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Title: Influence of U. S. Department of Agriculture Programs and Conservation Practices on Ecological Services Provided by Playa Wetlands in the High Plains

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INTRODUCTION

Wetlands are generally considered the most ecologically productive ecosystems in the world. However, these systems are also some of the most degraded. Indeed, more than 50% of the wetlands in the contiguous United States have been lost since European settlement (Dahl 2000). Most losses have been caused by draining or filling for urban expansion and agricultural production (Dahl 2000).

However, for the past 50 years, values of wetlands to a healthy functioning environment and human society have been increasingly recognized by scientists, conservationists, and the general public (Mitsch and Gosselink 2000). Moreover, worldwide wetland services have been valued at $1 trillion annually (Christensen 2005). The dominant wetland system in the High Plains region of the western Great Plains is a collection of shallow depressions called playas. Intensive agriculture in this region has resulted in USDA conservation practices being especially prominent and therefore, they have a substantial influence on playas (Smith et al. 2011). USDA conservation programs in the High Plains primarily involve practices within the Conservation Reserve Program (CRP). Perennial grasses have been planted on more than 1.5 million ha of the High Plains under this program using different conservation practices (CPs). In the Rainwater Basin (RWB) playas of south central Nebraska, many playas have benefited from practices under the Wetland Reserve Program (WRP), but few playas outside that region have been included in WRP. Because the Wildlife Habitat Incentives Program (WHIP) and the Environmental Quality Incentive Program (EQIP) have had relatively little (<1% of playas) influence on playas, they were not directly evaluated in this study.

Therefore, we primarily focused on evaluating effects of CRP practices on ecosystem services provided by playas relative to native grassland and cropland watersheds within the non-glaciated portion of the western High Plains as a whole, and for a subset of playas influenced by WRP in the RWB. The major services provided by playas and examined in this study include biodiversity conservation (including plants and amphibians), floodwater storage, and biomass accumulation. Because accumulation of sediment is the major threat to playa function in this intensively cultivated landscape (Smith et al. 2011), these services were primarily evaluated relative to this stressor.

Objectives

1) Determine sediment depth and High Plains playa characteristics within native grassland, CRP, and cropland landscapes (also WRP in the RWB). Data for this objective are archived in room 521 Life Sciences West, Oklahoma State University, Stillwater, OK 74078.

2) Examine the catchment influence (CRP, native grassland, and cropland) on plant and amphibian communities in High Plains' playas. Biomass data were also collected and analyzed for the western High Plains. Data for this objective are archived in room 110 and 521 Life Sciences West, Oklahoma State University, Stillwater, OK 74078.

3) Compare hydrology (watershed runoff) and flood storage capacity of playas within cropland, CRP, and native grassland landscapes in the High Plains (and WRP in RWB). Data for this objective are archived in room 521 Life Sciences West, Oklahoma State University, Stillwater, OK 74078.

METHODS

Study Area and Site Selection: Playas were sampled from within two regions, the western High Plains and the RWB. The western High Plains region was defined as the short-grass prairie eco-region of the non-glaciated High Plains (n = 252 playas sampled; some additional playas were sampled in the western High Plains beyond that required the 252 required in the IAG). This region extends over seven states, from western Nebraska and eastern Colorado and Wyoming, south to eastern New Mexico and western Texas, and can be considered to contain 3 sub-regions: the northern, central and southern High Plains (Fig. 1). The RWB is in south-central Nebraska (n = 48 playas sampled).

More than 300 (see above) playas and their catchments were sampled: 100 in native grassland or reference condition (native grassland, n = 84, is the reference or base condition in the western High Plains while reference, n = 16, is ‘best condition’ in the RWB), 100 in USDA conservation programs (CRP, n = 84, lands in the western High Plains and WRP, n = 16, lands in the RWB), and 100 in croplands, in a random design stratified by playa density/region and county. In the RWB, reference condition was determined in conjunction with scientists at the Nebraska Game and Parks Commission. Initially, playas in native grassland or reference catchments were randomly selected and then paired with the two other playa catchment types within the same county, generating geographically associated playa triplets that can be used as a blocking term in statistical analyses.

DATA COLLECTION

Objective 1 Methods: For the western High Plains, the area of each playa was determined using a Global Positioning System (GPS; Trimble GeoXT) based on visual edge. The visual edge of the playa boundary was determined based on changes of slope and vegetation, and sediment depths were measured in dry playas using similar methods of Tsai et al. (2007). Sediment depths were recorded for six locations within the playa basin, including the center and five equidistant points at approximately one-third the playa radius. Sediment depth (cm) was measured from the top of the sediment to the depth at which augured soil cores contained more than 50% hydric soil based on soil color and texture. Hydric and upland soil classifications were based on Muncell soil color charts and soil profiles presented in NRCS Web Soil Survey maps (websoilsurvey.nrcs.usda.gov). The hydric soil edge was determined by taking sediment cores along a transect perpendicular to the visual edge of the playa at two points opposite each other on the visual boundary. Soil edge was determined as the point at which augured soil core color and texture changed from clay to upland soil.

For the RWB, the area of each playa was measured with a GPS as described above. Sediment depth determinations for RWB playas were challenging compared to the western High Plains playas. Horizons A and E of the three hydric soils (Massie, Scott, Fillmore) typical of RWB playas may often be tilled with extensive mixing of any overlying sediments. Therefore, when possible two depths were recorded; sediment depth (imported soil overlying or mixed into the A/E horizon) and depth to clay (defined as the Bt horizon). Extremely saturated soils in most RWB playas made it difficult to extract soil cores from the ground, so depth to clay was not measureable in all cases.

Objective 2 Methods: A total of 156 playas in Texas, New Mexico, and Oklahoma, and 34 playas in the Rainwater Basin was visually monitored for amphibian presence at the time of floral and sediment surveys during the 2008 and 2009 sampling seasons to assess playa amphibian communities. One 300-m transect was walked along the edge of each playa during sediment surveys to detect terrestrial form amphibians. If playas were inundated at the time of the survey, transects and seine hauls were used to sample aquatic form amphibians. For seining amphibian larvae, each inundated playa was visually divided into 4 quadrats using compass azimuths, and a 10-m transect along a random bearing was walked within each quadrat. Community richness was determined from transect and seine haul data for comparison among catchment types.

Plant biodiversity provisioning was initially examined relative to community composition of wetland plants, natives/introduced, annuals/perennials, and overall species richness in more than 300 playas as noted above. Plant diversity was measured using step-point surveys (Evans and Love 1957) along two transects in each playa. Transects were conducted twice a year in playas selected for that year to account for species turnover and hydrologic variability (Smith and Haukos 2002). Transects extended the diameter of the playa. Plants were identified approximately every 1 m, using taxonomy presented in the USDA PLANTS database (USDA and NRCS 2010). Agricultural crops were identified when present. Voucher specimens were collected for verification of unknown plants. USDA PLANTS also was used to classify plants according to wetland indicator status (obligate wetland, facultative wetland, facultative, facultative upland, or obligate upland). Plants that were designated "NS" (non-sufficient data to classify) in the USDA PLANTS database were assumed to be upland plants for analysis purposes. Wetland indicator status of a species often differs by geographic region, and data collection in this study spanned multiple geographic regions as defined by the USDA. Consequently, we used the 'wettest' indicator status among all geographic regions surveyed as our wetland indicator status for a plant. USDA PLANTS also was used to classify plants as either annual or perennial, and as native or introduced within the Great Plains. We also used the species description in **Flora of the Great Plains** (Great Plains Flora Association 1986) to subjectively place plants with biennial or multiple life history modes into either an annual or perennial category. Plants with subspecies that are both native and introduced were categorized definitively using subspecies range maps on USDA PLANTS or species descriptions in **Flora of the Great Plains**. Definitions for native, introduced, and wetland indicator status are as defined by the USDA PLANTS database (see Appendix 1 and 2).

Plant standing crop biomass was also estimated in 30 wetlands of each western High Plains catchment type (CRP, cropland, native grassland) from within 50 X 50-cm quadrats. Quadrats were clipped to the soil surface of all aboveground vegetation in late summer and results were presented for oven-dried biomass.

<u>Objective 3 Methods:</u> Percent volume loss was calculated for western High Plains playas as sediment volume divided by original playa volume in a method similar to that used by Luo et al. (1997). Sediment volume and original playa volume were determined using the truncated cone model, after determining the sediment depth, elevation difference between the playa basin and visual edge, and distance from the playa basin edge to the hydric soil edge and also the distance from the hydric soil edge to the visual edge. Volume loss estimates were converted to cubic meters of loss to estimate flood storage effects based on historical estimates of flood storage capacity. At the time of each plant survey, we also noted whether a playa contained surface water to compare the probability of playas containing water among the different land use types.

Remaining volumes of RWB playas were determined based on visual area and depth. Depth was determined as the difference in elevation between the center of the playa basin and the visual edge.

Estimated water and sediment runoff were modeled for combinations of three soil types (clay loam, sandy loam, silt loam), two slopes (1 and 2%), four watershed areas (20, 79, 177, and 314 ha), and four land use types (cotton, wheat, native grass, and CRP). Native grass was defined as 90% sod grass cover and 5% litter cover, and CRP as 90% bunch grass cover and 10% litter cover in the Rangeland Hydrology and Erosion Model ((RHEM Web Tool, 2008; Nearing et al. A rangeland hydrology and erosion model (online documentation); apps.tucson.ars.ag.gov/rhem/.). The Water Erosion Prediction Project (WEPP) model was used to generate estimates for water and sediment runoff on cropland (NSERL). The RHEM was used to generate estimates for runoff on native grassland and CRP. In all cases, the topography was set as a uniform slope and climate variables were generated by each model using the embedded Cligen v5.3 weather generator. Climate input to Cligen was derived from available local climate weather stations as interfaced through each model. Finally, model simulations were always run for 300 years.

ANALYSES

Objective 1 Analyses: Sediment depth (cm) and playa area (ha) were calculated for all playas. However, playas in the RWB were analyzed separately from playas in the western High Plains. Sediment depth and area for western High Plains playas were compared among land use types, sub-regions (see sub-region Fig. 1), and land use*sub-region interactions (Proc GLM; SAS) to examine potential differences in ecosystem services provisioning among land use types and sub-regions to further direct geographic conservation effort (alpha=0.05). If the interaction between land use and sub-region was significant, we used one-way AVOVA to test land use types within sub-regions and vice versa for differences among sub-regions. A one-way ANOVA (Proc GLM; SAS) was used to test for effects of land use on sediment depth and area for RWB playas. A protected Duncan's multiple range test was also performed in conjunction with ANOVA for the RWB and western High Plains playa data sets (alpha=0.05). Three western High Plains playas were considered outliers as determined by Dixon's Q test (Dixon, 1950) or a modification thereof for sample sizes greater than 25 (Sokal and Rohlf, 1995). Summary statistics on data are presented with and without outliers included, but all statistical analyses were conducted on data minus outliers.

Objective 2 Analyses: Differences in amphibian species richness among land use types for the RWB were analyzed by one-way ANOVA (SAS). Statistical analysis of the amphibian data for the western playas was not performed due to insufficient numbers of playas with amphibians (summary statistics only).

