ELSEVIER

Aquatic Botany 71 (2001) 297–304

Aquatic botany

www.elsevier.com/locate/aquabot

Tree spade transplanting of *Spartina pectinata* (Link) and *Eleocharis macrostachya* (Britt.) in a prairie wetland restoration site

Alexandra Fraser*, Kelly Kindscher

Kansas Biological Survey, University of Kansas, 2041 Constant Ave., Lawrence, KS 66047-2906, USA

Received 5 March 1999; received in revised form 19 March 2001; accepted 30 May 2001

Abstract

Clonal vegetation was transplanted in an attempt to increase plant species diversity at a wetland restoration in northeast Kansas, USA. A total of 107 plugs of wetland sod were relocated to the 6.9 ha floodplain site from a local wetland in April 1994, using a 60 cm tractor-mounted tree spade. Perennial and clonal species were selected based on their regional suitability for prairie wetlands and their presence in adjacent wetlands. Four growing seasons after transplanting, the survival of the plugs was over 90%. Of the 107 transplants, 27 plugs were *Spartina pectinata* L. (eastern cordgrass) and 18 plugs were *Eleocharis macrostachya* Britt. (spikerush). The objective of our study was to determine the extent of transplant spread, and effect of microtopography on this spread. The area of each transplanted plug was determined in October 1994, 1995, 1996 and 1997. Mean area of *S. pectinata* plugs was 0.51 m^2 in 1994 and increased annually to reach 1.57 m^2 in 1997. Mean area of *E. macrostachya* was 2.19 m^2 in 1994 and increased annually to reach 26.4 m^2 in 1997. Elevation and the resulting water depth affected transplant spread of both species ($P < 0.05$), with *S. pectinata* spreading most at shallow (maximum depth 0.11–0.20 m) water levels within the site and *E. macrostachya* spreading most in medium (maximum depth 0.21–0.30 m) and deep (maximum depth 0.31–0.40 m) water levels. Survival and spread of these transplants indicate that the tree spade technique is useful for enhancing vegetation in restorations, especially for restoring clonal species that may be difficult to establish via seeding.

Keywords: Transplanting wetland restoration; Prairie; Wetlands; Mitigation; USA

*Corresponding author Tel.: +1-785-864-7694; fax: +1-785-864-5093.
E-mail address: afraser@ku.edu (A. Fraser).

PII: S0304-3770(01)00185-1

1. Introduction

Wetland restoration literature generally encourages transplanting in conjunction with seeding and natural revegetation (Odum, 1989; Kruczynski, 1990; Willard et al., 1990). Transplanted materials may include adult individuals, seedlings, rhizomes and sod (Allen et al., 1989). Planting of natural runners, rootstock, and small sod plugs (usually <30 cm) has been successful in restoration of wetlands (Allen et al., 1989; Davis and Short, 1997) and prairies (Christianson and Landers, 1969; Sperry, 1983; Clarke and Bragg, 1994). Sod plugs and local transplants may also contain beneficial soil materials such as seed banks and soil microbes (Bragg, 1988; Allen et al., 1989; Clarke and Bragg, 1994). Transplanting is especially appropriate for plants that are clonal or reproduce poorly by seed and when salvage plant materials are available (e.g. when proposed wetland loss requires mitigation).

Our study focused on a new transplanting method in a restoration of prairie floodplain wetlands in northeast Kansas, USA. Tallgrass prairie wetlands are dominated by hydrophytic clonal graminoids of the *Spartina pectinata–Eleocharis macrostachya–Carex* sp. herbaceous vegetation community type (Lauver et al., 1999). Other common plant species include sedges and rushes of the genera *Eleocharis*, *Juncus*, *Carex*, and *Cyperus* and *Tripsacum dactyloides* L. (eastern gamma grass) (Weaver, 1957). Literature on this wetland plant community or its dominant species, is scant. For example, our review of the literature found one study of the community (Weaver, 1957), no ecological studies of *E. macrostachya*, and only two ecological studies of *S. pectinata* (Thompson, 1984; Johnson and Knapp, 1993), although transplants of other species in the genus *Spartina* (especially *S. alterniflora*) are widely documented for coastal marshes (Frenkel and Boss, 1988; Broome, 1995). *S. pectinata* is a perennial grass with stout, sharp rhizomes, and is found in swales, ditches and

