			
		Remnant		Old-Field		Remnant		Old-Field	
		2000	2001	2000	2001	2000	2001	2000	2001
4	Paspalum setaceum	-	-	14	16	-	-	-	2.6
*	Poa pratensis	-	30	7	105	-	8.5	1.1	16.8
*	Polygonum persicaria	-	3	-	-	-	0.8	-	-
8	Potentilla agruta	8	26	-	4	1.5	7.4	-	0.6
2	Potentilla norvegica	-	1	-	-	-	0.3	-	-
?	ROSACEAE 1	-	-	-	2	-	-	-	0.3
?	ROSACEAE 2	1	-	-	-	0.2	-	-	-
*	Rumex acetosella	7	5	1	-	1.3	1.4	0.2	-
5	Schizacharium scoparium	164	134	14	243	42.1	38	2.2	38.9
4	Scirpus cyperinus	1	-	-	1	0.2	-	-	0.2
?	Scirpus sp.	-	-	-	1	-	-	-	0.2
5	Senecio pauperculus	58	-	-	88	10.9	-	-	14.1
*	Setaria faberi	16	2	-	-	3	0.6	-	-
4	Sorghastrum nutans	11	2	-	-	2.1	0.6	-	-
9	Sporobolus heterolepis	-	-	-	-	-	0.3	-	-
*	Verbascum thapsus	-	-	-	1	-	-	-	0.2
5	Verbena stricta	8	5	-	-	1.5	1.4	-	-

*=non-native species
?=Coefficient of Conservatism unknown

APPENDIX I

Non-statistical comparisons between the vegetation cover, seed bank and seed rain in the edge remnant and edge old-field sub-sites.

The vegetation, seed bank and seed rain were all sampled within the edge remnant and edge old-field. When the 2000 and 2001 vegetation, 2000 and 2001 seed rain and the pre-burned and post-burned fall 2000 seed bank was combined, 113 species were identified from these two sub-sites (Appendix B). There were 20 quadrats in the remnant and 11 quadrats in the old-field vegetation. There were five seed rain traps in the remnant and three in the old-field (Table I1). There were five soil cores taken in each of the remnant and old-field for a total of 10 soil cores. The three studies utilized the relative percent canopy cover in the vegetation, the relative number of seeds in the seed rain and the relative number of germinants from the seed bank. Due to the different methods of data collection, the three studies were not statistically analyzed.

Table I1: Number of species, the number of collected samples and the percent vegetative canopy cover, seed bank germinants or number of trapped seed rain seeds in the three studies for the edge remnant and edge old-field sub-sites. The vegetation and seed rain were sampled in 2000 and 2001 while the seed bank was sampled during the fall of 2000.

	Vegetation		Seed Bank		Seed Rain	
	ER	EOF	ER	EOF	ER	EOF
Species	60	45	21	29	29	22
Samples	20: 4 Sampling Dates	11: 4 Sampling Dates	5	5	5 Traps: 13 Harvests	3 Traps: 16 Harvests
Canopy Cover/ Seed(ling) Numbers	102% Cover	99% Cover	130 Germinant	780 Germinant	364 Seeds	393 Seeds

Of the 113 species in the ER and EOF, 16 were present in all 3 studies, eleven native and five non-native species (Appendix B). There were six species common in at least one of the three studies, with a relative percent vegetative cover, seed rain or seed bank value of 15% or higher (Table I2). While a seventh species, *A. millefolium*, did not have a high value in any of the studies, it was the second most common species at Cedar Hill Sand Prairie after *P. pratensis*. Of these seven species, *A. millefolium, P. pratensis* and *S. pauperculus* were present in the vegetation, seed rain and seed bank.

Combined, three studies contained ten native grasses in the ER and EOF although only two species, *Dichanthelium* sp. and *S. heterolepsis*, germinated from the seed bank (Appendix B). Both *A. gerardii* and *S. scoparium* occupied a large portion of the vegetation and seed rain, yet were not present in the seed bank (Table I2).

Table I2: Seven common species present in the edge remnant and edge old-field 2000 and 2001 vegetation, the 2000 pre-burn and post-burn seed bank and the 2000 and 2001 seed rain. Comparisons were made using the relative percent cover of the vegetation's species, the relative percent of germinants in the pre-burned and post-burned seed bank and the relative percent of species collected from the seed rain.