Plant data for playas in the RWB and western High Plains were summarized similarly, but analyzed separately. Percent cover for any item (plant species including agricultural crops, bare ground, and water) encountered was calculated by dividing the number of encounters for an item by the total number of encounters for any item on both transects. Plants observed in a playa but not encountered on transects were designated trace species and given an automatic cover of 0.0001. Plants that could not be identified were lumped together into one cover category called "unknown". Finally, to simplify analysis, we grouped wetland indicator status into broader categorizes: wetland plants (plants that range from wetland obligate to facultative wet$^-$) and upland plants (plants that range from facultative upland $^-$ to upland).

We compared plant communities among land use and sub-region (southern, central, and northern as defined in Fig.1). We used ANOVA with blocking on triplet to compare plant biomass among land use, sub-regions and land use*sub-region interactions. Additionally, we used separate repeated-measures ANOVAs with blocking on triplet to compare percent cover of wetland, upland, annual, perennial, native, and introduced plants among land use, sub-regions, and sub-region*land use interactions (independent variables). Early and late season surveys were the repeated value in these analyses. We assigned playas to sub-regions with overlay analysis of UTM locations with sub-region polygons ArcInfo 9.3 (ESRI, Redlands, CA). We assigned playas to the closest sub-region if they were outside sub-region borders. We square-root or arcsine transformed response variables when appropriate to achieve normality of residuals and reduce heterogeneity of variances. We also investigated differences in relationships between species richness and playa area among land uses with analysis of covariance (ANCOVA). Species richness and area has been modeled as $S = cA^z$, where S = species richness, A = area, and c and z are constants (MacArthur and Wilson 1967). Log-transformation will linearize this relationship, transforming the equation to $\log(S) = z{*}\log(A) + \log(c)$, allowing linear regression and generating estimates of c and z comparable to literature values (Rosenzweig 1995). To assess differences in intercepts among land uses, we coded land use categories (cropland, grassland, CRP) as separate dummy variables (1 = this land use, 0 = not this land use). We also included land use*area interactions to assess differences in slopes among land uses. We used total steps surveyed along transects as a proxy for playa diameter (1 step = approximately 1 m) and converted diameter to playa area. Steps surveyed better represents area surveyed for plants than diameter derived from soil maps (Smith and Haukos 2002). These analyses were repeated for the RWB except that plant biomass was not evaluated there.

In the Rainwater Basin, further analyses were necessary to determine if differences existed between reference and WRP playas. For this data set, we compared plant species composition using multivariate canonical correspondence analysis (CANOCO 4.5, Biometris, Wageningen, The Netherlands), with catchment type and survey time as explanatory variables for species prevalence. We down-weighted the effect of rare species (those with occurrence less than 20% of the species that were maximally abundant). We additionally only plotted species that were in greater than 1 % of wetland surveys and used only plotted species in our interpretation of community differences.

Objective 3 Analyses: We used a chi-square contingency test to compare the number of playas encountered wet versus dry by land use. Playas in the western High Plains and those in the RWB were analyzed separately. Land use and sub-region effects on original playa volume (m^3), sediment volume (m^3), percent volume loss, and remaining volume (m^3) of western High Plains playas were analyzed using ANOVA as described above in Objective 1. Land use effects on remaining volume and playa depth of RWB playas were analyzed using ANOVA as described in Objective 1.

RESULTS

Objective 1:

Western High Plains Playas

Significant interactive effects between land use and sub-region existed for wetland area ($F_{4,246}$=5.2, P<0.001) and sediment depth ($F_{4,246}$=25.8, P<0.001) of playas in the western High Plains (Table 2 and Fig. 2). Therefore, as described earlier, data were reanalyzed by 1-way ANOVA. Summary statistics are provided for all data (Table 1) and again minus outliers (Tables 2 and 3). Figure 2 is provided as an interpretive aid to visualize treatment interactions.

Land use effects on wetland area and sediment depth: Land use effects on playa area were observed in the south (P<0.001) and central (P<0.001) sub-regions, but not the north (P=0.268). In the south, playas in native grassland watersheds were about three times larger than those in CRP and cropland, which did not differ from each other. Similarly, native grassland playas in the central sub-region were over twice the size of playas in CRP and cropland, which did not differ. Sediment depth differed among land uses in all three sub-regions ($P\leq$0.001) (Table 2). Average sediment depth was greatest in southern cropland playas (48 cm), which was over twice as deep as in CRP playas. Similarly, sediment depth in southern CRP playas was 57% greater than for native grassland playas. This same land use effect was observed for playas in the central sub-region, as cropland playas had the deepest sediment at 22.7 cm, 23% more than CRP playas, which had 67% deeper sediments than native grassland playas. The pattern of land use effects differed somewhat in northern playas, as sediment depths were greatest in CRP playas, followed by cropland and then native grassland playas. However, sediment depths in CRP did not differ from cropland playas, but both averaged about twice the sediment depth as in native grassland playas.

Sub-region effects on wetland area and sediment depth: Playa area differed among sub-regions for all land use types. Native grassland playas in the south sub-region were nearly twice as large as those in the central region, which were over twice as large as those to the north (P<0.001; Table 2). Area of CRP (P=0.005) and cropland (P<0.001) playas was largest in the southern sub-region, averaging 48% to 64% larger than playas in the central region. Central and northern CRP and cropland playas did not differ.

Sediment depth differed among sub-regions for all land use types (Table 2). Sediment depths in south cropland playas were over twice that of central cropland playas, which themselves had sediment over twice as high as for northern cropland playas (P<0.001; Table 2). Sediment depths in CRP (P=0.002) and native grassland (P<0.001) playas were greater in the south than in the north playas where depths were 50 to 70% lower. Sediment depths in central grass playas were also about twice that of northern playas, but central CRP playas did not differ from their northern counterparts.

RWB Playas

Land use effects were observed for wetland area ($F_{2,45}$=1912, P=0.006) and sediment depth ($F_{2,44}$=1809, P<0.001), but not depth to clay ($F_{2,42}$=2.2, P=0.125) (Table 4). On average, reference playas were over six times larger than cropland playas, but neither reference or cropland playa size differed from WRP playas. Sediment depths in cropland playas were seven to nine times greater than for reference and WRP playas, which did not differ from one another.

<u>Objective 2:</u>

Amphibian community composition: No amphibians were observed in the absence of playa inundation and, of the 258 western playas monitored, only 14 were inundated at the time of the sediment survey (Table 5). Additionally, out of the 14 inundated playas, only 10 had amphibian species present at the time of the survey. Cumulatively, seven amphibian species were observed in the western playas, with *Ambystoma tigrinum* larvae and *Bufo cognatus* adults the most commonly occurring species (Table 6). Average amphibian richness ranged from 1.2 in cropland playas to 2.3 in native grassland playas.

Amphibians were observed in all but two of the RWB playas, with average richness ranging from 1.7 in cropland playas to 3.0 in WRP playas (Table 5). Overall, seven species were observed in RWB playas, and *Pseudacris triseriata* was the most frequently observed species, occurring in 31 of 34 playas (Table 6). Although, species richness did not statistically differ among land use types at the alpha = 0.05 level (P=0.082), playas in WRP tended to have nearly twice the number of species as in cropland playas. Species richness in reference playas was between that of WRP and cropland playas.

Plant community composition in the High Plains: We observed 254 plant species in playa basins throughout the western High Plains. We detected no sub-region effect or land use*sub-region interaction for plant biomass ($F_{2,52}$ = 0.02, P = 0.98 and $F_{4,52}$ = 0.16, P = 0.96, respectively). However, plant biomass differed by land use. Biomass in CRP playas was twice that of other land uses ($F_{2,52}$ = 4.4, P = 0.017, Fig. 3b).

Wetland plants had a significant sub-region*land use interaction. Wetland plants generally had reduced cover in cropland playas versus other land uses, except in the northern sub-region, where they were similarly low in CRP playas ($F_{4,421}$ = 2.92, P < 0.02, Fig. 3c). We detected no land use and sub-region interaction for upland plants ($F_{4,421}$ = 1.10, P = 0.36). Upland plant cover differed by land use and sub-region, and accordingly was 84% less in cropland playas than in grassland and CRP playas, and 28% greater in the central than in southern and northern sub-regions (land use: $F_{2,421}$ = 83.87, P < 0.001, region: $F_{2,421}$ = 3.58, P < 0.029, Fig. 3d).

All other models had significant land use*sub-region interactions. Annual plant cover was greatest in central CRP (x = 31%, SE 0.2) and northern grassland playas (x = 24%, SE 0.2); elsewhere annual plant cover ranged from 13-19% ($F_{4,421}$ = 4.06, P < 0.003, Fig. 3e). Perennial plant cover was 83% less in cropland than other land uses. Perennial cover was similar between grassland and CRP playas, except in the central sub-region, where grasslands had 20% greater cover than CRP playas ($F_{4,421}$ = 8.36, P < 0.001, Fig. 3f). Native plant cover was 300% greater in other land uses than in cropland playas. Grassland playas also had greater native cover than CRP, except in the southern sub-region where native cover was similar between grasslands and CRP ($F_{4,421}$ = 5.7, P < 0.001, Fig. 3g). Conversely, introduced plant cover was 400% greater in CRP playas than native grassland, while introduced cover generally was similar between grassland and cropland. The exception was in the central sub-region where croplands had three times greater cover of introduced species than grassland playas ($F_{4,421}$ = 3.43, P = 0.009, Fig. 3h).

Plant community composition in the Rainwater Basin: We observed 144 plant species in playa basins in the Rainwater Basin. Playas with cropland catchments had more upland plants and less wetland plants than playas in the other two land use types ($F_{2,78}$ = 12.55, P < 0.001 and $F_{2,78}$ = 12.69, P < 0.001, respectively, Fig. 4b). Cover of annual plants was 37% greater in cropland playas than the other two land use types ($F_{2,78}$ = 4.88, P = 0.01, Fig. 4c). Conversely, perennial plants in reference and WRP playas were more than double that in croplands ($F_{2,78}$ = 10.62, P < 0.001, Fig. 4c). Native plants had 50% less cover in cropland playas than in WRP and reference playas, while invasive plants had more than 300% greater cover in croplands than in other catchments ($F_{2,78}$ = 23.22, P < 0.001 and $F_{2,78}$ = 21.76, P < 0.001, respectively, Fig. 4d).

Community composition for individual species varied along CCA axes 1, 2, and 3 (F = 2.48, P = 0.002; Fig.5). Disturbance gradients loaded heavily onto axis one, with disturbance tolerant species more common on the right and disturbance intolerant species more common on left. Axis two contained additional information associated with land use type. CCA axis three contained information associated with survey time, which described very little variation in species composition and thus is not graphed here. Axis one accounted for 5 % of the total variance, while all three CCA axes together accounted for 17.2 % of total species composition variance.

Species richness: Species richness varied with playa area in the High Plains (Table 7, $F_{5,512}$ = 97.8, P < 0.001, R^2 = 0.49). Slopes of the relationship between richness and playa area (z-values) were similar for grassland and CRP playas and steeper for cropland playas. Intercepts (c-values) for the relationship between richness and playa area were similar for CRP and grassland, while cropland had lower c-values. In the Rainwater Basin, slopes were equal in all land uses, but the intercept was less in cropland playas than in the other two catchment types (Table 8, $F_{5,90} = 11.86$, $P < 0.001$, $R^2 = 0.40$).