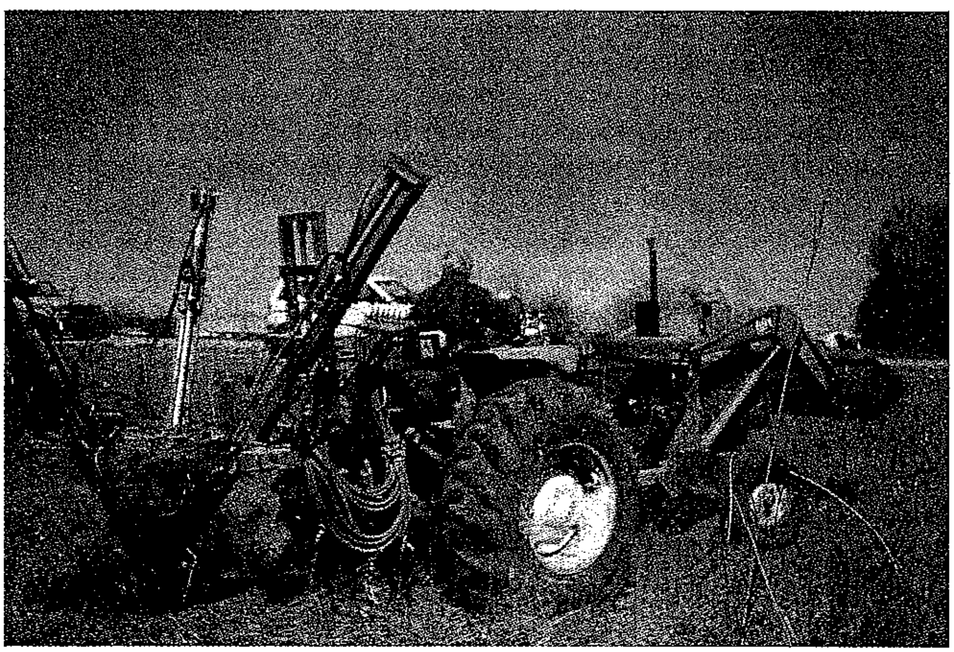

Fig. 1. A 60 cm tree spade, mounted on a tractor, was used to move plugs of sod from a native prairie wetland to the Santa Fe wetland restoration site in northeast Kansas.

wet prairies. *E. macrostachya* is a perennial graminoid with reddish rhizomes and filliform culms, and is common in marshy areas and roadside ditches. Both species are native to northeast Kansas (Great Plains Flora Association, 1991).

Moving plant materials with a tree spade (a nursery implement designed to dig, lift and transplant trees (Fig. 1)) is a technique that may be feasible for transplanting non-woody vegetation in many wetland restoration projects. We studied two aspects of tree spade transplanting as a restoration technique: (1) the extent to which transplants survive and spread over time, and (2) the effect of microtopography and resulting water depth on transplant spread.

2. Site description and methods

2.1. Study site

The Santa Fe wetland site was created to mitigate for the loss of wetlands proposed by the construction of a federal highway, which would destroy 5.2 ha of the 232 ha Haskell–Baker wetlands complex near Lawrence, Kansas (Federal Highway Adminstration, 1993). The Haskell–Baker wetlands is a seasonally flooded prairie floodplain marsh. Both the Haskell–Baker wetlands and the adjacent Santa Fe restoration site occur on hydric Wabash clay typic haplodoll soils (Dickey et al., 1977) in the floodplain of the Wakarusa River.

The 6.9 ha Santa Fe site was constructed in March 1994 when a 0.6 m earth berm was built around the perimeter of a relatively level cropped field. At this time, surface vegetation was removed through tillage, and a commercial native grass seed mix and locally collected native seed were broadcast into the site. *S. pectinata* was not seeded at all and only 8.8 g of *E. macrostachya* were seeded into the site.