	Vegetation		Pre Burn Seed Bank		Post Burn Seed Bank		Seed Rain	
	R	F	R	F	R	F	R	F
Achillea millefolium	1.4	0.3	2.3	0.4	8.6	0.7	3.7	0.7
Andropogon gerardii	6.4	31.6	-	-	-	-	17.1	16.8
Cyperus esculentus	-	-	-	0.5	-	30	0.3	-
Cyperus strigosus	-	-	21.5	43.7	-	0.4	-	-
Poa pratensis	37.8	22.9	25.4	34.4	32.9	32.2	6.8	9.2
Schizachyrium scoparium	17.7	10.8	-	-	-	-	22.6	55.5
Senecio pauperculus	1.5	16	6.2	0.8	-	1.9	15.3	-

APPENDIX J

Presence or absence of species in the local vegetation and seed rain. If the local vegetation was in fruit or flower around any of the traps the X was bolded.

	Local Vegetation				Seed Rain			
	Remnant		Field		Remnant		Field	
	2000	2001	2000	2001	2000	2001	2000	2001
Achillea millefolium	X	X	X	X	-	X	X	X
Agrostis hyemalis	-	-	-	-	-	X	X	-
Ambrosia sp.	X	X	X	X	X	X	-	X
Andropogon gerardii	X	X	X	X	X	X	X	X
Anemone canadensis	X	-	-	-	X	X	-	-
Anemone cylindrica	X	X	-	-	-	-	-	-
Artemisia ludoviciana	X	X	-	-	-	-	-	-
Aster azureus	X	X	-	-	-	-	X	-
Aster ericoides	X	-	X	X	X	X	-	X
Aster lanceolatus	-	-	-	-	X	-	X	X
Aster pilosus	-	-	-	-	X	X	X	-
Aster simplex	-	X	-	X	-	-	-	-
Aster sp.	X	-	X	-	-	X	-	X
Bromus inermis	-	X	X	X	-	-	-	X
Carex brachyglossa	-	-	-	-	-	-	X	-
Carex scoparia	-	-	-	-	-	-	X	-
Carex sp.	-	-	X	-	-	X	-	X
Cirsium discolor	-	X	-	-	-	-	X	-
Coreopsis palmata	X	-	-	-	-	-	-	-
CYPERACEAE	-	-	-	-	-	X	-	-
Cyperus esculentus	-	-	-	-	-	X	-	-
Desmodium sp.	-	-	-	-	-	X	-	X
Dichanthelium sp.	X	X	X	X	X	X	X	X
Equisetum arvense	X	X	X	X	-	-	-	-
Eupatorium maculatum	-	-	-	-	-	X	-	-
Euphorbia corollata	X	X	X	X	X	-	X	-
Euthamia graminifolia	-	-	-	X	X	-	X	X
Fragaria virginiana	X	X	-	-	-	-	-	-
Galium sp.	-	-	-	-	-	-	X	X
Hedeoma hispidum	-	-	-	-	-	X	-	-
Helianthus grosseserratus	X	X	X	X	-	-	-	-
Juncus greenei	-	-	-	X	-	-	-	-
Lactuca canadensis	-	-	-	-	-	X	-	X
Lespedeza capitata	-	-	X	X	-	X	-	-
Lithospermum canescens	X	-	-	-	-	-	-	-
Lycopus americanus	-	-	X	-	-	-	-	-
Medicago lupulina	-	-	X	-	-	-	-	-
Melilotus sp.	X	-	X	X	-	-	X	X
Monarda fistulosa	X	X	-	-	X	-	-	-

	Local Vegetation				Seed Rain			
	Remnant		Field		Remnant		Field	
	2000	2001	2000	2001	2000	2001	2000	2001
Oenothera biennis	-	-	-	-	X	-	X	X
Oenothera rhombipetala	-	-	-	-	X	-	X	-
Oxalis stricta	X	X	X	X	X	-	X	-
Panicum virgatum	-	X	-	-	X	-	X	-
Paspalum setaceum	-	-	X	X	-	-	-	X
Physalis virginiana	X	X	X	X	-	-	-	-
Poa pratensis	X	X	X	X	-	X	X	X
Polygonum persicaria	-	-	-	-	-	X	-	-
Potentilla arguta	-	X	-	-	X	X	-	X
Potentilla canadensis	-	-	-	-	-	X	-	-
Potentilla simplex	X	-	-	-	-	-	-	-
Rosa sp.	X	X	X	-	X	-	-	X
Rubus allegheniensis	X	-	X	-	-	-	-	-
Rubus fulleri	X	X	-	-	-	-	-	-
Rumex acetosella	X	X	X	-	X	X	X	-
Rumex crispus	-	X	-	-	-	-	-	-
Schizachyrium scoparium	X	X	X	X	X	X	X	X
Scirpus cyperinus	-	-	-	X	X	-	-	X
Scirpus sp.	-	-	-	-	-	-	-	-
Senecio pauperculus	X	X	X	X	X	-	-	X
Setaria faberi	-	-	-	-	X	X	-	-
Solidago canadensis	X	X	X	X	-	-	-	-
Solidago gigantea	-	X	-	X	-	-	-	-
Solidago missouriensis	-	X	-	-	-	-	-	-
Solidago sp.	-	-	X	-	-	-	-	-
Sorghastrum nutans	X	X	X	-	X	X	-	-
Spiraea alba	X	X	-	X	-	-	-	-
Sporobolus heterolepis	-	-	-	-	-	X	-	-
Unknown	X	X	X	-	-	-	-	-
Unknown grass	X	-	-	-	-	-	-	-
Verbascum thapsus	-	-	-	-	-	-	-	X
Verbena stricta	-	X	-	X	X	X	-	-

