FERMILAB-CONF-16-167-FESS

Results from Four Decades of Successional Prairie Restoration and an Update on Ecological Land Management at Fermilab in Batavia, Illinois

RYAN E. CAMPBELL[1] AND JACQUES L. HOOYMANS[1]

Fermi National Accelerator Laboratory (Fermilab), Batavia, Illinois 60510, USA (REC, JLH)

ABSTRACT Fermi National Accelerator Laboratory (Fermilab) is a 2,573-ha (6,800-acre) Department of Energy site located in Batavia, Illinois, USA. Tucked among the particle accelerators are nearly 1,619 ha (4,000 ac) of natural areas including remnant and restored grasslands, woodlands, and wetlands. Dr. Robert F. Betz began his large-scale prairie restoration project on the Fermilab site in 1975. During the course of that work, he defined 4 successional stages of prairie restoration and listed species occurring in each of the stages. We present results after 40 y of successional prairie restoration and summarize current ecological land management efforts at Fermilab. Ninety-five percent of the 110 species making up his 4 stages of successional restoration established in at least 1 of the 25 Fermilab prairie plantings. Three-fourths of species in Stage 1 were observed in 80% of the plantings and 54% of Stage 2 species were found in at least half of the plantings. Many Stage 3 and almost all Stage 4 species did not frequently establish in the plantings, but this may be an artifact of seed availability. Species richness and floristic quality index (FQI) increased over time in most plantings as seeded and spontaneous species established. As of 2015, 268 native plant species were recorded in the 25 prairie plantings combined. Current ecological land management includes continuing to enrich all 25 prairie plantings by targeted overseeding. Fermilab staff are attempting to create spatial and structural heterogeneity in plantings dominated by big bluestem (*Andropogon gerardii*) by experimenting with 2 hemiparasitic plants (wood betony [*Pedicularis canadensis*] and false toadflax [*Comandra umbellata*]) known to parasitize *A. gerardii* and thought to reduce its competitiveness. Fermilab staff have vastly improved invasive species control efforts and collection and spreading of native seeds in the prairie plantings thanks in part to the use of geographic information system technology. Volunteers help in the prairies as well as perform stewardship duties in remnant woodlands and oak savannas on site. Public outreach and partnership remains important aspects of the Fermilab prairie project. Wildlife monitoring and ecological research continue to provide information guiding adaptive land management at Fermilab.

KEY WORDS Betz, Fermi, Fermilab, hemiparasite, prairie, restoration, succession

INTRODUCTION

Throughout the Midwest, most of the original tallgrass prairie ecosystem has been lost since European settlement (Samson and Knopf 1994). In Illinois, the "Prairie State," less than 0.01% of the 8,906,833 ha (22,000,000 ac) of tallgrass prairie remains. This severe level of destruction of prairie led Dr. Robert F. Betz, a biologist from Northeastern Illinois University and Chicago native, to search for remaining acreages of this nearly extinct ecosystem. In the 1950s and 1960s, Betz found only very small parcels of degraded remnant prairie in railroad rights-of-way and pioneer cemeteries (Betz and Lamp 1989, 1990; Mlot 1990). It was during these field trips he began to envision a plan for recreating vast acreages of tallgrass prairie. When he learned that the new Fermi National Accelerator Laboratory (Fermilab), on the outskirts of Chicago, was seeking advice on how to manage unused land on their site, he set up a meeting with the laboratory director, Dr. Robert R. Wilson. After meeting with Betz and hearing that this prairie restoration project may take 40 y or more to accomplish, Dr. Wilson famously stated, "If that's the case, we should start this afternoon." In 1975, the first 3.64-ha (9-ac) prairie was planted by Fermilab Roads and Grounds on land within the main accelerator ring. Seed for that planting was hand-collected by Betz and volunteers mostly from prairie remnants within an 80.5-km (50-mi) radius of Fermilab (Betz 1986). The Fermilab prairie project had begun. The conversion of fallow fields and agricultural lands to tallgrass prairie continued from 1975 until 2000, ending with 25 plantings totaling nearly 405 ha (1,000 ac) (Table 1). Over the years, Betz's vision for a vast expanse of tallgrass prairie had become a reality. He published papers in the North American Prairie Conference proceedings describing the concept and results of successional prairie restoration during the first 2 decades of planting prairie at Fermilab (Betz 1986, Betzet al. 1997). Refer to these papers for a more in-depth account of planting methods, early prairie management, and results after 1 and 2 decades. The year 2015 marked 40 y of the prairie restoration effort at Fermilab. In this paper, we will examine the results of Betz's successional prairie restoration concept, analyze changes in species richness and floristic quality index (FQI), and relate lessons learned. Other aspects of ecological land management at Fermilab

[1] Corresponding author email address: ryancamp@fnal.gov; jhooyman@fnal.gov

This manuscript has been authored by Fermi Research Alliance, LLC under Contract No. DE-AC02-07CH11359 with the U.S. Department of Energy, Office of Science, Office of High Energy Physics.

are presented in this paper to update Betz et al. (1997). Plant species names follow Mohlenbrock (2014).

Project Site Location

Fermilab is a US Department of Energy particle physics research laboratory located in Batavia, Illinois, USA (41°50′30″N, 88°14′30″W). Elevation at the Fermilab site ranges from 217 to 244 m (711 to 802 ft) above sea level with the majority of prairie plantings on relatively flat land. The main soil types are Ozaukee, Wauconda, and Mundelein silt loams and Drummer silty clay loam (Jastrow et al. 2003). The Fermilab site is a mosaic of land uses and habitats ranging from agriculture and office buildings to buttonbush (*Cephalanthus occidentalis*) swamps and bur oak savannas. Natural areas account for nearly 1,619 ha (4,000 ac), or 58% of the land with the majority of prairie plantings inside the main accelerator ring and western half of the site (Figure 1). Habitat community types in this paper follow classifications found in the Chicago Wilderness Terrestrial Community Classification System (Chicago Wilderness 1999) and Plant Communities of the Midwest: Illinois Subset document (Faber-Langendoen 2001).

Successional Prairie Restoration Concept

Dr. Betz based the Fermilab prairie plantings on ideas rooted in plant competition and community succession (Clements 1916, Betz 1986). He identified 110 species and 4 successional stages of tallgrass prairie restoration (see Betz et al. 1997). This was largely a trial-and-error methodology for each planting and for each species. A seed mix of native prairie species thought to have wide ecological tolerances (e.g., readily establish across soil types and hydrologic gradients, compete well with weeds) was used in an initial planting on plowed and disked agricultural soil. This first group (termed Stage 1 plants or the "prairie matrix") comprised such species as big bluestem (*Andropogon gerardii*) and *Sorghastrum nutans* and aggressive forbs, for instance *Ratibida pinnata*, wild bergamot (*Monarda fistulosa*), *Silphium laciniatum*, and *Silphium terebinthinaceum*, and constituted 25% of the species in the target prairie plant community (refer to Betz et al.1997). More conservative species thought to have narrower ecological tolerances (e.g., lesser competitive abilities) were categorized into later successional stages and seeded into the established prairie matrix over time. These second-, third-, and eventually fourth-stage species would be seeded in sequence into plantings after surveys showed previous stage species were establishing in the plant community. Betz surmised a relationship between belowground soil organisms and plants of later successional stages. As soil structure and microbial communities changed, perhaps they provided the right conditions and feedbacks for later-stage species to thrive.

