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Alternative Methods for Wetland Restoration in the Rainwater Basin, Nebraska, USA

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ABSTRACT

South-central Nebraska is recognized as a focal point of the mid-continent migratory waterfowl flyway. Substantial wetland alterations led to a critical need for restoration. Managers have restored wetlands by scraping with heavy earthmoving equipment to remove excess organic material and near-monocultures of reed canarygrass (*Phalaris arundinacea* L.) but managers report high costs and topsoil perturbation. Moderate livestock grazing was tested to compare results with those achieved with mechanical techniques. Advantages of grazing could include low costs and less soil perturbation. During the 2006 and 2007 growing seasons, we compared cover of bare ground and open water and plant species composition in mechanically treated, grazed, and untreated wetlands dominated by reed canarygrass to determine restoration success. Significantly less reed canarygrass and a higher percent composition of desirable species were found in mechanically treated areas as compared to grazed or control treatments. However, waterfowl food plants and marsh species were similar between treatments. Significantly higher percent cover of open water was found at mechanically treated wetlands possibly improving shorebird and waterfowl habitats. Both restoration techniques increased bare ground. Our findings reject the proposition that moderate livestock grazing is an effective technique in restoring reed canarygrass dominated wetlands in Nebraska and suggest additional research be conducted on intense, short-duration grazing in early spring.

Keywords: grazing, wetland vegetation, invasive species control, *Phalaris arundinacea*, sediment removal

INTRODUCTION

The Rainwater Basin marshes of south-central Nebraska are valuable habitats for plant and animal species (Sharpe, et al., 2001) and provide important ecosystem services for the region (Stutheit, 2004; LaGrange 2005) including rangelands. The marshes are an internationally known, critical spring staging area for millions of waterfowl and shorebirds which need to feed, build nutrient reserves, and rest before continuing north to their breeding grounds (Krapu 1995). In 1984, only 10% of the original Rainwater Basin wetlands were remaining, due primarily to crop conversion (Schildman 1984). The remnant wetlands are subjected to hydrological alterations producing crucial changes in plant species composition and productivity (Mitsch and Gosselink 2000). Degradation lessens marsh value as habitat and reduces ecosystem services. The U.S. Fish and Wildlife Service identified the Rainwater Basin marshes in Nebraska as one of nine areas of critical concern for wetland loss in the U.S. (U.S. Fish and Wildlife Service and Canadian Wildlife Service 1986). The ecological, social, and economic value of wetland services demonstrates the need to restore remaining wetlands (Zedler 2000). However, wetlands are not easily returned to their predegraded vegetation structure and composition (Zedler and Callaway 1999; Ehrenfeld 2000; Brooks et al. 2005). The challenge is to find methods that are cost effective and achieve restoration goals.

Nebraska's Rainwater Basin wetlands are dynamic ecosystems that historically were largely controlled by a complex disturbance regime of waterhole use by large mammals (bison, elk, pronghorn antelope, and deer), wind deflation when dry (Frye 1950; Kuzila 1994), fire, and most important, fluctuating water levels (Smith 2003; Stutheit et al. 2004). These ecosystems are deteriorated by altering disturbance regimes resulting in year-round flooding, water diversions, drainage, sedimentation from cropland water erosion (Luo et al. 1999), elimination of fire, and filling (Stutheit, 2004; LaGrange 2005). In many deteriorated wetlands, structure and function are altered by the introduction of aggressive plant species that outcompete other marsh species (Smith and Haukos 2002; Smith 2003; Houlahan and Findley 2004). In the Midwest, wetlands can be degraded by spread of an aggressive cultivar of reed canarygrass (*Phalaris arundinacea*) or by aggressive native species such as narrow leaved cattail (*Typha angustifolia* L.) and river bulrush (*Bolboschoenus fluviatilis* (Torr.) Sojak). These species form dense, nearly uniform stands and provide little habitat for wetland wildlife.

Restoration in the Rainwater Basin focuses on returning the wetlands to their natural hydrology and native plant composition. Specific goals have included reducing invasive plant species, increasing the number of waterfowl food plants, and enlarging surface area of open shallow water. One of the standard restoration practices is removal of undesirable vegetation, sediment, and organic material with heavy earth moving equipment. The practice is expensive and could disturb the soil seed bank (Hausman et al. 2007). For example, wetlands restored with heavy equipment had higher soil bulk density, lower organic matter, and lacked diversity of substrate compared to high quality or degraded natural sites (Brooks et al. 2005). Nevertheless, species richness and plant cover were higher on mechanically restored sites.

The Rainwater Basin Joint Venture Information Seminar (2001 Hastings, NE) reported that high intensity, short duration livestock grazing may achieve many of the same results accomplished by heavy earth moving equipment but at a fraction of the cost. Cattle grazing appears to increase plant species diversity and open water while it reduces undesirable plant species. Livestock grazing is used in other parts of the world to maintain wetland vegetation (Aptroot et al. 2007; Krawczynski et al. 2008) and reduce nonnative plants (Marty 2005).

Although hoof action can cause increased soil compaction, it can increase light for seedling establishment of native species (Winkel 1991; Van Uytvank 2008). We hypothesize that hoof action will increase bare soil allowing greater use by shorebirds; however, moderate intensity, short term grazing will not eliminate reed canarygrass.