APPENDIX K

Number and percent of species and seeds present in the local vegetation and seed rain.

	Number of Species				Percent of Species			
	Remnant		Old-Field		Remnant		Old-Field	
	2000	2001	2000	2001	2000	2001	2000	2001
					Percent of Total Species			
Total Species	43	50	34	36	100	100	100	100
Total Local Vegetation	31	32	22	23	72	64	65	64
Total Seed Rain Species	23	28	22	27	54	56	65	75
Species In Vegetation and Seed Rain	12	10	10	14	28	20	29	39
Species Only in the Seed Rain	12	18	13	13	28	36	38	36
Species Only in the Vegetation	19	22	11	9	44	44	32	25
					Percent of Local Vegetation			
Local Vegetation in Fruit/Flower	18	21	16	15	58	66	73	65
Local Vegetation in Fruit/Flower With Seeds in Adjoining Seed Trap	7	7	2	8	23	22	9	35
Local Vegetation Not in Fruit/Flower With Seeds in Adjoining Seed Trap	2	2	2	3	7	6	9	13
					Percent of Seed Rain			
Seed Rain Species With Dropped Seeds	13	18	13	17	57	64	59	63
Seed Rain Species With Wind-Blown Seeds	9	9	8	9	39	32	36	33
Seed Rain Species With Dropped/Wind-Blown Seeds	1	1	1	1	4	4	5	4
Species in Seed Traps That Could Not Have Come From the Local Vegetation	16	21	14	19	70	75	64	70
					Percent of Occurrences			
Number of Times Vegetation Appears around the Seed Traps	79	83	53	55	100	100	100	100
Number of Times Vegetation Was in Fruit/Flower	33	44	31	28	42	53	59	51
Number of Traps With Vegetation in Fruit/Flower and Seeds in the Adjoining Traps	13	10	3	11	17	12	6	20

	Number of Species				Percent of Species			
	Remnant		Old-Field		Remnant		Old-Field	
	2000	2001	2000	2001	2000	2001	2000	2001
					Percent of Total Species			
Total Species	43	50	34	36	100	100	100	100
Total Local Vegetation	31	32	22	23	72	64	65	64
Total Seed Rain Species	23	28	22	27	54	56	65	75
Species In Vegetation and Seed Rain	12	10	10	14	28	20	29	39
Species Only in the Seed Rain	12	18	13	13	28	36	38	36
Species Only in the Vegetation	19	22	11	9	44	44	32	25
					Percent of Local Vegetation			
Local Vegetation in Fruit/Flower	18	21	16	15	58	66	73	65
Local Vegetation in Fruit/Flower With Seeds in Adjoining Seed Trap	7	7	2	8	23	22	9	35
Local Vegetation Not in Fruit/Flower With Seeds in Adjoining Seed Trap	2	2	2	3	7	6	9	13
					Percent of Seed Rain			
Seed Rain Species With Dropped Seeds	13	18	13	17	57	64	59	63
Seed Rain Species With Wind-Blown Seeds	9	9	8	9	39	32	36	33
Seed Rain Species With Dropped/Wind-Blown Seeds	1	1	1	1	4	4	5	4
Species in Seed Traps That Could Not Have Come From the Local Vegetation	16	21	14	19	70	75	64	70
					Percent of Occurrences			
Number of Times Vegetation Appears around the Seed Traps	79	85	53	55	100	100	100	100
Number of Times Vegetation Was in Fruit/Flower	33	44	31	28	42	52	59	51
Number of Traps With Vegetation in Fruit/Flower and Seeds in the Adjoining Traps	13	10	3	11	17	12	6	20

