
Spatial Distribution of *Spartina pectinata* Transplants to Restore Wet Prairie

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Abstract

Restoration of wet prairie in the central midwestern United States should include Prairie cordgrass (*Spartina pectinata*), but historic densities of this once dominant species are not easily achieved. *Spartina pectinata* was transplanted into a former agricultural field in three planting strategies: 20 small plugs, 4 medium-sized plugs, and a single large plug, with each treatment area totaling 0.6 m². Plugs were sampled annually for 3 years to determine which planting strategy produced highest survival, area, stem density (per unit vegetated area), and height of *S. pectinata*. It was also determined whether these factors varied with microtopography, and the resulting differences in flooding, within the restoration site. Stem density and height of restored *S. pectinata* were also compared to reference *S. pectinata* communities, including both pristine populations and the source of transplants. Because soil particle size and soil nitrogen content can influence *S. pectinata* stem density and height, these soil characteristics were also tested in restored and reference sites. Three years after planting, *S. pectinata* survived in all planted plots regardless of

planting strategy or microtopography, with an overall survival rate of 89.8% at the end of the study. The small plug treatment produced the greatest area after 3 years (3.99 m²), compared with the final area of medium (1.18 m²) and large plug treatments (0.79 m²). Stem density of small and medium plugs decreased dramatically during the sampling period, whereas density of large plugs increased. Height did not vary among planting strategies, and microtopography did not affect area, stem density, or height. Reference populations of *S. pectinata* had greater stem density and height than the transplanted plugs in the restoration, and these differences cannot be attributed to soil particle size or soil nitrogen. This study indicates that more than 3 years is needed to create area, density, or height of *S. pectinata* similar to established wet prairie populations. Planting many small plugs yields the greatest area of *S. pectinata*, and including some large plugs may add dense physical structure to wet prairie restoration.

Key words: clonal growth, Kansas, transplanting, wetland restoration.

Introduction

Wet prairie dominated by Prairie cordgrass (*Spartina pectinata*) was once abundant in sloughs, seeps, and along streams of central midwestern United States (Grossman et al. 1998; Lauver et al. 1999). After European settlement, over 95% of this moist grassland community was converted to cropland by draining, tiling, and tillage. Such impacts to wet prairie have resulted in a reduction of native graminoids across the region, including *S. pectinata* (Galatowitsch et al. 2000). Prairie restorations do not reproduce the diversity and community structure of natural prairie (Kindscher & Tieszen 1998), and wet prairie restoration is especially problematic (Galatowitsch & van der Valk 1996). Unlike mesic prairie restorations, where the grass matrix is easily established, many wet prairie restorations lack the dominant grasses found in undisturbed communities (Galatowitsch et al. 2000).

Dominance of *S. pectinata* is neither easily nor quickly established in wet prairie restorations, in part because this moisture-loving, clonal grass has poor seed production (Mobberly 1956). *Spartina pectinata* reproduces from stout, sharp rhizomes 6–10 cm in depth and can be transplanted as sod or sprigs into wet prairie restorations. *Spartina pectinata* sod plugs did not quickly spread throughout a restored wet prairie, and their growth in low microtopography areas was reduced by flooding at a depth of only 0.30 m (Fraser & Kindscher 2001). True restoration of wet prairie hinges upon the establishment of *S. pectinata*, but literature on restoration of this species is scant.

Successful restoration of *S. pectinata* requires that transplants survive and increase in area, and results in the appropriate physical structure (i.e., stem density and canopy height). Plant physical structure affects community composition and plays an important role in habitat value, especially for birds (Higgins et al. 2002). For example, a restoration of *Spartina foliosa* failed to provide habitat for the endangered Light-footed Clapper Rail (*Rallus longirostris levipes*) because the site's soil texture, which affected soil moisture, prevented this species of coastal cordgrass from reaching its optimum height and density (Zedler 1993). Although habitat preferences for grass

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height and density vary among bird species, dense stands of *S. pectinata* are required for nesting by some wet prairie birds such as Sedge Wren (*Cistothorus platensis*) (Herkert et al. 2001) and Yellow Rail (*Coturnicops noveboracensis*) (Bookhout 1995). Because wet prairie is often restored where the former or surrounding land use is agricultural, nitrogenous fertilizers may impact physical structure of restored *S. pectinata* populations.

We introduced *S. pectinata* into a wet prairie restoration utilizing three planting strategies: several small sod plugs, fewer medium plugs, and a single large plug. To enhance knowledge of wet prairie restoration via transplanting of *S. pectinata*, we addressed two questions:

- (1) Which of the three planting strategies produces highest survival, area, stem density, and height of *S. pectinata*, and do these factors vary with microtopography of the restoration site?
- (2) Are density and height of transplanted plugs in the restored site different from that in reference *S. pectinata* communities, and if yes, are the differences consistent with variation in soil texture or soil nitrogen?