To assess the effectiveness of livestock grazing and earth-moving as restoration techniques, we compared grazed, mechanically treated, and control marshes dominated by reed canarygrass. Using Nebraska Game and Park Commission's Rainwater Basin restoration goals, success was defined as increased open water, no more than 10% cover composition of nonnative undesirable species, no more than 10-20% cover composition of native undesirable species, vegetation dominated by marsh plants typical of these areas, and a high composition of waterfowl food plants (Steinauer and Rolfsmeier 2003; LaGrange 2005). Specifically, we hypothesized that percent cover composition of waterfowl food plants and native marsh species would increase similarly between mechanical and high intensity grazing treatments and would be higher than in the control treatment. Both high intensity grazing and mechanical treatments would increase cover of bare ground and open water and decrease undesirable plant species percent cover composition compared to the control treatment. Further, we hypothesized that moderate intensity grazing and control treatments would be comparable.

METHODS

Study Sites

Research was conducted in the Rainwater Basin, Nebraska, USA, (Fig.1) a region occupying 10,880 km^2 in south-central Nebraska in basins with potentially seasonal and semipermanent palustrine emergent wetland vegetation (Cowardin et al. 1979). The wetlands are playas or pond marshes with open water lying in depressions surrounded by level uplands (LaGrange 2005). They have hydric soils in contrast to the soils on sloping watersheds and uplands. Hydrological inputs are precipitation and surface water inflow from rainwater and snowmelt. A 15-183 cm thick silty clay subsoil underlies the depressions and becomes nearly impermeable when wet, resulting in pools of water (Kuzila 1994). Hydroperiod varies between basins and years; differences depend on soil type, basin morphology and climate (Cowardin et al. 1979; Stutheit et al. 2004). Basins fill between February and June but evapotranspiration usually exceeds inflows, thus, most wetlands dry out over summer (Stutheit et al. 2004). Length of hydroperiod is the main factor that influences vegetation composition (sensu van der Valk 1981; Keddy 2000).

The most abundant plant species in intact Rainwater Basins are river bulrush, plains coreopsis (*Coreopsis tinctoria* Nutt.), common spikerush (*Eleocharis palustris* (L.) Roem & J.A.Schulles), duckweeds (*Lemna* species), and smartweeds (*Polygonum* species) (Steinauer and Rolfsmeier 2003). Common hydric soils are Fillmore, Scott, and Massie series. The climate is continental with cold, dry winters and warm, wet summers. Average daily high temperatures (1971-2000) vary from 0.3 ^{0}C in January to 30.6 ^{0}C in July (National Climate Data Center 2008). The average annual precipitation is 69.5 cm, with the majority occurring from April to September.

Seven basins were chosen as study sites because all had a near-monoculture of reed canarygrass; four U.S. Fish and Wildlife Service Waterfowl Production Areas and three Nebraska Game and Parks Commission Wildlife Management Areas. The study sites are approximately 3 to 35 km apart having similar soils, vegetation, and topography (Fig.1). Three adjacent plots were randomly located in each study site; four study sites had one control, one high intensity, and one moderate intensity grazed treatment plot and three study sites had three mechanical treatment plots with no control plot. When the basins are mechanically scraped the basin depth and hydrology is changed which indirectly affects the entire basin, thus, there could not be a mechanically treated plot in each study site.

In 2005, four U.S. Fish and Wildlife Service Waterfowl Production Areas were divided into three plots by installing three-strand barbed wire fencing to delineate the plots and water tanks were placed in grazed plots to ensure drinking water for the cattle (Table 1). The study was conducted in two approximately 8 ha grazed plots and one 2-7 ha control plot at each study site. An Index of Grazing Pressure (cattle number/ha x calendar days of grazing) was calculated to estimate forage utilization. Starting in 2006 and continuing in 2007, one plot was moderately grazed (10 Index) by cattle, one highly grazed (30 Index) and the third plot was untreated (Table 1). The moderate intensity treatment plots (Plot 1) were grazed first beginning in late spring with farmers' appraisal of forage production. Cattle were moved into the high intensity treatment plots (Plot 2) where livestock numbers were increased. Both treatments were grazed for approximately two weeks. The control treatment (Plot 3) was continually protected from domestic grazing but allowed native herbivores such as deer and rabbits.

In 2002, three Nebraska Game and Parks Commission Wildlife Management Areas were divided into three, 2 ha plots (Table 1). In January 2003, 15 to 30 cm of sediment and all vegetation were removed from Bluebill North and South (Table 1). About 23 to 30 cm of sediment and all vegetation was removed from Gadwall in December 2004. Sediment removal depths were determined by a survey conducted by a Natural Resources Conservation Service soil scientist.

The experiment was a two-factor incomplete block design where every restoration treatment (mechanical, high intensity grazed, moderate intensity grazed, and control) was not included in every block (study site). The second factor was two times; one pre- and two post-treatment years. The advantage of this design is that the initial condition of plots could be compared with post-treatment, so differences in ground cover and vegetation composition of the treatments can be attributed to a restoration method or control.