	Number of Species				Percent of Species			
	Remnant		Old-Field		Remnant		Old-Field	
	2000	2001	2000	2001	2000	2001	2000	2001
					Percent of Local Vegetation			
Number of Species in Local Vegetation With Wind Blown Seeds	12	12	10	8	39	38	46	35
Number of Species in Local Vegetation With Dropped Seeds	17	18	10	13	55	56	46	57
Number of Species in Local Vegetation With Dropped/Wind Blown Seeds	2	2	2	2	7	6	9	9
Local Vegetation in Fruit/Flower With Wind Blown Seeds	8	8	6	7	26	25	27	30
Local Vegetation in Fruit/Flower With Dropped Seeds	9	13	9	8	29	41	41	35
Local Vegetation in Fruit/Flower With Dropped/Wind Blown Seeds	1	-	2	-	3	-	9	-
Local Vegetation in Fruit/Flower With Wind Blown Seeds in Adjoining Seed Trap	3	2	-	4	10	6	-	17
Local Vegetation in Fruit/Flower With Dropped Seeds in Adjoining Seed Trap	4	5	1	4	13	16	5	17
Local Vegetation in Fruit/Flower With Dropped/Wind Seeds in Adjoining Seed Trap	-	-	1	-	-	-	5	-
Local Vegetation in Fruit/Flower With No Blown Seeds in Adjoining Seed Trap	5	6	6	3	16	19	27	13
Local Vegetation in Fruit/Flower With No Dropped Seeds in Adjoining Seed Trap	5	8	8	4	16	25	36	17
Local Vegetation in Fruit/Flower With No Dropped/Wind Seeds in Adjoining Seed Trap	1	-	1	-	3	-	5	-

	Number of Seeds				Percent of Seeds			
	Remnant		Old-Field		Remnant		Old-Field	
	2000	2001	2000	2001	2000	2001	2000	2001
					Percent of Total Seeds			
Total Number of Seeds	466	353	643	624	100	100	100	100
Number of Seeds in the Traps which could have come from the Local Vegetation	162	94	207	247	35	27	32	40
Number of Seeds in the Traps NOT from the Local Vegetation	300	260	438	377	65	73	68	60
Total Number of Wind Blown Seeds in the Seed Traps	382	240	290	443	83	68	45	71
Total Number of Dropped Seeds in the Seed Traps	62	82	141	73	13	23	22	12
Total Number of Dropped/ Wind Blown Seeds in the Seed Traps	18	31	212	110	4	9	33	18
					Percent of Total Seeds			
Number of Wind Blown Seeds in the Traps That Could Have Come From the Local Vegetation	139	77	-	218	30	22	-	35
Number of Dropped Seeds in the Traps That Could Have Come From the Local Vegetation	24	17	1	29	5	5	-	5
Number of Dropped/Wind Blown Seeds in the Traps That Could Be From the Local Vegetation	-	-	206	-	-	-	32	-
Wind Blown Seeds in Seed Traps Not in the Local Vegetation	244	164	290	225	53	46	45	36
Dropped Seeds in Seed Traps Not in the Local Vegetation	38	65	141	44	8	18	22	7
Dropped/Wind Blown Seeds in Seed Traps Not in the Local Vegetation	18	31	7	110	4	9	1	18
					Percent Potentially From The Local Vegetation			
Number of Wind Blown Seeds in the Traps That Could Have Come from the Local Vegetation	139	77	-	218	85	82	-	88
Number of Dropped Seeds in the Traps That Could Have Come from the Local Vegetation	24	17	1	29	15	18	1	12
Number of Dropped/Wind Blown Seeds in the Traps That Could Be From the Local Vegetation	-	-	206	-	-	-	100	-
					Percent Not From The Local Vegetation			
Wind Blown Seeds in Seed Traps Not in the Local Vegetation	244	164	290	225	81	63	66	60
Dropped Seeds in Seed Traps Not in the Local Vegetation	38	65	141	44	13	25	32	12
Dropped/Wind Blown Seeds in Seed Traps Not in the Local Vegetation	18	31	7	110	6	12	2	29

APPENDIX L

Species list and number of seedlings from the spring 2000 soil seed bank covering the entire remnant and entire old-field.