Methods

Study Site

Our 17.4-ha study site is a former agricultural field in a floodplain in northeast Kansas, near the town of Somerset (lat 38°36'N, long 94°46'W; elevation 268 meters above sea level). Soils are Verdigris silt loam, which are occasionally flooded and contain inclusions of hydric Osage silty clays. Precipitation at the site averages 97 cm per year. Only the lowest 20% of the site acreage had saturated soil or low standing water in the spring and early summer, although nearby South Wea Creek flooded most of the site for 2–3 weeks in July 1999 and June 2000. The site was cultivated with soybeans until 1998, when we planted it with a sterile sorghum nurse-crop. In April 1999 the site was drilled with a mix of native prairie grass seed and hand broadcast with a mix of tallgrass prairie forb seed. The site was managed by spring mowing in 2000 and 2001.

Transplanting and Experimental Design

In June 1999 we transplanted *Spartina pectinata* sod in three different planting strategies: 20 small plugs (each 20 cm in diameter), 4 medium-sized plugs (each 46 cm in diameter), or 1 large plug (each 91 cm in diameter). Each of the three treatments had approximately the same initial area (0.6 m²) of *S. pectinata*. We transplanted small plugs by hand, but due to size and weight we transplanted large and medium plugs with a truck-mounted hydraulic tree spade (Vermeer Manufacturing Co., Pella, IA, U.S.A.) following the techniques of Fraser and Kindscher (1999, 2001). Plugs of all three sizes were cone-shaped, such that

the maximum depth of the plug was approximately equal to the plug diameter. The tree spade created plugs that were slightly irregular and oval in shape. Due to the angle of the tree spade's prongs, larger plugs had greater depth and soil mass which helped to maintain plug shape and integrity during transplanting.

Costs of implementing each treatment varied based on the labor and equipment required. The small plug treatment required 160 person-hours but no special equipment. The medium plug treatment required 120 person-hours and rental of the tree spade for 1 week. The large plug treatment required 80 person-hours and rental of the tree spade for 1 week. Regular personnel can easily learn to operate a tree spade, and an experienced operator is not essential. In 1999 the tree spade we used rented for \$1,200 per week from a national equipment rental chain.

The transplanting experiment required planting accurately sized plugs of each treatment. During plug removal we used a circular cardboard template to maintain a consistent size of small, hand-dug plugs. For large and medium plugs we marked the tree spade prongs to ensure that we removed plugs of a consistent depth, and thus corresponding area. When plugs were planted into the restoration site, we measured the areas of 20 randomly selected plugs of each size to confirm the consistency of area planted.

We obtained our *S. pectinata* transplant material from roadsides in agricultural areas of Douglas and Miami counties, Kansas. Source locations were within 100 km of the restoration site. We planted all plugs on the same day that they were removed from the source location. So that we could monitor the fate of each transplanted plug, we carefully measured the planting distances and spaced the plugs uniformly throughout the 20 × 20-m plots with a 2-m buffer between plots.

Each of the three transplanting treatments was replicated in a total of 20 plots, for a total of 60 plots in the experiment. Five replicates per transplanting treatment were assigned to each of four microtopography categories within the site: (1) 0–0.29 m; (2) 0.30–0.58 m; (3) 0.59–0.88 m; and (4) 0.89–1.16 m, which are based on the elevation above the lowest plot in the site. Prior to transplanting we surveyed the elevation of each plot and grouped plots into microtopography groups. Planting treatments were assigned randomly to the individual plots within each elevation category, although plots of similar elevation tended to be grouped within the site. During the sampling period, the lowest elevation category had standing water in spring and early summer, while the second lowest category had moist soil in the spring and early summer. The two highest elevation categories had moist soils only following heavy rains.

Monitoring

We monitored the 500 transplanted plugs in September 1999, 2000, and 2001 by recording survival, area, and

number of stems. Survival was determined as the presence of at least one living stem or shoot per transplanted plot. We estimated the area of each plug by measuring the extent of *S. pectinata* at ground level in two perpendicular directions, so that we could calculate the area of each plug using the formula for the area of an oval ($A = \pi r_1 r_2$) to allow for uneven rhizomatous spread. We also counted the total number of stems in each plot, including both flowering and non-flowering stems. Height of *S. pectinata* transplants was recorded in October 2001 only, and was measured as the mean of the height of three randomly selected ramets per plot, including both flowering and non-flowering stems. In the case of flowering stems, inflorescences were included in height measurements.