Field Methodology

Botanical composition and ground cover were assessed in the mechanical, grazed, and control plots before treatments were applied (pre-treatment) and for two years following treatment application (2006 and 2007; Table 1). National Climatic Data Center (2008) records at York, NE indicated precipitation in the form of snow and rain was below normal during the study except for 2007 which was above normal (Fig. 2). Pre-treatment data were collected one year before the grazing treatments began and four and five months before scraping Gadwall and Bluebill, respectively. All post-treatment measurements were gathered in 2006 and 2007. Measurements were made in August of each year during peak plant growth and after grazing was completed for the season.

Each plot had three subsamples, one 60 m long, east-west transect which crossed two 20 m long, north-south transects parallel and 100 m equidistant from each other. Each year the transects were relocated using Trimble Global Positioning System, accurate to 1 m. We measured cover of bare ground, open water, and composition of species using a modified step point every 1 m along the transects (Bonham 1989). This method more precisely estimates cover than other methods (Bonham 1989). Along transects with standing water, we measured the nearest plant that was either above the surface of the water or observable submerged. If the water was too deep or turbid, plants were not observable and were not counted. Thus, submerged plant composition was probably underestimated. Plant species nomenclature is from Kaul et al. (2006).

To determine the effectiveness of the treatments for plant species used by waterfowl, we pooled species that are considered important waterfowl foods. These were selected based on values created for the Nebraska Rainwater Basin Wetland Plant List, 1999 (T. LaGrange, Nebraska Game and Parks Commission; L. Smith, Texas Tech University; L. Fredrickson, University of Missouri). On a scale of 1-10, with 10 values being highly important, we chose only those species with values above 5 to be included in our analyses of waterfowl food plants. Effectiveness of treatments on removing invasive species was determined by pooling these undesirable species for analyses. We also pooled species that are considered diagnostic for marsh vegetation (Steinauer and Rolfsmeier 2003). Desirable species were considered all other non-woody vegetation.

Statistical Analyses

For each transect, percent ground cover data were calculated as the number of cover type point intercepts/total point intercepts X 100. Data for species' percent cover composition were calculated as the number of individual plant species point intercepts/number of all plant species intercepts X 100. Data were non-normal and variances were unequal; therefore, a nonparametric analysis of variance (Scheirer-Ray-Hare) was used (Dytham 1999). Ground cover and species composition were compared among the four treatments and between pre- and post-treatment years using a two-way treatment in a randomized design ANOVA structure because the Scheirer-

Ray-Hare test analyses only main effects and their interaction. The Wilkins 2006 control plot was eliminated from undesirable and reed canarygrass analyses because the three transects were deliberately placed in areas with low cover of reed canarygrass. Three community parameters were calculated; species richness (number of species, S), Simpson's Diversity Index ($D = 1-\sum (p_i)^2$, where p_i is the proportion of individuals of species "i" in the plot), and Simpson's Evenness ($E = (1/D)/S$, where D is Simpson's Diversity Index) (Krebs 1999). All analyses were conducted with SPSS v. 12.

RESULTS

The moderate and high intensity grazing treatments were pooled into a single grazed treatment due to fluctuating numbers of cattle within study sites that were beyond the control of the investigators (Table 2). Post-treatment plots averaged 17.6 and 17.3 Index of Grazing Pressure in the moderate and high intensity grazed treatments, respectively. In 2007, grazing intensity was increased but this was an above average rainfall year and the cattle grazing could not keep up with reed canarygrass production. Much of the reed canarygrass was untrampled and shoots remained standing. Overall, grazing level was considered moderate rather than high.

Seventy-nine plant species were observed during the study. Pretreatment plots were dominated by reed canarygrass, Kentucky bluegrass (*Poa pratensis* L.), and smartweed (*Polygonum* species). After grazing began, the vegetation continued to be dominated by pretreatment species with the addition of smooth brome (*Bromus inermis* Leyss.). Sedge (*Carex cristatella* Britton) became a co-dominant species with reed canarygrass, Kentucky bluegrass, and smartweed in the control plots. Vegetation in the mechanical treatment was converted to annual spikerush (*Eleochoris ovata* (Roth) Roem. & J.A. Schultes) and plains coreopsis (*Coreopsis tinctoria* Nutt.).

Higher cover composition of desirable species occurred in the mechanical compared to the grazed treatment in the post-treatment years (H = 8.4, p = 0.02; Table 3). Desirable species cover was significantly lower in the pretreatment plots compared to 2006 and 2007 (H = 8.4, p = 0.02).

Waterfowl food plants averaged 7.0%, 5.3%, and 5.1% of the species cover composition in mechanical, grazed, and control treatments, respectively, but treatments were not significantly different. For waterfowl foods, we found greatest cover composition of yellow nutsedge (*Cyperus esculentus* L.) in the grazed treatment and Pennsylvania smartweed (*Polygonum pensylvanicum* L.) in the control plots. No significant differences were found between years.

Typical marsh species were common spikerush, large-fruited bur-reed (*Sparganium eurycarpum* Engelm. ex Gray), pepperwort (*Marsilea vestita* Hook. & Grev.), and barnyard grass (*Echinochloa crus-gallii* (L.) Beauv.). Marsh species cover composition averaged 4.0% and was not significantly different among years or treatments.