2.2. Transplanting technique, monitoring, and analysis

Using a 60 cm diameter tree spade, 107 plugs of wetland sod were moved to the Santa Fe site between March 15 and 25, 1994. Plant materials were moved less than 2 km from the proposed highway route through Haskell–Baker wetlands to the Santa Fe restoration site. Each sod plug was planted within 1 h of the time it was moved from its original location. Species selected for transplanting were obligate or facultative wetland perennials (Reed, 1988), many of which reproduce clonally.

Two species were transplanted in quantities great enough to allow detailed study. Twenty-seven plugs of *S. pectinata* and 18 plugs of *E. macrostachya* were monitored in October 1994, 1995, 1996 and 1997 to determine their survival and growth. To determine basal area, we measured the perimeter of each transplant and created scale drawings of the transplant area. With a planimeter we measured the scale drawings, and then calculated the actual area of each plug.

In April 1996, we surveyed the center of each plug (using a total laser station) to determine elevations and spatial orientation within the site. Elevations of the transplanted plugs ranged from 248.26 to 248.59 m above sea level. The lowest elevation within the entire site was 248.06 m above sea level. When the site is completely inundated water flows over the 0.6 m berm, thus the maximum water depth in the site is 0.6 m. Although, depth and duration of innundation in the site vary annually and seasonally, water levels at maximum depth are reported to illustrate the range of hydrologic variation. In 1996, nine plugs of *S. pectinata* and six plugs of *E. macrostachya* were placed post-hoc into each of the three equal water depth categories: shallow (maximum depth 0.11–0.20 m), medium (maximum depth 0.21–0.30 m), and deep (maximum depth 0.31–0.40 m).

To compare changes in transplant areas over time we used Friedman's block tests, since each plug was sampled repeatedly in successive years. To determine differences in transplant spread for the three elevation categories, we used Wilcoxon's signed rank tests and Mann–Whitney *U*-tests. We used non-parametric statistical tests because the data were non-normal with unequal variances, even after we transformed the data. We calculated statistics with SPSS software (SPSS, 1997).

3. Results

Over 90% of the plugs survived. Of the original 107 transplants, 97 had survived four years following transplanting. We observed two dead plugs, of which one was *S. pectinata* and the other was *Carex hyalinolepis* Steud. We could not find the remaining eight transplanted plugs again, thus we regarded them as missing data and could not determine their survival or mortality.

Mean area of both *S. pectinata* and *E. macrostachya* plugs increased with each consecutive year from 1994 to 1997 (Fig. 2). Mean area of *S. pectinata* plugs was 0.51 m^2 in 1994 and