Reference Communities

We sampled four established *S. pectinata* communities in October 2001 as reference sites: two pristine wet prairie communities in nature preserves (Haskell-Baker Wetlands and Lawrence Prairie Park) and two roadside populations that served as a source of transplants. All four reference sites were located in Miami and Douglas counties in northeast Kansas and were within 100 km of the restoration site. The soils at the two pristine reference sites, respectively, were Wabash clay and Sibleyville loam. One of the source reference sites had Verdigris silt loam (the same soil type as the restoration), and the other had Wabash clay soils. We sampled the pristine and source reference sites for stem density and mean height with three 0.25×0.25 -m quadrats per reference site. For each quadrat, we counted all stems and measured the height of three randomly selected ramets.

To determine if differences in *S. pectinata* height and density between restored and reference sites could be attributed to soil texture or soil nutrient content, we collected soil samples in November 2001 using a Dutch or Belgique auger and analyzed particle size and nitrogen content. We collected samples from 20 plots in the restoration site to include potential variation among microtopography groups and treatments: five plots randomly selected from each of the four microtopography groups, with seven plots each from the small and medium plug treatments, and six plots from the large plug treatment. At each of the two pristine reference sites and two source reference sites, we collected three soil samples. For particle size analysis we collected soils at a depth of 50–60 cm (Bt horizon). We studied particle size in the Bt horizon, or illuvial layer, because the maximum accumulation of materials, especially clay particles, occurs here. The Bt horizon, therefore, is the soil horizon that most limits movement of soil moisture (Brady & Weil 1996). Particle size was estimated by the hydrometer method (Bouyoucos 1962). Samples for total nitrogen analysis were collected at a depth of 0–10 cm (A horizon) and frozen within 6 hr of collection to halt the microbial activity that can alter N

readings. Total nitrogen by percent weight was analyzed by combustion for a 0.5-g dried sample, using a CNS 2000 instrument (LECO Corp., St. Joseph, MI, U.S.A.).

Data Analysis

First, we determined how survival, area, stem density, and height varied among the three planting strategies and four microtopography categories. The unequal number of plugs among the three treatments did not allow us to make statistical comparisons of survival for the three planting strategies. Instead, we considered a plot-to-plot comparison, monitoring total *S. pectinata* survival in a plot, for the planting treatments. We also used observational data on the survival of individual plugs to illustrate survival of same-sized plugs planted in different elevations. We reported area of *S. pectinata* in two ways: plug area describes the mean area of individual plugs surviving in a plot, whereas plot area describes the sum of the area of all surviving plugs in a plot. Plug area and plot area were, therefore, the same for plots planted with only one large plug, but different for the plots planted with 4 medium or 20 small plugs. Stem density was the number of stems per square meter of *S. pectinata*, which we calculated as the sum of the stem count for all plugs in a plot divided by the vegetated area of *S. pectinata* in that plot. To test differences in plug area, plot area, and stem density among the three planting treatments and four elevation categories (3×4 factorial design with five replicates), we conducted a two-way analysis of variance (ANOVA) with repeated measures because the same transplants were sampled in successive years 1999–2001. We also used a two-way ANOVA to test differences among treatments and microtopography categories for stem height, which was only measured in 2001. Prior to statistical testing we log transformed plug area and plot area. We square root transformed stem density. Height data were normal without transformation. For post hoc multiple comparisons among planting strategies and microtopography groups we used Hochberg's GT2 tests (Sokal & Rohlf 1995).

Next, we asked if stem density and height of *S. pectinata* in the restored site differed from that in pristine and source reference communities, and if any differences were consistent with variation in soil texture or soil nitrogen between restored and reference locations. We compared reference populations to 2001 data for the subset of 20 restored plots in which we collected soils. *Spartina pectinata* stem density, height, soil texture (percent sand, silt, and clay), and soil nitrogen were compared via one-way ANOVA among six groups: restored plots from each of the four microtopography categories ($n = 5$ plots per category) plus pristine wet prairie communities ($n = 6$ samples) and source locations of transplant materials ($n = 6$ samples). We performed statistical analyses on square root transformed data for percent sand, silt, clay, and total nitrogen of the soil, as well as stem density. Height data were normal without transformation. To test differences

between pairs of microtopography groups or reference types, we used Hochberg's GT2 post hoc comparisons (Sokal & Rohlf 1995). We calculated all statistics with SPSS software, version 10.0 (Statistical Package of the Social Sciences, Chicago, IL, U.S.A.).

Results

Overall survival across plots did not differ with planting strategy and microtopography because all 60 of the experimental plots contained living ramets of *Spartina pectinata* throughout the 3-year sampling period. Of the total of 500 sod plugs we planted, 449 survived throughout the sampling period (until September 2001), yielding an overall survival of 89.8% (Table 1). Mean survival of individual plugs at the final 2001 sampling was greater than 90% in the three highest of the four microtopography groups (Table 1). In plots of the lowest microtopography group, where flooding was greatest, survival was 72.5% for individual small plugs, and 83.3% for individual medium plugs.