Table 1. Chronology and acreage of the Fermilab prairie plantings.

Plot	Planted	Acres	Hectares
Prairie 1	Spring 1975	9	3.6
Prairie 2	Spring 1976	11	4.5
Prairie 3	Spring 1977	29	11.7
Prairie 4	Fall 1977	16	6.5
Prairie 5	Fall 1978	11	4.5
Prairie 6	Fall 1979	60	24.3
Prairie 7	Spring 1981	17	6.9
Prairie 8	Fall 1981	46	18.6
Prairie 9	Fall 1982	56	22.7
Prairie 10	Spring 1983	53	21.4
Prairie 11	Spring 1984	32	12.9
Prairie 12	Spring 1984	33	13.6
Prairie 13	Spring 1985	47	19.0
Prairie 14	Spring 1985	19	7.7
Prairie 15	Spring 1986	50	20.2
Prairie 16	Summer 1988	60	24.3
Prairie 16B	Summer 1988	6	2.4
Prairie 17	Summer 1990	84	34.0
Prairie 17 East	Summer 1990	71	28.7
Prairie 18	Spring 1992	10	4.0
Prairie 19	Spring 1993	55	22.3
Prairie 21	Spring 1995	35	14.2
Prairie 22	Spring 1998	34	13.8
Prairie 23	Spring 2000	18	7.3
Prairie 24	Spring 1999	24	9.7

Weeds and Fire

After approximately 3 growing seasons, the prairie matrix had sufficient biomass to burn (Betz et al. 1997). Burning of the young plantings on an annual or near annual basis was a requirement for Betz. He assumed that all weeds and nonnative plants would eventually succumb to repeated fire and native plant competition (Betz et al. 1997). Grassland managers across the Midwest now know that invasive species must be managed at the onset of tallgrass prairie restoration if long-term success is to be realized (Pollock 2009, Helzer et al. 2010). Dr. Betz was correct, however, in that a high fire-return interval is needed for successful management of remnant and restored tallgrass prairies in the Chicago region (Bowles and Jones 2013, Saxton et al. 2016). To date, the Fermilab prairie plantings have had a mean fire-return interval of approximately 2 y.

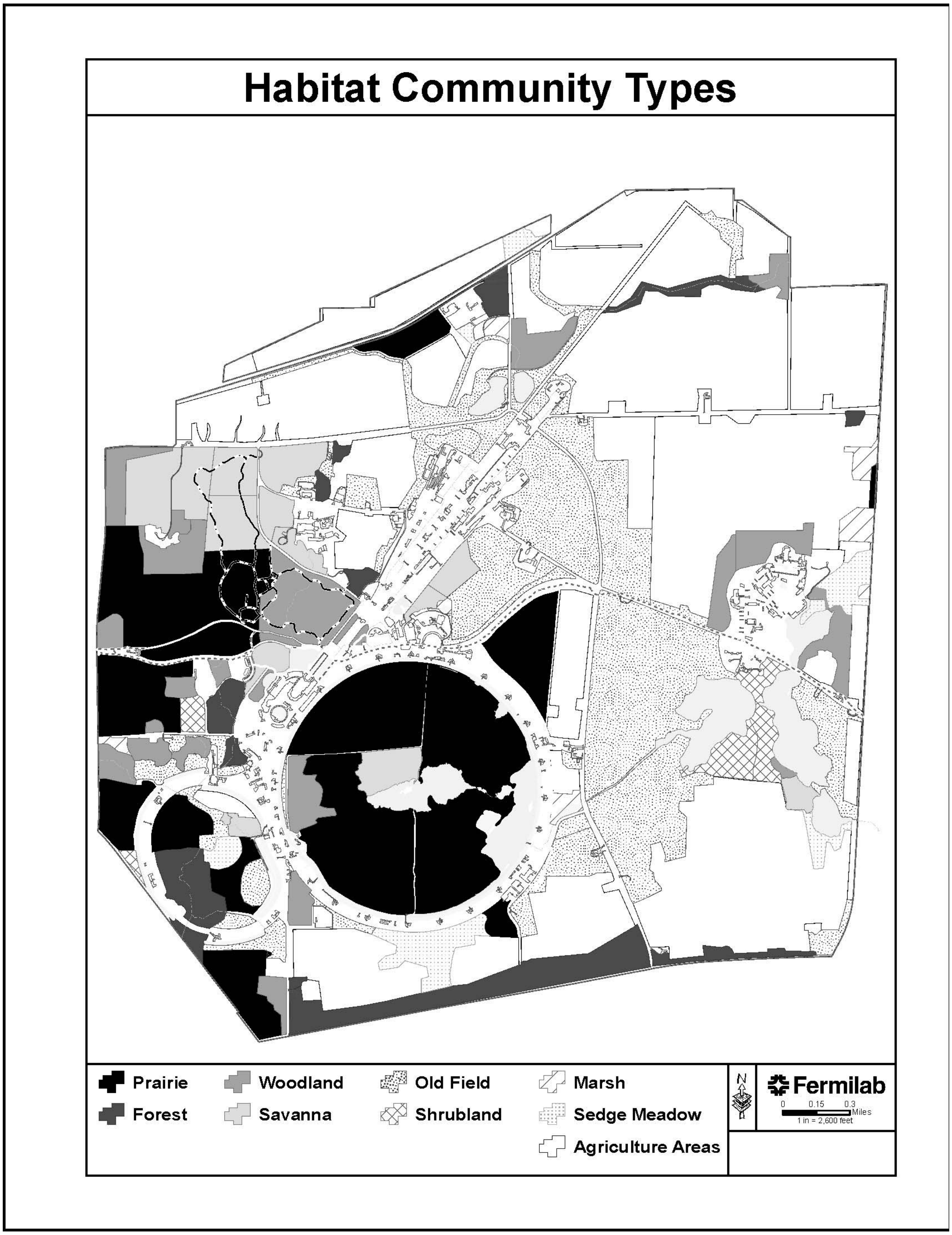

Figure 1. Map of Fermilab site habitat community types. Prairie plantings depicted in black.

Plant Survey Methods

Since the start of the prairie restoration efforts at Fermilab, Dr. Betz and others did regular plant surveys via meandering transects. Mostly they recorded whether a species was observed in a planting. However, qualitative measures of abundance were also recorded during the first decade of the project (see Betz 1986). Betz used a survey sheet containing 285 prairie and wet meadow species. This list comprised his understanding of what the species composition of restored mesic and wet prairie plant communities could be, based on the predominant soil types found at Fermilab and his work in cemetery prairies and railroad remnants (Betz 1972 and Betz and Lamp 1989). Species recorded for each planting were maintained in a running tally year after year. Nonplanted, weedy natives and invasive species were often not recorded on surveys. Betz's goal was to create a prairie plant community, and he focused survey efforts on determining whether or not sown seed was actually establishing.

METHODS

For this manuscript, we calculated the frequency of species recorded in the 25 Fermilab prairie plantings from each of Betz's 4 successional prairie restoration stages. We further examined plant species richness and FQI for the plantings using all available data from prairie and wet meadow species. In addition, the fourth decade of survey data (2006–2015) was analyzed for species richness and FQI to determine if it was a more realistic measure of actual prairie and wet meadow species composition in the Fermilab prairie plantings.