Objective 3:

Frequency of encountering wet playas: In the western High Plains, playas in CRP were encountered wet 48% less often than other catchments ($N_{grass} = 40$; $N_{crop} = 39$; $N_{CRP} = 21$; $\chi 2 = 9.9$, df = 2, $P = 0.007$, Fig. 3a). We detected no difference in the number of inundated playas encountered between grassland and cropland playas. In the Rainwater Basin, we detected no difference in frequency of inundated playas encountered among land use types ($N_{reference} = 16$; $N_{crop} = 13$; $N_{WRP} = 16$; $\chi 2 = 0.75$, df = 2, $P = 0.69$, Fig. 4a). (Remember CRP is not present in the RWB.)

Volume of wetlands and volume loss (western High Plains): Patterns for original volume of playas was similar to that of playa area, with southern (P<0.001) and central (P<0.003) grassland playas having as much as six to eight times the volume as cropland and CRP playas, which did not differ from one another (Table 2). No land use effects were observed for playas in the north (P=0.153). Sub-region effects were also observed, with the largest volumes in southern playas (Table 2). Specifically, grassland playas in the south had four times the volume of those in the north (P=0.031), although central grassland playas did not differ from either northern or southern playas. Cropland (P=0.002) and CRP (P=0.003) playas in the south had about twice the volume of those in the central and northern sub-regions, although the later two did not differ from one another.

Sediment volume also showed a clear sub-region response for all land use types, with the highest volumes in south playas compared to those in the north (Table 2). Grassland playas (P<0.001) and CRP playas (P<0.001) in the south had about twice the sediment volume as central playas, which did not differ from northern playas. South cropland playas also had three times the sediment in central playas, which had about three times more sediment than northern cropland playas (P<0.001). Land use effects on sediment volume were observed in the north (P=0.040) and south (P=0.001), but not in the central sub-region (P=0.452). Northern CRP playas had twice the sediment volume as both cropland and grassland playas. Conversely, grassland and crop playas in the south had 70% more sediment than CRP playas (Table 2). However, this is largely due to size differences as is apparent in the percent volume loss analyses (see below). No land use effects on sediment volume were observed for central playas (P=0.452).

Percent volume loss only differed among sub-regions for cropland playas (*P*=0.002; Table 2). Southern cropland playas experienced the greatest volume loss, averaging 290%, four times more than northern cropland playas. Central cropland playas lost on average 175% of their volume, but did not significantly differ from either southern or northern cropland playas. Land use affected volume loss in playas in the south and central regions (Table 2). Southern cropland playas had about four times the volume loss as those in CRP or grassland watersheds (*P*<0.001). All land use types differed for central playas (*P*<0.001), as cropland playas had 46% more volume loss than CRP playas, which have experienced twice the volume loss of grassland playas. Finally, volume loss in northern playas did not differ among land use types (*P*=0.061).

Remaining volume in playas, as defined by the hydric soil, reflect a combination of the amount of sediment deposited into the basin and the original volume of playas. Only cropland playas demonstrated an effect due to sub-region, and south and central cropland playas averaged negative remaining volumes (*P*=0.003) (Table 2). Remaining volume of cropland playas in the north was about 2.5 times that of central cropland playas, which did not differ from playas in the south. Although not significantly different (*P*=0.162), south grassland playas had the most remaining volume, averaging over 60,000 m^3, twice that of central playas and four times that of northern grassland playas. Further, remaining volume of south (*P*<0.001) and central (*P*=0.003) grassland playas was several fold greater than both CRP and cropland playas, which did not differ from one another. The same land use trend was observed for northern playas, but differences were not significant (*P*=0.070).

Volume and depth of playas (RWB): Land use did not statistically affect mean playa depth ($F_{2,45}$=2.24, *P*=0.118), however, reference playas were on average 23% deeper than WRP playas, which in turn were 23% deeper than cropland playas (Table 4). Playa volume differed among land use types ($F_{2,45}$=5.82, *P*=0.006) as reference playas had eleven times the volume of cropland playas. WRP playas, despite having half the volume of reference playas and nearly six times the volume of cropland playas, were not significantly different from either of these land use types.

Water and sediment runoff simulations: Annual water and sediment runoff estimates generated using WEPP and RHEM demonstrated clear land use related differences, and sensitivity to soil type, slope, and watershed size (Fig. 6). Water and sediment runoff from cropland watersheds was always greater than for native grassland, with CRP showing the least water and sediment runoff. For example, water runoff from cropland ranged from about 100% to 300% greater than from native grassland, varying with changes in watershed size, slope, and soil type. Sediment runoff varied more, with 300% to nearly 7000% greater sediment runoff from cropland than native grassland. CRP reduced water and sediment runoff compared to cropland with reductions in water and sediment runoff ranging between about 80% and 100%. Not surprisingly, this effect was also observed when compared to native grassland, with reductions in runoff from CRP ranging from about 10 to 50% (sediment) and 40 to 50% (water). Although water and sediment runoff increased with watershed size for all land use types, the magnitude of this effect was most pronounced on cropland watersheds. Slope had marginal effects on water runoff, but pronounced effects on sediment runoff as 2% slopes produced 2 to 4-fold greater runoff than for 1% slopes on clay loam and sandy loam soils. This effect of slope was negligible on silt loam soils.

DISCUSSION

Objective 1

In the western High Plains, playas within cropland catchments predictably had the highest amount of sediment accumulation compared to playas within other land use catchments. The high sediment loads in cropland playas reflect the impact of cultivation of surrounding playa watersheds, facilitating significant sediment input from runoff and erosion of topsoil (Luo et al. 1997). Cropland playas also had the smallest identifiable hydric areas compared to the other catchment types, which may also reflect the severity with which the potential hydroperiod of these cropland playas has been impacted. Accumulation of sediment can overwhelm a wetland and alter or inhibit its normal hydroperiod and subsequent ecosystem functions as sites of biodiversity, flood-water catchments, and recharge points for underlying aquifers (Smith 2003). Therefore, it would be expected that effective playa conservation programs would be focused on reducing sedimentation to historical levels (e.g., as seen in native grassland playas) while preserving a natural hydroperiod.

In southern and central region CRP playas, sediment accumulation was found to be significantly less than sediment loads in cropland playas, but similar between watershed types in the north. Also, CRP playas in the south and central regions had significantly lower volume loss than cropland playas. Our results demonstrate that CRP is effective as a means to reduce sediment accumulation. However, CRP is causing shorter hydroperiods in those playas altering many other ecosystem services. This is because the largest input into the hydrological budget of a playa is watershed runoff. Currently, most CRP consists of exotic perennial grass (e.g., old world bluestem) which is typically taller and bulkier than native vegetation, and although very effective in reducing sediment accumulation, it also reduces water runoff into playas (Smith et al. 2011). This is supported by our model results and the frequency of inundation detected in CRP playas compared to cropland and grassland playas in this study. Less water runoff will inhibit the frequency of inundation and hydroperiod, negatively influencing the biodiversity service by reducing ecological diversity among playas. If future guidelines specify the use of native short-grass prairie plants in all CRP or similar conservation plantings, all services provided by playas in this land use would be more sustainable.

Sediment depth and size of playas in the RWB showed a similar trend as those in the western High Plains. Deeper sediments in cropland playas are expected given the lack of any barrier between the wetland and cultivated upland. This extensive sediment input was also evident in the reduction of wetland size in cropland. As discussed for western playas, large sediment inputs and reduced surface area of wetlands in cropland landscapes will negatively impact function and ecosystem services. Indeed, several cropland playas were essentially non-existent, with either no remaining visual edge or reduced to a negligible patch of wetland plants surrounded by cultivation. Management strategies that mitigate sediment input into wetlands can effectively slow this degradation. For example, WRP playas contained substantially less sediment than cropland playas, and although not a significant difference, were on average four times larger than cropland playas. Thus WRP playas on average are capable of supporting a greater level of ecosystem services than those in cropland catchments. The WRP practice that was most commonly used in the RWB was sediment removal. This practice effectively restored hydrology and has provided substantial benefit in this region. The WRP could provide similar benefits in the western High Plains if it was applied in that region.

Objective 2

Amphibians

The cumulative amphibian data collected for playas in the western High Plains were limited by the absence of inundated playas during sampling and also by the timing at which surveys occurred. Typically, playas do not fill with water every year due to relatively low annual precipitation and geographically variable occurrence of precipitation events in the Great Plains (Smith 2003). In addition, the reproductive cycles and larval periods of resident amphibians vary among species such that single sampling events likely do not capture the full spectrum of species that may colonize a given playa (Venne 2006). A comprehensive evaluation of amphibian community richness requires multiple sampling events from initial inundation until the playa dries or amphibian activity ceases for the season (Venne 2006).

Fourteen species of amphibians occur in the High Plains (Smith, 2003), seven of which were detected during our surveys of western playas. The most commonly detected species were *A. tigrinum* and *B. cognatus*, two of the four most common amphibian species in the Southern Great Plains (Gray et al. 2004). *B. cognatus* was found in similar frequency throughout playas in different catchment types, demonstrating the reproductive versatility of this species which exhibits a short, high-density, opportunistic mating pattern particularly adapted to short hydroperiods (Degenhardt et al. 1996). Additionally, *Rana blairi*, which require a longer hydroperiod for metamorphosis, were only detected in playas in native grassland catchments, which likely provide the needed longer hydroperiods more so than either cropland or CRP playas.

Overall, the mean richness of amphibian communities in cropland playas was about half that for native grassland and CRP playas, however our inability to statistically analyze any land use related effects preclude clear interpretation of these data. Despite the low number of wet playas in this study and the single sampling events, we detected comparable numbers of species as in previous studies designed to measure amphibian community richness. For example, a total of eight and 10 species were detected across 80 playas split between native grassland and cropland watersheds in a 2003 and 2004 study in the SHP (Venne 2006). The most notable difference between this study and previous amphibian studies was the lack of spadefoot toads (*Spea* spp.) detected across playa types. Spadefoot toads are typically observed in most wet playas, but can be easily missed by single sampling events due to their immediate breeding after inundation and short development period (e.g., 2-3 weeks). Therefore, it is likely that these species completed metamorphosis and left the playa environment before we started surveys on those particular wetlands.

It is worth noting however, that any robust assessment of land use effects on amphibian communities will require repeated monitoring of amphibians immediately following inundation, and evaluation of hydroperiod lengths of playas in different catchment types. Cumulative amphibian richness positively correlates with longer hydroperiods and average rates of playa inundation. For example, cumulative richness decreases rapidly when hydroperiods fall below 50 days in length as species with extended larval periods are unable to survive until metamorphosis (Venne 2006). One could predict that repeated occurrence of short hydroperiods (as in cropland playas) would eventually lead to loss of species with longer developmental periods. Similarly, if inundation frequency is reduced in CRP playas, as suggested by model simulations of water runoff and the lower number of inundated CRP playas in this study, certain amphibian species may not be available to colonize CRP playas when they do fill with water.