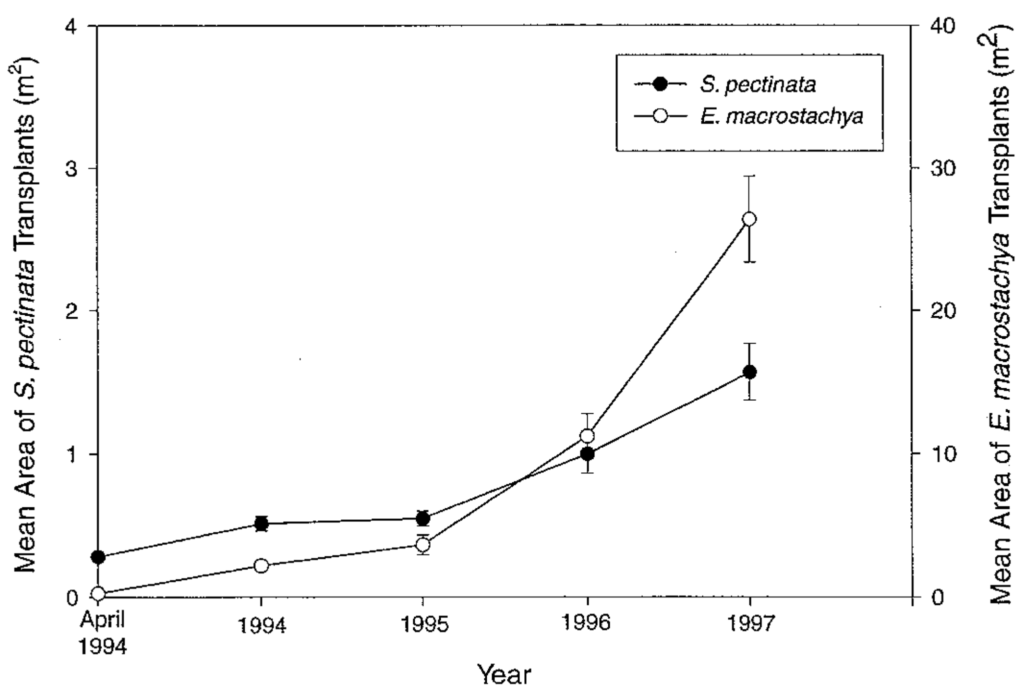

Fig. 2. Tree spade transplants of *S. pectinata* and *E. macrostachya* increased each year during the sampling period, with *E. macrostachya* spreading more rapidly than *S. pectinata*. Initial transplant area in April 1994 was 0.28 m^2. Transplant areas were measured in October of each year 1994–1997.

Table 1
Clonal spread and exponential growth rates of transplanted plugs *S. pectinata* and *E. macrostachya* as expressed by the exponential growth coefficient R (m_t^2/m_{t-1}^2, where t = time), and an absolute change in area (m^2), for each growing season from 1994 to 1997[a]

Year	*S. pectinata*		*E. macrostachya*	
	R	Change in area (m^2)	R	Change in area (m^2)
1994	1.82	0.23	7.78	1.92
1995	1.07	0.04	1.66	1.45
1996	1.82	0.45	3.08	7.57
1997	1.58	0.57	2.35	15.18
Mean	1.49	0.35	2.36	8.07

[a] For the 1994 growing season, October measurements were divided by initial transplant area (0.28 m^2)

increased in size each year to reach 1.57 m^2 in 1997. For *E. macrostachya* plugs, mean area was 2.19 m^2 in 1994 and increased more dramatically in size each year to reach 26.4 m^2 in 1997. For both species, clonal growth rates fluctuated throughout the sampling period, although area of clonal spread increased each year after the first year (Table 1).

Elevation contributed to variation in spread over time for both species. For *S. pectinata*, transplant area in 1997 was greatest for shallow areas, and least for the deep areas (Fig. 3). For *E. macrostachya*, transplant area in 1997 was greatest in the medium water depth areas,

