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What Do You Do With A Nuclear Accelerator Ring? Thirty Years of Prairie Restoration at Fermilab – Batavia Illinois

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Introduction

Five hundred years ago in Batavia Illinois, twenty miles (32.2 km) west of Chicago, the land that now houses Fermilab, one of the most hi-tech physics laboratories in the United States, was covered with tallgrass prairie. One hundred years ago, the same land was cultivated for farming. Thirty years ago, the US Department of Energy and a consortium of Universities purchased the land, stopped cultivation, and turned the land into a nuclear accelerator ring. Shortly after the nuclear accelerator ring was placed below the soil, Robert Betz, Professor of Biology at Northeastern Illinois University, and The Nature Conservancy started work to bring back the prairie (Sullivan 1988).

Restoration began on the site in 1974 using 390 acres (157.8 hectares) of Fermilab land in Batavia, Illinois (Betz 1986). Fermilab is a physics laboratory that through the US Department of Energy owns approximately 6800 total acres (2720 hectares) in Batavia. In the south central region of the Fermilab site is a four-mile underground nuclear accelerator ring that uses electromagnets to study the energy released when protons collide and are broken down into smaller particles (Sullivan 1988). The accelerator ring encloses a total of 455 acres (182 hectares) that include 390 acres (157.8 ha) restored as native long grass prairie, a service road, a fifty-foot wide moat around the perimeter to cool the ring, and a small artificial lake used to feed the moat (Betz 1996).

In 1974, Professor Robert Betz started restoration on the 390 acres (157.8 ha) within the accelerator ring with the help of The Nature Conservancy and cooperation of Fermilab. The goal of the restoration at Fermilab was to restore an Illinois black silt-loam prairie using native species. The native species were to be restored using seed collected within fifty miles (80.5 km) of the site to ensure restoration of precultivation Illinois native long grass prairie vegetation (Betz 1986). The restoration goals further encompassed ongoing monitoring and seeding to increase genetic diversity to precultivation levels (Fermilab ecology (mainpage) 2001).

Dr. Betz, the Fermilab Ecological Land Management Committee volunteers, and lab staff completed the initial 390 acre (157.8 ha) restoration and for the past thirty years have been responsible for maintenance of the restored prairie. Maintenance needs are determined through the annual creation of short and long range Fermilab land goals as set by The Fermilab Ecological Land Management Committee (ELM). The ELM develops the annual goals for the 390 acres (157.8 ha) erestored within the accelerator ring and, through the last thirty years, has initiated further restorations on Fermilab land. To date, 1200 acres (480 hectares) both inside and outside of the accelerator ring have been restored (Fermilab ecology mainpage 2001).

The Site

The interior of the accelerator ring, on which the restoration was completed, is on relatively flat land and averages 57.4 cm (22.6 inches) of precipitation during the growing season from April through September (Jastrow 1987). Three different types of soils are found within accelerator ring including – Udollic Ochraqualf (Barrington silt loam) and Aquic Arqiudoll (Mendelein silt loam) and Typic Haplaquall (Drummer silty clay loam) (Betz 1986). Prior to construction of the accelerator ring, the land was cultivated as farmland for over one hundred years because the soil, which was historically grassland, was highly aggregated and stabilized by rhizomous prairie grasses making it ideal for agriculture (Jastrow 1987). The perennial grasses also created extensive root systems that helped to maintain a high level of nutrients near the soil surface and to reduce leaching of organic nutrients (Krohne 2001). Due to its attractiveness as farmland, most of the Fermilab site's original long grass prairie was destroyed, but some small remnant prairie areas have survived along old fencerows and ditches (Betz 1986). Cultivation not only destroyed the native stands of prairie, it also changed the distribution of aggregate soil size classes causing significant losses of larger water stable aggregates and decreasing the soil's ability to support native vegetation (Jastrow 1987).