Plant community composition

In the western High Plains, species richness varied with land use and was reduced in cropland playas. This was reflected in lower intercept (c-values) in croplands vs. other land uses. C—values are the intercept in log-log space for the relationship between species richness and area, but reflect the slope of the relationship in arithmetic space (i.e., they are the rate determining factor in the equation $S = cA^z$), and are more important for determining area corrected species density than z-values (Rosenzweig 1995). Therefore, there were more species per unit area in grassland and CRP than in cropland. This implies that CRP catchments increase richness relative to the cropland catchments they replace, although many CRP plants are introduced, upland species (see discussion below). This differs from results in an earlier playa study that compared cropland to grassland plant communities in playas of the south and central High Plains sub-regions of this study (Smith and Haukos 2002). In the earlier study, croplands had similar richness to grassland catchments. However, Smith and Haukos (2002) excluded cultivated basins from their cropland samples. This misrepresents the condition of most cropland playas, because cultivating wetland basins is common. Further, in our study, uncultivated cropland playas still had lower richness than grassland and CRP playas.

Z-values for plant richness also varied with land use, averaging 0.14 in CRP and grassland, and 0.48 in cropland. Z-values typically range from 0.15 to 0.6, with larger values more common in isolated habitats and smaller values more common in habitats contiguous to large species pools (Rosenzweig 1995). Larger z-values in cropland playas may reflect increased isolation from non-crop species pools, causing cropland playas to act more like islands. However, disturbance such as cultivation also can alter z-values. For example, de Bello et al (2007) demonstrated that in semi-arid landscapes, intense grazing disturbance increased z-values. In general, differing c and z-values in croplands imply that decreased species richness results from a reduction in ecosystem function beyond what might be expected from a reduction in area.

Plant composition also differed by sub-region and land use perhaps because land use changes also altered disturbance regimes. To understand how land use could influence plant communities, we first describe playas in native grasslands, our reference condition. Grassland playas were dominated by perennial, native plants. Cover of wetland relative to upland plants varied from slightly more upland plants in the south, to roughly equal in the central sub-region, to more wetland plants in the north. This may relate to evaporation gradients, which are greater in the south than the north. We also expect natural fluctuation in hydroperiods in the semi-arid High Plains where precipitation is infrequent and unpredictable. Wetland plants in grassland playas are common during inundation, and upland plants germinate during extended dry periods. In native grassland playas, we expect perennial species to be prevalent during static dry conditions (upland plants) or during extended wet periods (wetland emergents). Annuals are less common, dominating grassland playas only during the moist soil phase of playa hydrology.

Cropland playas, in contrast, had low cover of non-crop plants and increased cover of bare ground and crops. Both plowed and unplowed cropland playas had reduced plant cover, though cultivated playas had substantially less cover. Reduced plant cover in unplowed playas may be from crop recruitment in wetland basins, as a result either of crop seed in wetland sediments, or of previous cultivation. Additionally, unplowed playas only were uncultivated at the sampling period, perhaps because the playa was too wet to plow. This is supported by greater cover of wetland plants relative to upland plants in cropland playas. In accordance with the Swampbuster provision, which allows cultivation of dry wetlands, such playas may be plowed in future seasons (Glaser 1985). Playas have natural wet and dry fluctuations. Therefore, Swampbuster provides little protection to playas from a cultivation perspective.

Of the non-crop plants present in cropland playas, annuals and introduced species were more common. The high prevalence of annuals versus perennials suggests cultivation disturbance prevents both perennial wetland and upland plants from establishing. Further, our modeling results suggest upland run-off, and therefore probably also initial frequency of inundation, may be higher in croplands. Reduced cropland playa volume also increases both water surface area and evaporation, causing higher water loss rates (Tsai et al. 2007) which may increase the prevalence of mudflat conditions in cropland playas, promoting moist-soil annual plant production. Such frequent wet-drying events also may prevent both wetland and upland perennial plants from establishing. In general, this demonstrates that biodiversity is severely reduced in cropland playas. Moreover, cropland playas have reduced areas and depths due to accumulated sediments. This limits water volume and ecosystem functions that rely on wetland plants, such as nutrient cycling. Habitat for wetland wildlife may be severely reduced in cropland playas because there is little plant cover. Swampbuster provisions permit plowing of dry wetlands, provided it does not result in “the destruction of natural wetland characteristics” (Glaser 1985). Our data suggest cultivating playa basins causes destruction of wetland characteristics, and therefore, should be prohibited under Swampbuster.

CRP playas, in contrast, were dominated by perennial and introduced plants. Numbers of annuals were similar only to perennials in central CRP playas. CRP also had greater upland than wetland plant cover. This is supported by our playa inundation results showing that water ponded 48% less often in CRP catchments. This allowed persistence of introduced grasses in wetlands, particularly because introduced grasses were frequently planted in playas (Smith et al. 2011). Reduced water ponding may partially be attributed to lower volumes of CRP playas resulting from sediments imported during the agricultural phase of CRP history. However, CRP playas also were wet less often than cropland playas, suggesting that upland CRP plant assemblages prevent water runoff and dry CRP playas more than sedimentation. Introduced upland plant cover was greatest in CRP and is likely altering function by reducing overland runoff that reaches playas. We also observed increased plant biomass in CRP playas because of the persistence of tall, mostly introduced, grasses rather than native wetland species in playas. This is an ecosystem service trade-off. CRP catchments will trap more precipitation and prevent flooding to a greater degree than other catchments but CRP will shorten playa hydroperiods, allowing persistence of introduced species. Introduced species in playas are problematic because they commonly alter ecosystem properties and disturbance regimes (Lodge 1993, D’Antonio and Meyerson 2002). Here, introduced species play a similar role by reducing water available on the landscape, thereby influencing all other ecosystem attributes. This is troublesome in a landscape where water is limited and cultivation places high demand on water-use (Ryder 1996).

In the RWB, reference playas were dominated by native wetland perennials and had greater average species richness of plants (i.e., c values) than observed in the western High Plains. RWB playas have more elevational heterogeneity than western High Plains playas likely creating more hydric zones and increasing diversity (Smith 2003). This also suggests that playas in the RWB are wetter on average than those in the western High Plains, which is supported by annual rainfall patterns between the regions. In addition, many wetlands are provided supplemental water in the RWB. State and federal conservation agencies actively pump water into playas to provide habitat for birds during spring migration. Cropland playas in the RWB were dominated by annuals with roughly equal proportions of native and introduced plants and slightly more wetland than upland plants. This suggests that cropland playas in the RWB are drier than reference playas, though likely only slightly so as inundation frequency did not differ between the two. The high percentage of upland annuals rather than upland perennials was due to a predominance of annual crops in these playas. Excluding crops from cover estimates increases the proportion of perennial plants, but not to the extent seen in reference playas. As was demonstrated in High Plains cropland playas, plant cover is less than in other catchments while bare soil was higher. Species richness also is less than that seen in RWB reference playas. Low species richness and domination by annual plants also further demonstrates that disturbance from plowing, planting, and harvesting prevents establishment of perennial playa plants and encourages encroachment by introduced species.

WRP playas, like reference playas, were dominated by wetland perennial natives and had similar species diversity relationships as grassland playas, suggesting that these playas may be approaching the reference condition biodiversity. However, multivariate community analyses suggest that these communities contain different species sets. There are clear plant groups surrounding each catchment type, showing that species distributions are not similar in all catchments. In particular certain plant guilds seem under-represented in WRP sites. These results mirror those of Galatowitsch (2006) in prairie potholes. She found that prairie pothole sedge-meadow species, several of which we also observed in the Rainwater basin, such as *Leersia oryzoides, Carex vulpinoidea, and Helianthus grosseserratus* are dispersal limited and do not readily colonize restoration sites by natural means. We see similar patterns in our data, where the above three species are present in reference sites, but not in WRP sites.

Objective 3

Overall, western High Plains playas in all land use types were larger in the south, a result strongly influenced by larger southern grassland playas. Larger playas in the south likely stem from a natural gradient in playa size, and larger grassland playas in the south may be further influenced by the relative ease of cultivating through smaller playas and concomitant difficulty in cultivating around and through large, deeply incised playas. These larger playas have greater storage capacity, particularly those in native grassland watersheds, and thus a potential for greater provisioning of ecosystem services. Larger playas and more storage capacity in southern playas provide useful information for strategically allocating resources directed at playa conservation, as these playas will hold more water and thus provide more long-term services.

We also observed land use related effects on playa characteristics, both in the western High Plains and RWB. Properly functioning playas fluctuate through wet and dry periods and their ability to receive and store water for a period of time is critical to supporting the biotic cycles that rely on these wetlands. Continual accumulation of sediments in playas overwhelms any natural loss of sediments from wind deflation, ultimately rendering the playa non-functional, or fossilized. Although, we observed essentially similar sediment volumes between grassland and cropland playas across all sub-regions in the western High Plains, this response was reflective of the interaction between playa area and sediment depth. Despite that similarity however, the accumulation and greater depth of sediment in cropland playas resulted in an overall average volume loss of 200% compared to less than 100% in CRP and native grassland. This same trend was observed for remaining volume in RWB playas as cropland playa volumes were roughly 10% and 20% of that seen in reference and WRP playas, respectively. This level of volume loss and the resulting effect on remaining volume in cropland playas shows a progressive trend toward fossilization. Indeed, many cropland playas in the western High Plains and RWB were actively being cultivated at the time of sampling and had little to no discernable visual edge. Increased sediment loads and resulting volume loss spread water over a larger area, increasing water loss rates through evaporation and possibly infiltration, resulting in shorter hydroperiods (Tsai et al. 2007).

Compared to cropland playas, the positive effects of CRP and WRP on volume loss and sediment depth demonstrate the protection from sediment accumulation afforded playas when removed from cultivation and by stabilizing upland soil. Results from models for prairie potholes in cropland and CRP/WRP catchments show the same protective effects of these USDA conservation programs on sedimentation, with over 90% mean reduction in soil loss from CRP/WRP uplands compared to cropland (Tangen and Gleason, 2008). As noted above however CRP plantings often consisted of tall, dense grasses which inhibited runoff of precipitation in addition to sediment (Cariveau et al. 2011, Smith et al. 2011). Our model results show that although annual sediment runoff on CRP is less than native grassland, the magnitude of the difference is negligible (e.g., 20 vs. 15 m^3 of sediment from clay loam and a 314 ha watershed with 2% slope). Conversely, under the same conditions, precipitation runoff on CRP is about 225,000 m^3, about half that for native grassland and representing a major loss of water input to a playa. These projections are further supported by empirical observations on inundation frequency, wherein inundated CRP playas were encountered half as often as inundated crop and native grassland playas. These results demonstrate the protection of playas provided by CRP toward sediment input, but also the need to be strategic about the type of plants used in CRP plantings. Native mixes of short-grass species will facilitate increased water runoff into playas while also stabilizing the soil, thus increasing the frequency of inundation and sustainability of playa function.