RESULTS

Successional Prairie Restoration

Analysis of the survey data collected during the last 40 y shows that 104 of the 110 plant species making up Betz's 4 stages of successional restoration occurred in at least 1 of the 25 Fermilab prairie plantings. Tables 2a–2d display the frequency of each species in the plantings separated by stage. All 36 Stage 1 (i.e., prairie matrix) species were recorded in the plantings at Fermilab. Almost half (49%) were found in all 25 plantings, and 80% were recorded in at least three-fourths of the plantings. Only 2 species
23 (*Symphyotricum drummondii* and *Solidago nemoralis*)in the prairie matrix were in less than half of the plantings. Fifty-four percent of species from Stage 2 occurred in at least half of the prairie plantings with 6 Stage 2 species observed in all plantings. Three species from Stage 2 (*Asclepias tuberosa*, *Lathyrus palustris*, and *Salix humilis*) were found in only one planting each while *Prenanthes aspera* was not found in any of the plantings. All Stage 3 species were recorded as occurring in less than half of the

Table 2a. Total number of plantings and frequency in which Betz successional Stage 1 prairie species were found.

Stage 1 Species	No. of Plantings	Frequency
Allium canadense	16	64%
Allium cernuum	21	84%
Andropogon gerardii	25	100%
Baptisia leucantha	22	88%
Coreopsis tripteris	25	100%
Desmodium canadense	25	100%
Elymus canadensis	23	92%
Euthamia graminifolia	23	92%
Euthamia gymnospermoides	23	92%
Helianthus mollis	22	88%
Heliopsis helianthoides	24	96%
Lespedeza capitata	24	96%
Monarda fistulosa	25	100%
Oligoneuron riddellii	14	56%
Oligoneuron rigidum	25	100%
Packera paupercula	20	80%
Panicum virgatum	25	100%
Parthenium integrifolium	25	100%
Penstemon calycosus	14	56%
Penstemon digitalis	25	100%
Pycnanthemum virginianum	25	100%
Ratibida pinnata	25	100%
Rudbeckia hirta	25	100%
Rudbeckia subtomentosa	24	96%
Silphium integrifolium	25	100%
Silphium laciniatum	25	100%
Silphium terebinthinaceum	25	100%
Solidago gigantea	15	60%
Solidago juncea	19	76%
Solidago nemoralis	11	44%
Sorghastrum nutans	25	100%
Spartina pectinata	24	96%
Symphyotrichum drummondii	12	48%
Thalictrum dasycarpum	25	100%
Thalictrum revolutum	23	92%
Vernonia fasciculata	14	56%
Zizia aurea	25	100%

plantings, except for lead plant (*Amorpha canescens*) and prairie dropseed *Sporobolus heterolepis* (72% and 54% occurrence, respectively). Two species from Stage 3 were not found in any of the plantings (*Asclepias hirtella* and

Table 2b. Total number of plantings and frequency in which Betz successional Stage 2 prairie species were found.

Stage 2 Species	No. of Plantings	Frequency
Agalinis tenuifolia	8	32%
Anemone canadensis	8	32%
Anemone cylindrica	12	48%
Arnoglossum plantagineum	4	16%
Asclepias sullivantii	13	52%
Asclepias tuberosa	1	4%
Carex bicknellii	24	96%
Cicuta maculata	20	80%
Comandra umbellata	9	36%
Coreopsis palmata	21	84%
Dalea candidum	19	76%
Dalea purpurea	19	76%
Desmodium illinoense	5	20%
Dodecatheon meadia	22	88%
Echinacea pallida	19	76%
Eryngium yuccifolium	25	100%
Euphorbia corollata	13	52%
Galium boreale	7	28%
Galium obtusum	8	32%
Gentiana alba	22	88%
Gentiana andrewsii	14	56%
Gentianella quinquefolia occidentalis	11	44%
Helianthus pauciflorus	11	44%
Krigia biflora	6	24%
Lathyrus palustris	1	4%
Liatris aspera	16	64%
Liatris pycnostachya	8	32%
Liatris spicata	21	84%
Lobelia spicata	15	60%
Oxypolis rigidior	16	64%
Pedicularis canadensis	21	84%
Pedicularis lanceolata	13	52%
Phlox glaberrima interior	16	64%
Phlox pilosa	9	36%
Physostegia virginiana	25	100%
Polytaenia nuttallii	6	24%
Potentilla arguta	5	20%
Prenanthes aspera	0	0%
Prenanthes racemosa	7	28%
Psoralea tenuiflora	4	16%
Salix humilis	1	4%

Table 2b. Continued.

Stage 2 Species	No. of Plantings	Frequency
Schizachyrium scoparium	16	64%
Sisyrinchium albidum	16	64%
Symphyotrichum ericoides	25	100%
Symphyotrichum novae-angliae	25	100%
Tradescantia ohiensis	25	100%
Veronicastrum virginicum	25	100%
Vicia americana	3	12%

Asclepias viridiflora). Stage 4 plants comprised 9 species. Two Stage 4 species were not recorded (*Asclepias meadii* and *Platanthera leucophaea*) and only *Lilium philadelphicum* var. *andinum* was found in 5 or more prairie plantings.

Species Richness and Floristic Quality Index

Species richness in single prairie plantings ranged from 206 (Prairie 6) to 38 (Prairie 17 East) with a mean species richness of 113 across all plantings (Table 3). FQI ranged from 79 to 29 with a mean FQI of 54 (Table 4). Using only the fourth decade of survey data, species richness ranged from 163 to 38 with a mean richness of 98 plant species (Table 5). Not all prairie plantings were included due to lack

Table 2c. Total number of plantings and frequency in which Betz successional Stage 3 prairie species were found.

Stage 3 Species	No. of Plantings	Frequency
Amorpha canescens	18	72%
Asclepias hirtella	0	0%
Asclepias viridiflora	0	0%
Baptisia leucophaea	10	40%
Bromus kalmii	3	12%
Chelone glabra	4	16%
Dichanthelium leibergii	7	28%
Heuchera richardsonii	7	28%
Lithospermum canescens	7	28%
Lysimachia quadriflora	4	16%
Polygala senega	7	28%
Spiranthes magnicamporum	2	8%
Sporobolus heterolepis	14	56%
Symphyotrichum laeve	11	44%
Symphyotrichum oolentangiense	6	24%
Valeriana ciliata	1	4%

Table 2d. Total number of plantings and frequency in which Betz successional Stage 4 prairie species were found.

Stage 4 Species	No. of Plantings	Frequency
Asclepias meadii	0	0%
Cypripedium candidum	4	16%
Gentiana puberulenta	5	20%
Hypoxis hirsuta	5	20%
Lilium philadelphicum andinum	9	36%
Oxalis violacea	1	4%
Platanthera leucophaea	0	0%
Scutellaria parvula	1	0%
Viola pedatifida	3	12%

of data for some plantings. On average, richness of selected plantings using the comprehensive data set had 15 more species than when using the fourth decade of survey data only. FQI of selected plantings using the data from the fourth decade ranged from 69 to 29 with a mean FQI of 50 (Table 5).