Cultivation of the land ceased in 1971 when construction of the accelerator ring began and drain tile lines were removed to allow placement of the below ground nuclear accelerator ring (Betz 1986). During the first two to three years after cessation of cultivation, the vegetation was mainly annual and biennial weeds. After three years, old-field Eurasian, non-native, perennial vegetation including *Ambrosia spp (*ragweed), *Brassica spp* (mustard) *Chenopodium spp* (lamb's quarter), *Lepidium spp* (pepper grass), *Medicago spp* (medick), *Plantago spp* (pantain), *Setaria spp* (foxtail), *Trifolium spp* (clover)*Carduus nutans* (nodding thistle), *Cirsium vulgare* (bull thistle) and *Melilotus alba* (white sweet clover), and a few native forbs dominated the landscape with some woody shrubs and cottonwood groves (Betz 1996).

Techniques

The first planting at Fermilab occurred in 1975 using 400 pounds (180 kg) of native seed and included seventy species, which were hand collected by volunteers in the autumn of 1974. In February of 1975, the seeds were cleaned using screens, mixed with vermiculite, and placed in plastic bags (Betz 1986). The seed bags were moistened and stored at 5^{O} Celsius for just over four months. As shown through research completed by Robert Schramm at Knox College, this type of cold, damp stratification (for a minimum of three weeks but up to six months) is profitable for prairie species, especially forbs (Schramm 1990). After the four months of cold stratification, the seeds were spread on a wooden floor and dried (Betz 1986).

While the seeds were in storage, soil preparation began. Initial soil preparation included disking the soil three separate times to remove the above ground weed biomass, reduce light competition for the native prairie seeds, and allow good soil contact (Betz 1996). The soil was disked once in the fall and twice in the spring prior to planting. After the final disking was completed in June, the seeds were planted using a Nesbit drill and a light harrow was used on the seeded areas (Betz 1996).

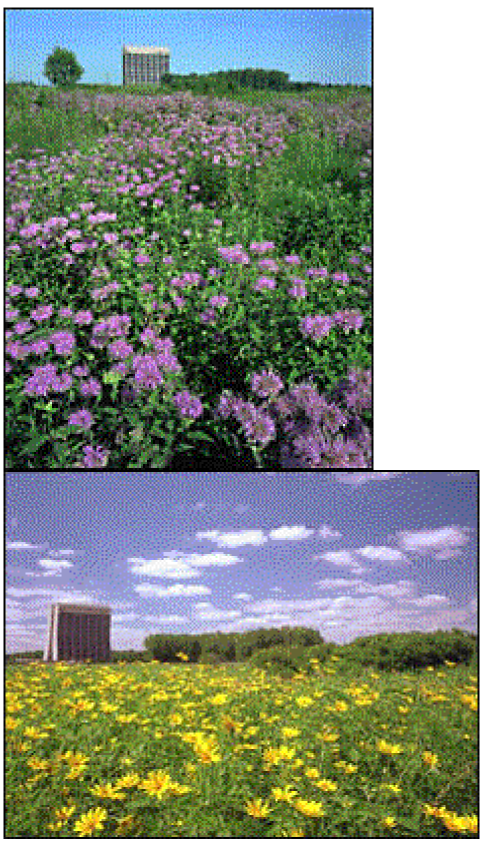
After the seeding was completed the land was left untouched for three growing seasons to allow time for native prairie species to begin to out-compete weed populations and to form a relatively dense carpet. After the third growing season, the native prairie species populations were well established and could withstand a burn. A burn was completed the spring of the fourth year and annually thereafter (Betz 1986).

Monitoring

Through the last thirty years at Fermi-lab, monitoring has been conducted to track the progress of the restoration. Since 1974, Professor Betz and the Fermilab staff have monitored the floristic composition and animal populations on site. For animal monitoring, the staff records animal citings in the restored prairie areas, but no formal testing has been completed to document the exact number of animals returning to Fermilab lands (Fermilab ecology mainpage 2001). Many animal species rarely seen on Fermilab lands before restoration have been seen in the restored prairie, wetlands and forests during the past thirty years (Fermilab ecology mainpage 2001). A partial list of animals seen on the Fermilab sites includes herons, egrets, sandhill cranes, woodcocks, upland sandpipers, snipes, vireos, bob-o-links, hawks, vultures, bald eagles, foxes, coyotes, deer, mink, weasels, badgers and fifty-one species of butterflies (Fermilab ecology mainpage 2001).