CONCLUSIONS

Cultivation agriculture has clearly altered or eliminated wetland services provided by most playa wetlands in the High Plains. Therefore, the potential for USDA programs and practices to improve societal ecosystem services provided by these wetlands is immense especially considering that this region has the densest CRP enrollments nationally. However, under current CRP practices in the western High Plains the effects of this program has been variable. This is primarily due to the planting of exotic grasses in playa watersheds and basins. WRP is prevalent only in the RWB of Nebraska in the High Plains and favorable effects have been seen for most studied services. The WRP would provide similar benefits if applied in the western High Plains playas.

The effects of planting exotic perennial grasses in CRP has resulted in wide trade-offs in the services provided by playas. For example, although CRP has effectively reduced sediment loads in playas, enhancing the floodwater storage and biomass services, it has also reduced the amount of water entering playas reducing biodiversity provisioning and potentially reducing the amount of water available for aquifer recharge. Playa basins are believed to be the primary sites of focused recharge in the High Plains. Replanting native short-grass prairie species surrounding playas would prevent unsustainable sediment accumulation and allow water runoff to enter playa basins, restoring biodiversity provisioning and potentially recharge.

In the western High Plains, plant cover also differed somewhat by sub-region. Such differences likely are explained by community assembly rules defined by patterns in environmental gradients. Assembly rules describe how species tolerances to environmental conditions filter species pools into observed communities (van der Valk 1981). For example, regional differences in plant cover show that proportion of annual, perennial, native and introduced species generally increased from south to north, while bare ground decreased. This pattern may follow variation in soil texture, growing season length, and solar radiation (which influences temperature and evaporation rates). Precipitation, another filter for plant recruitment, generally increases from west to east, rather than south to north in the High Plains, but is highly variable. For example in our study, upland plant cover was greatest in the central region and wetland plant cover was greatest in grassland playas of the northern region. This probably followed precipitation patterns during our sampling period. Regional precipitation patterns vary yearly in the High Plains and patterns will likely alter in subsequent years.

The potential to use WRP in the western High Plains is great. The application of this program in the western High Plains would provide immediate benefits for all services provided by playas as well as diversifying local economies (Smith et al. 2011). Moreover, strengthening the Swampbuster provision by restricting planting of domestic crops in wetlands in the region would improve most playa services.

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Table 1. Mean (±SE) summary statistics for physical attributes of playas sampled in Texas, New Mexico, Oklahoma, Kansas, Colorado, and Nebraska from 2008 through 2010. Data are presented by region (north, central, and south) and dominant land use type in surrounding watershed (native grassland, cropland, and Conservation Reserve Program, CRP).

	Grassland	Cropland	CRP
North			
n	14	15	15
Playa area (ha)	3.8 (0.7)	2.5 (0.4)	4.5 (1.4)
Playa volume (m^3)	19563 (6446)	17669 (11140)	12265 (4297)
Sediment depth (cm)	6.3 (0.9)	11.2 (1.4)	15.1 (2.0)
Sediment volume (m^3)	2463 (561)	3262 (882)	5421 (1348)
Volume loss (%)	30.8 (9.0)	67.3 (16.7)	84.8 (19.7)
Remaining volume (m^3)	17100 (6135)	14407 (10378)	6843 (3064)
Central			
n	33	33	33
Playa area (ha)	10.5 (2.2)	3.6 (0.3)	4.6 (0.7)
Playa volume (m^3)	68695 (26085)	5929 (975)	15289 (2998)
Sediment depth (cm)	11.2 (1.3)	22.7 (1.9)	18.5 (1.2)
Sediment volume (m^3)	12882 (3046)	8668 (1133)	8623 (1445)
Volume loss (%)	55.7 (9.4)	175.0 (20.8)	607.3 (487.8)
Remaining volume (m^3)	55813 (24819)	-2740 (923)	6666 (2371)
South			
n	39	38	38
Playa area (ha)	18.1 (1.8)	5.9 (0.4)	7.1 (0.3)
Playa volume (m^3)	85582 (16383)	15512 (2647)	28866 (3306)
Sediment depth (cm)	13.9 (0.8)	48.0 (2.8)	21.8 (0.7)
Sediment volume (m^3)	24776 (3175)	24166 (1949)	14246 (814)
Volume loss (%)	54.0 (6.4)	289.8 (45.6)	68.3 (6.5)
Remaining volume (m^3)	60806 (15074)	-8653 (2682)	14620 (2872)

Table 2. Mean (±SE) summary statistics for physical attributes of playas sampled in Texas, New Mexico, Oklahoma, Kansas, Colorado, and Nebraska from 2008 through 2010, **excluding outliers** (one cropland playa in the north, and one grassland and one CRP playa in the central region). Data are presented by region (north, central, and south) and dominant land use type in surrounding watershed (native grassland, cropland, and Conservation Reserve Program, CRP). Uppercase letters designate differences among land use types within regions (land use effects), while lower case letters designate differences within the same land use across regions (sub-region effects) ($P \leq 0.05$).

	Grassland	Cropland	CRP
North			
n	14	14	15
Playa area (ha)	3.8 (0.7) A a	2.3 (0.3) A a	4.5 (1.4) A a
Playa volume (m^3)	19563 (6446) A a	6640 (1687) A a	12265 (4297) A a
Sediment depth (cm)	6.3 (0.9) A a	10.9 (1.5) B a	15.1 (2.0) B a
Sediment volume (m^3)	2463 (561) A a	2509 (494) A a	5421 (1348) B a
Volume loss (%)	30.8 (9.0) A a	71.5 (17.3) A a	84.8 (19.7) A a
Remaining volume (m^3)	17100 (6135) A a	4132 (1563) A a	6843 (3064) A a
Central			
n	32	33	32
Playa area (ha)	10.7 (2.2) A b	3.6 (0.3) B a	4.8 (0.7) B a
Playa volume (m^3)	46653 (14391) A ab	5929 (975) B a	15767 (3054) B a
Sediment depth (cm)	11.0 (1.3) A b	22.7 (1.9) B b	18.4 (1.3) C ab
Sediment volume (m^3)	11891 (2972) A a	8668 (1133) A b	8888 (1466) A a
Volume loss (%)	57.2 (9.6) A a	175.0 (20.8) B ab	119.9 (22.3) C a
Remaining volume (m^3)	34761 (13565) A a	-2740 (923) B b	6879 (2436) B a
South			
n	39	38	38
Playa area (ha)	18.1 (1.8) A c	5.9 (0.4) B b	7.1 (0.3) B b
Playa volume (m^3)	85582 (16383) A b	15512 (2647) B b	28866 (3306) B b
Sediment depth (cm)	13.9 (0.8) A b	48.0 (2.8) B c	21.8 (0.7) C b
Sediment volume (m^3)	24776 (3175) A b	24166 (1949) A c	14246 (814) B b
Volume loss (%)	54.0 (6.4) A a	289.8 (45.6) B b	68.3 (6.5) A a
Remaining volume (m^3)	60806 (15074) A a	-8653 (2682) B b	14620 (2872) B a

Table 3. Pooled mean (±SE) summary statistics for physical attributes of playas sampled in Texas, New Mexico, Oklahoma, Kansas, Colorado, and Nebraska from 2008 through 2010, **excluding outliers** (one cropland playa in the north, and one grassland and one CRP playa in the central region). Data are pooled by region (north, central, and south) and dominant land use type in surrounding watershed (native grassland, cropland, and Conservation Reserve Program, CRP).

	North	**Central**	**South**
n	43	97	115
Playa area (ha)	3.6 (0.5)	6.3 (0.8)	10.4 (0.8)
Playa volume (m^3)	12810 (2697)	22609 (5128)	43688 (6358)
Sediment depth (cm)	10.8 (1.0)	17.4 (1.0)	27.8 (1.7)
Sediment volume (m^3)	3510 (561)	9804 (1157)	21095 (1350)
Volume loss (%)	62.9 (9.8)	118.0 (11.7)	136.7 (18.3)
Remaining volume (m^3)	9300 (2421)	12805 (4792)	22593 (5891)
	Grassland	**Cropland**	**CRP**
n	85	85	85
Playa area (ha)	12.9 (1.3)	4.4 (0.3)	5.8 (0.4)
Playa volume (m^3)	60053 (9650)	10330 (1361)	21005 (2146)
Sediment depth (cm)	11.5 (0.7)	32.1 (2.2)	19.3 (0.7)
Sediment volume (m^3)	16250 (2045)	14582 (1371)	10671 (789)
Volume loss (%)	51.4 (5.0)	209.3 (23.6)	90.7 (9.8)
Remaining volume (m^3)	43802 (8777)	-4252 (1362)	10334 (1703)

Table 4. Mean (±SE) summary statistics for physical attributes of playas sampled in the Rainwater Basin of Nebraska in 2011. Data are presented by dominant land use type in surrounding watershed (reference, cropland, and Wetland Reserve Program, WRP).

	Reference	Cropland	WRP
n[1]	16	16	16
Playa area (ha)	26.1 (6.7)	4.3 (1.5)	16.4 (3.8)
Sediment depth (cm)	3.4 (0.6)	21.7 (6.3)	2.4 (0.6)
Depth to clay (cm)	17.6 (3.5)	29.9 (5.5)	21.0 (3.7)
Playa depth (cm)	43.6 (5.4)	28.8 (5.7)	35.4 (3.5)
Remaining volume (m^3)	117259 (34230)	10610 (2942)	58010 (17044)

[1]n=16 except for cropland sediment depth and depth to clay for all land use types (n=15).

Table 5. Species richness of amphibians in playas of native grassland, cropland, and CRP dominated watersheds surveyed in Texas, Oklahoma, and New Mexico in 2008 and reference, cropland, and WRP dominated wetlands in the Rainwater Basin of Nebraska in 2009.

	n*	Min observed	Max observed	Mean # species observed
Land use				
Texas/New Mexico/Oklahoma				
Cropland	6	0	3	1.2
Native grassland	6	0	4	2.3
CRP	2	1	3	2.0
Cumulative	14	0	4	1.8
Rainwater Basin				
Cropland	10	0	4	1.7
Reference	12	1	4	2.3
WRP	12	0	5	3.0
Cumulative	34	0	5	2.4

* number of wet playas sampled in each land use type

† min and max represent the species observed per playa at time of survey

Table 6. Occurrence of amphibian species in wet playas in native grassland (n=6), cropland (n=6), and Conservation Reserve Program (CRP; n=2) dominated watersheds surveyed in Texas, Oklahoma, and New Mexico in 2008 and reference (n=10), cropland (n=12), and WRP (n=12) playas in the Rainwater Basin of Nebraska in 2009.

	Occurrence* per land use			
	Cropland	Native grass/Reference	CRP/WRP	Total
Species†				
Texas/New Mexico/Oklahoma				
Ambystoma tigrinum larvae	2	3	1	6
Spea multiplicata	-	2	-	2
Spea bombifrons	1	2	-	3
Pseudacris clarkii	1	1	-	2
Rana blairi	-	2	-	2
Bufo cognatus	2	2	2	6
Scaphiopus couchii	-	1	-	1
Spea spp. larvae	1	1	1	3
Rainwater Basin				
Ambystoma tigrinum	0	1	0	1
Pseudacris triseriata	9	12	10	31
Acris crepitans	1	0	1	2
Rana blairi	3	4	8	15
Rana catesbiana	0	2	3	5
Hyla chrysoscelis	3	5	5	13
Bufo woodhousii	1	4	9	14

* number of playas with species present at time of surveying.