DISCUSSION

Creating a Tallgrass Prairie using Successional Restoration Methods

The method of successional planting can work to create prairie plant communities. The vast majority of Stage 1 and Stage 2 prairie species established in all or most plantings. It is impossible to determine if this is the result of actual competitive differences and wide ecological tolerances or an anthropogenic filtering effect. Were these species frequently found simply because they were seeded into plantings at a higher rate relative to Stage 3 and Stage 4 species? Perhaps the more land these species grew on, the more their seeds were collected and planted. Examining species in Stage 2, there are several in over 90% of plantings. These are copper-shouldered oval sedge (*Carex bicknellii*), *Eryngium yuccifolium*, *Physostegia virginiana*, *Symphyotrichum ericoides*, New England aster (*Symphyotrichum novae-angliae*), *Tradescantia ohiensis*, and *Veronicastrum virginicum*. While these species might be more competitive than originally thought, it is possible that observed high frequency is correlated to relative ease of seed collection by hand. Stage 1 and 2 species that did not establish well in plantings can likely be attributed to identification difficulties (e.g., *Penstemon calycosus* vs. *Penstemon digitalis*) or habitat preference. *Lathyrus palustris*, Riddell's goldenrod (*Oligoneuron riddellii*), and common ironweed (*Vernonia fasciculata*) are wetland species while *Asclepias tuberosa*, *Prenanthes aspera*, and *Solidago nemoralis* prefer dry soil, and *Symphyotrichum drummondii* is a savanna or woodland edge species.

Amorpha canescens is the only Stage 3 species that established well (18 of 25 plantings). Most Stage 3 and all Stage 4 species were found in fewer than 10 plantings. These species appear not to have been limited in plantings due to narrow ecological tolerances but seed availability. If seed availability for all 110 species was equal, we would expect to observe a much greater frequency of Stage 3 and Stage 4 species across the plantings. Dr. Betz would collect seed from remnant prairies within the Chicago region, often alone, and many of these uncommon plants produced few seeds in cryptic fruits that had a short dispersal window. Native plant nurseries did not exist at that time. The establishment of species in the 4 successional stages proposed by Betz could, at least partially, be attributed to the multiplier effect and logistically driven, anthropogenic

Table 3. Species richness over time for the Fermilab prairie plantings using the comprehensive data set.

Fermilab Planting	1985	1990	1995	2000	2005	2010	2015
Prairie 1	61	77	90	101	110	114	122
Prairie 2	43	57	70	78	85	88	88
Prairie 3	43	60	85	98	101	109	109
Prairie 4	28	53	58	82	111	121	121
Prairie 5	25	39	53	55	60	68	68
Prairie 6	41	105	140	169	179	193	206
Prairie 7	14	38	49	69	84	95	95
Prairie 8	33	69	85	86	93	109	109
Prairie 9	17	58	96	111	121	126	126
Prairie 10	16	77	89	96	107	115	115
Prairie 11	10	82	110	128	131	134	134
Prairie 12	5	68	93	114	130	138	154
Prairie 13		65	117	132	143	155	155
Prairie 14		26	61	90	110	123	139
Prairie 15		45	77	106	121	131	157
Prairie 16		30	59	75	91	106	122
Prairie 16B			35	50	71	81	92
Prairie 17			51	83	96	106	122
Prairie 17 East						38	38
Prairie 18			14	44	67	85	99
Prairie 19			10	33	62	86	99
Prairie 21				32	43	66	80
Prairie 22					37	73	100
Prairie 23					40	54	59
Prairie 24							110

Table 4. Floristic quality index over time for the Fermilab prairie plantings using the comprehensive data set.

Fermilab Planting	1985	1990	1995	2000	2005	2010	2015
Prairie 1	49	54	58	59	62	63	64
Prairie 2	35	40	43	45	47	47	47
Prairie 3	35	42	47	50	51	54	54
Prairie 4	25	35	37	47	61	62	62
Prairie 5	25	33	37	38	39	42	42
Prairie 6	33	52	62	70	73	77	79
Prairie 7	18	32	34	44	50	54	54
Prairie 8	31	42	46	46	49	54	54
Prairie 9	19	37	44	49	54	56	56
Prairie 10	17	40	42	45	49	52	52
Prairie 11	13	44	50	56	58	59	59
Prairie 12	9	38	45	51	58	61	64
Prairie 13		37	51	57	61	64	64
Prairie 14		22	36	49	57	60	62
Prairie 15		31	43	51	58	61	67
Prairie 16		23	36	42	48	52	54
Prairie 16B			33	37	46	50	54
Prairie 17			32	43	48	51	53
Prairie 17 East						29	29
Prairie 18			13	29	41	46	51
Prairie 19			9	25	38	46	47
Prairie 21				25	32	41	41
Prairie 22					33	43	49
Prairie 23					35	39	39
Prairie 24							51

filtering of the species pool. These data show that if seeds were available in sufficient quantities and planted on appropriate soil types, establishment occurred with time.

Not all 110 species making up the 4 stages of successional prairie restoration turned out to be appropriate for the Fermilab soil types. Bowles and McBride (unpublished report, 2013) summarized the original land survey records of the Fermilab area, which detailed many wet-mesic prairies and marshes intermixed with woodlands and floodplain forests. Fermilab is relatively flat and has soil types reflective of a high water table. Prairie species that require well-drained soil may establish but do not thrive. Successional species that did not do well and that we would remove from the planting list are: *Solidago nemoralis* (Stage 1), *Asclepias tuberosa*, *Desmodium illinoense*, *Prenanthes aspera* (Stage 2), *Asclepias hirtella*, *Asclepias viridiflora*, and *Valeriana ciliata* (Stage 3). Conversely, plants typically obligated to wetlands do well here, but would not remain on the list of plant species necessary to build a tallgrass prairie community. Examples are: *Oligoneuron riddellii*, *Vernonia fasciculata* (Stage 1), *Arnoglossum plantagineum*, *Pedicularis lanceolata* (Stage 2), and *Chelone glabra* (Stage 3).

In nearly all plantings, both species richness and FQI increased over time. Five representative prairie plantings (Prairies 1, 6, 15, 19, and 23) across the Fermilab chronosequence exhibit the trajectory of species richness and FQI changes using a revolving 10-y data set (Figures 2 and 3, respectively). The appearance of abrupt increases in richness is explained by survey intensity. For example, Prairies 1 and 6 were intensively surveyed in 2015 but not for at least 5 y prior. The gradual, temporal increase of species richness and FQI observed in many plantings can be attributed to several factors. While 110 species made up the 4 stages of successional prairie restoration, Dr. Betz referred to 292 species ideal for creating prairie ($n = 160$) and wet meadow ($n = 132$) plant communities (Betz et al. 1997). Remnant wetland species and spontaneous native plants were observed in plantings and usually recorded. Seeds from other prairie and wet meadow species were sown into existing plantings and many of them established. Today, 268 native prairie or wet meadow plant species have been found within the 25 prairie plantings. Last, the data were cumulative.

We now look at richness and FQI calculated using the fourth decade (2006–2015) of survey data. It is rationalized by Fermilab staff that a species not observed during the last decade of surveys either died out or individuals are so few they are nearly undetectable. We think this may be a better way to capture the actual plant community richness and FQI than to count everything ever seen in a planting. Using comprehensive data may exaggerate total richness and by extension, FQI. For example, *Salix humilis* was last seen in 1993 in Prairie 13 and *Gentiana andrewsii* had not been recorded in 3 plantings in the last 10 y. When looking at just the fourth decade of survey data, we found an average of 15 fewer species than the comprehensive data for the plantings analyzed. Were these early successional species that dropped out of the plantings over time or species with less competitive ability that never established? It appears that neither is correct for the most frequently absent species (Table 6). Survey timing (early spring vs. late summer) and cryptic differences between similar species (e.g., *Pycnanthemum tenuifolium* vs. *Pycnanthemum virginianum*) seem to be the driving factors. This highlights the need to continue thorough surveys several times during the growing season and provides a list of cryptic species for Fermilab staff to become more familiar with. The most frequently "lost" species are probably still present in plantings while others may have dropped out or persist at a nearly undetectable level.

