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

2

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14

15 ABSTRACT

16

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

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

36

INTRODUCTION

37 The Rainwater Basin marshes of south-central Nebraska are valuable habitats for plant and
38 animal species (Sharpe, et al., 2001) and provide important ecosystem services for the region
39 (Stutheit, 2004; LaGrange 2005) including rangelands. The marshes are an internationally
40 known, critical spring staging area for millions of waterfowl and shorebirds which need to feed,
41 build nutrient reserves, and rest before continuing north to their breeding grounds (Krapu 1995).
42 In 1984, only 10% of the original Rainwater Basin wetlands were remaining, due primarily to
43 crop conversion (Schildman 1984). The remnant wetlands are subjected to hydrological
44 alterations producing crucial changes in plant species composition and productivity (Mitsch and
45 Gosselink 2000). Degradation lessens marsh value as habitat and reduces ecosystem services.
46 The U.S. Fish and Wildlife Service identified the Rainwater Basin marshes in Nebraska as one of
47 nine areas of critical concern for wetland loss in the U.S. (U.S. Fish and Wildlife Service and
48 Canadian Wildlife Service 1986). The ecological, social, and economic value of wetland services
49 demonstrates the need to restore remaining wetlands (Zedler 2000). However, wetlands are not
50 easily returned to their predegraded vegetation structure and composition (Zedler and Callaway
51 1999; Ehrenfeld 2000; Brooks et al. 2005). The challenge is to find methods that are cost
52 effective and achieve restoration goals.

53 Nebraska's Rainwater Basin wetlands are dynamic ecosystems that historically were
54 largely controlled by a complex disturbance regime of waterhole use by large mammals (bison,
55 elk, pronghorn antelope, and deer), wind deflation when dry (Frye 1950; Kuzila 1994), fire, and
56 most important, fluctuating water levels (Smith 2003; Stutheit et al. 2004). These ecosystems
57 are deteriorated by altering disturbance regimes resulting in year-round flooding, water
58 diversions, drainage, sedimentation from cropland water erosion (Luo et al. 1999), elimination of

59 fire, and filling (Stutheit, 2004; LaGrange 2005). In many deteriorated wetlands, structure and
60 function are altered by the introduction of aggressive plant species that outcompete other marsh
61 species (Smith and Haukos 2002; Smith 2003; Houlahan and Findley 2004). In the Midwest,
62 wetlands can be degraded by spread of an aggressive cultivar of reed canarygrass (*Phalaris*
63 *arundinacea*) or by aggressive native species such as narrow leaved cattail (*Typha angustifolia*
64 L.) and river bulrush (*Bolboschoenus fluviatilis* (Torr.) Sojak). These species form dense, nearly
65 uniform stands and provide little habitat for wetland wildlife.

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

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

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

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

98 METHODS

99 **Study Sites**

100 Research was conducted in the Rainwater Basin, Nebraska, USA, (Fig.1) a region occupying
101 10,880 km² in south-central Nebraska in basins with potentially seasonal and semipermanent
102 palustrine emergent wetland vegetation (Cowardin et al. 1979). The wetlands are playas or pond

103 marshes with open water lying in depressions surrounded by level uplands (LaGrange 2005).
104 They have hydric soils in contrast to the soils on sloping watersheds and uplands. Hydrological
105 inputs are precipitation and surface water inflow from rainwater and snowmelt. A 15-183 cm
106 thick silty clay subsoil underlies the depressions and becomes nearly impermeable when wet,
107 resulting in pools of water (Kuzila 1994). Hydroperiod varies between basins and years;
108 differences depend on soil type, basin morphology and climate (Cowardin et al. 1979; Stutheit et
109 al. 2004). Basins fill between February and June but evapotranspiration usually exceeds inflows,
110 thus, most wetlands dry out over summer (Stutheit et al. 2004). Length of hydroperiod is the
111 main factor that influences vegetation composition (sensu van der Valk 1981; Keddy 2000).

112 The most abundant plant species in intact Rainwater Basins are river bulrush, plains
113 coreopsis (*Coreopsis tinctoria* Nutt.), common spikerush (*Eleocharis palustris* (L.) Roem &
114 J.A.Schulles), duckweeds (*Lemna* species), and smartweeds (*Polygonum* species) (Steinauer and
115 Rolfsmeier 2003). Common hydric soils are Fillmore, Scott, and Massie series. The climate is
116 continental with cold, dry winters and warm, wet summers. Average daily high temperatures
117 (1971-2000) vary from 0.3⁰C in January to 30.6⁰C in July (National Climate Data Center 2008).
118 The average annual precipitation is 69.5 cm, with the majority occurring from April to
119 September.