When we measured initial plug area of 20 randomly selected plugs per treatment, we found that initial areas were both accurate and precise: 0.032 m² (SE ± 0.0017), 0.167 m² (SE ± 0.0062), and 0.65 m² (SE ± 0.028) for small, medium, and large plugs, respectively. Three years after planting, mean small plug area was 0.22 m², whereas mean medium and large plug areas were 0.28 m² and 0.79 m², respectively (Fig. 1A). Increase in plug area over time varied among the three planting strategies, as indicated by the significant interaction between year and treatment ($F = 3.015, p = 0.031, df = 4$). Large plug area decreased over the sampling period, with a dip in the second growing season followed by a slight recovery. Small and medium plugs increased over the sampling period, starting with a decrease in area during the first growing season then increasing somewhat in subsequent years. Plug area increased significantly over the sampling period ($F = 33.212, p < 0.001, df = 2$) and differed among treatments ($F = 77.353, p < 0.001, df = 2$). Plug area did not vary significantly among the four microtopography categories ($F = 0.436, p = 0.728, df = 3$; Fig. 2A).

Table 1. Mean percent survival of individual transplanted plugs of *Spartina pectinata* 3 years after transplanting, for three planting strategies and four microtopography categories.

Microtopography	Small (%)	Medium (%)	Large (%)	Mean (%)
1 (Lowest)	72.5	83.3	100.0	85.5
2	91.0	90.0	100.0	93.7
3	91.0	100.0	100.0	96.8
4 (Highest)	95.0	96.9	100.0	97.3
Mean	88.5	93.8	100.0	89.8

Microtopography categories are based on the elevation above the lowest plot in the site: (1) 0–0.29 m; (2) 0.30–0.58 m; (3) 0.59–0.88 m; and (4) 0.89–1.16 m.

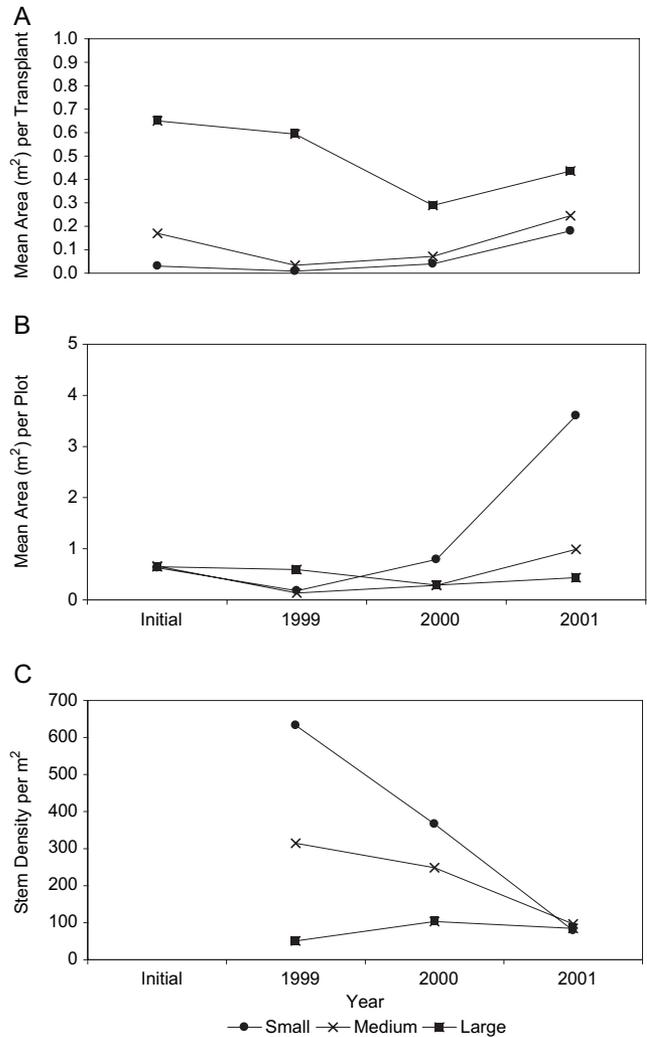


Figure 1. Plug area (A), plot area (B), and stem density (C) of *Spartina pectinata* planted in three planting strategies with the same initial area: 20 small plugs, 4 medium plugs, or a single large plug. Means (± 95% C.L. for area (A and B), ± SE for density (C)) are reported. The initial data refer to time of transplanting in June 1999, and plugs were sampled each September 1999–2001. Differences in area and stem density among planting strategies were tested using repeated measures ANOVA.