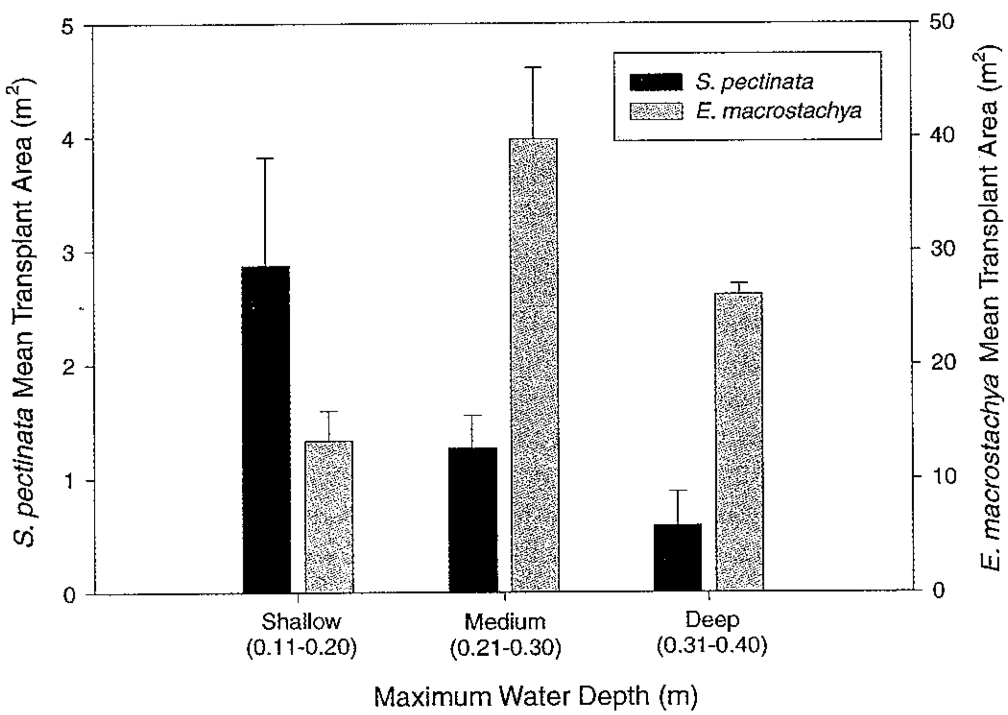

Fig. 3. Mean area of *S. pectinata* and *E. macrostachya* transplants at three water depths after four growing seasons. Nine plugs of *S. pectinata* and six plugs of *E. macrostachya* were placed post-hoc into each of the three water depth categories. For each species, differences between all pairs of elevation categories were significant ($P < 0.05$) using non-parametric Mann–Whitney U-tests.

and area in deep areas was greater than in shallow areas (Fig. 3). For both *S. pectinata* and *E. macrostachya* differences in relative percent cover between all pairs of elevation categories were significant ($P < 0.05$). Wilcoxon's signed rank tests of overall differences among the elevation categories were not significant for either *S. pectinata* or *E. macrostachya*, perhaps due to high standard deviations in transplant area (Fig. 2), and reduced sample size ($n = 9$ for *S. pectinata* and $n = 6$ for *E. macrostachya*) in the post-hoc elevation categories.

4. Discussion

Using a tree spade to transplant plugs of sod is a useful and practical technique for transplanting vegetation into wetlands. The technique seems especially appropriate for species that spread quickly, such as *E. macrostachya* in the Santa Fe site. Although, *S. pectinata* did not exhibit rapid clonal spread in the Santa Fe site, likely due to hydrologic conditions, this technique remains useful since the species has limited seed reproduction (Mobberley, 1956) and may be difficult to establish in some restored wetlands.

For both species, clonal area increased with each successive year during the sampling period (Fig. 3). This J-shaped curve of clonal growth suggests that the transplants displayed exponential growth or the early stages of logistic growth. Four years of data are insufficient to determine if logistic growth will occur. The rapid early-stage growth of the transplants is consistent with clonal growth patterns of other plant species (Tsujimura, 1987; Clevering and van Guilik, 1997; Brewer et al., 1998). Results on the clonal growth of other species suggest that clonal species may continue to spread at fairly consistent rates for a long time. *Spartina patens* Ait. (Muhl.), a coastal species, exhibited clonal growth for over 42 years without diminished expansion rates (Frenkel and Boss, 1988). Other studies indicate that clones may exhibit sustained growth for centuries (Oinonen, 1969) or millennia (Steinger et al., 1996). While we cannot predict future clonal growth rates, our transplants of *S. pectinata* and *E. macrostachya* may reach a more consistent growth rate and continue spreading for decades, or longer.