† adults or metamorphs (Gossner stage 42-46) unless otherwise indicated as larval

Table 7. Log-log relationship of plant species richness with playa area (ha) among different land uses in the western High Plains (N = 174 surveys, 2 surveys/playa). Uppercase letters indicate significant differences across land uses (*P* < 0.05).

Land use	Slope (z)	95 % CI of slope	Intercept (c)	95 % CI of intercept
Grassland	0.12 A	0.06 – 0.18	2.67 A	2.52 – 2.83
CRP	0.15 A	0.09 – 0.21	2.55 A	2.41 – 2.69
Cropland	0.48 B	0.39 – 0.57	1.22 B	1.03 – 1.42

Table 8. Log-log relationship of plant species richness with playa area (ha) among different land uses in the Rainwater Basin (N = 96 surveys, 2 surveys/playa). Uppercase letters indicate significant differences across land uses (*P* < 0.05).

Land use	Slope (z)	95 % CI of slope	Intercept (c)	95 % CI of intercept
Reference	0.12 A	0.04 – 0.19	3.29 A	2.77 – 3.81
WRP	0.12 A	0.04 – 0.19	3.29 A	2.77 – 3.81
Cropland	0.12 A	0.04 – 0.19	2.61 B	2.44 – 2.78

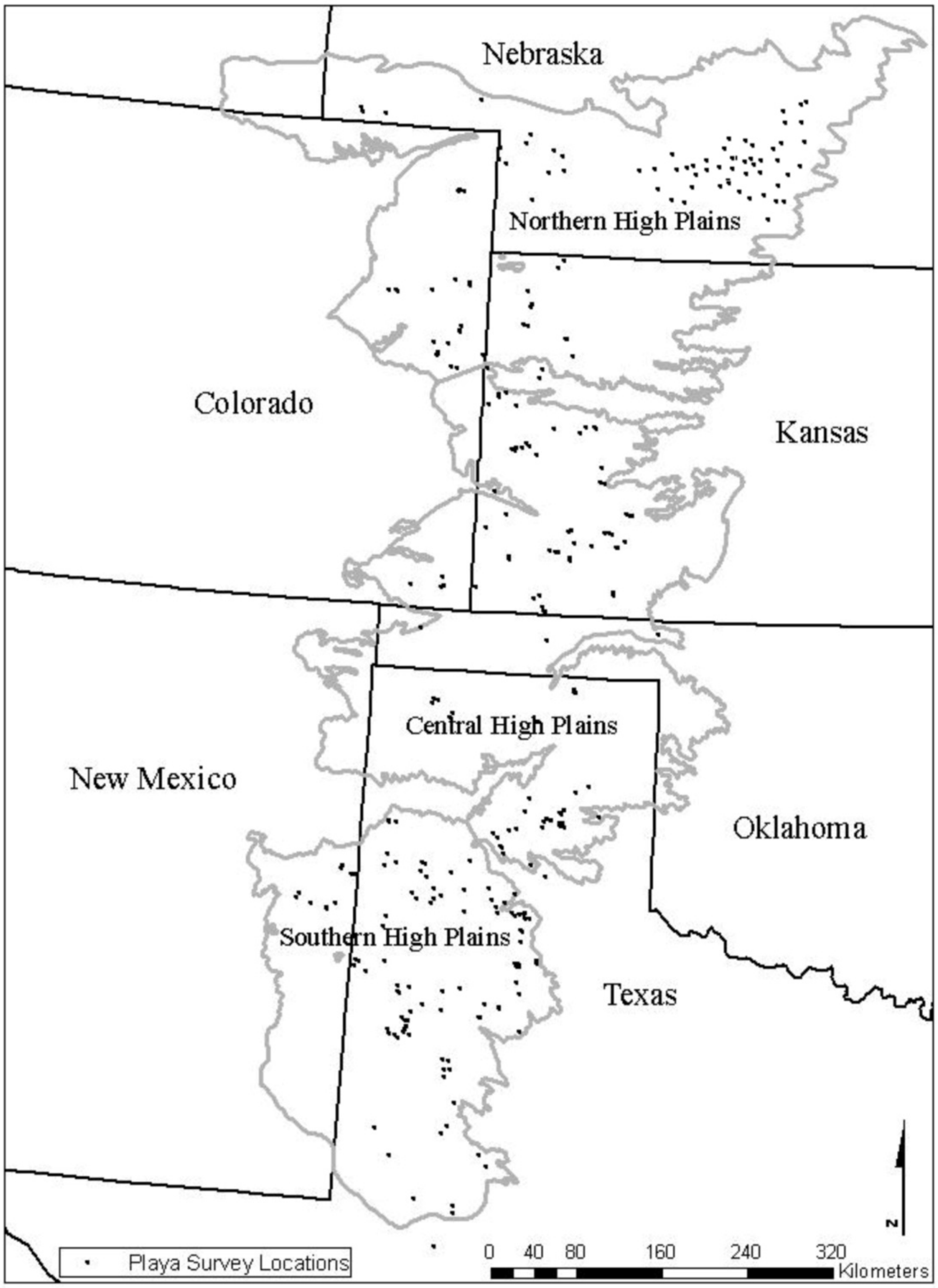


Figure 1. Locations of playas surveyed (N > 300) for plant community composition (modified from Smith et. al (2011a), created by M. McLachlan, Playa Lakes Joint Venture)

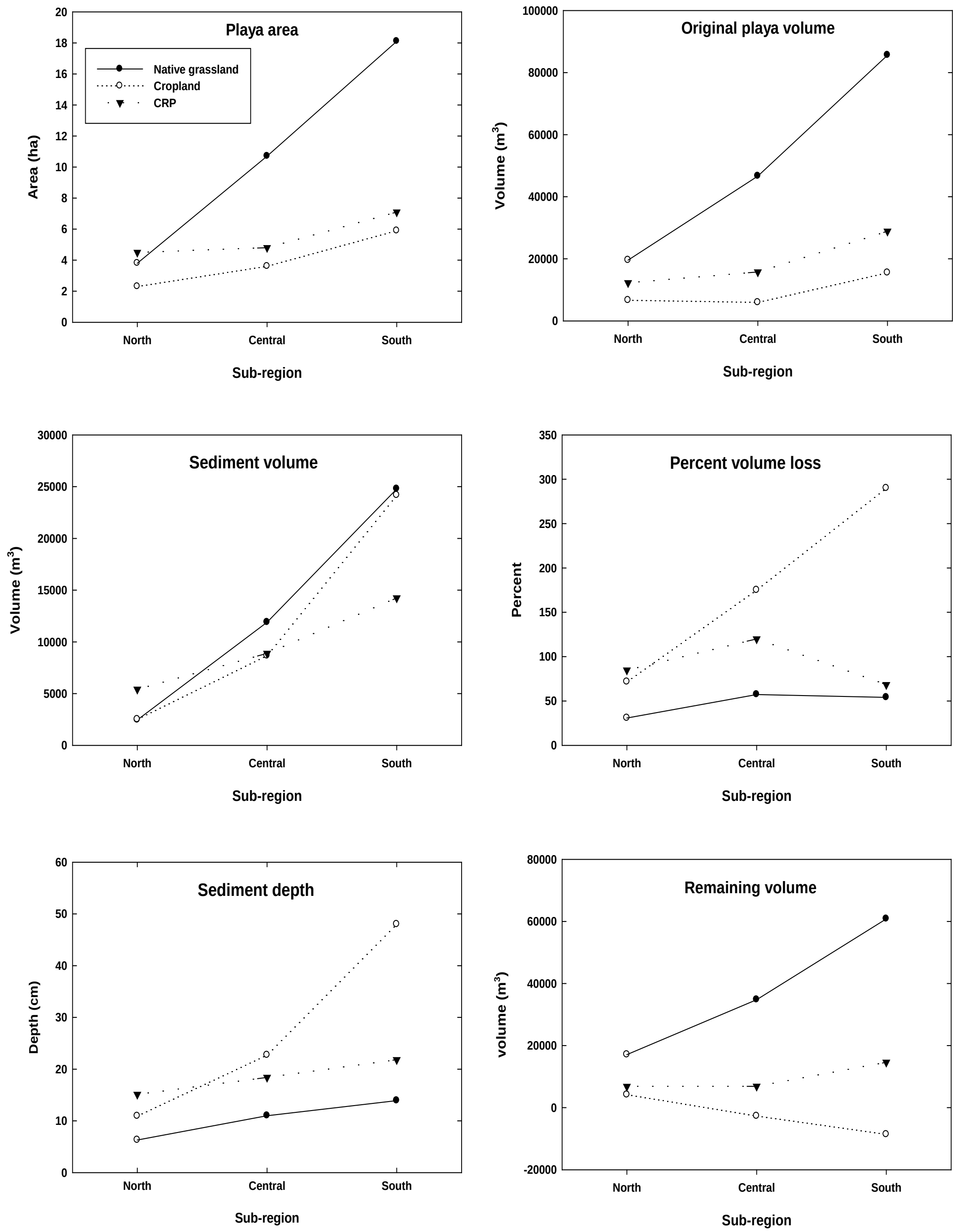
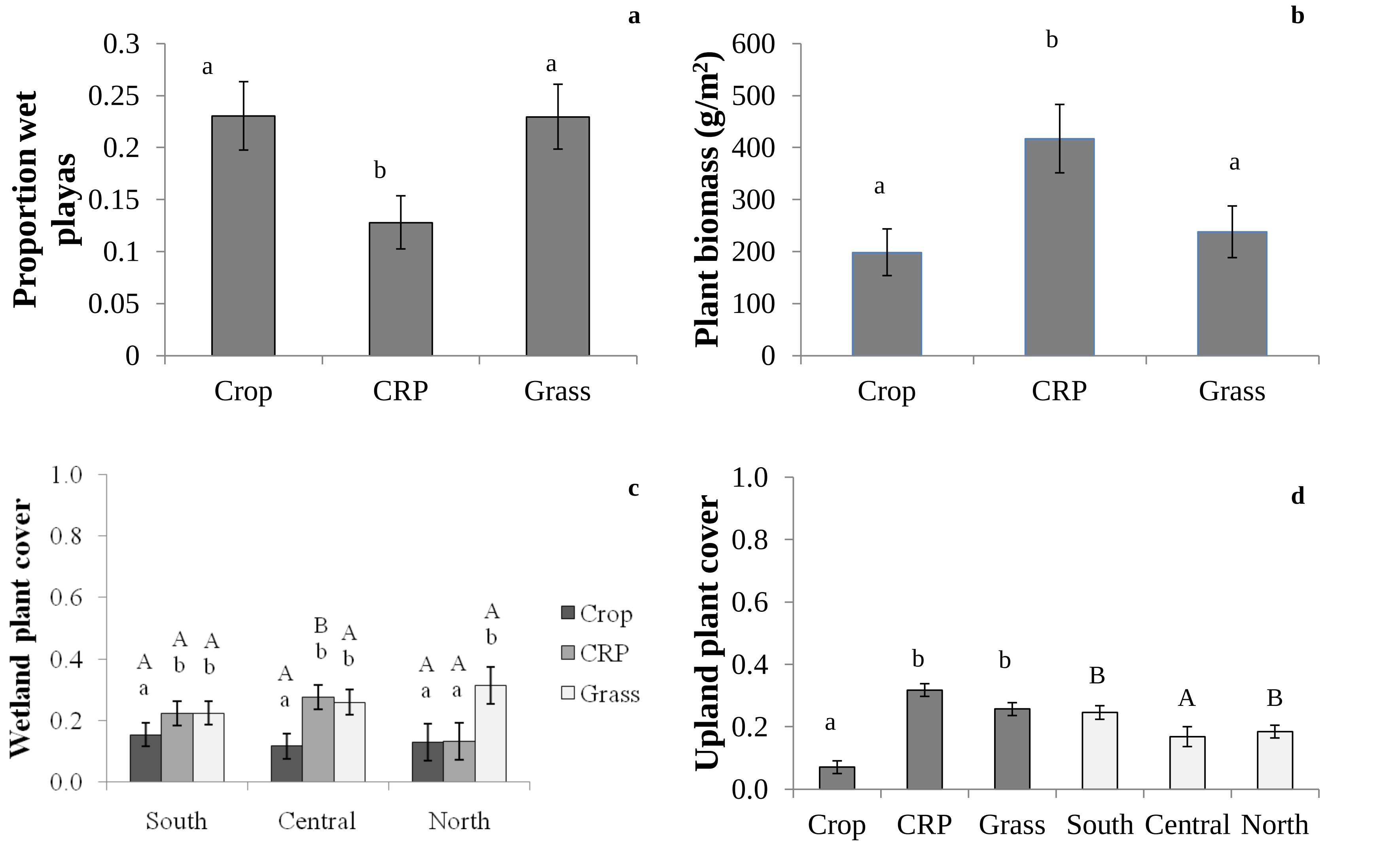


