3-1-1998

Comparison of Seeding and Sod-Transplant Methods for Restoring Tallgrass Prairie in Southeastern Nebraska.

Gary P. Sullivan

Comparison of Seeding and Sod-Transplant Methods for Restoring Tallgrass Prairie in Southeastern Nebraska

A Thesis

Presented to the

Department of Biology

and the

Faculty of the Graduate College

University of Nebraska

In Partial Fulfillment

of the Requirements for the Degree

Master of Arts

University of Nebraska at Omaha

by

Gary P. Sullivan

March 1998

THESIS ACCEPTANCE

Acceptance for the faculty of the Graduate College, University of Nebraska, in partial fulfillment of the requirements for the degree Master of Arts, University of Nebraska at Omaha.

Committee

Name	Department/School
David M. Sutherland	Biology
Jeffrey A. Peake	Geography - Geology

Chairperson Thomas B. Bragg

Date 22 April 1998

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Acknowledgments

I would like to thank the National Park Service and the University of Nebraska Foundation for providing access to the study locations. I also thank Dr. Tom Bragg who was very patient and supportive throughout the process. Without his support, guidance, and patience, this project would not have been completed. Dr. David Sutherland provided a great deal of help with the identification of difficult plant specimens and I thank him. I am continually amazed by the breadth of his knowledge of the flora of the Plains. I also, wish to thank Dr. James Stubbendieck for providing access to Nine-Mile Prairie and to Ernest Rousek for both his recollections on the management history of that site and his early efforts at preserving this unique resource.

My supervisors Ron Hiebert, and Steve Cinnamon, were also very helpful in providing financial, emotional, and technical support and I thank them. The late Randy Baynes was a key factor in my decision to undertake this project; he will always be fondly remembered.

Finally, I wish to thank my family, especially my wife Marcia and my son and daughter, for their understanding, devotion, and support

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Abstract

Data were collected in Fall, 1993 from a 55-year-old re-established grassland to determine the degree of success of seeding and sodding in re-establishing native prairie species. Species Richness of native species was highest in one seeded re-established site (S = 44), but lowest in a second re-established site (S = 23). Species Richness was second highest at the native site (S = 42). There was a significant difference ($P \leq 0.05$) in Species Diversity between the one seeded and the native treatments. The high diversity in re-established treatments is consistent with that expected of the Intermediate-Disturbance-Hypothesis suggesting the seral nature of the re-established sites. Of the 69 species recorded, 13 occurred in all treatment areas: Seven native grasses (*Andropogon gerardii*, *Andropogon scoparius*, *Bouteloua curtipendula*, *Dichanthelium oligosanthes* var. *scribnerianum*, *Eragrostis spectabilis*, *Panicum virgatum*, and *Sorghastrum nutans*), four native forbs (*Achillea millefolium*, *Ambrosia psilostachya*, *Asclepias verticillata*, and *Rosa arkansana*), and two exotic grass *species* (*Bromus inermis* and *Poa pratensis*). The high proportions of woody (e.g. *Rhus glabra*, *Cornus drummondii*, and *Symphoricarpos orbiculatus*) and non-woody species, particularly *Bromus inermis*, emphasize the concern for appropriate management to minimize the impact of these species on either re-established or native sites. This study indicates that efforts to re-establish native tallgrass prairie, whether they include seeding or sodding, can be successful for at least some of the dominant species. However, successful re-establishment of the diversity of uncommon vascular plants cannot be concluded from the results of this study. Thus, preservation of extant grassland ecosystems remains the best means by which to ensure their preservation.

Introduction

Of the original 58 million ha of tallgrass prairie (*Andropogon-Panicum-Sorghastrum*) (Küchler 1985), an estimated 90% have been destroyed (Madison 1990) with the remainder occurring mostly in small fragments (Klopatek *et al.* 1979). West of the Missouri River, an average of 85% of the original prairie has been lost. In Nebraska the loss exceeds 97% (Noss *et al.* 1995). This substantial decline in the extent of the tallgrass prairie ecosystem may have been the driving force behind the creation of the field of ecological restoration (Jordan *et al.* 1987) and has made restoration an attractive conservation tool (Ewel 1987, Fahselt 1988). Restoration efforts, however, give the erroneous impression that natural ecosystems can be re-created thereby softening the decision to destroy natural areas or deplete their resources, such as using sod-transplants in restoration efforts (Fahselt 1988). Re-establishment of some of the original native vegetation can be relatively easy to accomplish and may serve to protect against soil erosion, provide sites at which to preserve gene pools of selected species, and provide visual approximations of historic landscapes. However, in the case of the tallgrass prairie, the re-establishment of some species can restore none of the functions of a natural prairie (Fahselt 1988) nor the genetic diversity of historic populations. Sperry (1983) quoted J.E. Weaver, the noted prairie ecologist, as saying that a prairie, once destroyed, will require a thousand years to be restored. It seems unlikely that restoration efforts can significantly shorten this process.

Despite its less-than-desirable consequences, prairie re-establishment is a process that has grown increasingly more common. Re-establishing native prairie vegetation at a site can be accomplished in many ways of which three are relevant to the present study: (1) transplanting sod from existing prairies, (2) introducing seeds collected from local prairies, and (3) using prairie hay as a mulch and seed source.

Transplanting prairie sod can successfully be accomplished by digging up sod pieces approximately shovel-width (30 X 30 cm) and depth (25 cm), whether centered on a particular plant or not (Bragg 1988). One of the advantages of transplanting sod is that, along with plants, mychorrizal fungi, seeds, insects, and rhizobia bacteria are introduced into a new site (Monro 1994, Kearns 1986). Plants successfully transplanted can then move from the transplanted sod into an adjacent re-established grassland (Clarke and Bragg 1994). Transplanting prairie, however, is costly, labor intensive, and destroys donor sites which may explain why use of this technique is uncommon.

In contrast to sod transplants, the use of locally collected seeds whether broadcast, drilled, or incorporated in broadcast prairie hay, have the advantage of not excessively disturbing native sites as well as being both less expensive and relatively less labor-intensive. Machine collections, such as combining can rapidly collect a wide variety of seeds but it is difficult to collect sufficient quantities of less dominant species (Whitney 1997). Olson (1986), for example, reports that seeds combined from prairies in Minnesota and South Dakota contained up to 37 native species. For many species and situations, however, hand-collection remains the only practical solution (Whitney 1997). The use of locally harvested seeds is an important consideration since resulting plants are more adapted to local conditions, such as photoperiod, which ultimately influences winter hardiness (Olson 1986).

The methods available for introducing seeds in grassland re-establishment have various degrees of success (e.g. see Bragg 1988, Whitney 1997). The success of grassland re-establishment has been evaluated by comparing plant species composition of re-established sites with that of native sites (Cottam and Wilson 1966, Anderson and Cottam 1968, Kindscher 1994). One result of such studies is that plant composition of re-established stands of tallgrass prairie differs substantially from native stands as many as 25-35 years after planting, even though evidence suggests some development towards a more native composition. Not surprisingly, the component of non-prairie species in these studies was greater in re-established sites than in native sites.

Among the various techniques used to re-establish prairie vegetation, studies are few and results are contradictory. For example, Thomson (1937) found sod transplants to yield better results than seeding. However, Blewett (1981), summarizing the unpublished work of the Madison Arboretum Botanist, David Archbald, found these procedures to yield similar results, although the sod transplants did result in a slightly greater number of species. My study was conducted in light of this scarcity of information. Specifically, the objective of this study was to assess the success in re-establishing native prairie plants using (1) seeding and (2) seeding in combination with sod transplants.