120 Seven basins were chosen as study sites because all had a near-monoculture of reed
121 canarygrass; four U.S. Fish and Wildlife Service Waterfowl Production Areas and three
122 Nebraska Game and Parks Commission Wildlife Management Areas. The study sites are
123 approximately 3 to 35 km apart having similar soils, vegetation, and topography (Fig.1). Three
124 adjacent plots were randomly located in each study site; four study sites had one control, one

125 high intensity, and one moderate intensity grazed treatment plot and three study sites had three
126 mechanical treatment plots with no control plot. When the basins are mechanically scraped the
127 basin depth and hydrology is changed which indirectly affects the entire basin, thus, there could
128 not be a mechanically treated plot in each study site.

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

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

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

153 **Field Methodology**

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

163 Each plot had three subsamples, one 60 m long, east-west transect which crossed two 20
164 m long, north-south transects parallel and 100 m equidistant from each other. Each year the
165 transects were relocated using Trimble Global Positioning System, accurate to 1 m. We
166 measured cover of bare ground, open water, and composition of species using a modified step
167 point every 1 m along the transects (Bonham 1989). This method more precisely estimates cover
168 than other methods (Bonham 1989). Along transects with standing water, we measured the

169 nearest plant that was either above the surface of the water or observable submerged. If the
170 water was too deep or turbid, plants were not observable and were not counted. Thus,
171 submerged plant composition was probably underestimated. Plant species nomenclature is from
172 Kaul et al. (2006).

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

183 **Statistical Analyses**

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

191 Ray-Hare test analyses only main effects and their interaction. The Wilkins 2006 control plot
192 was eliminated from undesirable and reed canarygrass analyses because the three transects were
193 deliberately placed in areas with low cover of reed canarygrass. Three community parameters
194 were calculated; species richness (number of species, S), Simpson's Diversity Index ($D = 1/\sum$
195 $(p_i)^2$, where p_i is the proportion of individuals of species "i" in the plot), and Simpson's Evenness
196 ($E = (1/D)/S$, where D is Simpson's Diversity Index) (Krebs 1999). All analyses were conducted
197 with SPSS v. 12.

198

199

RESULTS

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

207 Seventy-nine plant species were observed during the study. Pretreatment plots were
208 dominated by reed canarygrass, Kentucky bluegrass (*Poa pratensis* L.), and smartweed
209 (*Polygonum* species). After grazing began, the vegetation continued to be dominated by
210 pretreatment species with the addition of smooth brome (*Bromus inermis* Leyss.). Sedge (*Carex*
211 *crisatella* Britton) became a co-dominant species with reed canarygrass, Kentucky bluegrass,
212 and smartweed in the control plots. Vegetation in the mechanical treatment was converted to

213 annual spikerush (*Eleocharis ovata* (Roth) Roem. & J.A. Schultes) and plains coreopsis
214 (*Coreopsis tinctoria* Nutt.).

215 Higher cover composition of desirable species occurred in the mechanical compared to
216 the grazed treatment in the post-treatment years ($H = 8.4, p = 0.02$; Table 3). Desirable species
217 cover was significantly lower in the pretreatment plots compared to 2006 and 2007 ($H = 8.4, p =$
218 0.02).

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

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

228 Undesirable species percent cover composition was significantly lower in mechanical
229 than grazed or control treatments ($H = 17.8, p < 0.001$; Table 3). No significant differences were
230 detected among years. Reed canarygrass was by far the most common undesirable species with
231 cover composition ranging from 3.5% to 94.6% in treatments. Significantly lower cover was
232 found in mechanical compared to grazed or control treatments ($H = 22.6, p < 0.001$), and cover
233 was lower after treatment compared to pretreatment ($H = 8.8, p = 0.005$). Narrow-leaf cattail
234 averaged 2.1% species cover composition. It was found in the mechanical treatment during 2007

235 only: a year with above average precipitation. River bulrush averaged 1.8% species cover
236 composition and was not significantly different among treatments or years. We tested the
237 correlation between area of hydric soils in the study areas and percent cover composition of
238 undesirable species, desirable species, marsh species, and waterfowl food plants to determine if
239 the disparate areas influenced results. Spearman's rank correlation was negative for most
240 variables because the smaller study areas were mechanically treated and they had the greater
241 cover.

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

250 Bare ground was higher in grazed and mechanical treatments compared to the control (H
251 $= 15.6, p < 0.001$). There was a significant year by treatment interaction ($H = 12.0, p < 0.01$;
252 Fig. 3A) due to bare ground replacement by open water in 2007. Open water was significantly
253 higher in the mechanical treatment compared to grazed or the control ($H = 6.5, p = 0.05$). This
254 result differed among years because precipitation returned from drought levels in 2006 to above
255 average levels in 2007 ($H = 10.4, p = 0.003$; Fig. 3B). A significant interaction was caused by
256 reduced open water in the control plots in 2007 ($H = 12.6, p < 0.001$).