In addition to animal monitoring, floristic populations within the prairie are monitored. During the past thirty years, floristic monitoring has shown that the total number of prairie species has doubled from the initial seventy prairie species introduced.   The Fermilab prairie, including the land restored inside and outside the accelerator ring, now consists of 147 prairie species (See Tables 2 through 5 for a partial list of the species present within the Fermilab prairie) (Betz 1996). The attached tables include 109 of the 147 species and figure 1 provides pictures of the restored prairie. The dominant species in the prairie are *Andropogon gerardii* (Big Blue Stem), *Sorghastrum nutans (*Indian grass), *Panicum virgatum (*Switch Grass), *Andropogan scoparius (*Little Blue Stem) and *Sporobolus heterolepis (*Prairie Dropseed) (Lootens 2001).   The dominant native forbs are *Solidago spp* (golden rod), *Coreopsis tripteris* (tall coreopsis), *Monarda fistulosa* (wild bergamont), *Ratibida pinnata* (yellow coneflower), *Pycnanthemum virginanum* (mountain mint), and*Silphium integrifolium* (rosinweed) (Lootens 2001). The prairie still lacks 25 species necessary to obtain precultivation species diversity, and when native sources of these species are located they will be added to the Fermilab prairie (Betz 1996). Some of the missing species include: *Castilleja coccinea*(Indian paintbrush), *Ceanothus americanus* (New Jersey tea), *Habenaria leucophaea* (Eastern prairie fringed orchid), *Prenanthes aspera* (Rough white lettuce), *Tomanthera auricula* (Eared false foxglove), *Acrous calamus* (Sweet flag), and *Dryopteris thelypteris* (Marsh shield fern) (Betz 1996). While floristic monitoring shows a significant increase in the total number of species present, no data exists detailing whether species in the prairie were introduced through manual seeding or through natural seed dispersal from restored or remnant prairie.

Figure 1. Restored Prairie within the Fermilab Nuclear Accelerator Ring
(with permission of Robert Betz and the Fermilab).



Along with monitoring of the species present in Fermilab prairies, monitoring of the successional stages of reestablishment was also completed. A rough restoration time line has been established based on monitoring species reestablishment. In the autumn after a spring planting annual weeds, first year biennials and small seedling of highly competitive prairie species dominate the site (Betz 1996). Within two to three growing seasons, sufficient fuel has accumulated and burns are completed annually for five years. After five years of burns, the highly competitive prairie species of the prairie matrix (see Table 2) began to dominate large portions of the site (Betz 1996). At this point second stage species could be seeded since weed populations are almost completely suppressed, with the exception of the biennial weed *Melilotus alba* (White sweet clover) (Betz 1996). *Melilotus alba* was able to co-exist within the annually burned prairie, as if were a true native plant, and the population was only reduced as the diversity of prairie species increase over time (Betz 1996). Five to ten years after restoration, *Andropogon gerardii* (Big blue stem) became dominant and the prairie took on the appearance of a monoculture field, but below the grasses, forbs and second stage successional species (See Table 3) were beginning to take hold (Betz 1996). From ten to twenty years the second stage species continued to increase and third and fourth stage species (See Tables 4 and 5) became noticeable and gave the prairie a more diverse appearance (Betz 1996).

As well as floristic and animal monitoring at Fermilab, soil composition and mycorrhizal association research have been completed. Soil composition prior to restoration at Fermilab showed a breakdown in aggregate soil sizes caused by cultivation, which created conditions unfavorable to native biological activity. After cessation of cultivation and restoration of native prairie species, increased soil aggregation similar to that of remnant prairie segments was noted over time (Jastrow 1987). Restored prairie segments not only showed increased aggregation over time, they also reverted faster toward a close approximation of precultivation soil conditions than did a pasture in non-native weed cover (Jastrow 1987). Similar to the increases seen in soil aggregation, mycorrhizae also increased in restored prairie segments. Testing at Fermilab showed that between the second and fifth growing seasons mycorrhizal colonized root length and percent colonization increased. After the fifth growing season, however, mycorrhizal associations achieved a steady state while root length continued to increase (Cook et al. 1988). The cause of the decrease in percentage of mycorrhizal colonization after the fifth growing season was not clearly identified, but may have occurred either due to limitations in linear rates of extension or because increases in root structures caused decreased need for the benefits, associated with mycorrhizal infection (Cook et al. 1988). Soil, floristic, and animal monitoring within the restored prairie have allowed Professor Betz and the Fermilab staff to understand the progress of the prairie over time and to use that understanding in subsequent restoration efforts.