Undesirable species percent cover composition was significantly lower in mechanical than grazed or control treatments (H = 17.8, p < 0.001; Table 3). No significant differences were detected among years. Reed canarygrass was by far the most common undesirable species with cover composition ranging from 3.5% to 94.6% in treatments. Significantly lower cover was found in mechanical compared to grazed or control treatments (H = 22.6, p < 0.001), and cover was lower after treatment compared to pretreatment (H = 8.8, p = 0.005). Narrow-leaf cattail averaged 2.1% species cover composition. It was found in the mechanical treatment during 2007 only: a year with above average precipitation. River bulrush averaged 1.8% species cover composition and was not significantly different among treatments or years. We tested the correlation between area of hydric soils in the study areas and percent cover composition of undesirable species, desirable species, marsh species, and waterfowl food plants to determine if the disparate areas influenced results. Spearman's rank correlation was negative for most variables because the smaller study areas were mechanically treated and they had the greater cover.

Community variables revealed an inconsistent pattern among species richness, diversity, and evenness. Average species richness increased from 4.7 species in pretreatment plots to 12.3 and 15.2 species in 2006 and 2007, respectively ($H = 6.55$, $p = 0.05$). This result may be due to increased rainfall or unmeasured factors because the control treatment increased similarly (Table 3). In contrast, no significant differences were found among years for Simpson's Diversity Index. Instead, a higher diversity index was found in the mechanical treatment compared to the grazed and control treatments ($H = 7.11$, $p = 0.03$; Table 3). Simpson's Evenness Index was not significantly different among years or treatments.

Bare ground was higher in grazed and mechanical treatments compared to the control ($H = 15.6$, $p < 0.001$). There was a significant year by treatment interaction ($H = 12.0$, $p < 0.01$; Fig. 3A) due to bare ground replacement by open water in 2007. Open water was significantly higher in the mechanical treatment compared to grazed or the control ($H = 6.5$, $p = 0.05$). This result differed among years because precipitation returned from drought levels in 2006 to above average levels in 2007 ($H = 10.4$, $p = 0.003$; Fig. 3B). A significant interaction was caused by reduced open water in the control plots in 2007 ($H = 12.6$, $p < 0.001$).

DISCUSSION

Based on criteria for success, we conclude that none of the restoration goals were achieved with cattle grazing or mechanical scraping two to four years after restoration begun. Nevertheless, our results show a trend toward opening up dense vegetation for seedling establishment and bird use compared to pretreatment measurements. In 2007, the mean open water was 2% in the grazed treatment while it was 63% in the mechanical treatment. Increasing open water provides resting habitat for waterfowl during migration. The increased open water at our sites also provide habitat for emergent and submergent plant species. Observations indicate that migratory waterfowl and breeding dabbling ducks use wetlands with open water because emergent species have high nutritional value (Gersib 1989). By creating more bare ground, habitats were created for shorebirds to use during migration and nesting. Davis and Smith (1998) found that shorebirds used Texas basin wetlands with sparse stands of emergent vegetation. Observations in Nebraska indicate shorebirds prefer to forage on mudflats and shallow water.

The results showed a trend toward improved vegetation structure. The mechanical treatment had higher species diversity and desirable species composition while reducing the composition of undesirable species, compared to the grazed treatment. These results support Hausman et al. (2007) and Nebraska Game and Parks Commission observations that sediment removal improves plant species composition of wetlands. However, neither treatment improved marsh species composition nor waterfowl food plants when compared to the control. Most wetland recovery requires many years to achieve vegetation structure similar to undisturbed wetlands (Hammer 1997). In order to hasten success, seeds of these species may need to be sown because seed sources for the highly desirable marsh and waterfowl food plants are typically over a mile away. Portions of the basins are usually unscraped, however, the native vegetation has been displaced for many years and seed bank diversity may be low. In isolated basin wetlands in Wisconsin, Reinarz and Warne (1993) found seeded wetlands had higher diversity and richness after two years than naturally colonizing wetlands while reducing the invasive *Typha* species. Sowing with waterfowl food plants and marsh species may improve the Rainwater Basin plant composition because naturally immigrating seeds may come from distant sources.

We found invasive species were an unimportant component of species richness making up only 4% of the total number of species observed, however, they had the highest percentage of species cover composition. Both mechanical and grazed treatments reduced undesirable species composition similarly during 2006 and 2007, particularly reed canarygrass, but mechanical scraping was significantly better at removing it than the grazed treatment. In our study, machinery removed most of the undesirable vegetation along with sediment whereas cattle foraging was unable to significantly remove and trample reed canarygrass. As long as invasive species remain common, the mechanical treatment may be the most effective method to restore vegetation structure in the Rainwater Basin wetlands.

Moderate levels of late spring/early summer grazing slightly improved the wetland vegetation, but it reduced composition of desirable species. Nicol et al. (2007) also found sheep grazing significantly reduced seed densities of desirable and nonnative species. We found cattle removed most inflorescences from waterfowl food plants that were unable to regrow by our survey in August. Even though annual species may be able to regrow in the fall, we found that grazing may have occurred too late in the spring to regrow desirable species. The timing of grazing during seed production is known to reduce populations in sensitive species (Hobbs and Huenneke 1992).