Mean plot area in 2001 was 3.99 m² for the small treatment, 1.18 m² for the medium treatment, and 0.79 m² for the large treatment (Fig. 1B). The increase in plot area over the sampling period was dependent on treatment, as demonstrated by the significant interaction of year and planting strategy ($F = 59.237, p < 0.001, df = 4$; Fig. 1B). Over the course of the study the small treatment exhibited the greatest increase in plot area. Multiple comparisons indicated that during the sampling period the small plug treatment yielded a greater plot area than the medium (mean difference = 0.3928, $p < 0.001$) and large plug treatments (mean difference = 0.3250, $p < 0.001$), whereas medium and large treatments did not differ in plot area

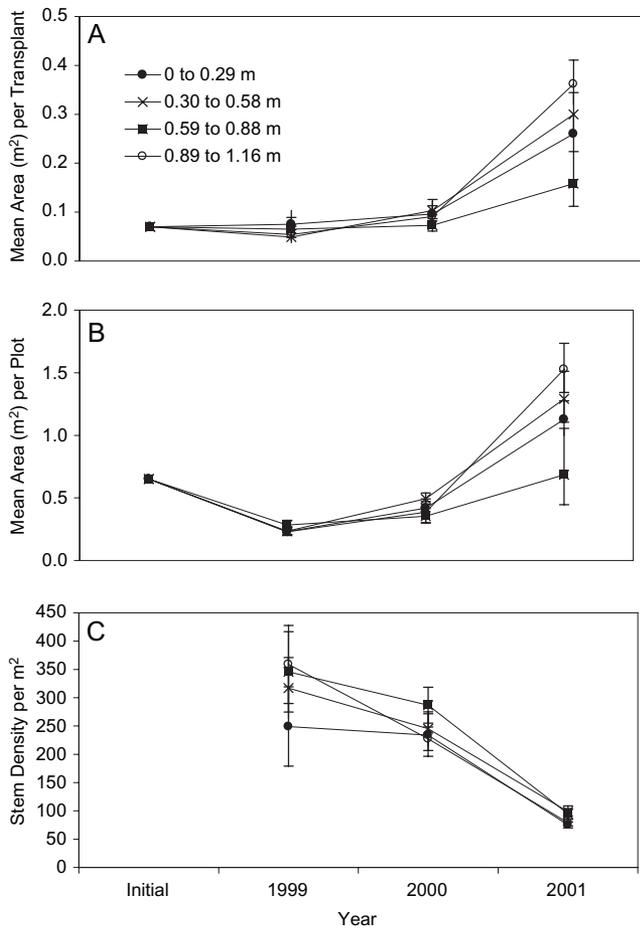


Figure 2. Plug area (A), plot area (B), and stem density (C) of *Spartina pectinata* planted into four microtopography categories within a wet prairie restoration site. Microtopography categories are based on the elevation above the lowest plot in the site. Means (\pm 95% C.L. for area (A and B), \pm SE for density (C)) are reported. The initial data refer to time of transplanting in June 1999, and plugs were sampled each September 1999–2001.

(mean difference = -0.067 , $p = 0.463$). As with plug area, plot area of the small and medium treatments decreased slightly in the first growing season, whereas plot area of the large treatment decreased in the second growing season. Although all treatments increased after these dips in area, small plugs took off in the third growing season, expanding to a plot area nearly four times that of the other treatments (Fig. 1B). Plot area also differed significantly among the three planting strategies ($F = 77.353$, $p < 0.001$, $df = 2$) and across years ($F = 33.212$, $p < 0.001$, $df = 2$). Plot area did not vary among the four microtopography categories ($F = 2.307$, $p = 0.089$, $df = 3$; Fig. 2B).

Stem density changed significantly during the sampling period, and over time the densities of the three treatments appeared to converge (for year \times strategy, $F = 43.216$, $p = 0.00$, $df = 4$; Fig. 1C). During the sampling period stem density decreased sharply in the small plug treatment, decreased gradually in the medium plug treatment,

and increased gradually among the large plug treatment (all $p < 0.01$ by multiple comparisons). Three years after planting, the small, medium, and large treatments had 79.01 stems/m², 96.7 stems/m², and 84.81 stems/m², respectively. Stem density also differed significantly among the three planting strategies ($F = 94.361$, $p < 0.001$, $df = 2$) and across years ($F = 88.456$, $p < 0.001$, $df = 2$). Stem density did not differ significantly among the four microtopography categories ($F = 0.535$, $p = 0.661$, $df = 3$; Fig. 2C).