Lessons learned

Through the last thirty years, prairie restoration has remained a priority at Fermilab and through monitoring and observation of the restored sites many lessons have been learned. The lessons learned have prompted changes in seed collection, seed mix, seed dispersal, fire regimes, and on-going maintenance. Through the last three decades, the timing of species introduction into the prairie has continually evolved. The 1974 restoration used 70 species without regard for species' ability to compete with non-native weeds and survive in degraded soils. Years of floristic monitoring have shown, however, that while many species show a consistent ability to survive and out-compete weeds, many other species are not able to survive until weed populations have been reduced and soil aggregation has increased (Betz 1986). The differences in species' competitiveness have given rise to successional restoration in which initial cites are seeded using aggressive species with wide ecological tolerances. The initial planting, called the 'prairie matrix', eliminates many weedy species, prepares the site for less competitive species, and provides fuel loads for fire (Betz 1996). The prairie matrix included 25 species in 1986, but as of 1996 it has evolved to include 36 species (Betz 1996). Tables 1 and 2 list the 1986 and 1996 prairie matrix species and shows how the matrix has been adjusted over time as additional information on species survival has been obtained.

As the prairie matrix evolved, so did the Fermilab application of successional restoration. As of 1986 prairie was restored using a 25 species prairie matrix and a 23 species secondary matrix. After the 48 species were established, the restoration was monitored and interseeded with additional species to increase diversity (Betz 1986). Since 1986, successional restoration has changed from the two step seeding program using 48 species to a four step seeding program using 109 species. The current successional restoration program plants less competitive species only after earlier successional species have become established, reduced weed populations and increased soil productivity. Lists of species in the later successional matrices are in Tables 3 through 5.

Since the initial restoration, seed collection efficiency has increased and hand harvesting of seed is no longer the main method of seed acquisition, but is still utilized at offsite locations to increase the diversity in the Fermilab prairie by capturing missing or under represented species (Fermilab Ecology mainpage 2001). Currently, the majority of seed used for restorations at Fermilab is harvested on site using a converted farm combine. Mechanical harvesting on the original 390 acres (157.8 ha) and additional restored prairie sites yields 8,000 to 10,000 pounds (3600 to 4500 kg) of uncleaned seed annually (Betz 1996). The high volumes of seed collected allows Fermilab to trade with or donate approximately 350 pounds (157.5 kg) of seed annually to schools, forest preserves and local county governments within Illinois (Lootens 2001).

Methods of seed dispersal have also changed significantly since the first restoration occurred at Fermilab. Seed dispersal was first completed using a Nesbit drill, but after the restoration of four plots use of the Nesbit drill was discontinued. The Nesbit drill was discontinued because it deposited seed in straight rows giving the prairie an agricultural appearance as opposed to the random distribution of vegetation found in native prairie segments (Betz 1986). Another problem with the Nesbit drill was that it required the seeds to be cleaned and dried prior to planting which increased the labor necessary to prepare the collected seed (Betz 1986). The Nesbit drill was replaced by a hydro-mulcher that spread a seed-slurry on the site. The Hydro mulcher allowed for more random seed placement and eliminated the need for clean, dry seed, but significantly increased compaction (Betz 1986). To alleviate the compaction problem, seeding is now completed by either an adapted seed spreader or an all-terrain spreader (Betz 1996). No specific data was available regarding differences in seeding success rate based upon the type of equipment used for seed dispersal.