Table 5. Compared species richness and floristic quality index using the comprehensive data set and previous decade of data in
?11 ~~select~~ Fermilab prairies.

Fermilab Planting	1975–2015 Species Richness	2006–2015 Species Richness	1975–2015 Floristic Quality Index	2006–2015 Floristic Quality Index
Prairie 1	122	98	64	57
Prairie 6	206	163	79	69
Prairie 12	154	123	64	56
Prairie 14	139	126	62	59
Prairie 15	157	141	67	65
Prairie 16	122	99	54	48
Prairie 16B	92	77	54	50
Prairie 17	122	106	53	50
Prairie 17 East	38	38	29	29
Prairie 18	99	83	51	48
Prairie 19	99	89	47	44
Prairie 21	80	77	41	40
Prairie 22	100	96	49	48
Prairie 23	59	48	39	33
Prairie 24	110	110	51	51
Mean	113	98	54	50

~~Note: missing plantings do not have sufficient surveys in last 10 y.~~

Almost 75% of plantings had an FQI above 50. Swink and Wilhelm (1994) wrote "areas registering in the 50's and higher are extremely rare and of paramount importance; they represent less than 0.5% of the land area of the Chicago region." It is for this reason we have set 50 as our minimum target FQI for all land management units at Fermilab, including the prairie plantings. Fermilab staff are proud of the fact that the majority of the plantings are represented with such an impressive FQI, especially since this project was done on the side, after needs were met to fulfill services to the particle physics community.

Species presence data are necessary for frequency, richness, and FQI calculations. However, this provides no information on how probable species population persistence is in each planting. Species abundance is equally important for creating diverse and resilient tallgrass prairie commu-

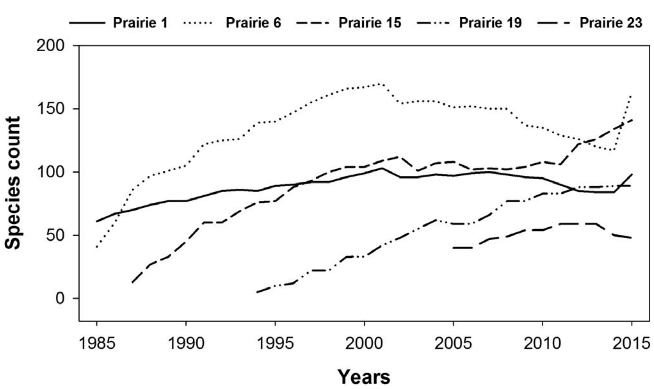

Figure 2. Species richness over time in representative prairie plantings at Fermilab.

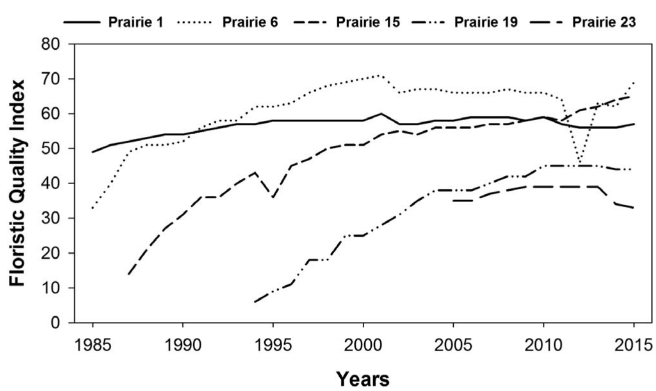

Figure 3. Floristic quality index over time in representative prairie plantings at Fermilab.

Table 6. List of species most frequently not seen during surveys in the last decade but recorded in earlier years.

Scientific Name	Count
Pycnanthemum tenuifolium	6
Mimulus ringens	5
Symphyotrichum lanceolatum	5
Viola sororia	5
Helianthus mollis	4
Helianthus pauciflorus	4
Penstemon calycosus	4
Physalis heterophylla	4
Rorippa palustris fernaldiana	4
Schizachyrium scoparium	4
Solidago gigantea	4
Bidens frondosa	3
Bidens trichosperma	3
Boltonia asteroides	3
Carex brachyglossa	3
Cyperus esculentus	3
Elymus canadensis	3
Epilobium coloratum	3
Gentiana andrewsii	3
Glyceria striata	3
Penthorum sedoides	3
Smilacina stellata	3
Stachys tenuifolia	3
Symphyotrichum drummondii	3
Zizia aptera	3

nities. Since 2011, Fermilab staff have used an abundance scale to estimate population size of each species (Table 7) during the meandering plant surveys. Abundance not only indicates how common a species is, but also helps determine trends in population size, where to dedicate seed resources, and how to prioritize invasive species control efforts.

Overseeding the Fermilab Prairies

Every Fermilab planting has its own suite of native plant species either absent or in low abundance. Over the years, Betz and Fermilab Roads and Grounds experimented with a combination of hand sowing, seed drills, broadcast wagons, and fertilizer spreaders to overseed established plantings with species of later successional stages. To accommodate the seed drill, fruits and seed heads were processed finely. Artificial cold–moist stratification of seed mixes and scarification and inoculation of legumes were also performed during parts of the second and third decade of planting.

Today, staff at Fermilab no longer use a seed drill, artificially stratify, scarify, or inoculate seed indoors. Hand sowing and machine-broadcasting seed mixes before the onset of winter allows for natural stratification and scarification. These simplified methods of overseeding are preferred as no significant difference in establishment has been observed between methods. During the growing season, seeds of native plants are located by staff, summer students, and volunteers using a seed collection geographic information system (GIS) map layer on tablets equipped with a global positioning system (GPS). Seeds from spring prairie forbs are hand sown immediately into assigned plantings. All summer and fall harvested fruits are air-dried then hand processed or put through a hammer mill to release the seed from the chaff and to break up stem material.

Table 7. Abundance scale used in current plant surveys at Fermilab.

Abundance Value	Estimated Population Size	Notes
1	1–5 plants	Very rare, overseeding necessary
2	6–25 plants	Rare, overseeding needed
3	26–100 plants	Small population, overseeding recommended
4	101–1,000 plants	Low 4 = overseeding possible High 4 = stable population
5	>1,000 plants	Sustainable population
1p	1–5 patches	Patches are clonal or rhizomatous species
2p	6–25 patches	
3p	26–100 patches	
4p	101–1,000 patches	
5p	>1,000 patches	

Between 2006 and 2015, an average of 72 species have been hand collected, mixed, and sown each year from tallgrass prairie and wet meadow habitats. Prior to 2011, general prairie seed mixes were made based on hydrology (e.g., mesic prairie mix, wet prairie mix) and spread randomly across plantings. Since staff began collecting species abundance data, custom seed mixes are being made for each planting based on the abundance of each species in that particular planting. This tailored approach to overseeding better utilizes seed, staff, and volunteer resources.