Methods

Study Sites.

The study was conducted at two sites in southeastern Nebraska, a 38 ha (92 acre) re-established grassland situated at Homestead National Monument of America (Homestead) in Gage County (latitude 40°17'30", longitude 96°50'38"), and Nine-Mile Prairie (Nine-Mile), a 95 ha (230 acre) native prairie in Lancaster County (latitude 40°52'07", longitude 96°49'37") (Fig. 1) located approximately 75 km to the north of Homestead.

Homestead National Monument of America

Homestead is managed by the U.S. Department of Interior, National Park Service (NPS). The present grassland areas at the monument were re-established in 1939 by seeding using locally collected, native grasses and forbs. This project, like the prairie restoration at Madison, Wisconsin, the first known attempt at such a restoration, used Civilian Conservation Corps labor (Sperry 1983; Sutton *et al.* 1984; Stubbendieck and Willson 1987). In addition to seeding, native sod was transplanted from a nearby prairie during the first year in order to stabilize highly eroded areas. These initial efforts were followed in 1942 by seeding and sodding

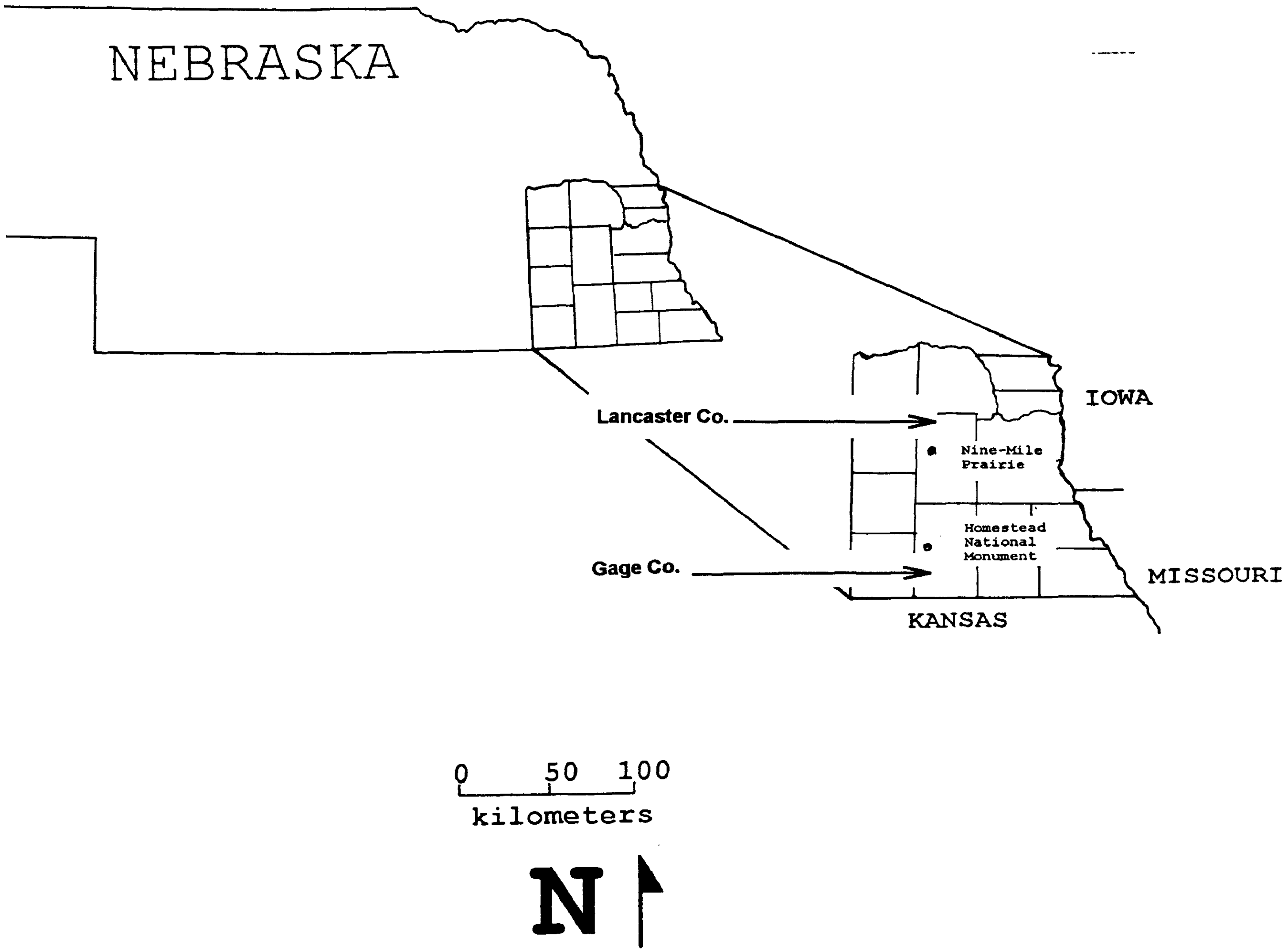


Fig. 1. Study Site Locations in southeastern Nebraska

some portions. In 1947, other portions were seeded, covered with prairie hay, and sodded. In 1948 still other areas were spot-seeded and sodded (Stubbendieck and Willson 1987). No parts of any of these re-established areas have been grazed or mowed since 1978 although, since 1983, they have all been burned approximately every other year. The most recent burn occurring before the study period, was in the spring of 1991 (Appendix Table 1).

From within the re-established grassland areas at Homestead, three different treatment areas were identified using photographs taken during the project, written records, and visual evidence, such as markedly different strips of vegetation transecting highly erodable drainages. These treatment areas are (1) *Sodded*, an area re-established by a combination of seeding and sodding on a 8-18 % slope of severely eroded clay loam soil (Morrill soil series), (2) *Seeded-1*, re-established by seed scattering only, on the same soil and condition as the sodded treatment, and (3) *Seeded-2*, also re-established by seed scattering but on a silty clay loam soil on a 5-8 % slope (Geary soil series) (Table 1). The Morrill soil is a fine-loamy, mixed, mesic Typic Argiudoll of the Mollisol soil order that typically forms under prairie vegetation of mid- and tallgrass prairies. The Geary silty clay loam is a mesic Udic Argiustoll also of the Mollisol soil order (Beesley *et al.* 1964). No replicate sites were available for these treatments. The absence of replicate sites was an obvious weakness in the design of this study. However, no other efforts to re-establish grasslands using these techniques were found anywhere in the region at or since 1939. Rather than ignore this opportunity simply because of the lack of replication, I felt it important to assess the success of this particular re-establishment but caution against how far to extrapolate from my results. In this way, site-specific success could be measured as could the possibility of success from such procedures at other locations in the general region.

Climate for the region is typified by hot summers and cool winters. In 1993, the year of the study, temperatures averaged 9.3° C (48.7° F) and ranged from 37° C (98° F) to -22° C (-7° F). Monthly precipitation totals for April through September 1993 averaged 15 cm (6 in) with a total accumulation for the year of 90 cm (35 in) (U.S. Department of Commerce 1993). Most

Table 1. Treatment area attributes. Soil descriptions are from Beesley *et al.* (1964) and Brown *et al.* (1980).