In addition to changing the method of seed dispersal, alteration in the timing of seed dispersal has also been completed. In the original 1974 restoration, seeding was completed in June, but in subsequent seedings between 1977 and 1982, fall seedings were regularly completed (Betz 1986). The fall seedings however were discontinued because they showed lower success rates than the spring plantings. Fall seeding were less successful than spring seeding because in the fall old-field and weed vegetation established before the native species could germinate, and the natives were out-competed (Betz 1986). Schramm's Knox College research supports spring versus fall plantings and showed that native seed planted in the fall experienced increased animal predation. In addition to increased predation in fall seedings cool season weeds also were able to germinate before the warm season natives because the damp hot soil needed for warm season natives to germinate does not occur May at the earliest (Schramm 1990).

Reducing the weed population within a restored prairie is critical to increasing the diversity and soil aggregation within the site. Planting of highly competitive species in the early stages of restoration have been shown to decrease weed populations but only when used in conjunction with repeated burns (Betz 1996). Research at the University of Wisconsin showed that annual biomass production in burned prairie exceeded biomass production in unburned prairie by almost twofold. Prairie at the University of Wisconsin Arboretum showed biomass production of 4180 pounds per acre for unburned sites and 8478 pounds per acre on burned sites (Anderson 1978). The research further showed that the increase in biomass was due to more favorable growth conditions on the burned sites, such as increased light exposure and more rapid spring warming allowing warm season native grasses to germinate earlier in the growing season (Anderson 1978). Earlier germination increases the native grasses ability compete with cool season weedy species. Burning further enhanced growing conditions by reducing the litter layer, increasing wind movement during the hottest times of the day, and lowering leaf temperatures. Especially for *Andropogon gerardii* (Big Blue Stem) increased wind movement reduces respiration and brings leaf temperatures closer to the photosynthetic optimum temperature of 26^{o} Celsius (Anderson 1978).

In addition to the use of fire as a maintenance tool, mowing was completed on the restored sites, but was later discontinued. Monitoring determined that mowed sites showed increased growth of non-native species. Increased growth in non-native species shaded out the native species and reduced their competitive ability (Betz 1986). Research by Peter Schramm at Knox College supported the decision to eliminate mowing. The Knox College research showed that mowing resulted in incomplete litter removal and suppressed photosynthetic productivity in native prairie species (Schramm 1990). Discontinuing mowing as a maintenance practice as well as the other practices discussed above have evolved through thirty years of restoration, monitoring, and adapting to create restoration practices that attempt to return to the Fermilab land to a precultivation prairie ecosystem

Maintenance

The Ecological Land Management Committee and the Fremilab staff are responsible for maintaining the restored prairie and all additional restored lands within the Fermilab site. To facilitate maintenance the ELM has divided the Fermilab land into subareas as seen in Figure 2. Eleven subdivisions, as discussed in the ELM plan, currently have prairie on site or will have prairie in the future. Four subdivisions are slated for future prairie restoration. These four subdivisions are labeled ELM 4, 22, 23 and 26 (Fermilab ecology mainpage 2001). For each of these four subdivisions, the plan is to mow, disk and seed with the primary seed matrix. After seeding, the prairie is to be burned every two to three years and overseeded after burns to increase species diversity. ELM 6 and 9 include some remnant prairie, but future restoration plans are to be completed after restoration of wetlands in those subdivisions. The remaining seven ELM subdivisions are to be managed with burns every two to three years and overseeding to increase species diversity but limit the effect on above ground arthropods (Fermilab ecology mainpage 2001).

Discussion

In order to restore the prairie at Fermilab, critical aspects of the prairie ecosystem had to be replaced and removal of early successional fast-growing annual or biennial vegetation needed to be accomplished. To effectively restore the prairie reestablishment of species diversity that increases ecosystem resistance to environmental stressors was necessary. The restoration also needed to replace prairie plant root structures and mycorrhizal associations in order to capture nutrients, ensure efficient water uptake, and reduce erosion. Increases seed production also aid in recovery by improving the native seed bank in the soil. Finally, the introduction of fire into the ecosystem is essential to help control weed populations, to allow natural replacement of species from the seed bank, and to allow for the increased biomass production that occurs after burns.