Fermilab continues to use a modified agricultural combine to harvest forb-rich areas in order to bulk overseed some of the prairie plantings. Bulk harvested prairie seed from weed-free areas is also used for trading. Fermilab has seed trading partnerships with nearly 3 dozen federal, state, county, and municipal agencies as well as not-for-profit groups. Fermilab receives seed from the staff wish list and trades either bulk amounts of machine-harvested prairie seed or hand-collected seed of forbs, sedges, and grasses. These partnerships remain crucial for maintaining genetic diversity among restoration sites throughout the region and for maximizing species diversity in the Fermilab prairie plantings.

Tallgrass Prairie Plantings and Hemiparasites

The successional restoration method used at Fermilab to plant prairie relied on large amounts of seed from tall-stature, warm-season grasses. Why did Dr. Betz explicitly include these grasses as part of the Stage 1 prairie matrix? The most obvious answer is in the name of the system in question. This was tallgrass prairie. *Andropogon gerardii* and *Sorghastrum nutans* were both consistently found in silt–loam prairie remnants (Betz and Lamp 1989) and their persistence in the corners of settler cemeteries was indicative of their competitive ability. Further, warm-season grasses could provide the spatially consistent fuel necessary for burning a young planting (Betz et al. 1997). Today, many of our prairie plantings continue to be dominated by *Andropogon gerardii*. Long-term ecological research from the western tallgrass prairie points to the role of grazing in conjunction with fire for maintaining prairie plant community diversity (Collins and Steinauer 1998). While Fermilab does have a herd of bison (*Bison bison*) on the property, they are not located within the prairie plantings. Research from planted prairies throughout the Midwest has shown that a high abundance of warm-season grasses adversely affects species richness and forb diversity (Sluis 2002, Williams et al. 2007, McCain et al. 2010, Wilsey 2010), and many prairie managers are now drastically limiting or omitting tall-stature, warm-season grasses at planting (Dickson and Busby 2009, Helzer et al. 2010, Goldblum et al. 2013). Suggested techniques for reducing tall-stature, warm-season grasses in planted prairies vary. Grazing with bison in eastern tallgrass prairie is being tested (e.g., Nachusa Grasslands) while cattle grazing holds promise (Helzer 2010). Land managers have tried light disking, harrowing, mowing, and grass-specific herbicides (Helzer et al. 2010). We are experimenting with 2 hemiparasitic plants, wood betony (*Pedicularis canadensis*) and false toadflax (*Comandra umbellata*), in an attempt to create islands of heterogeneity and increased richness throughout the prairie plantings. Armstrong et al. (1996) found a decrease in height and flowering stems of vegetation growing among *Pedicularis canadensis* in prairie. We have observed this same phenomenon. Similar to observations noted by Henderson (2003), Fermilab staff have noticed an abundance of spring prairie forbs, grasses, and prairie annuals within *Pedicularis canadensis* patches compared to neighboring areas dominated by warm-season grasses. DiGiovanni (2016) reported a significantly higher FQI in Fermilab prairie plantings when *Pedicularis canadensis* was present and species richness was positively correlated with *Pedicularis canadensis* cover in a study of remnant prairie in central Illinois (Hedberg et al. 2005). While more scientific experimentation is needed (Henderson 2003), we are actively collecting and spreading *Pedicularis canadensis* seed into bluestem-dominated areas and sowing a diverse mix of spring forbs, grasses, and prairie annuals into each established *Pedicularis canadensis* patch (Table 8) within the Fermilab prairie plantings. We are also transplanting sods of *Comandra umbellata* into bluestem-dominated areas and will be observing results. Like the prairies at Fermilab, many older prairie plantings in the Midwest are dominated by tall-stature, warm-season grasses. Most of these are not able to support large grazers due to resource limitations, preserve size, or geographic location. Perhaps this "pseudograzing" by native hemiparasitic prairie plants can increase patchiness and community richness in grass-dominated prairie plantings without the use of mowers, farm implements or herbicides.

Invasive Species Management

As early-successional agricultural weeds gave way to the establishing tallgrass prairie matrix, some nonnative plants continued to increase in abundance. Despite a 2-y mean fire-return interval in the Fermilab prairie plantings, widely established invasive species include *Melilotus albus*, *Securigera varia*, and *Phalaris arundinacea*. In 2010, Fermilab began control efforts for these species, and initial results are encouraging. Scattered plants of *Melilotus albus* are hand cut each year in priority prairie areas determined by Fermilab staff. When *Melilotus albus* has extreme bloom years, it is mowed at peak flowering. *Securigera varia* was planted many years ago on accelerator ring berms and escaped into the prairie. This species is now established throughout the Fermilab site because of lack of management and unintentional seed dispersal via mower decks, especially in firebreaks. Staff have been mapping this species using GIS technology and aggressively controlling it throughout all prairie plantings using selective herbicides. *Phalaris arundinacea* has established readily in wet-mesic and wet soils within many prairie and wetland habitats at Fermilab. We have not observed the replacement of this species by native sedges and grasses suggested by Betz et al. (1997). Because of its high abundance, we attempt to control *Phalaris arundinacea* only in priority locations using selective herbicides. After the second or third season of control, a native seed mix of 15 graminoids and 24 forbs is sown (Table 9). Other invasive plant species found within the Fermilab prairie plantings, such as *Dipsacus* spp., *Lythrum salicaria*, and *Phragmites australis*, have been managed annually by Fermilab staff for over 15 y and do not represent a threat as long as management continues. For these species, staff, summer students, and volunteers use GIS maps on tablets equipped with GPS to find each location and continue their control (Figure 4).

Wildlife Monitoring at Fermilab

Betz used the "build it and they will come" philosophy in how he related wildlife to the Fermilab prairie plantings. There is little doubt that wildlife benefitted from creating expansive tallgrass prairie habitat within the mosaic of remnant woodlands and wetlands at Fermilab. Since the 1980s, researchers from academic institutions, partnering agencies, volunteers, students, and friends of the Betz prairie project have all performed some type of wildlife monitoring. The resultant data points are helpful, but varied. Grassland birds such as dickcissel (*Spiza americana*), bobolink (*Dolichonyx oryzivorus*), and Henslow's sparrow (*Ammodramus henslowii*) use the prairie plantings. However, their numbers are limited as several species do not prefer the tall, dense vegetation (Kasper 2016). Prairie insects were surveyed by Betz's friend, Ron Panzer (Panzer and Gnaedinger 1986) with several conservative species found within the prairie plantings. The Fermilab prairie plantings are also important pollinator habitat. The federally endangered rusty patched bumble bee (*Bombus affinis*) was observed in the Main Ring prairies in the 1990s (P. Franzen, unpublished report, 1993) and was last vouchered in September 2014 in Prairie 15 (T. Miesle, unpublished report, 2015). Regular Lepidoptera monitoring has provided location records for remnant-dependent and -responsive species (e.g., dion skipper [*Euphyes dion*], banded hairstreak [*Satyrium calanus*], and purplish copper [*Lycaena helloides*]) and distributions for many moths (approx. 100 species) and other butterflies ($n = 54$). Five years of dragonfly and damselfly monitoring reveals impressive species richness ($n = 55$) and rare species occurrences (e.g., unicorn clubtail [*Arigomphus villosipes*], comet darner [*Anax longipes*]). Reptiles and amphibians were periodically surveyed many years ago (K. S. Mierzwa, D. Mauger, and D. W. Stillwaugh, Jr., unpublished report, 1990). However, renewed vigor has produced an extensive, updated status report (T. Schramer and T. Anton, unpublished report, 2017). A population of smooth green snake (*Opheodrys vernalis*) has been reverified, and distribution records across the site (in both Kane and DuPage counties) for common and uncommon species increased dramatically. Small mammal surveys have also documented changes in species occurrence and abundance over time within the prairie plantings (D. Pigage and H. Pigage, unpublished report, 1983; Jewell 1992, G. Perricone, unpublished report, 2016). Wildlife can be an important response variable to plant community restoration, and persistent monitoring efforts will continue to inform management actions within the prairie plantings and other habitat types found at Fermilab.