SITE ATTRIBUTE	TREATMENT AREAS			
		RE-ESTABLISHED		
	NATIVE	SEEDED		SODDED
		1	2	
Aspect (°)	307 (NW)	345 (NW)	324 (NW)	330 (NW)
Slope (%)	6.5	5.0	5.5	5.5
Soil Type	Steinauer loam	Geary silty clay loam	Morrill clay loam	Morrill clay loam
Elevation (m)	396	396	396	396

precipitation occurs during the growing season. These were unusual conditions representing the highest mean annual precipitation and the lowest mean annual temperature on record (U.S. Department of Commerce 1993).

Nine-Mile Prairie.

Nine-Mile Prairie, the site against which the success of re-establishment was measured, is the closest native prairie to Homestead that has a similar management history. This site is owned by the University of Nebraska Foundation and managed by the University of Nebraska-Lincoln. Aerial photographs from the 1950's show numerous cattle paths and a general heavily-grazed condition. In 1978, however, the prairie appeared only lightly grazed. Evidence of aerial and tractor spraying with a broad leaf herbicide was recorded in 1978. From 1978-1981 the entire prairie was hayed. Since 1983, approximately one-third of the prairie has been burned each year (Rousek, E. 1995. personal communication). The most recent burn before the study period occurred in the spring of 1992 (Stubbendieck, J. 1995. personal communication). From within the Nine-Mile site, a control area was identified that was located so as to most closely approximate the management history and topography of the Homestead treatment areas. This area, designated Native, was situated on a loam soil (Steinauer soil series) with an 11-30 percent slope. Steinauer soils are mesic Typic Udorthents of the Mollisol soil order. (Brown *et al.* 1980). Climate for Nine-Mile is essentially the same as that for Homestead (U.S. Department of Commerce 1993).

Methods.

This study measures the success of two different grassland re-establishment techniques used at Homestead by comparing their present plant composition both with that of each other and with that of Nine-Mile prairie, a nearby native site. Treatment areas were (1) *Sodded*, (2) *Seeded-1,* and *Seeded 2*, the difference between these two being soil type, and (3) *Native*. Sampling procedures were the same for all treatment areas.

Plant Composition.

Vegetative evaluations were conducted from August 30 through September 19, 1993. Plant composition within each treatment area was assessed using thirty, 30 X 50 cm sub-plots randomly located within each of four, 10 X 10 m plots that were randomly situated along a 100-meter-long transect centrally located in each of the 4 treatment areas (Appendix Fig. 1). The transect was located at the 396 m topographic contour interval in all treatment areas.

Within each 30 X 50 cm sub-plot, plant species composition was sampled by estimating canopy cover for all species. Canopy cover categories were, 0%, <1%, 1-5%, 5-25%, 25-50%, 50-75%, 75-95%, 95-99%, and > 99%, (modified from Daubenmire 1959). Species identification is based on Great Plains Flora Association (1986). With the exception of *Carex* species, which were considered native, plants that could not be identified to species were excluded from comparisons. Designation of species as exotics or native was based on the National List of Scientific Plant Names (U.S. Department of Agriculture 1982).

The Shannon-Wiener Index of Diversity (H') was used to test for significant differences between each possible pair-wise combination of treatments (Zar 1984). While this procedure is not the most appropriate means by which to assess differences among treatments, neither multivariate tests nor multiple comparison tests appear to be available to make such comparisons between Shannon-Wiener diversity values. Inferences from these results, then, were limited to prevent making unwarranted conclusions.

In addition to differences in diversity, treatment effects were tested by species using a ONE-WAY ANOVA Scheffee procedure (Zar 1984, Hedderson and Fisher 1993). The parametric ANOVA test was determined to be appropriate based on histograms of each species which, for all cases tested, were normally distributed.

Results

Individual Species Occurrences.

Sixty-nine plant species were identified during the study, of which 5 were exotics and 4 were native, but non-prairie, woody species (Table 2). Of the 57 native, herbaceous plant species, 7 were found only in the native prairie and 21 only in re-established treatments. Of species found only in the native prairie, the most frequent were *Conyza canadensis,* an annual, rudual species that may persist due to timing of mowing and burning (3% cover, 37% frequency), *Gaura longiflora* (5% cover, 17% frequency), and *Heliopsis helianthoides* var. *scabra* (2% cover, 9% frequency) (Table 2). Exotic species, most notably *Bromus inermis* (12% cover, 86% frequency) and *Poa pratensis* (2% cover, 62% frequency), were both most frequent and highest in cover in the native prairie. Of these *Bromus inermis* was significantly lower ($P \leq 0.05$) in the re-established areas. *Symphoricarpos orbiculatus* an invasive woody species (2.7% cover, 14% frequency), *Solidago rigida* (0.7% cover, 10% frequency), *Cornus drummondii*, another invasive woody species, (1.4% cover, 5% frequency), and *Muhlenbergia racemosa* (0.3% cover, 5% frequency) were found only at Seeded treatment areas. *Dalea purpurea* (0.4% cover, 4% frequency), *Agalinis tenuifolia* (0.5 % cover, 3% frequency), and the woody invader *Prunus virginiana* (1% cover, 2% frequency) were found only at sodded sites (Table 2).

Table 2. Mean percent canopy cover % and frequency (number out of 120 total possible occurrences) for all species. Asterix (*) = exotic species, tr = < 5%. When alphabetic characters are not shown, no significant differences (P < 0.05) occurred between treatments. Where alphabetic superscripts are shown, those with different characters differ significantly between the treatments for that species.

Scientific Name	TREATMENT							
	Native		Seeded-1		Seeded-2		Sodded	
	Cover ± SE	Freq.	Cover ± SE	Freq.	Cover ± SE	Freq.	Cover ± SE	Freq.
Achillea millefolium	tr ± 0.0	1	tr ± 0.1	6	tr ± 0.0	3	tr ± 0.0	1
Agalinis tenuifolia	0 ± 0.0	0	0 ± 0.0	0	0 ± 0.0	0	tr ± 0.1	3
Ambrosia psilostachya	tr^{D} ± 0.6	27	tr^{B} ± 0.3	36	tr^{A} ± 0.2	25	tr^{C} ± 0.2	29
Amorpha canescens	tr^{A} ± 0.6	43	0^{A} ± 0.0	0	tr^{B} ± 0.8	35	8^{C} ± 1.2	88
Andropogon gerardii	20^{B} ± 2.1	63	28^{B} ± 2.3	84	12^{A} ± 1.5	50	20^{B} ± 1.9	77
Andropogon scoparius	15^{A} ± 2.1	53	30^{B} ± 2.4	84	30^{B} ± 2.6	70	23^{AB} ± 2.2	65
Antennaria neglecta	0^{A} ± 0.0	0	tr^{A} ± 0.0	2	tr^{AB} ± 0.2	18	tr^{B} ± 0.3	19
Apocynum cannabinum	0 ± 0.0	0	tr ± 0.0	3	tr ± 0.0	1	tr ± 0.3	1
Artemisia ludoviciana	tr ± 0.1	2	0 ± 0.0	0	0 ± 0.0	0	tr ± 0.1	6
Asclepias sullivantii	0 ± 0.0	0	0 ± 0.0	0	0 ± 0.0	0	tr ± 0.1	1
Asclepias syriaca	tr ± 0.1	2	0 ± 0.0	0	0 ± 0.0	0	0 ± 0.0	0
Asclepias tuberosa	tr ± 0.1	1	0 ± 0.0	0	0 ± 0.0	0	0 ± 0.0	0
Asclepias verticillata	tr ± 0.0	6	tr ± 0.0	8	tr ± 0.0	8	tr ± 0.0	2
Aster ericoides	0^{A} ± 0.0	0	8^{B} ± 1.0	67	tr^{A} ± 0.5	48	13^{C} ± 1.3	73
Bouteloua curtipendula	tr^{AB} ± 0.4	26	tr^{AB} ± 0.3	23	tr^{A} ± 0.1	19	tr^{B} ± 0.7	38
Bromus inermis *	12^{B} ± 1.2	86	tr^{A} ± 0.0	1	tr^{A} ± 0.0	6	tr^{A} ± 0.0	2