Replacement of the most of the critical ecosystem functions has been successful at Fermilab. The native species populations have doubled in the restored prairie segments through supplemental seedings. The soil structure shows increased aggregation and mycorrhizal association and fire has been reintroduced to help control weed populations and increase native species biomass production. While these accomplishments have helped return the land to a closer approximation of a precultivation prairie, the most remarkable aspect of the restoration has been the development of the successional planting method. Nearly thirty years of monitoring and continued restoration has allowed Professor Betz and the Fermilab staff to create a method of seeding which increases diversity and soil productivity while decreasing weed populations without excessive use of herbicides. Through successional restoration species are seeded into the prairie according to their ability to survive and thrive. Early successional species that are highly competitive work to displace weed populations while helping to improve soil conditions for later successional species. Later successional species are separated into three additional seed matrices (see tables 3 through 5) and are planted, through a twenty-year period, only after the previous stage has become well established. The work completed at Fermilab has created a model for long-grass prairie restorations which allows future restorations to maximize seeding efficiency, species survival, and weed control by introducing a species only when its likelihood of survival the highest. The Fermilab prairie, through development of the successional planting method, has contributed substantially to improve understanding of prairie restoration and still has many lessons yet to teach.

Table 1. Prairie Species of the First stage as of 1986 (with permisssion of Robert Betz).

Allium cernuum (nodding wild onion)	*Parthenium integrifolium* (wild quinine)
*Andropogon gerardii (*big blue stem)	*Ratibida pinnata* (yellow coneflower)
Baptisia leucantha (white wild indigo)	*Silphium integrifolium* (rosin weed)
Carex bicknellii (prairie sedge)	*Silphium laciniatum* (compass plant)
Coreopsis palmate (prairie coreopsis)	*Silphium terebinthinaceum* (prairie doci)
Coreopsis tripteris (tall coreopsis)	*Solidagp gymnospermoides* (grass-leaved
Desmodium canadense (showy tick trefoil)	goldenrod)
Desmodium illinoense (Illinois tick trefoil)	*Solidago juncea* (early goldenrod)
Eryngium yuccifolium (rattlesnake master)	*Solidago nemoralis* (gray goldenrod)
Echinacea pallida (purple coneflower)	*Solidago riddellii* (Riddell’s goldenrod)
Lespedeza capitata (round-headed bush clover)	*Solidago rigida* (prairie goldenrod)
Monarda fistulosa (wild bergamot)	*Sorghastrum nutans* (indian grass)
Panicum virgatum (switch grass)	*Spartina pectinata* (prairie cord grass

Table 2. Prairie Species of the First Stage as of 1996 (with permisssion of Robert Betz).

Allium canadense (wild onion)	*Rudbeckia subtomentosa* (sweet black eyed Susan)
Allium cernuum (nodding wild onion)	Goldenrod)
Andropogon gerardii (big bluestem grass)	*Senecio paurperculus balsamitae* (balsam ragwort)
Aster sagittifolius drummondii (Drummond's	*Silphium integrifolium* (rosin weed)
aster)	*Silphium lacinatum* (compass plant)
Baptisia leucantha (white wild indigo)	*Silphium terebinthinaceum* (prairie dock)
Coreopsis tripteris (tall coreopsis)	*Solidago gigantea* (late flowering goldenrod)
Desmodium canadense (showy tick trefoil)	*Solidago graminifolia* (narrow leaved grassleaved
Elymus canadensis (Canadian wild rye)	*Solidago gymnospermoides* (wide leaved grassleaved
Helianthus mollis (downy sunflower)	goldenrod)
Heliopsis helianthoides (false sunflower)	*Solidago juncea* (early goldenrod)
Lespedeza capitata (round headed bush clover)	*Solidago nemoralis* (gray goldenrod)
Monarda fistulosa (wild bergamot)	*Solidago riddellii* (Riddell's goldenrod)
P*anicum virginicum* (switch grass)	*Solidago rigida* (stiff goldenrod)
Parthenium integrifolium (wild quinine)	*Sorghastrum nutans* (Indian grass)
Penstemon calycosus/digitalis (smooth/foxglove	*Spartina pectinata* (prairie cord grass)
breard tongue)	*Thalictrum dasycarpum* (purple meadow rue)
Pycnanthemum virginianum (common mint)	*Thalictrum revolution* (waxy meadow rue)
Ratibida pinnata (yellow coneflower)	*Vernonia fasciculata* (common ironweed)
Rudbeckia hirta (black eyed Susan)	*Zizia aurea* (golden alexanders)

Table 3. Prairie Species of the Second Stage (Proposed) (with permisssion of Robert Betz).