Clonal spread of *S. pectinata* and *E. macrostachya* is affected by site microtopography (Fig. 3), emphasizing the impact of water regime on wetland vegetation. The transplanted plugs have an elevation range of only 0.29 m. This range corresponds to a 0.29 m range in water depths and also affects hydroperiod since lower, deeper areas will remain inundated for longer periods of time. For example, the lower and wetter areas of the Santa Fe site are generally flooded throughout the growing season, while higher areas are dry in late summer and fall. Our data suggest that even small changes in elevation impact survival and spread of transplanted species within a restored wetland. Since microtopography affects water depth and duration, thereby affecting the plant community, restoration planners must consider the type of vegetation desired when designing a wetland and its hydrologic regime (Kusler and Kentula, 1990; Mitsch and Wilson, 1996). Species transplanted should be well suited to the site since elevation and resulting water depth can affect establishment of transplants and will vary by species (Wilson and Keddy, 1986; Coops et al., 1994; van der Valk et al., 1994). For example, if a wet prairie is desired, water levels should be seasonal and relatively shallow, reflecting the native environment to which such species are adapted. *E. macrostachya* flourished in the hydrologic conditions at the Santa Fe site during the sampling period, but its spread appears to have been reduced by shallow water levels in the post-hoc experiment. In contrast, spread of *S. pectinata* may have been increased by shallow water levels.

Although, the present vegetation composition of the restoration site is not indicative of a *S. pectinata–E. macrostachya–Carex* sp. herbaceous vegetation community (Fraser and Kindscher, unpublished data), our transplants have contributed to the presence of *E. macrostachya* and *S. pectinata* in this wetland restoration. Considering the transplant frequency and short time since site construction, it may be unrealistic to expect these species to dominate the restoration, especially since restored wetlands often need more than a few years to meet expected guidelines for plant community composition (Mitsch and Wilson, 1996).

5. Conclusion

Tree spade transplanting is a promising restoration technique, as indicated by the high survival and impressive spread over time of transplants in our project. Selecting species well suited to the site's hydrologic regime is a key component of success in this and any other type of wetland transplanting project. Our technique is potentially appropriate for other grassland restoration schemes, in both wetland and upland communities, especially when vegetation can be salvaged from a native area slated for impact. Tree spade transplanting is well suited to clonal and herbaceous plant species, and should be considered for species that do not easily reproduce by seed.

Acknowledgements

This research was supported by grants from Douglas County, Kansas. We express our appreciation to Todd Aschenbach, Lisa Kahn, Megan Mehaffey and Jason Wozniak for assistance in the field, and to Helen Alexander, Sharon Ashworth, Jennifer Delisle, Dana Price, and Val Smith for editing, advice, and criticism.

References

Allen, H.H., Pierce, G.J., Van Wormer, R., 1989. Considerations and techniques for vegetation establishment in constructed wetlands. In: Hammer, D.A. (Ed.), Constructed wetlands for Wastewater Treatment. Lewis Publishers, Inc. Chelsea, Mich, pp. 405–416.

Bragg, T.B., 1988. Prairie transplants: preserving ecological diversity. In: Proceedings of the Tenth North American Prairie Conference, Lincoln, Nebraska, USA, pp. 214–219.

Brewer, J.S., Rand, T., Levine, J.M., Bertness, M.D., 1998. Biomass allocation, clonal dispersal, and competitive success in three salt marsh plants. Oikos 82, 347–353.

Broome, S.W., 1995. Relative growth of *Spartina patens* (Ait.) Muhl. and *Scirpus olneyi* gray occurring in a mixed stand as affected by salinity and flooding depth. Wetlands 15, 20–30.

Christianson, P.A., Landers, R.Q., 1969. Notes on prairie species in Iowa. II. Establishment by sod and seedling transplants. Proc. Iowa Acad. Sci. 76, 94–104.

Clarke, W.M., Bragg, T.B., 1994. Movement of tallgrass prairie plant species from sod transplant into adjacent reestablished grassland. Prairie Nat. 26, 67–81.

Clevering, O.A., van Guilik, W.M.G., 1997. Restoration of *Scirpus lacustris* and *Scirpus maritimus* stands in a former tidal area. Aquat. Bot. 55, 229–246.

Coops, H., Geilen, N., van der Velde, G., 1994. Distribution and growth of the helophyte species *Phragmites australis* and *Scirpus lacustris* in water depth gradients in relation to wave exposure. Aquat. Bot. 48, 273–284.

Davis, R.C., Short, F.T., 1997. Restoring eelgrass, *Zostera marina* L., habitat using a new transplanting technique: the horizontal rhizome method. Aquat. Bot. 59, 1–15.