Figure 2. Mean values for selected characteristics of western High Plains playas by dominant land use and sub-region. Means are from Table 2 and presented as an aid for interpreting main effects and interactions (see results for Objective 1 and 3 in text).

Figure 3. See next page for legend.



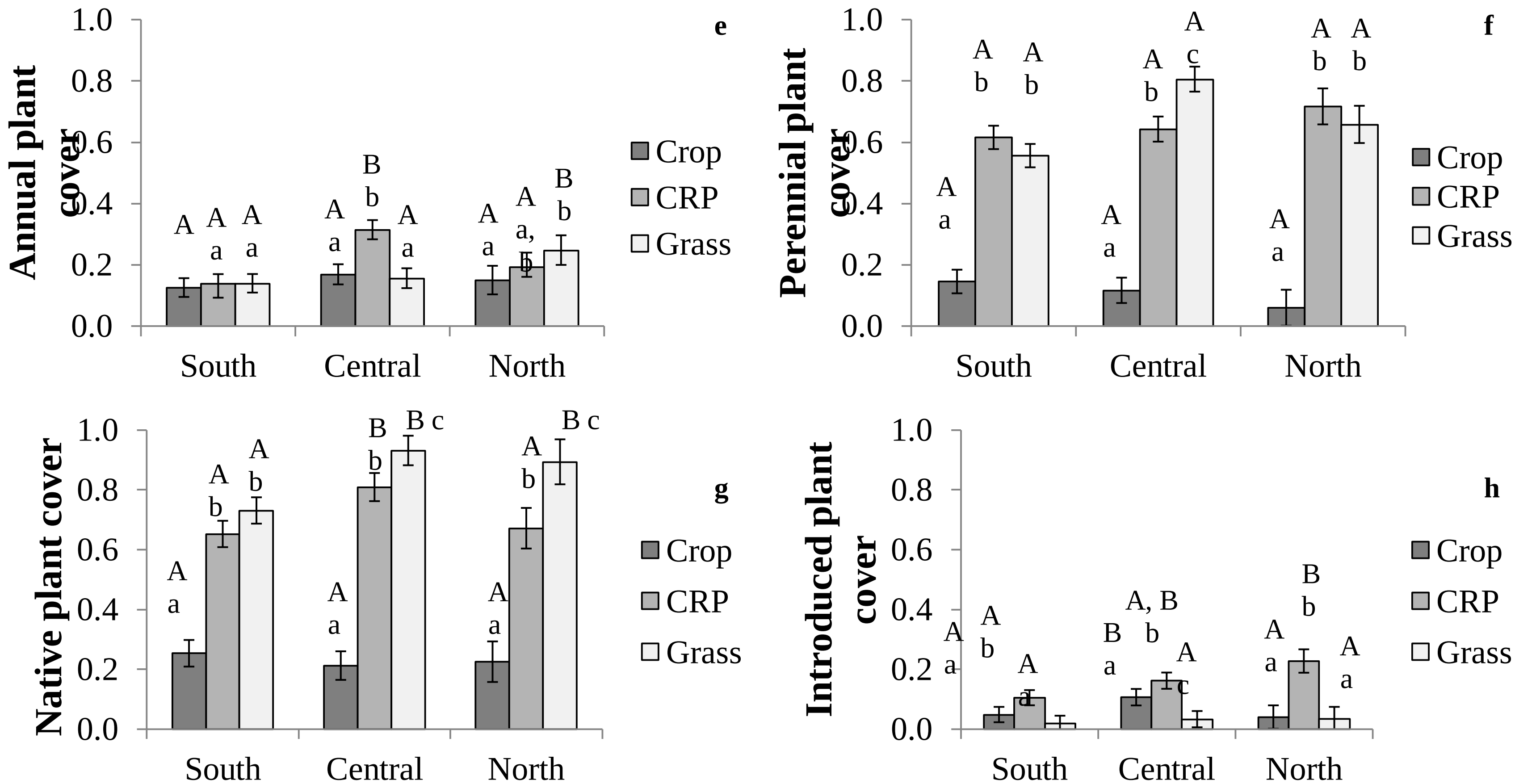


Figure 3. Mean (± SE) among playas of different land uses and different regions of a) percent wet playas; b) aboveground biomass; significant models for land use, region, or region*land use interactions for cover of c) wetland plants; d) upland plants; e) annual plants; f) perennial plants; g) native plants; h) introduced plants. Uppercase letters designate differences of the same land use across regions (P < 0.05), while lower case letters designate differences among land use types within regions.

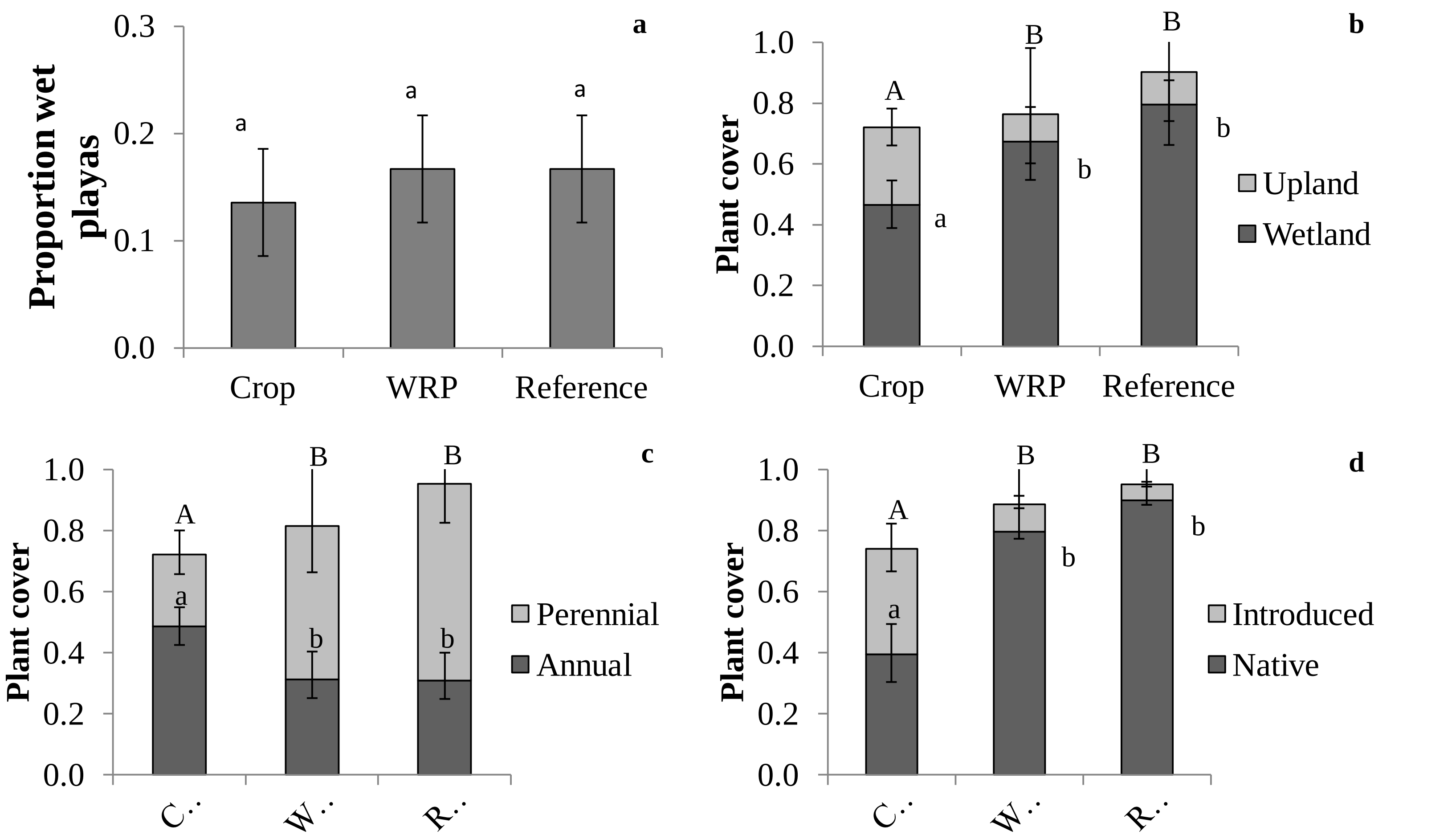


Figure 4. Mean (±SE) cover of plants in the Rainwater Basin among playas of different land use of a) wetland and upland plants; b) annual and perennial plants; and c) native and introduced plants. Similar means are marked with the same letter ($P > 0.05$).