Scientific Name	TREATMENT							
	Native		Seeded-1		Seeded-2		Sodded	
	Cover ± SE	Freq.	Cover ± SE	Freq.	Cover ± SE	Freq.	Cover ± SE	Freq.
Carduus nutans subsp. leiophyllus *	0 ± 0.0	0	0 ± 0.0	0	tr ± 0.0	2	0 ± 0.0	0
Carex species	tr^{A} ± 0.1	17	tr^{A} ± 0.1	5	tr^{AB} ± 0.3	33	tr^{B} ± 0.5	36
Cassia chamaecrista	0^{A} ± 0.0	0	0^{A} ± 0.0	0	tr^{B} ± 0.8	45	tr^{A} ± 0.0	1
Ceanothus Americanus var. pitcheri	tr ± 0.3	1	0 ± 0.0	0	0 ± 0.0	0	0 ± 0.0	0
Chenopodium album *	0 ± 0.0	0	0 ± 0.0	0	0 ± 0.0	0	tr ± 0.0	1
Convolvulus arvensis *	tr ± 0.0	3	0 ± 0.0	0	0 ± 0.0	0	0 ± 0.0	0
Conyza canadensis	tr ± 0.6	37	0 ± 0.0	0	0 ± 0.0	0	0 ± 0.0	0
Cornus drummondii	0^{A} ± 0.0	0	0^{A} ± 0.0	0	tr^{B} ± 0.7	5	0^{A} ± 0.0	0
Dalea candida	tr^{B} ± 0.3	7	0^{A} ± 0.0	0	tr^{AB} ± 0.0	13	tr^{A} ± 0.0	1
Dalea purpurea	0 ± 0.0	0	0 ± 0.0	0	0 ± 0.0	0	tr ± 0.2	4
Desmodium illinoense	tr ± 0.1	2	tr ± 0.1	3	0 ± 0.0	0	tr ± 0.1	6
Dichanthelium oligosanthes var. scribnerianum	tr ± 0.2	43	tr ± 0.3	45	tr ± 0.1	68	tr ± 0.2	68
Elymus canadensis	0 ± 0.0	0	0 ± 0.0	0	tr ± 0.0	3	tr ± 0.0	1
Eragrostis spectabilis	tr ± 0.1	1	tr ± 0.1	3	tr ± 0.1	1	tr ± 0.2	2
Erigeron strigosus	0^{A} ± 0.0	0	tr^{B} ± 0.1	18	tr^{AB} ± 0.0	13	tr^{AB} ± 0.0	8
Euthamia gymnospermoides	0 ± 0.0	0	tr ± 0.3	18	0 ± 0.0	0	0 ± 0.0	0
Gaura longiflora	tr^{B} ± 1.2	17	0^{A} ± 0.0	0	0^{A} ± 0.0	0	0^{A} ± 0.0	0
Gentiana puberulenta	0 ± 0.0	0	0 ± 0.0	0	tr ± 0.0	1	0 ± 0.0	0
Helianthus rigidus	tr^{A} ± 0.8	18	0^{A} ± 0.0	0	15^{B} ± 1.4	76	0^{A} ± 0.0	0

Scientific Name	TREATMENT							
	Native		Seeded-1		Seeded-2		Sodded	
	Cover ± SE	Freq.	Cover ± SE	Freq.	Cover ± SE	Freq.	Cover ± SE	Freq.
Heliopsis helianthoides var. scabra	tr ^{B} ± 0.7	9	0 ^{A} ± 0.0	0	0 ^{A} ± 0.0	0	0 ^{A} ± 0.0	0
Hieracium longipilum	0 ^{A} ± 0.0	0	tr ^{B} ± 0.2	12	tr ^{AB} ± 0.0	4	0 ^{A} ± 0.0	0
Koeleria pyramidata	0 ± 0.0	0	0 ± 0.0	0	tr ± 0.0	3	0 ± 0.0	0
Kuhnia eupatorioides var. corymbulosa	tr ^{A} ± 0.3	2	0 ^{A} ± 0.0	0	tr ^{B} ± 0.5	57	tr ^{A} ± 0.1	15
Lactuca species	tr ± 0.4	3	tr ± 0.0	2	0 ± 0.0	0	0 ± 0.0	0
Lespedeza capitata	tr ± 0.3	3	0 ± 0.0	0	tr ± 0.3	13	0 ± 0.0	0
Linum sulcatum	tr ± 0.0	3	0 ± 0.0	0	tr ± 0.0	3	tr ± 0.0	5
Lithospermum species	0 ± 0.0	0	tr ± 0.0	2	0 ± 0.0	0	0 ± 0.0	0
Lotus purshianus	0 ± 0.0	0	0 ± 0.0	0	tr ± 0.1	6	tr ± 0.0	3
Muhlenbergia racemosa	0 ± 0.0	0	0 ± 0.0	0	tr ± 0.2	5	0 ± 0.0	0
Oenothera biennis	6 ^{B} ± 1.0	36	tr ^{A} ± 0.0	3	tr ^{A} ± 0.0	7	0 ^{A} ± 0.0	0
Oxalis dillenii	tr ± 0.0	1	tr ± 0.0	5	tr ± 0.0	3	tr ± 0.0	3
Panicum virgatum	tr ± 0.9	6	tr ± 0.7	12	tr ± 0.3	25	tr ± 0.6	18
Physalis pubescens	tr ^{B} ± 0.4	7	0 ^{A} ± 0.0	0	0 ^{A} ± 0.0	0	0 ^{A} ± 0.0	0
Physalis species	tr ± 0.0	1	0 ± 0.0	0	0 ± 0.0	0	0 ± 0.0	0
Physalis virginiana	tr ^{B} ± 0.0	5	0 ^{A} ± 0.0	0	tr ^{AB} ± 0.0	3	tr ^{A} ± 0.0	1
Poa pratensis *	tr ^{B} ± 0.5	62	tr ^{A} ± 0.1	53	tr ^{A} ± 0.1	29	tr ^{AB} ± 0.2	61
Prunus virginiana	0 ± 0.0	0	0 ± 0.0	0	0 ± 0.0	0	tr ± 0.4	2
Rhus glabra	tr ^{B} ± 0.8	6	tr ^{A} ± 0.1	2	0 ^{A} ± 0.0	0	0 ^{A} ± 0.0	0
Rosa arkansana	tr ^{B} ± 1.1	15	tr ^{A} ± 0.0	10	tr ^{A} ± 0.1	13	tr ^{B} ± 0.8	33
Senecio plattensis	0 ^{A} ± 0.0	0	0 ^{A} ± 0.0	0	tr ^{B} ± 0.0	9	tr ^{A} ± 0.0	6