Research and Data Collection

Ecological research has been conducted since the onset of the prairie project. Fermilab has been a research site to many scientists for close to 30 y due to the US Department of Energy National Environmental Research Park program. Research has been conducted aboveground in the prairie plant community (Sluis 2002), belowground among the roots and mycorrhizal fungi (Jastrow 1987, Cook et al. 1988), in the woodlands (Anderson and Kelley 1995) and agricultural fields (Matamala et al. 2008), and within groups of wildlife (refer to previous section). Dr. Betz collected plant survey data in the prairies, and Fermilab staff have expanded botanical data collection for all habitat communities on site. Scientists continue to inquire about ecological research and we have a growing list of questions and project ideas in need of study. Dr. Betz used to say that his role was to build a large-scale prairie at Fermilab. Other scientists would ask questions and perform research on the resultant product. He further predicted that others would modify or change his methods of successional prairie restoration as the body of existing prairie research grew across the tallgrass prairie range. Betz was one of the first to put a voice to the restoration of tallgrass prairie, and now others have learned from and built upon his deep-rooted passion for this unique and endangered ecosystem.

Volunteers and Public Engagement

Volunteers are and have been a necessary ingredient of the Fermilab prairie project. They helped Dr. Betz collect and mix prairie seeds for the first planting in 1975 and ran the Fermilab Prairie Committee for many years. While the Fermilab Roads and Grounds crew did and continues to do the "heavy lifting" for the prairie project, including plowing, disking, seeding, and burning, volunteers have always been present to support the fine-scale duties. Today, thanks to the friends group

?212 Table 8. Seed mix list for *Pedicularis canadensis* and *Comandra umbellata* patches.

Scientific Name	Common Name	Associate of Wood Betony[a]	Associate of False Toadflax[a]	Notes	Wetland Status[a]
Allium canadense	Wild onion				FACU
Allium cernuum[b]	Nodding wild onion		X		FAC−
Amorpha canescens	Lead plant		X	Legume	UPL
Antennaria neglecta	Pussy toes			Clonal	UPL
Antennaria plantaginifolia	Field pussy toes			Clonal	UPL
Asclepias sullivantii	Prairie milkweed				UPL
Baptisia bracteata[b]	Cream wild indigo			Legume	UPL
Bromus kalmii	Prairie brome			Early summer grass	FAC
Carex bicknellii	Copper-shouldered oval sedge		X	Sedge	UPL
Castilleja coccinea	Scarlet Indian paintbrush	X	X	Hemiparasite	FAC
Ceanothus americanus	New Jersey tea				UPL
Chamaecrista fasciculata[b]	Partridge pea			Annual	FACU−
Comandra umbellata	False toadflax	X	n/a	Hemiparasite	FACU
Coreopsis palmata	Prairie coreopsis		X	Clonal	UPL
Dalea candida	White prairie clover			Legume	UPL
Dalea purpurea	Purple prairie clover	X		Legume	UPL
Dichanthelium leibergii[b]	Prairie panic grass			Early summer grass	FACU+
Echinacea pallida	Pale purple coneflower		X		UPL
Euphorbia corollata	Flowering spurge	X			UPL
Gaura biennis	Biennial gaura				FACU−
Gentiana puberulenta[b]	Downy gentian	X	X		UPL
Gentiana quinquefolia occidentalis[b]	Stiff gentian	X		Annual	FAC
Helianthus mollis	Downy sunflower		X	Clonal	UPL
Helianthus pauciflorus	Stiff sunflower		X	Clonal	UPL
Heterostipa spartea	Porcupine grass	X	X	Early summer grass	UPL
Heuchera richardsonii[b]	Prairie alum root	X	X	Spring forb	FAC−
Hypoxis hirsuta[b]	Yellow star grass	X	X	Spring forb	FAC
Krigia biflora[b]	False dandelion	X	X	Spring forb	FACU
Liatris aspera	Rough blazing star		X		UPL
Liatris pycnostachya	Prairie blazing star		X		FAC−
Lilium philadelphicum andinum	Prairie lily		X		FAC−
Lithospermum canescens[b]	Hoary puccoon	X	X	Spring forb	UPL
Lobelia spicata[b]	Pale-spike lobelia	X	X	Spring forb	FAC
Oenothera pilosella	Prairie sundrops			Spring forb	FAC−
Oxalis violacea[b]	Violet wood sorrel			Spring forb	UPL
Packera paupercula	Balsam ragwort	X	X	Spring forb	FAC+
Pedicularis canadensis	Wood betony	n/a	X	Hemi-parasite	FACU+
Phlox pilosa[b]	Prairie phlox	X	X	Spring forb	FAC+
Polygala senega[b]	Seneca snakeroot	X	X	Spring forb	FACU
Polytaenia nuttallii [b]	Prairie parsley				UPL
Rudbeckia hirta	Black-eyed Susan	X	X	Annual	FACU

Table 8. Continued.

Scientific Name	Common Name	Associate of Wood Betony[a]	Associate of False Toadflax[a]	Notes	Wetland Status[a]
Schizachyrium scoparium	Little bluestem grass	X	X	Early summer grass	FACU−
Scutellaria parvula[b]	Small skullcap		X	Spring forb	FACU
Sisyrinchium albidum[b]	Common blue-eyed grass	X	X	Spring forb	FACU
Spiranthes magnicamporum	Great Plains ladies' tresses				FAC−
Sporobolus heterolepis[b]	Prairie dropseed		X	Early summer grass	FACU-
Symphyotrichum oolentangiense	Sky-blue aster				UPL
Symphyotrichum laeve	Smooth blue aster		X		UPL
Viola pedatifida[b]	Prairie violet		X	Spring forb	FACU−
Zizia aurea	Golden Alexanders	X	X		FAC+

[a] From *Plants of the Chicago Region* by Swink and Wilhelm (1994). [b] Seeding exclusively in patches of hemiparasites.

Fermilab Natural Areas, volunteers are taking on stewardship roles in woodlands, monitoring wildlife and rare plants, and attending regular work days within the prairie plantings.

Public engagement has been an important aspect of the Fermilab prairie project. Betz presented results from the project countless times at national conferences, at group meetings, and to clubs. Fermilab is a long-standing member of the Chicago Wilderness alliance, and staff share results and information related to the prairie plantings and ecological land management methods. The Fermilab prairies are a great asset to employees, neighbors, and students. Fermilab's first director, who approved the prairie project, thought those studying the smallest particles of nature should work and be surrounded by a natural environment. Fermilab hosts educational prairie tours and talks for members of our neighboring communities, and offers miles of hiking trails and bountiful green space for the public to enjoy (MacDonald 2015). The Fermilab Lederman Science Center provides prairie science education programs to over 15,000 students per year and the annual prairie seed harvest events, going strong since 1974, still draw over 200 families, scouts, school groups, and friends.