Agalinis tenulfolia (slender false foxglove)	*Krigia biflora* (false dandelion)
Andropogon scoparius (little bluestem)	*Lathyrus palustris* (marsh vetchling)
Anemone canadensis (Canadian anemone)	*Liatris pycoostachya* (prairie blazing star)
Anemone cylindrica (thimbleweed)	*Liatris spicata* (marsh blazing star)
Asclepias tuberosa (butterflyweed)	*Liatris aspera* (rough blazing star)
Asclepias sullivantti (prairie milkweed)	*Lobelia spicata* (pale spiked lobelia)
Aster novae angliae (New England aster)	*Oxypolis rigidior* (cowbane)
Aster ericoides (heath aster)	*Pedicularis canadensis* (prairie betony)
Cacalia plantaginea (Indian plantain)	*Pedicularis lanceolata* (marsh betony)
Carex bicknellii (prairie sedge)	*Petalostemum candidum* (white prairie clover)
Cicuta maculate (water hemlock)	*Petalostemum purpureum* (purple prairie clover)
Comandra umbellata (false toadflax)	*Phlox glaberrima interior* (marsh phlox)
Coreopsis palmata (prairie coreopsis)	*Phlox pilosa* (prairie phlox)
Desmodium illinoense (Illinois tick trefoil)	*Physostegia virginiana* (false dragonhead)
Dodecatheon meadia (shooting stars)	*Polytaenia nuttallii* (prairie parsley)
Echinacea pallida (purple coneflower)	*Potentilla arguta* (prairie cinquefoil)
Eryngium yuccifolium (rattlesnake master)	*Prenanthes aspera* (rough white lettuce)
Euphorbia corollata (flowering spurge)	*Prenanthes racemosa* (glaucus white lettuce)
Galium boreale (northern bedstraw)	*Psoralea tenuifolia* (scurfy pea)
Galium obtusum (wild madder)	*Salix humilis* (prairie willow)
Gentiana andrewsli (bottle gentian)	*Sisyrichium albidum* (blue eyed grass)
Gentiana flavida (yellow gentian)	*Tradescantia ohiensis* (common spiderwort)
Gentiana quinquefolia (still gentian)	*Veronicastrum virginicum* (Culver's root)
Helianthus rigidus (prairie sunflower)	*Vicia americana* (American vetch)

Table 4. Prairie Plants of the Third Stage (Proposed) (with permisssion of Robert Betz).

Amorpha canaescens (lead plant)	*Heuchera richardsonii grayana* (alum root)
Asclepias hirtella (tall green milkweed)	*Lithospermum canescens* (hoary puccoon)
Asclepias viridiflora (short green milkweed)	*Lysimachia quadriflora* (narrow leaved loosestrife)
Aster azureus (sky blue aster)	*Panicum leibergli* (prairie panic grass)
Aster laevis (smooth aster)	*Polygala senega* (Seneca snakeroot)
Haptisia leucophaea (cream wild indigo)	*Spiranthes magnicamporum* (ladies' tresses orchid)
Bromus kalmli (Kalm's brome grass)	*Sporobolus heterolepis* (prairie dropseed)
Chelone glabra (turtlehead)	*Valeriana ciliate* (common valerian)

Table 5. Prairie Plants of the Fourth Stage (tentative)(with permisssion of Robert Betz).

Asclepias meadii (Mead's milkweed)	*Lilium philadelphicum andinum* (prairie lily)
Cypripedium candidum (white ladies's slipper)	*Oxalis violacea* (purple wood sorrel)
Gentiana puberulenta (prairie gentian)	*Scutellaria parvula* leonardii (small skullcap)
Habenaria leucophaea (white fringed orchid)	*Viola pedatifida* (prairie violet)
Hypoxis hirsute (yellow star grass)	

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