The mean height of *S. pectinata* in 2001 was 124.83 (SE \pm 3.9 cm), 125.11 (SE \pm 3.43 cm), and 123.74 (SE \pm 4.84 cm) for small, medium, and large treatments, respectively. For the four elevation categories, from lowest to highest, mean height of *S. pectinata* in 2001 was 122.33 (SE \pm 3.97 cm), 127.28 (SE \pm 3.53 cm), 132.49 (SE \pm 5.48 cm), and 118.12 (SE \pm 2.68 cm), respectively. Height of the *S. pectinata* canopy did not vary significantly with planting strategy ($F = 0.163$, $p = 0.850$, $df = 2$) or microtopography ($F = 1.746$, $p = 0.170$, $df = 3$).

Stem density and height varied significantly among restored plots, source populations, and pristine populations of *S. pectinata* ($F = 11.904$ and $F = 9.314$, respectively, $p < 0.000$). Post hoc comparisons indicated that neither stem density nor height varied among the four microtopography groups (all $p > 0.05$). Source and pristine locations were, however, both more dense and taller than all four microtopography categories in the restoration site (Fig. 3A & 3B). Neither stem density nor height differed significantly between source and pristine sites. The sand and silt components of soil particle size varied significantly among restored, source, and pristine sample locations ($F = 3.794$, $p = 0.010$, and $F = 18.442$, $p < 0.000$, respectively). Pristine soils in the Bt horizon were more sandy and less silty than source and restoration soils, but particle size did not vary significantly among groups of restored and source soils in post hoc paired comparisons (Fig. 3C). However, our two pristine sites were disparate in particle size composition in this soil horizon. One pristine site had high sand (52.7%) and low clay content (20.7%), whereas the other site had low sand (16%) and high clay content (55.7%). Total percent nitrogen did not differ among restored plots of the four elevation categories, and source and pristine sites ($F = 3.197$, $p = 0.22$).

Discussion

Because *Spartina pectinata* survived in all plots, regardless of planting strategy or microtopography, we conclude that transplant mortality did not limit this species' overall establishment in our wet prairie restoration. The reduced survival observed in individual plugs planted in low microtopography plots could be a result of deep or prolonged flooding in these low-lying areas. Perhaps prolonged inundation contributes to mortality of *S. pectinata*, given that flooding has been suggested to reduce clonal growth of *S. pectinata* in other studies (Galatowitsch et al. 2000;

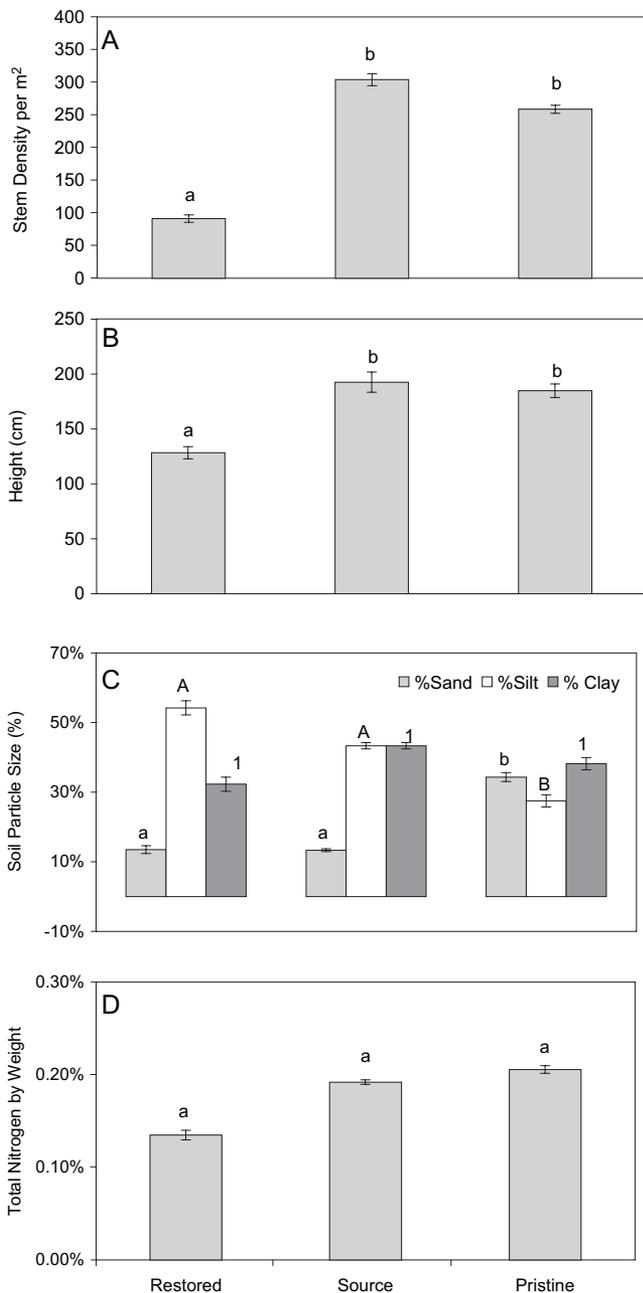


Figure 3. Plant structural characteristics (stem density (A) and height (B)) and soil characteristics (particle size of Bt horizon [50–60 cm deep] (C) and percent total N [0–10 cm deep] (D)) for populations of *Spartina pectinata* in restored sites, source locations of transplants, and pristine wet prairie reference sites in 2001 (mean \pm SE). Unlike letters of the same case or numbers indicate significant differences between restored, source, and pristine locations.