257

DISCUSSION

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

270 The results showed a trend toward improved vegetation structure. The mechanical
271 treatment had higher species diversity and desirable species composition while reducing the
272 composition of undesirable species, compared to the grazed treatment. These results support
273 Hausman et al. (2007) and Nebraska Game and Parks Commission observations that sediment
274 removal improves plant species composition of wetlands. However, neither treatment improved
275 marsh species composition nor waterfowl food plants when compared to the control. Most
276 wetland recovery requires many years to achieve vegetation structure similar to undisturbed
277 wetlands (Hammer 1997). In order to hasten success, seeds of these species may need to be
278 sown because seed sources for the highly desirable marsh and waterfowl food plants are typically

279 over a mile away. Portions of the basins are usually unscrapped, however, the native vegetation
280 has been displaced for many years and seed bank diversity may be low. In isolated basin
281 wetlands in Wisconsin, Reinartz and Warne (1993) found seeded wetlands had higher diversity
282 and richness after two years than naturally colonizing wetlands while reducing the invasive
283 *Typha* species. Sowing with waterfowl food plants and marsh species may improve the
284 Rainwater Basin plant composition because naturally immigrating seeds may come from distant
285 sources.

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

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

301 grazing during seed production is known to reduce populations in sensitive species (Hobbs and
302 Huenneke 1992).

303 The soil seed bank plays a major role in restoration success. Van der Valk (1981) stated
304 that for prairie wetlands, including closed basin types, species composition is influenced
305 primarily by hydroperiod as reflected through the seed bank. Wilkins Study Site had more
306 upland species on the transect farthest from the hydric soil center which may reflect a longer
307 period between flooding at that elevation. Depth of the study sites is unknown, nevertheless, by
308 removing sediment the mechanically treated basins are deeper than the grazed, providing habitat
309 for aquatic plant species. In a greenhouse study, we found that none of the restoration treatments
310 eliminated reed canarygrass from the soil seed bank (mechanical 1.9, grazed 32.5, and control
311 10.4 average seedlings m⁻²), thus, further restoration efforts will be needed or plots will return to
312 pretreatment levels. Furthermore, the mechanical treatment did not remove the soil seed bank as
313 demonstrated by seedling densities of all native species (average 193.3 seedlings m⁻²) and
314 waterfowl food plants (average 56.1 seedlings m⁻²) following treatment. These results suggest
315 the possibility that mechanical techniques retain desirable species' seeds when sediment is
316 removed at the levels cut in our study.

317 Irrigated cropland and its associated disturbances to hydrology and increased erosion
318 have impacted all the Rainwater Basin wetlands in Nebraska at one time or another and
319 undisturbed native vegetation communities are rare. All study site wetlands continue to be
320 disturbed by soil eroding from croplands partially surrounding the hydric soil footprint.
321 Increased erosion leads to higher sedimentation rates in the wetlands (Smith 2003). Altered
322 hydrological regimes and increased sediment have resulted in nonnative and invasive plant

323 species expansion in Midwestern basins (Smith 2003). It is hypothesized that sediments and
324 soils eroding from surrounding uplands get trapped in the dense cover of reed canarygrass
325 vegetation more than natural vegetation; scouring of the basin by wind when dry (deflation)
326 cannot occur. Thus, soils and sediments continue increasing until the basin becomes shallow and
327 the hydroperiod is too short to support wetland plant species. Therefore, restoration efforts
328 should include joint practices to reduce undesirable vegetation cover and upland erosion.

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

335 IMPLICATIONS

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

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

470

471 **Figure 2.** Total yearly, summer and spring precipitation near the Rainwater Basin study sites,
472 2002-2007, and average yearly total precipitation from 1896 to 2007. Data are from York,
473 Nebraska (National Climate Data Center 2008).

474

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

478

479 **Table 1.** Description of wetland study sites in Rainwater Basin, Nebraska, USA. Sites were
 480 measured using the Geographical Information Software ArcView 3.5. Area of hydric soils
 481 include the entire wetland. County Line, Nelson, Wilkins and Mallard Haven are U.S. Fish and
 482 Wildlife Service Waterfowl Production Areas. Bluebill North, Bluebill South and Gadwall are
 483 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

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

485

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

Site	Index of Grazing Pressure		Date Grazing Began	
	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	--	--

489

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

496

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

497

498