Scientific Name	TREATMENT							
	Native		Seeded-1		Seeded-2		Sodded	
	Cover ± SE	Freq.	Cover ± SE	Freq.	Cover ± SE	Freq.	Cover ± SE	Freq.
Sisyrinchium campestre	0 ± 0.0	0	0 ± 0.0	0	tr ± 0.0	1	0 ± 0.0	0
Solidago missouriensis	0 ^{A} ± 0.0	0	tr ^{A} ± 0.0	9	tr ^{B} ± 0.5	43	tr ^{A} ± 0.0	3
Solidago rigida	0 ± 0.0	0	0 ± 0.0	0	tr ± 0.4	10	0 ± 0.0	0
Sorghastrum nutans	11 ^{B} ± 1.9	39	9 ^{B} ± 1.4	61	7 ^{AB} ± 0.9	58	tr ^{A} ± 0.6	30
Sporoblous asper	tr ^{A} ± 0.9	9	0 ^{A} ± 0.0	0	0 ^{A} ± 0.0	0	6 ^{B} ± 1.4	18
Sporobolus cryptandrus	0 ± 0.0	0	0 ± 0.0	0	tr ± 0.0	1	0 ± 0.0	0
Stipa comata	tr ^{B} ± 0.2	10	0 ^{A} ± 0.0	0	tr ^{A} ± 0.0	2	tr ^{AB} ± 0.0	6
Symphoricarpos orbiculatus	0 ^{A} ± 0.0	0	0 ^{A} ± 0.0	0	tr ^{B} ± 1.1	14	0 ^{A} ± 0.0	0
Teucrium canadense	tr ± 0.0	1	0 ± 0.0	0	0 ± 0.0	0	0 ± 0.0	0
Ulmus species	tr ± 0.0	1	0 ± 0.0	0	0 ± 0.0	0	0 ± 0.0	0
Unidentifiable forb	0 ± 0.0	0	tr ± 0.0	1	0 ± 0.0	0	tr ± 0.0	2
Vernonia baldwinii	0 ± 0.0	0	0 ± 0.0	0	tr ± 0.0	2	tr ± 0.1	2
Viola pedatifida	tr ± 0.0	2	0 ± 0.0	0	0 ± 0.0	0	tr ± 0.0	4
Viola species	tr ± 0.0	1	0 ± 0.0	0	0 ± 0.0	0	0 ± 0.0	0
Forb	30 ^{BC}	93	12 ^{A}	94	36 ^{C}	99	28 ^{B}	98
Grass/grass like	63 ^{B}	100	74 ^{C}	100	53 ^{A}	100	61 ^{B}	100
Woody	2 ^{AB}	7	0 ^{A}	2	4 ^{B}	18	1 ^{A}	2
Total	95		86		93		90	

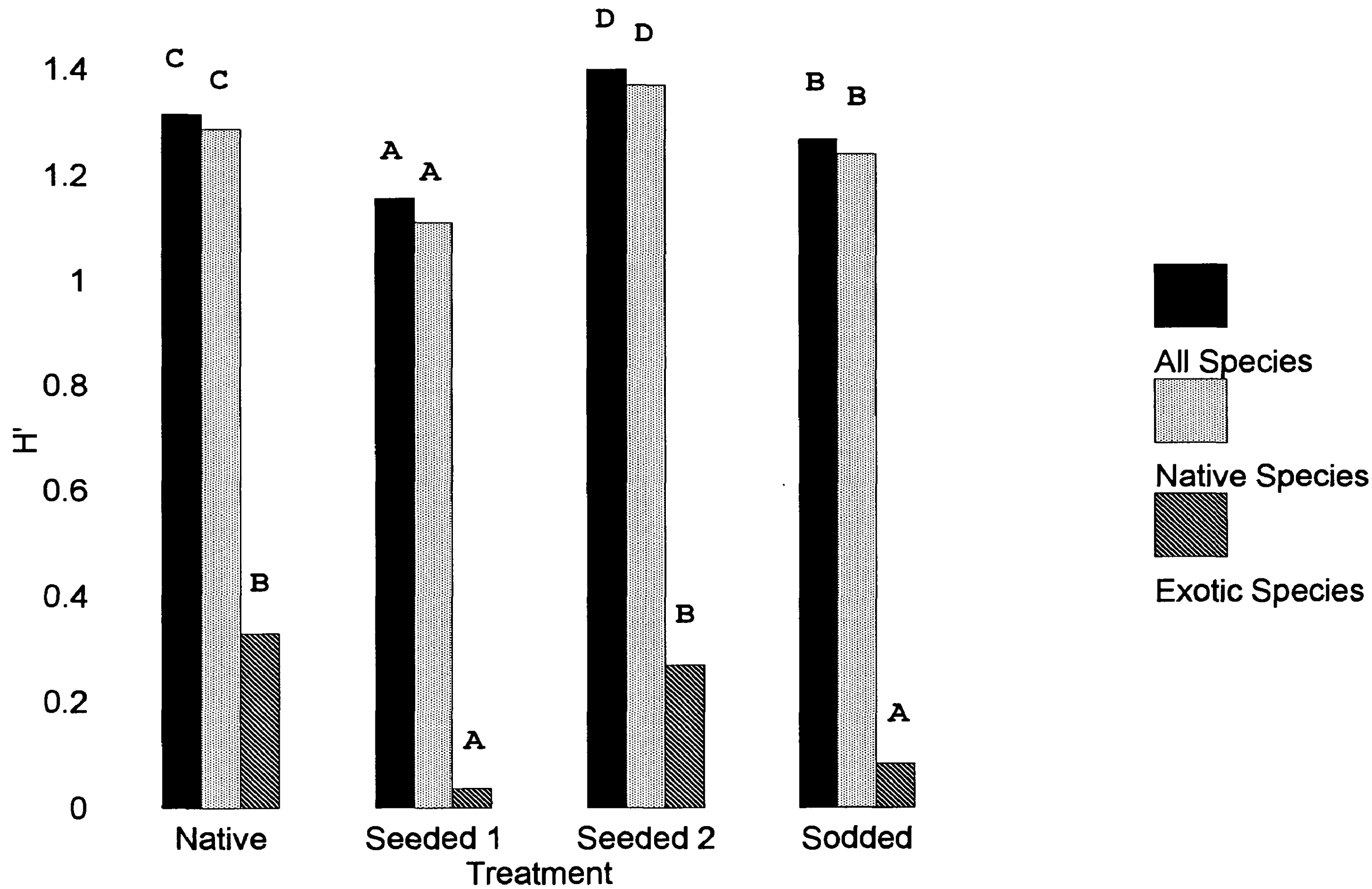
Species Diversity.

Considering all species, native and exotic the *Seeded-2* treatment area was found to be most diverse for both all species and for native prairie species based on both species richness (S = 44 and S = 41 respectively) and species equitability ($H' = 1.40$ and $H' = 1.37$ respectively) (Tables 3 and 4). For native plant species, the difference was significant ($P \leq 0.05$) (Table 5 and Fig. 2). For forb diversity alone ($H' = 1.13$ and $H' = 1.18$) and for exotic species diversity alone ($H' = 0.33$ and $H' = 0.27$), the *Native* and *Seeded-2* treatments did not differ significantly ($P \leq 0.05$). Although, the *Native* treatment had the highest Species Richness for forbs (S = 28), no significant difference ($P \leq 0.05$) was found when comparing this treatment with *Seeded-2* for forb and grass diversity (Fig. 3). In contrast to the high diversity of the *Seeded-2* plots, the *Seeded-1* plots were the lowest in both total diversity ($H' = 1.15$) and native plant diversity ($H' = 1.11$) of all treatments (Table 4).