Fraser & Kindscher 2001). The species' native habitat of moist wet prairies in the central midwestern United States is typically only shallowly and periodically inundated in the spring (Weaver 1957). Although Bonilla-Warford and Zedler (2002) demonstrated that *S. pectinata* is capable of establishment and growth under various timings of pulse-

flooding, no experimental studies on the long-term flood tolerance of *S. pectinata* have been published. A better understanding of *S. pectinata* flood tolerance could advance restoration of this important species.

Although large plugs maintained the greatest plug area throughout the study, mean small plug area may eventually overtake large plug area. In September 2001 mean area of a single small plug was 27.8% of mean large plug area, compared to only 5% in June 1999.

Planting many small plugs produced the highest plot area. Multiple small clones also yielded greater basal area than fewer, larger, clones in a study of Little bluestem (*Schizachyrium scoparium*) (Briske & Anderson 1990). Many small plugs produce greater area than fewer large plugs because the higher perimeter-to-area ratio creates more clonal edge for ramet expansion. Given equal clonal growth rates for plugs of different sizes, the collective area of our small plug treatment would eventually surpass the single large plug with the same initial area (Auld et al. 1979; Moody & Mack 1988). Rapid expansion of invasive plant populations often results from establishment and spread of multiple small foci (Moody & Mack 1988). Our small plug treatment follows the same principle. Thus, in wet prairie restorations where rapid establishment of cover by appropriate clonal grasses is the primary goal, we recommend transplanting multiple small plugs.

During our 3-year study stem density decreased disproportionately in the small plug treatment and decreased in the large plug treatment, such that stem density of all three treatments became similar over time. Although stem density was initially higher in the small plug treatment, after one growing season, stem density in the small plug treatment declined, as also seen in *S. scoparium* (Briske & Anderson 1990). Based on this decline, and coupled with the more consistent but increasing stem density of large plugs, we recommend planting large plugs for density and physical structure. We cannot know from this study if stem density will continue to converge, or if the treatments will continue their present trends and diverge in subsequent years. Because transplanted plugs of all sizes came from the various source populations, we do not attribute the disparate initial stem densities among the treatments to environmental or genetic variation among the source populations. Changes in stem density can, however, be explained by differences in perimeter-to-area ratio of the treatments. Over time a planting strategy with a high perimeter-to-area ratio is more likely to produce new ramets at the plugs' edges, in contrast to a low perimeter-to-area ratio, which is more likely to produce new ramets within the existing plug area. In other words many small plugs could be predicted to increase in area, whereas fewer large plugs increase in density. Higher density in larger clonal patches has also been observed in studies of Dogbane (*Apocynum cannabinum*) (Webster et al. 2000). Large plugs appear to be most effective for establishing and increasing dense physical structure of *S. pectinata* with time, and could be useful for creating bird habitat. Neither

planting strategy nor microtopography affected height of *S. pectinata* plugs in our study.

Our restoration site was seeded with a mix of native grass and forb species in addition to our transplanting experiment. We recognize that competition between seeded species and transplanted plugs had the potential to affect survival and area of plugs and that the influence of competition could vary with planting strategy or microtopography. But because the cover of seeded species was low (<30%) throughout the restoration site, and we did not observe plugs that were crowded by seeded grasses or forbs, we conclude that the influence of interspecific competition on *S. pectinata* was negligible in this study.

Transplanted plugs were shorter and less dense per unit area than reference populations of *S. pectinata*, and this difference cannot be attributed to soil differences between restoration and reference sites. Height and stem density were similar in established pristine and source populations with different soil types and soil textures (i.e., percent silt and sand) but different in restored and reference populations of the same soil type and similar soil textures. We therefore deduce that physical structure was not strongly affected by soil texture, and resulting differences in soil moisture, in our study locations. The similarity of soil nitrogen content among restored, source, and pristine locations indicates that differences in stem density and height could not be attributed to past use of nitrogenous fertilizers at the restoration site or nitrogenous run-off from agricultural use adjacent to source and pristine populations. Instead, it seems likely that transplanted *S. pectinata* is shorter and less dense because the 3-year-old populations were somewhat affected by transplant shock or lacked the developed root structure of older, more established populations.