Type	C		Remnant	Old-Field
NNF	*	Abutilon theosposti	1	-
NF	0	Achillea millefolium	1	-
NNF	*	Amanthus hybridus	1	-
SR	?	Carex sp.	-	1
NNF	*	Chenopodium album	1	1
SR	2	Cyperus strigosus	-	1
NF	2	Erigeron strigosus	2	2
SR	8	Hemicarpha micrantha	-	1
NF	7	Hypericum majus/mutilum	-	3
NNF	*	Medicago lupulina	1	-
NNF	*	Mollugo verticillata	2	9
NF	2	Monarda fistulosa	-	1
NF	0	Oenthera biennus	-	2
NF	0	Oxalis stricta	2	1
NG	5	Panicum virgatum	-	1
NNG	*	Poa pratensis	10	4
NNF	*	Portulaca oleracea	1	2
NF	8	Potentilla arguta	25	5
NF	2	Potentilla norvegica	-	5
NNF	*	Rumex acetosella	6	-
NNG	*	Setaria faberi	2	4
NNG	*	Setaria virudus	1	-
NG	9	Sporobolus heterolepsis	1	3
NNF	*	Trifolium pratensis	1	-
NF	1	Verbena stricta	-	1
		Total	58	47

*	Non-Native Species
NF	Native Forb
NNF	Non-Native Forb
NG	Native Grass
NNG	Non-Native Grass
SR	Sedges and Rushes

APPENDIX M

Coordinates mapped using a global positioning system (GPS) for all the vegetation quadrats. Locations were mapped in 2005 and include additional quadrat points.

Sub Site	Quadrat Number	North Degree	North Minute	North Second	West Degree	West Minute	West Second	Elevation (m)	Transect Side
IR	21	42	35	628	92	33	219	283	E
IR	22	42	35	632	92	33	219	282	W
IR	1	42	35	636	92	33	217	281	E
IR	23	42	35	640	92	33	216	283	W
IR	2	42	35	644	92	33	215	284	E
IR	24	42	35	649	92	33	214	284	W
IR	3	42	35	652	92	33	213	284	E
ER	25	42	35	656	92	33	212	282	W
ER	4	42	35	660	92	33	210	283	E
ER	26	42	35	663	92	33	208	285	W
ER	5	42	35	668	92	33	206	285	E
ER	27	42	35	672	92	33	206	286	W
ER	6	42	35	674	92	33	205	282	E
ER	28	42	35	678	92	33	205	283	W
EOF	7	42	35	683	92	33	203	286	E
EOF	**29**	**42**	**35**	**687**	**92**	**33**	**202**	**284**	W
EOF	8	42	35	691	92	33	200	284	E
EOF	**30**	**42**	**35**	**695**	**92**	**33**	**199**	**285**	W
EOF	9	42	35	698	92	33	198	284	E
EOF	**31**	**42**	**35**	**702**	**92**	**33**	**197**	**285**	W
MOF1	10	42	35	706	92	33	196	286	E
MOF1	**32**	**42**	**35**	**711**	**92**	**33**	**195**	**286**	W
MOF1	11	42	35	714	92	33	194	284	E
MOF1	**33**	**42**	**35**	**719**	**92**	**33**	**194**	**285**	W
MOF1	12	42	35	722	92	33	192	285	E
MOF1	**34**	**42**	**35**	**725**	**92**	**33**	**190**	**285**	W
MOF1	13	42	35	729	92	33	189	284	E
MOF2	**35A**	**42**	**35**	733	**92**	**33**	**189**	**286**	W
MOF2	14	42	35	739	92	33	184	285	E
MOF2	**36A**	**42**	**35**	**741**	**92**	**33**	**183**	**285**	W
MOF2	15	42	35	744	92	33	182	285	E
MOF2	**37A**	**42**	**35**	**749**	**92**	**33**	**180**	**285**	W
MOF2	16	42	35	752	92	33	178	286	E
MOF2	**38A**	**42**	**35**	**758**	**92**	**33**	**177**	**285**	W
MOF2	17	42	35	760	92	33	176	282	E
DOF	**39A**	**42**	**35**	**766**	**92**	**33**	**175**	**285**	W
DOF	18	42	35	766	92	33	173	286	E
DOF	**18A**	**42**	**35**	**770**	**92**	**33**	**171**	**285**	W
DOF	19	42	35	775	92	33	170	284	E
DOF	**19A**	**42**	**35**	**778**	**92**	**33**	**169**	**285**	W
DOF	20	42	35	782	92	33	167	286	E
DOF	**20A**	**42**	**35**	**785**	**92**	**33**	**166**	**284**	W
DOF	**40A**	**42**	**35**	**788**	**92**	**33**	**164**	**285**	E
DOF	**41A**	**42**	**35**	790	**92**	**33**	**166**	**284**	W

The Garmin GPS unit used is typically accurate to with 5 meters. As a result, if the transect line is re-laid, it should be strait with each quadrat located 7.5 meters apart. This distance is measured from the southernmost point of each 2 X 5 meter quadrat; in essence there are only 5.5 meters from the northern border of one quadrat and the southern border of the next quadrat.

Bolded rows were added during the fall 2005 sampling and the results were not presented in this thesis.