Table 3. Species Richness by species groups and treatment.

SPECIES GROUP	NATIVE	SEEDED 1	SEEDED 2	SODDED
		TREATMENT AREAS		
		RE-ESTABLISHED		
Native	34	23	41	37
Exotic	3	2	3	3
Forb	28	16	26	27
Grass	12	10	16	13
Woody	2	1	2	0
All Species	42	27	44	39

Fig. 2. Shannon-Wiener Diversity Indices (H') for all species combined, native, and exotic categories by treatment. Bars capped with different alphabetic symbols indicate significant differences between treatments that were based on logical comparisons of treatment-by-treatment tests of Shannon-Wiener diversity indices (Table 5).



1.4
1.2
1
0.8
0.6
0.4
0.2
0
H'
C
C
B
A
A
A
D
D
B
B
B
A
Native
Seeded 1
Seeded 2
Sodded
Treatment
All Species
Native Species
Exotic Species

Fig. 3. Shannon-Wiener Diversity Indices (H') for forb, grass, and woody species categories by treatment. Bars capped with different alphabetic symbols indicate significant differences between treatments that were based on logical comparisons of treatment-by-treatment tests of Shannon-Wiener diversity indices (Table 5).

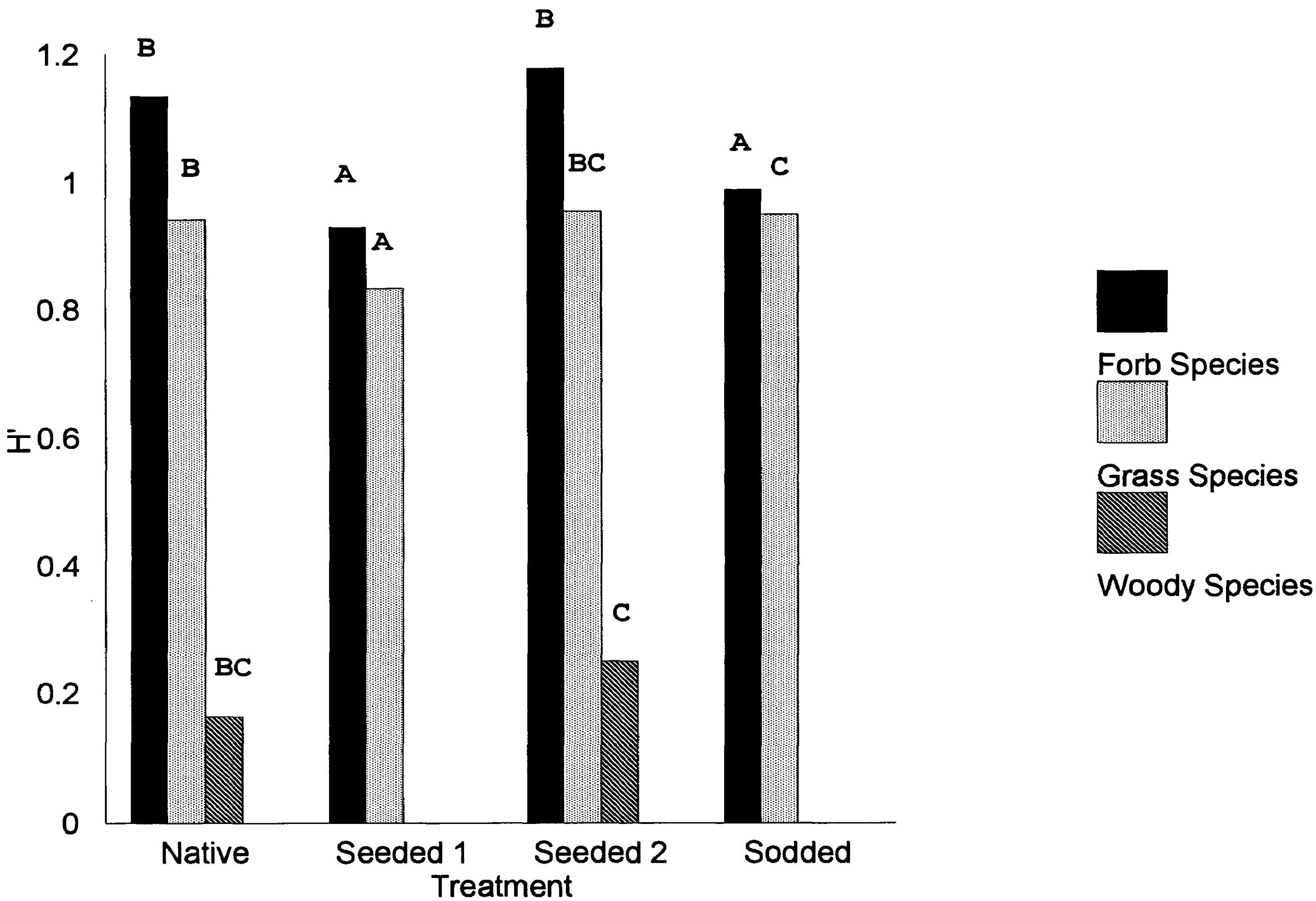

1.2
1
0.8
H' 0.6
0.4
0.2
0
B
B
BC
A
A
B
BC
C
A
C
Native
Seeded 1
Seeded 2
Sodded
Treatment
Forb Species
Grass Species
Woody Species

Table 4. Species diversity (Shannon-Wiener H') by species group and treatment area.

SITE ATTRIBUTE	TREATMENT AREAS			
		RE-ESTABLISHED		
	NATIVE	SEEDED		SODDED
		1	2	
Native	1.28	1.11	1.37	1.24
Exotic	0.33	0.03	0.27	0.08
Forb	1.13	0.93	1.18	0.99
Grass	0.94	0.83	0.95	0.95
Woody	0.16	0.00	0.25	0.00
All Species	1.31	1.15	1.40	1.26

Table 5. Pair-wise test of significant differences between diversity indices for native species. The Shannon-Wiener Index of Diversity (H') was used to test for significant differences between each possible pair-wise combination of treatments (Zar 1984).

PAIR-WISE COMBINATION	t TEST RESULTS
NATIVE vs. SEEDED-1	$t_{0.05(2),\,1232} = 1.1$ E -15 $P \leq 0.05$, therefore indices not the same
NATIVE vs. SEEDED-2	$t_{0.05(2),\,1287} = 1$ E -05 $P \leq 0.05$, therefore indices not the same
NATIVE vs. SODDED	$t_{0.05(2),\,1382} = 0$ $P \leq 0.05$, therefore indices not the same
SEEDED-1 vs. SEEDED-2	$t_{0.05(2),\,1242} = 0$ $P \leq 0.05$, therefore indices not the same
SEEDED-1 vs. SODDED	$t_{0.05(2),\,1359} = 1.7$ E -09 $P \leq 0.05$, therefore indices not the same
SEEDED-2 vs. SODDED	$t_{0.05(2),\,1625} = 5.2$ E -12 $P \leq 0.05$, therefore indices not the same

Discussion

Each of the three methods evaluated in this study showed some degree of success in re-establishing native prairie plants and vascular plant diversity to a previously cultivated site. Differences between successful methods, while inconclusive because of the unavailability of replicate sites, provide some more information than has been previously documented. However, they serve primarily as a basis for the conduct of additional, more controlled, studies on the means by which to re-establish tallgrass prairie throughout the geographic range of this ecosystem.