Conclusions

We recommend planting many small plugs to increase area of *Spartina pectinata* in restoration of wet prairie. Including large plugs could be helpful when dense physical structure is an important restoration goal. Our findings clearly demonstrate some limitations in restoring wet prairie. Percent cover of *S. pectinata* was low, and physical structure (i.e., stem density and height) did not approximate native communities. Wet prairie restoration requires a great deal of time, probably decades, for reestablishment of the native perennial graminoid community. However, *S. pectinata* was present in our restoration site only because we planted it there. This important species needs to be transplanted into wet prairie restorations in some form for restoration of this community to succeed.

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LITERATURE CITED

- Auld, B. A., K. M. Menz, and N. M. Monahan. 1979. Dynamics of weed spread: implications for policies of public control. *Protection Ecology* **1**:141–148.
- Bonilla-Warford, C. M., and J. B. Zedler. 2002. Potential for using native plant species in stormwater wetlands. *Environmental Management* **29**:385–394.
- Bookhout, T. A. 1995. Yellow rail (*Coturnicops noveboracensis*). Number 139 in A. Poole, and F. Gill, editors. *The birds of North America*, volume IV. The Birds of North America, Inc., Philadelphia, Pennsylvania.
- Bouyoucos, G. J. 1962. Hydrometer method improved for making particle size analysis of soils. *Agronomy Journal* **54**:464–465.
- Brady, N. C., and R. R. Weil. 1996. *The nature and property of soils*. 11th edition. Prentice Hall, Upper Saddle River, New Jersey.
- Briske, D. D., and V. J. Anderson. 1990. Tiller dispersion in populations of the bunchgrass *Schizachyrium scoparium*: implications for herbivory tolerance. *Oikos* **59**:50–56.
- Fraser, A., and K. Kindscher. 1999. Tree spade used to establish wetland grasses, rushes and sedges. *Ecological Restoration* **17**:162–163.
- Fraser, A., and K. Kindscher. 2001. Tree spade transplanting of *Spartina pectinata* (Link) and *Eleocharis macrostachya* (Britt.) in a prairie wetland restoration site. *Aquatic Botany* **71**:297–304.
- Galatowitsch, S. M., and A. V. van der Valk. 1996. Characteristics of recently restored wetlands in the prairie pothole region. *Wetlands* **16**:75–83.
- Galatowitsch, S. M., D. C. Whited, R. Lehtinen, J. Husveth, and K. Schik. 2000. The vegetation of wet meadows in relation to their land-use. *Environmental Monitoring and Assessment* **60**:121–144.
- Grossman, D. H., D. Faber-Langendoen, A. S. Weakely, M. Anderson, P. Bourgeron, R. Crawford, et al. 1998. International classification of ecological communities: terrestrial vegetation of the United States. Volume I: The national vegetation classification system. The Nature Conservancy, Arlington, Virginia.
- Herkert, J. R., D. E. Kroodsmas, and J. P. Gibbs. 2001. Sedge wren (*Cistothorus platensis*). Number 582 in A. Poole, and F. Gill, editors. *The birds of North America*, volume XV. The Birds of North America, Inc., Philadelphia, Pennsylvania.
- Higgins, J. J., G. E. Larson, and K. F. Higgins. 2002. Managing tallgrass prairie remnants: the effects of different types of land stewardship on grassland bird habitat. *Ecological Restoration* **20**:18–22.
- Kindscher, K., and L. L. Tieszen. 1998. Floristic and soil organic matter changes after five and thirty-five years of native tallgrass prairie restoration. *Restoration Ecology* **6**:181–196.
- Lauver, C. L., K. Kindscher, D. Faber-Langendoen, and R. Schneider. 1999. A classification of the natural vegetation of Kansas. *Southwest Naturalist* **44**:421–444.
- Mobberly, D. 1956. Taxonomy and distribution of the genus *Spartina*. *Iowa State Journal of Science* **30**:471–574.
- Moody, M. E., and R. N. Mack. 1988. Controlling the spread of plant invasions: the importance of nascent foci. *Journal of Applied Ecology* **25**:1009–1021.

- Sokal, R. R., and F. J. Rohlf. 1995. *Biometry: the principles and practice of statistics in biological research*. 3rd edition. W.H. Freeman, New York.
- Weaver, J. E. 1957. Flood plain vegetation of the Central Missouri Valley and contacts of woodland with prairie. *Ecological Monographs* **30**:37–64.
- Webster, T. M., J. Cardina, and S. J. Woods. 2000. Spatial and temporal expansion patterns of *Apocynum cannabinum* patches. *Weed Science* **48**:728–733.
- Zedler, J. B. 1993. Canopy architecture of natural and planted cordgrass marshes: selecting habitat evaluation criteria. *Ecological Applications* **3**:123–138.