Dickey, H.P., Zimmerman, J.L., Plinsky, R.O., Davis, R.D., 1977. Soil Survey of Douglas County, Kansas. Soil Conservation Service. US Department of Agriculture. US Government Printing Office, Washington, DC.

Federal Highway Adminstration, 1993. Final environmental impact statement for the south Lawrence Trafficway. FHWA-KS-EIS-87-01-F.

Frenkel, R.E., Boss, T.R., 1988. Introduction, establishment, and spread of *Spartina patens* on Cox Island, Siuslaw Estuary, Oregon. Wetlands 8, 33–49.

Great Plains Flora Association, 1991. Flora of the Great Plains. University Press of Kansas, Lawrence.

Johnson, S.R., Knapp, A.K., 1993. The effect of fire on gas exchange and aboveground biomass production in annually versus biennially burned *Spartina pectinata* wetlands. Wetlands 13, 299–303.

Kruczynski, W.L., 1990. Options to be considered in preparation and evaluation of mitigation plans, In: Kusler, J.A., Kentula, M.E. (Eds.), Wetland Creation and Restoration, the Status of the Science. Island Press, Washington, DC, pp. 555–570.

Kusler, J.A., Kentula, M.E., 1990. Wetland Creation and Restoration, the Status of the Science. Island Press, Washington, DC.

Lauver, C.L., Kindscher, K., Faber-Langendoen, D., Schneider, R., 1999. A classification of the natural vegetation of Kansas. Southwest. Nat. 44, 421–444.

Mitsch, W.J., Wilson, R.F., 1996. Improving the success of wetland creation and restoration with know-how, time, and self-design. Ecol. Appl. 6, 77–83.

Mobberley, D., 1956. Taxonomy and distribution of the genus *Spartina*. Iowa State J. Sci. 30, 471–574.

Odum, H.T., 1989. Ecological engineering and self-organization. In: Mitsch, W.J., Jorgensen S.E. (Eds.), Ecological Engineering. Wiley, New York, pp. 79–101.

Oinonen, E., 1969. The time-table of vegetative spreading of the lily-of-the-valley (*Convallaria majalis* L.) and the wood small-reed (*Calamagrostis epigeios* (L.) Roth) in southern Finland. Acta For. Fenn. 97, 1–35.

Reed Jr., P.B., 1988. National list of plant species that occur in wetlands: national summary. US Fish and Wildlife Service, Biological Report 88 p. 24.

Sperry, T.M., 1983. Analysis of the University of Wisconsin, Madison prairie restoration project. In: Proceedings of the Eighth North American Prairie Conference, pp. 140–147.

SPSS, 1997. Statistical package of the social sciences. Chicago, Illinois.

Steinger, T., Körner, C., Schmid, B., 1996. Long-term persistence in a changing climate: DNA analysis suggests very old ages of clones of alpine *Carex curvula*. Oecologia 105, 94–99.

Thompson, C.S., 1984. Experimental practices in surface coal mining-creating wetland habitat. National Wetlands Newsletter 6, 15–16.

Tsujimura, A., 1987. The ecology of *Carex oxyandra* II. The behavior of seedlings and tillers. Ecol. Res. 2, 279–288.

van der Valk, A.G., Squires, L., Welling, C.H., 1994. Assessing the impacts of an increase in water level on wetland vegetation. Ecol. Appl. 4, 525–534.

Weaver, J.E., 1957. Flood plain vegetation of the Central Missouri Valley and contacts of woodland with prairie. Ecol. Monogr. 30, 37–64.

Willard, D.E., Finn, V.M., Levine, D.A., Klarquist, J.E., 1990. Creation and restoration of riparian wetlands in the agricultural midwest. In: Kusler, J.A., Kentula, M.E. (Eds.), Wetland Creation and Restoration, the Status of the Science. Island Press, Washington, DC.

Wilson, S.D., Keddy, P.A., 1986. Species competitive ability and position along a natural stress/disturbance gradient. Ecol. 67, 1236–1242.