The absence of consistent, significant differences in species diversity between the sodded site and both seeded sites suggests that either process may be equally likely to succeed. In the present study, sodding was successful in re-establishing some native plant diversity although opposing results for *Seeded-1* (sodding better than seeding) and *Seeded-2* (seeding better than sodding), do not indicate whether one technique or the other is best. As with the present study, Bragg (1986) found that sodding was successful at re-establishing some prairie species (8 forbs) to a previously cultivated area although his results did not indicate the degree to which the native prairie diversity was approximated. One advantage of sodding, however, is the likely introduction of soil organisms which would not occur with seeding. This aspect of prairie restoration was not a component of my study but, due to its potential significance, should be the focus of additional research.

Differences, such as soil, may effect the degree of success of seeding, a consequence suggested in my study. Blewett (1981), for example, found that species occurrences in restorations were related to soil moisture, depth, pH, and organic matter conditions. In the present study, however, differences in soil between *Seeded-1* and *Seeded-2* plots are less likely to explain the results noted in past management. For example, park records suggest that the past use of broad-leaf herbicides at Homestead (Stubbendieck and Willson 1987) may not have been uniformly applied in all re-established sites which could result in the differences noted. In addition differences could simply reflect variations in the species composition or amount of viable seeds collected. Olson (1986), for example, found only four forb species (of 20 total) exceeding one percent in a large scale seed harvest of 929 hectares of native prairie.

Native prairie efforts to re-establish grasslands are faced with the potential encroachment by non-prairie, woody species (Bragg and Hulbert 1976), for example, *Prunus virginiana*, *Rhus glabra*, *Symphoricarpos orbiculatus*, and *Ulmus* sp., all woody species, were most common the in *Seeded-2* site (4% cover, 18% frequency). The high frequency of invading woody species in re-established areas may reflect (1) the availability of seeds in nearby woodlands, (2) the effect of substantial bare ground in re-established sites (Bragg and Stevens 1979) and the susceptibility of sites with such conditions to invasion (Glenn *et al.* 1992, Burke and Grime 1996), and (3) the lack of resistance of species-poor sites to invasibility (Tilman 1997). Management of re-established sites must address this concern since some of these species are clonal and, with time, become an increasingly greater threat to the re-establishment of prairie species.

In addition to concerns of woody species, is the concern about non-native, herbaceous species. The high frequency and cover of the non-native *Bromus inermis* and *Poa pratensis* found at the *Native* site in this study emphasizes the need for concern. In this study both of these species were high in frequency in all treatment areas (Table 2). However, *Bromus inermis* had significantly higher canopy cover at the native than at the re-established sites. Given what is known about the aggressive nature of *Bromus inermis*, this difference should not be interpreted to indicate that re-established sites are unsuitable for this species but more likely that the sites were some distance from locations where *Bromus inermis* had been introduced or that its management has been able to prevent extensive establishment of the species. The high frequency of these species in the *Native* site suggests both that past management has not prevented their invasion and that continuation of past management may further encourage their invasion.

The overall higher diversity in re-established sites rather than in the *Native* site is consistent with results that might be predicted by the Intermediate-Disturbance-Hypothesis (Connell 1978). Prairie destruction, such as by cultivation, is a disturbance that will be followed by ecological succession if the disturbance is discontinued. The re-established site, then, may be considered to represent a seral community in this succession in which diversity is high, particularly as exaggerated by the intentional introduction of species by human activity. These observations support the hypothesis that re-established grasslands, such as the ones at Homestead, are temporally distant from whatever composition represents native prairie.

Overall, then, this study suggests that re-establishment efforts, using sodding or seeding, can successfully increase vascular plant community diversity of a site to a point that begins to approach the dominant plant community in a native prairie ecosystem. Whether the less frequently found vascular plants, as well as micro-organisms, mycorrhizal fungi, and other soil biota are equally well established, however, remains to be assessed in future studies. Because of these unresolved questions, prairie re-establishment should be used only as a last-resort in efforts to preserve native biota and ecosystems. Preservation and appropriate management of extant relatively undisturbed ecosystems are still the best means by which to ensure the continued presence of all components and processes of a natural ecosystem.

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Appendix

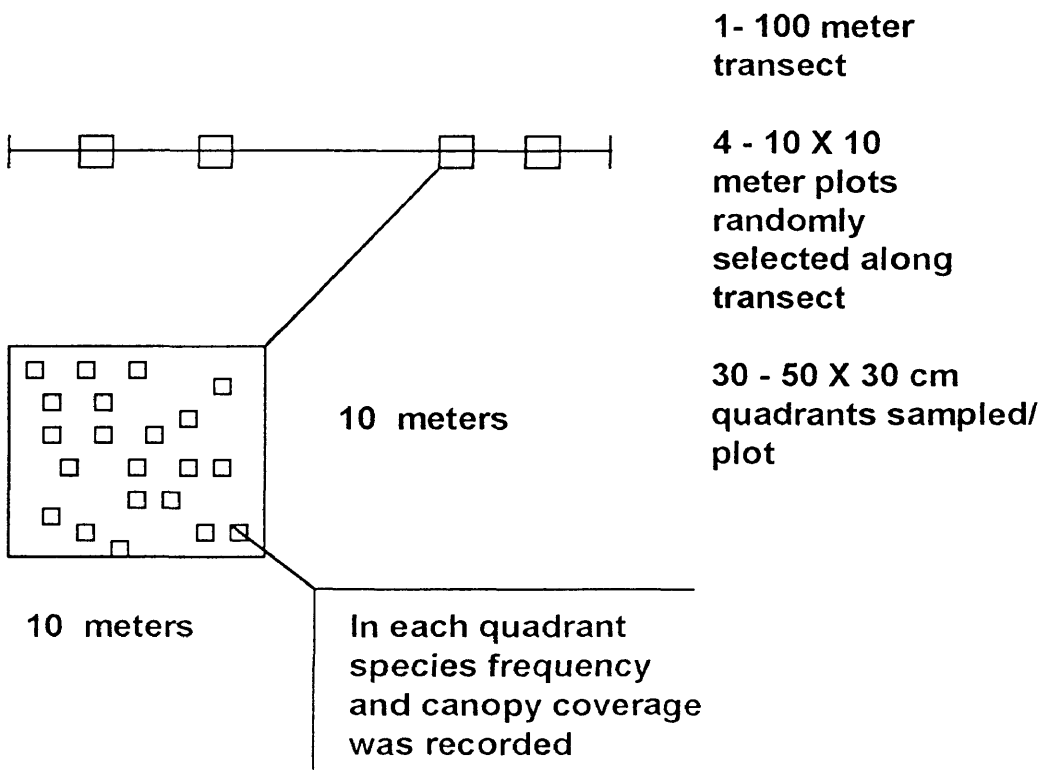
History of Homestead Restoration.