The soil seed bank plays a major role in restoration success. Van der Valk (1981) stated that for prairie wetlands, including closed basin types, species composition is influenced primarily by hydroperiod as reflected through the seed bank. Wilkins Study Site had more upland species on the transect farthest from the hydric soil center which may reflect a longer period between flooding at that elevation. Depth of the study sites is unknown, nevertheless, by removing sediment the mechanically treated basins are deeper than the grazed, providing habitat for aquatic plant species. In a greenhouse study, we found that none of the restoration treatments eliminated reed canarygrass from the soil seed bank (mechanical 1.9, grazed 32.5, and control 10.4 average seedlings m^{-2}), thus, further restoration efforts will be needed or plots will return to pretreatment levels. Furthermore, the mechanical treatment did not remove the soil seed bank as demonstrated by seedling densities of all native species (average 193.3 seedlings m^{-2}) and waterfowl food plants (average 56.1 seedlings m^{-}2) following treatment. These results suggest the possibility that mechanical techniques retain desirable species' seeds when sediment is removed at the levels cut in our study.

Irrigated cropland and its associated disturbances to hydrology and increased erosion have impacted all the Rainwater Basin wetlands in Nebraska at one time or another and undisturbed native vegetation communities are rare. All study site wetlands continue to be disturbed by soil eroding from croplands partially surrounding the hydric soil footprint. Increased erosion leads to higher sedimentation rates in the wetlands (Smith 2003). Altered hydrological regimes and increased sediment have resulted in nonnative and invasive plant species expansion in Midwestern basins (Smith 2003). It is hypothesized that sediments and soils eroding from surrounding uplands get trapped in the dense cover of reed canarygrass vegetation more than natural vegetation; scouring of the basin by wind when dry (deflaction) cannot occur. Thus, soils and sediments continue increasing until the basin becomes shallow and the hydroperiod is too short to support wetland plant species. Therefore, restoration efforts should include joint practices to reduce undesirable vegetation cover and upland erosion.

Our findings reject the proposition that moderate livestock grazing is an effective technique in restoring reed canarygrass dominated wetlands in the Rainwater Basin. Instead, more intense grazing should be evaluated for success criteria and for seed production by waterfowl plant foods. Grazing should be intensive, for short periods in the spring, to better utilize and reduce reed canarygrass. However, if grazed at moderate levels or late in the spring, our results indicate that grazing hinders restoration.

IMPLICATIONS

Livestock grazing is a potentially suitable restoration method in Nebraska's Rainwater Basin wetlands because the vegetation community is adapted to large mammalian disturbances and it could include low costs and less soil perturbation. Nevertheless, our study showed that mechanical scraping is needed to remove sediment and invasive species. Neither treatment increased highly desirable marsh species or waterfowl food plants compared with the control. Seed sources are distant and degradation over many years has probably depleted the seed bank of these species, thus, additional efforts will be needed to return these species to degraded wetlands in the Rainwater Basin.

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Figure 1. Location of the study sites in the Rainwater Basin, Nebraska, USA.

Figure 2. Total yearly, summer and spring precipitation near the Rainwater Basin study sites, 2002-2007, and average yearly total precipitation from 1896 to 2007. Data are from York, Nebraska (National Climate Data Center 2008).

Figure 3. A, Bare ground (%) during pretreatment and post treatment (2006 and 2007) at mechanical, grazed and control treatments in the Rainwater Basin, Nebraska n = 189 transects. **B,** Open water (%) n = 189 transects. Data are mean +/- S. D.

Table 1. Description of wetland study sites in Rainwater Basin, Nebraska, USA. Sites were measured using the Geographical Information Software ArcView 3.5. Area of hydric soils include the entire wetland. County Line, Nelson, Wilkins and Mallard Haven are U.S. Fish and Wildlife Service Waterfowl Production Areas. Bluebill North, Bluebill South and Gadwall are Nebraska Game and Parks Commission Wildlife Management Areas.

Wetland Site	Location (UTM coordinates)	Plot Area (ha)	Hydric Soils Area[1] (ha)	Treatment Date	Treatment Method
County Line	623009 4506327	Plot 1 (8) Plot 2 (8) Plot 3 (3)	100	Springs of 2005-2007	Moderate High Control
Nelson	589849 4512659	Plot 1 (7) Plot 2 (7) Plot 3 (3)	132	Springs of 2005-2007	Moderate High Control
Wilkins	611309 4496023	Plot 1 (8) Plot 2 (8) Plot 3 (7)	284	Springs of 2005-2007	Moderate High Control
Mallard Haven	606381 4478047	Plot 1 (8) Plot 2 (8) Plot 3 (8)	348	Springs of 2005-2007	Moderate High Control
Bluebill North	609660 4499247	Plot 1 (2) Plot 2 (2) Plot 3 (2)	10	1/2003	Mechanical Mechanical Mechanical
Bluebill South	609660 4499247	Plot 1 (2) Plot 2 (2) Plot 3 (2)	10	1/2003	Mechanical Mechanical Mechanical
Gadwall	581035 4532470	Plot 1 (2) Plot 2 (2) Plot 3 (2)	66	12/2004	Mechanical Mechanical Mechanical

[1] At most sites, hydric soils extended onto private lands.