Woodland and Oak Savanna Restoration

Twenty years ago, the Fermilab Prairie Committee transitioned to the Ecological Land Management (ELM) Committee. The purpose of the Fermilab ELM Committee is to provide sound ecological advice to the laboratory and a plan for enhancing the natural resources of the Fermilab site. This expanded role to cover all ecosystems provided an opportunity to recommend land management methods using a more comprehensive mindset. For example, Fermilab Roads and Grounds led an initiative to plant local-genotype hardwood trees and shrubs on over 46.5 ha (115 ac) of old-field, connecting 2 fragmented woodlands. Oak savannas and woodlands were degraded by legacy overgrazing and invasive species. In the past 2 decades, 3 oak savannas and 14 woodlands totaling 130 ha (320 ac) have been added to the prescribed burn program at Fermilab. Volunteer stewards have hosted work days to remove invasive woody shrubs such as bush honeysuckle (*Lonicera mackii*) and buckthorn (*Rhamnus cathartica*) and to overseed native plant species. Changes in woodland and savanna FQI as a result of burning and volunteer stewardship are encouraging (Table 10).

CONCLUSIONS

We have learned from the Fermilab prairie project that successional planting as developed and described by Dr. Robert F. Betz can work. Results after 4 decades of successional prairie restoration show that species occurrence appeared to be controlled more by whether or not a sufficient quantity of seeds were planted than if the planting was successionally "ready" to receive that species. If new areas were to be planted, several changes in methodology would be made based on information gathered during this project and advancements in prairie restoration and management throughout the Midwest. Limiting the abundance of tall grasses (e.g., *Andropogon gerardii* and *Sorghastrum nutans*) and controlling known invasive plant species from the onset would be critical because of observed dominant effects within the community. Most species would be broadcast-planted the first year with greater volumes of forb seeds from all successional stages. Targeted overseeding would be

Table 9. List of species used for overseeding in areas managed for *Phalaris arundinacea*.

Scientific Name	Common Name
Amorpha fruticosa	Indigo bush
Angelica atropurpurea	Great angelica
Asclepias incarnata	Swamp milkweed
Bolboschoenus fluviatilis	River bulrush
Carex cristatella	Crested oval sedge
Carex frankii	Bristly cattail sedge
Carex hystericina	Porcupine sedge
Carex molesta	Field oval sedge
Carex pellita	Broad-leaved woolly sedge
Carex stipata	Common fox sedge
Carex stricta	Common tussock sedge
Carex vulpinoidea	Brown fox sedge
Cephalanthus occidentalis	Buttonbush
Cicuta maculata	Water hemlock
Eleocharis erythropoda	Red-rooted spike rush
Eupatorium perfoliatum	Common boneset
Euthamia gymnospermoides	Grass-leaved goldenrod
Eutrochium maculatum	Spotted Joe Pye weed
Helenium autumnale	Sneezeweed
Juncus dudleyi	Dudley's rush
Juncus torreyi	Torrey's rush
Liatris spicata	Dense blazing star
Lycopus americanus	Common water horehound
Lysimachia ciliata	Fringed loosestrife
Mimulus ringens	Monkey flower
Monarda fistulosa	Wild bergamot
Oligoneuron riddellii	Riddell's goldenrod
Penthorum sedoides	Ditch stonecrop
Pycnanthemum virginianum	(Common) mountain mint
Rudbeckia hirta	Black-eyed Susan
Scirpus atrovirens	Dark green rush
Scirpus cyperinus	Wool grass
Scirpus pendulus	Red bulrush
Silphium integrifolium	Rosinweed
Silphium perfoliatum	Cup plant
Sium suave	Water parsnip
Symphyotrichum novae-angliae	New England aster
Verbena hastata	Blue vervain
Vernonia fasciculata	Common ironweed

prescribed as needed based on observed abundances of all species recorded during meandering transect surveys. Resources would also be dedicated to better understand the response of wildlife to the new planting methods and resultant tallgrass prairie restorations.

The Fermilab prairies were not planted in a vacuum, nor were they planted to be just showy flower gardens. The prairies exist amongst a matrix of oak woodlands, sedge meadows, marshes, and mesic forests as well as particle accelerators, research buildings, and row-crop agriculture. Rare and common wildlife species use these intermixed habitats at Fermilab. The site is an important green space for local communities and a corridor between the Fox and DuPage river watersheds and local forest preserves. Fermilab partners with regional agencies, will continue to host ecology research projects, and train students and volunteers.

The Next Decade

The next decade of work on the Fermilab site will continue to be challenging and rewarding. Prescribed burning is to remain at the forefront. We will increase control of rampant invasive species in all habitat types and continue targeted overseeding within all 25 prairie plantings. We hope to decrease *Andropogon gerardii* abundance in the prairie plantings using native hemi-parasites while creating sustainable populations of spring prairie forbs, grasses, and other rare species. We plan to connect and restore isolated remnant wetlands to core natural areas. Fermilab staff and Fermilab Natural Areas volunteers will continue to advance oak savanna and woodland stewardship. We acknowledge our limited understanding of the response of wildlife to restoration efforts and plan to collect a greater amount of scientific data overall to guide our adaptive approach to the management of ecosystems at Fermilab.

ACKNOWLEDGMENTS

This work would not have been possible without the foresight, enthusiasm, and dedication of Dr. Robert F. Betz. Bob helped us all catch "prairie fever," for which the only known cure was to see more prairie. The authors would also like to thank Fermilab management and staff, especially the Roads and Grounds crew charged with implementing the prairie project since its inception. Special thanks go to Bob Lootens, Mike Becker, Dave Shemanske, Martin Valenzuela, Robert Wilson, Rod Walton, and everyone on the early Fermilab Prairie Committee, now the Fermilab Ecological Land Management Committee, as well as the thousands of volunteers and students who have helped over the years. We also thank the reviewers of this manuscript, especially Roger C. Anderson.

Figure 4. Invasive species GIS layer over aerial image of Fermilab.

Table 10. Floristic quality index of select Fermilab savannas and woodlands over time using a 10-y dataset.

Land management unit	Ha	Acres	2007	2008	2009	2010	2011	2012	2013	2014	2015
Indian Creek Woods	18.6	46					43	65	68	70	71
Big Woods South	4.5	11						52	56	62	66
Big Woods	31.6	78	34	38	37	47	56	60	63	65	65
MR Savanna	11.7	29	38	45	48	49	49	52	53	53	57
Morgan's Woods	4.5	11		27	27	40	42	47	47	53	55
Site 29 Woods West	14.2	35						31	31	47	47
Big Woods North	5.7	14					32	41	47	49	49
Owl's Nest Woods	1.2	3						28	32	44	48
Site 29 Woods East	2.0	5		18	18	26	30	40	43	46	46
Ed Center Woods	3.2	8					28	40	44	46	46
Kingnut Woods	3.2	8							12	24	29
Bison Savanna	6.9	17						16	24	34	34
Giese Woods	7.7	19									33
LBNF Woods	4.9	12									21

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Submitted 00 Month 201X. Accepted 00 Month 2018.

Queries for napc-24-01-04

1. Author: Please add scientific name of bur oak. Copy editor
2. Author: Please provide common names at first mention of each species if necessary. Copy editor
3. Author: Please add common names for *Symphyotricum drummondii* and *Solidago nemoralis*. Copy editor
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11. Author: If possible, please turn note at end of Table 5 into a footnote with superscript a as a designator in the appropriate places in table. Copy editor
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