An early attempt at restoring a native plant community was started in 1939 at the then newly-established Homestead National Monument of America (Homestead), near Beatrice, Nebraska. In the mid-1930's, wildlife technician Adolph Murie outlined plans for the Homestead restoration (Sutton *et al.* 1984) and recommended both direct placement of prairie sod transplanted from nearby native prairies, and seeding native grasses and herbs. This restoration, like the first known prairie restoration at Madison, Wisconsin (Madison) used CCC labor in the project (Sutton *et al.* 1984; Stubbendieck and Willson 1987) and involved the U.S. National Park Service (NPS), which was also involved in the restoration at Madison (Sperry 1983). The common use of CCC and NPS may explain the similarities between the Homestead and Madison restorations. The Homestead restoration was possibly the second attempt at ecosystem restoration. Supporting evidence for this possibility includes a memo written in the mid-1930's by wildlife technician Adolph Murie (Sutton *et al.* 1984) in which he referenced a discussion with Dr. J.E. Weaver about the feasibility of restoring a prairie and the benefits of using sod from nearby prairies in the restoration process. Although, Murie did not mention collecting seeds from a nearby native prairie, he did indicate that the major grasses could be planted with various herbs.

In contrast to the Madison restoration, the number of studies documenting the efforts at Homestead are considerably fewer and far less in-depth. (Stubbendieck *et al.* 1987) (Appendix Fig. 2). Sutton *et al.* (1984), however, provide a survey of the management history of the restoration. No intensive, quantitative study of the vegetation is known to have been published. Thus, one objective of this study has been to fill this void, at least with respect to quantitative information on the above-ground prairie vegetation.

Appendix Table 1. Burn history of treatment areas. Burn history is from (Batzer and Dahle-Lacome (1993); and Stubbendieck (personal communication, 1995). C = Complete Burn; P = Partial Burn

SITE ATTRIBUTE	TREATMENT AREAS AND TREATMENT			
	NATIVE	RE-ESTABLISHED		
		SEEDED		SODDED
		1	2	
1970	Burned	C	P	P
1983	every third	C	P	P
1985	year	C	C	C
1986	beginning	P	P	P
1988	in 1983	C	C	C
1990		P	P	P
1991		C	C	C



Appendix Figure 1: Schematic of Research Design

Prairie Restoration/Management At Homestead: A History

By James Stubbendieck and Gary D. Willson

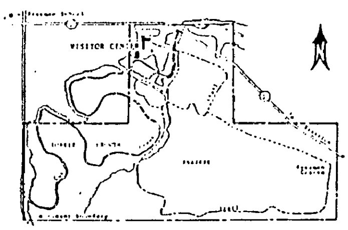
Homestead National Monument of America (HOME) is located 5 miles west of Beatrice, Neb., on 160 acres first homesteaded by Daniel Freeman in 1862. In 1936, Congress set aside the 100 acres of formerly abused pasture and cropland and 60 acres of woodland as a permanent monument to the homesteading era. Physical features of the site are dominated by Cub Creek, a major tributary to the Big Blue River, and its adjacent bottomlands. The balance of the site is made up of moderately steep glacial till with eroded sandy and gravelly side slopes.

Because of the importance of prairie to the settler, the primary objective of HOME has been restoration of the landscape to approximate the original conditions encountered by Daniel Freeman. This goal has been evident from the first management plan written by Wildlife Technician Adoph Murie circa 1938. Murie described two possible restoration methods; one was transplanting sod from a local prairie, and the second was seeding. He realized the advantages of sodding by stating, " . . . not only is prairie grass brought into the area, but also native species of prairie herbs." In preparing this first management plan, Murie contacted the eminent prairie ecologist, Dr. J.E. Weaver of the University of Nebraska, who felt that this project, "contained the possibilities of an excellent experiment . . . "

When the site was acquired by the National Park Service, severe erosion had occurred on the upland slopes, heavy depositions of silt were on the lower slopes, and the woodlands were cutover and heavily grazed. Management during the early years at HOME centered around stabilizing the severely abused soil and protecting newly planted native grasses.

At least 40 acres of the site were under cultivation as late as November 1939. Park records indicate that the first seeding took place in 1939 with seed gathered from a prairie located approximately 5 miles to the west. The approximate seed mixture was 45 percent big bluestem; 50 percent little bluestem; and 1 percent each of Kentucky bluegrass, needleandthread, indiangrass, prairie dropseed, and sideoats grama. The first sodding also was carried out in 1939 to control severe sheet, rill, and gully erosion on the coarse-textured south upland slopes. Source of the sod is unknown.

Park map.



Cropped upland and overgrazed woodland at Homestead NM in 1939.

Recent view of restored upland prairie at Homestead NM.

The following is a selected summary from park records of the management history at HOME between 1942-1986.

1942 – Additional seeding and sodding along with the construction of small check dams to slow erosion.

1943 – Weed control; sunflowers were mowed and bindweed was treated with sodium chlorate.

1947 – Sodding in upland gullies; seeding and local prairie hay mulch used in eroding areas.

1948 – Additional spot seeding; sod added to the uplands; selective grazing suggested as a means of reducing fire hazard.

1949 – First use of a herbicide other than sodium chlorate (2,4-D).

1951 – 40 acres mowed.

1952 – Upland hayed.

1953 – Bottomland hayed.

1954 – Seeds harvested.

1955 – Smooth bromegrass infestation noted.

1963 – 2,4-D used for weed control.

1964 – Lowlands heavily infested with weeds. Dalapon used for smooth brome control and 2,4-D for broadleaf weeds.

1965 – Thatch buildup leads to complete mowing.

1968 – Smooth brome mowed.

1969 – 7-11 acres of lowland seeded.

1970 – First prescribed burn; 2,4-D applied.

1976 – Four acres of lowland reseeded.

1979 – Woody plants sprayed with ammonium sulfamate; routine 2,4-D spraying program stopped.

1980 – 17-acre wildfire occurred.

1982 – Quantitative vegetative sampling begun; prescribed burn in April (8 acres); manual removal of musk thistles and common mullein.

1983 – Entire prairie burned; 4 acres of weedy lowland mowed.

1984 – Weedy lowland mowed; fall burn of small overgrown sumac; herbarium assembled.

1986 – Lowland area sodded and planted with approximately 3,000 greenhouse grown seedlings from locally collected prairie seed.

This chronolngical summary shows clear changes in management emphasis as prairie restoration at HOME evolved. The first priority of soil stabilization gave way to an interest in more natural management of vegetation. For example, prescribed burning replaced mowing and the general use of herbicides. A logical, progressive understanding that management procedures can be integrated and selected to obtain certain results has occurred. Interest has also moved from native grasses in the early stabilizing years of HOME management in the 1930s and 1940s, to an interest in legumes in the 1950s, and on to a more recent and complex understanding of the role of forbs. Quantitative sampling of the vegetation was initiated in 1982 and a herbarium was assembled in 1983 and 1984. A recent concern has emerged over the use of local gene pool sources for future introduction of plants, which indicates a further evolution of the park's understanding of the prairie ecosystem.

HOME is one of the oldest ongoing prairie restorations on a man-altered landscape. The only other nearly contemporaneous example is restoration of the Curtis Prairie in Madison, Wis., in the 1930s. The Curtis Prairie started with a less disturbed site and benefitted from the intensive labor of CCC crews and close association with Dr. John Curtis and University of Wisconsin graduate students.

Stubbendieck is Professor of Range Ecology at University of Nebraska – Lincoln; Willson is Ecologist/ Operations for the NPS Midwest Region, Omaha, Neb.

Appendix Figure 2 Management History of Homestead (Stubbendieck and Willson 1987)