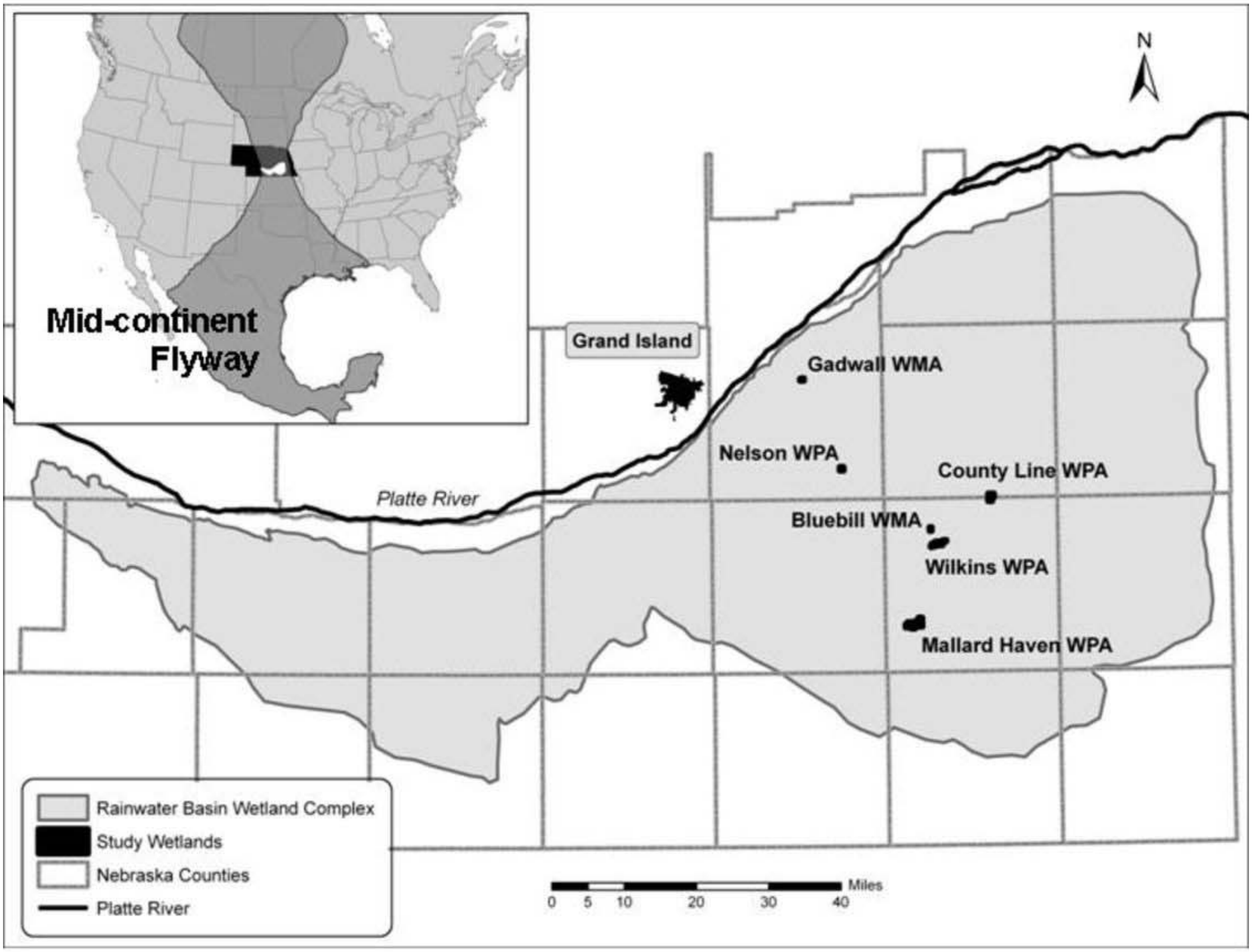
Table 2. Index of Grazing Pressure [Density (number/ha) x calendar days of grazing] and time of cattle grazing at four study sites, 2006 and 2007, in intensive, moderate and control treatments. -- indicates no grazing in the plot.

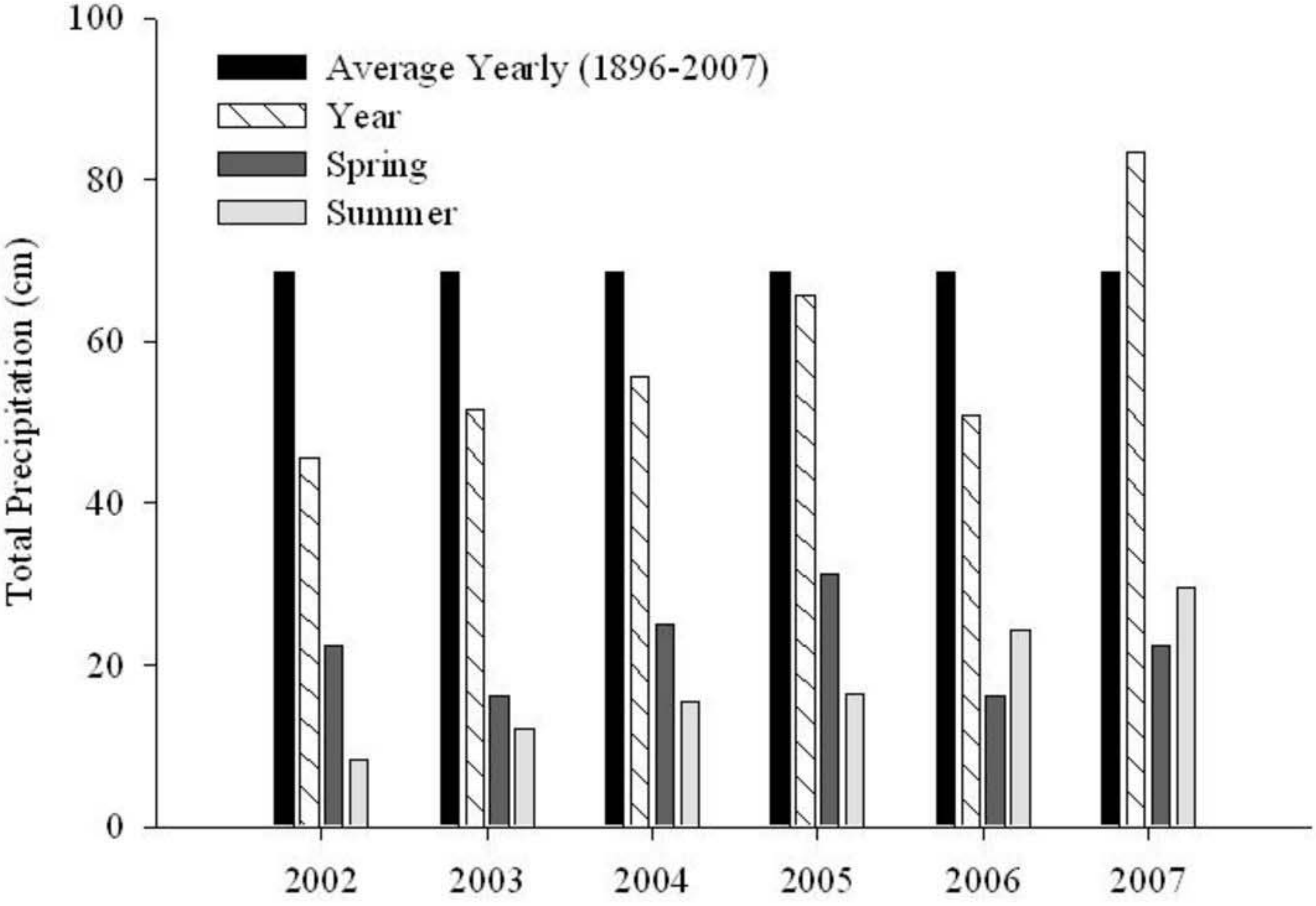
	Index of Grazing Pressure		Date Grazing Began	
Site	2006	2007	2006	2007
Mallard Haven				
Plot 1 Moderate	4.6	11.1	27 April	14 April
Plot 2 Heavy	5.9	3.9	3 June	25 May
Plot 3 Control	0.0	0.0	--	--
Nelson				
Plot 1 Moderate	27.0	48.8	4 June	22 April
Plot 2 Heavy	10.2	61.2	2 July	5 June
Plot 3 Control	0.0	0.0	--	--
Wilkins				
Plot 1 Moderate	9.0	12.0	1 May	7 April
Plot 2 Heavy	11.3	28.5	1 June	22 May
Plot 3 Control	0.0	0.0	--	--

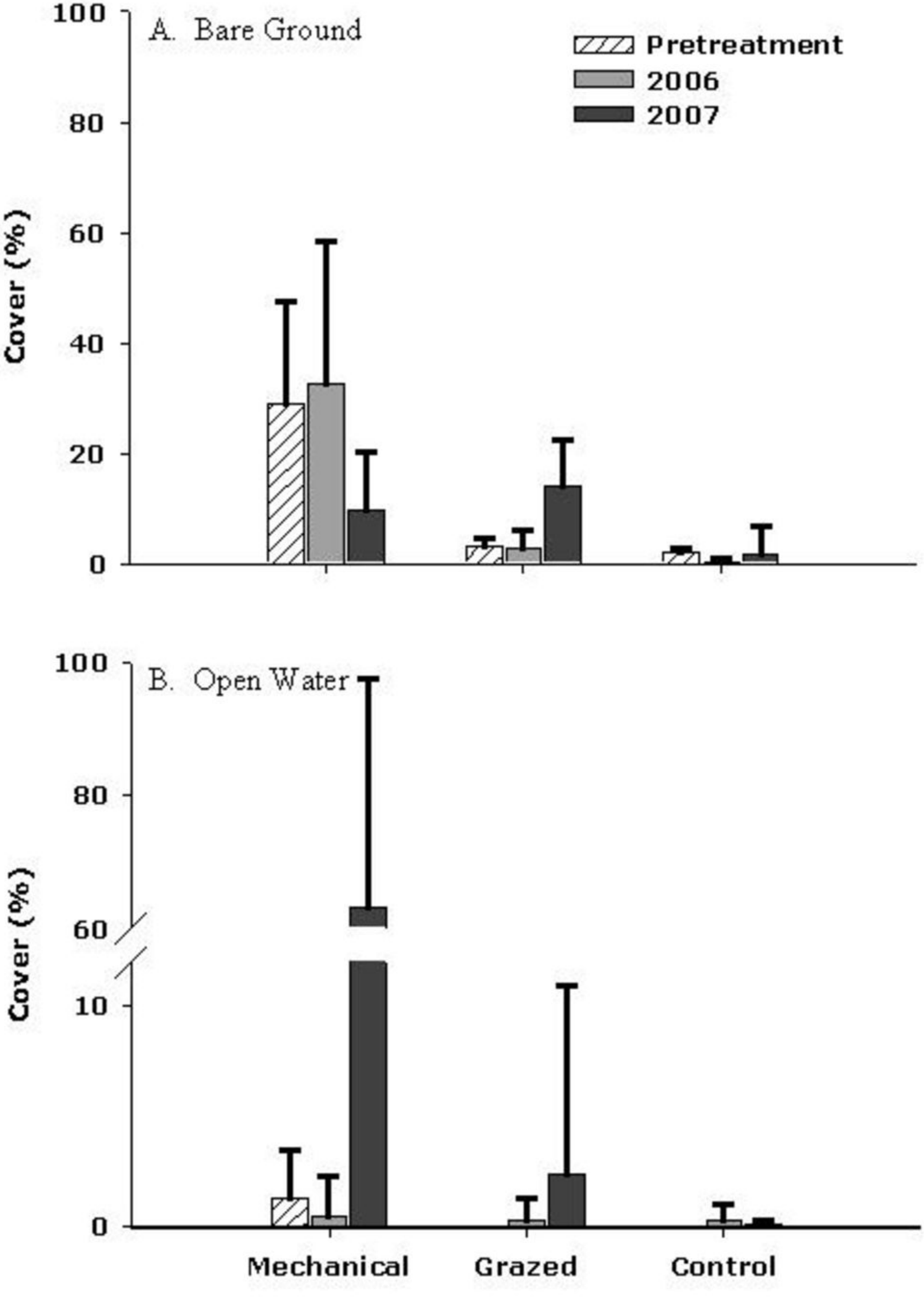
County Line Moderate	16.4	11.8	20 May	14 April
Heavy	8.0	9.2	3 July	1 May
Control	0.0	0.0	--	--

Table 3. Species cover composition (%) of desirable and undesirable species, species richness, and Simpson's Diversity Index, at pre-treatment and post-treatment (2006 and 2007) in mechanical, grazed and control treatments, Rainwater Basin, Nebraska. Data are means ± S. D. n = total plants for species cover and n = 63 plots for richness and Simpson's Diversity Index. Different lowercase letters indicate significant differences among treatments, Dunnett T3 multiple comparisons.

Year	Treatment	Desirable Species	Undesirable Species	Species Richness	Simpson's Diversity
Pretreatment	Mechanical	2.0 ±3.6 ^{a}	4.3 ±1.1 ^{a}	8.0 ±0.9 ^{a}	0.61 ±0.15 ^{a}
	Grazed	1.9 ±1.6 ^{b}	92.8 ±3.5 ^{b}	3.3 ±0.9 ^{a}	0.14 ±0.06 ^{b}
	Control	1.5 ±1.3 ^{c}	94.6 ±2.2 ^{b}	2.8 ±0.5 ^{a}	0.08 ±0.05 ^{b}
2006	Mechanical	10.4 ±12.9 ^{a}	8.5 ±12.1 ^{a}	16.0 ±4.0 ^{b}	0.76 ±0.08 ^{a}
	Grazed	4.8 ±7.7 ^{b}	67.2 ±35.0 ^{b}	11.4 ±5.6 ^{b}	0.37 ±0.27 ^{b}
	Control	6.4 ±8.6 ^{c}	54.1 ±34.2 ^{b}	9.5 ±3.0 ^{b}	0.48 ±0.20 ^{b}
2007	Mechanical	9.9 ±12.4 ^{a}	5.7 ±8.0 ^{a}	19.4 ±8.6 ^{b}	0.62 ±0.16 ^{a}
	Grazed	3.2 ±5.5 ^{b}	65.4 ±28.4 ^{b}	16.8 ±10.2 ^{b}	0.38 ±0.29 ^{b}
	Control	8.8 ±17.2 ^{c}	72.6 ±23.5 ^{b}	9.3 ±3.0 ^{b}	0.35 ±0.10 ^{b}


Mid-continent Flyway
N
Grand Island
Gadwall WMA
Nelson WPA
County Line WPA
Platte River
Bluebill WMA
Wilkins WPA
Mallard Haven WPA
Rainwater Basin Wetland Complex
Study Wetlands
Nebraska Counties
Platte River
Miles
0
5
10
20
30
40


100
80
60
40
20
0
Total Precipitation (cm)
Average Yearly (1896-2007)
Year
Spring
Summer
2002
2003
2004
2005
2006
2007


A. Bare Ground
Pretreatment
2006
2007
Cover (%)
100
80
60
40
20
0
B. Open Water
Cover (%)
100
80
60
10
0
Mechanical
Grazed
Control