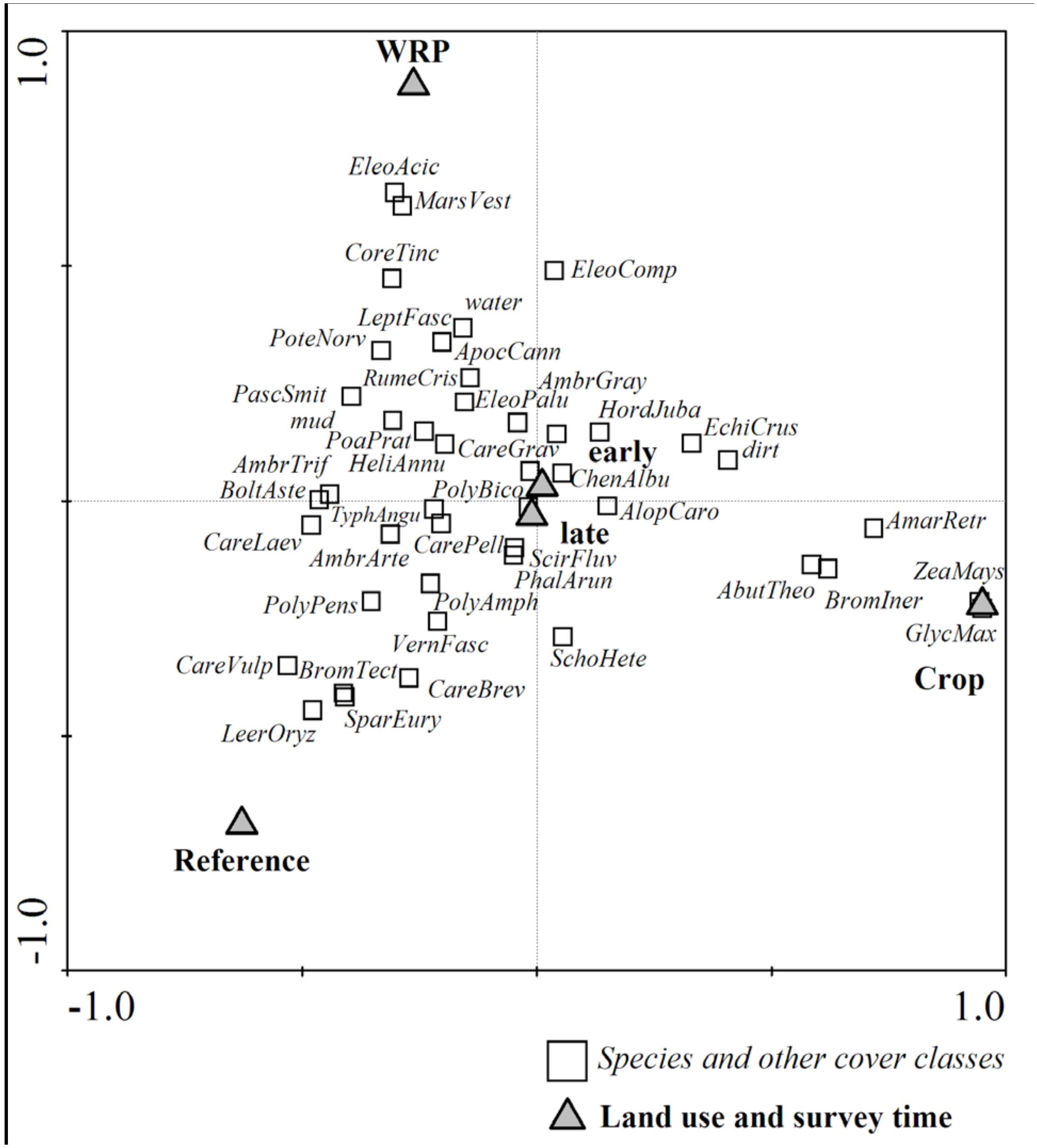


Figure 5. Centroids for plant species cover in the Rainwater Basin as a function of the first and second CCA axis, where land use and survey time are explanatory factors. For readability, species names are shortened into the first four letters of the genus and species. See Appendix 2 for full species names.

Fig. 6. See page 39 for legend.

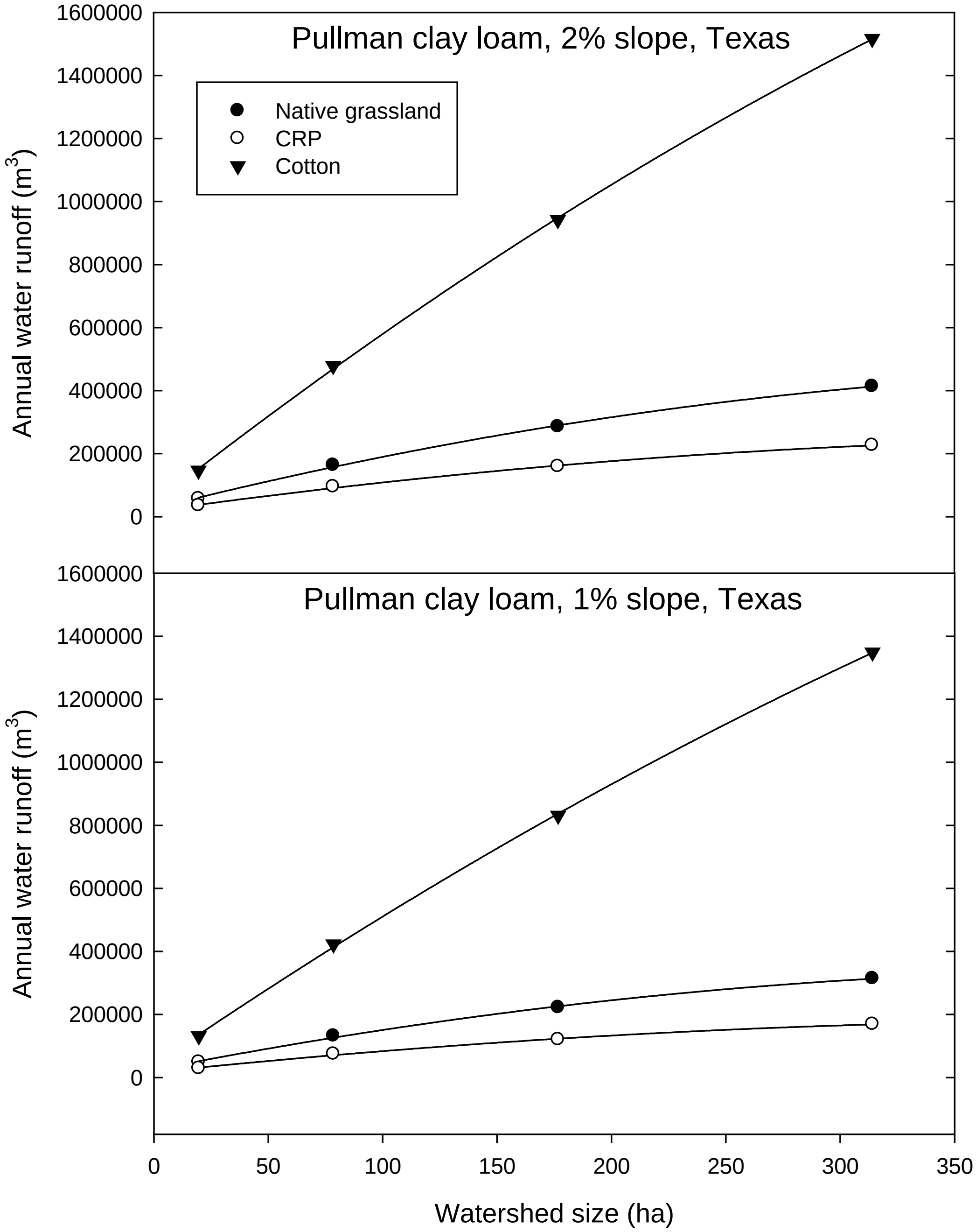


Fig. 6. See page 39 for legend.

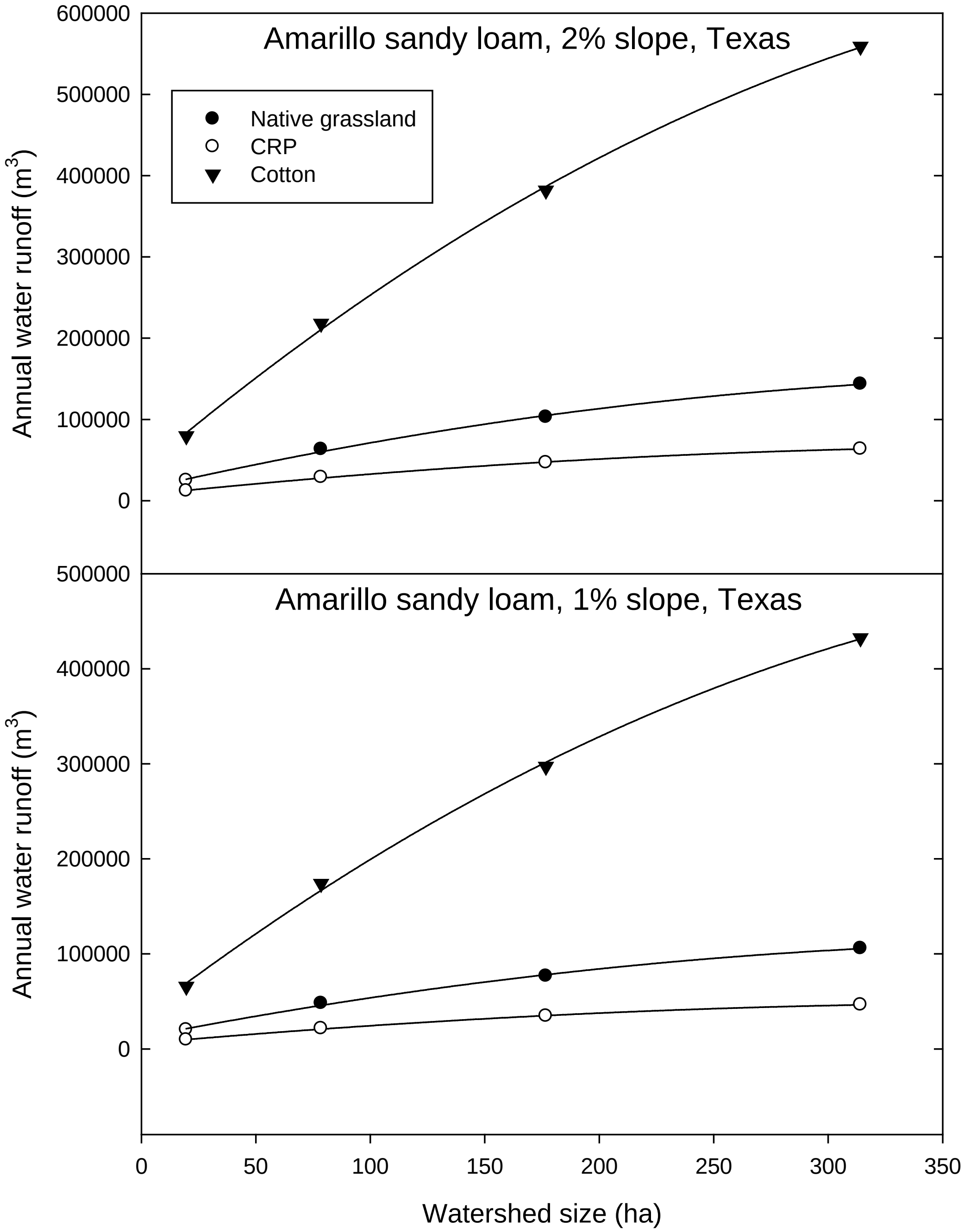


Fig. 6. See page 39 for legend.

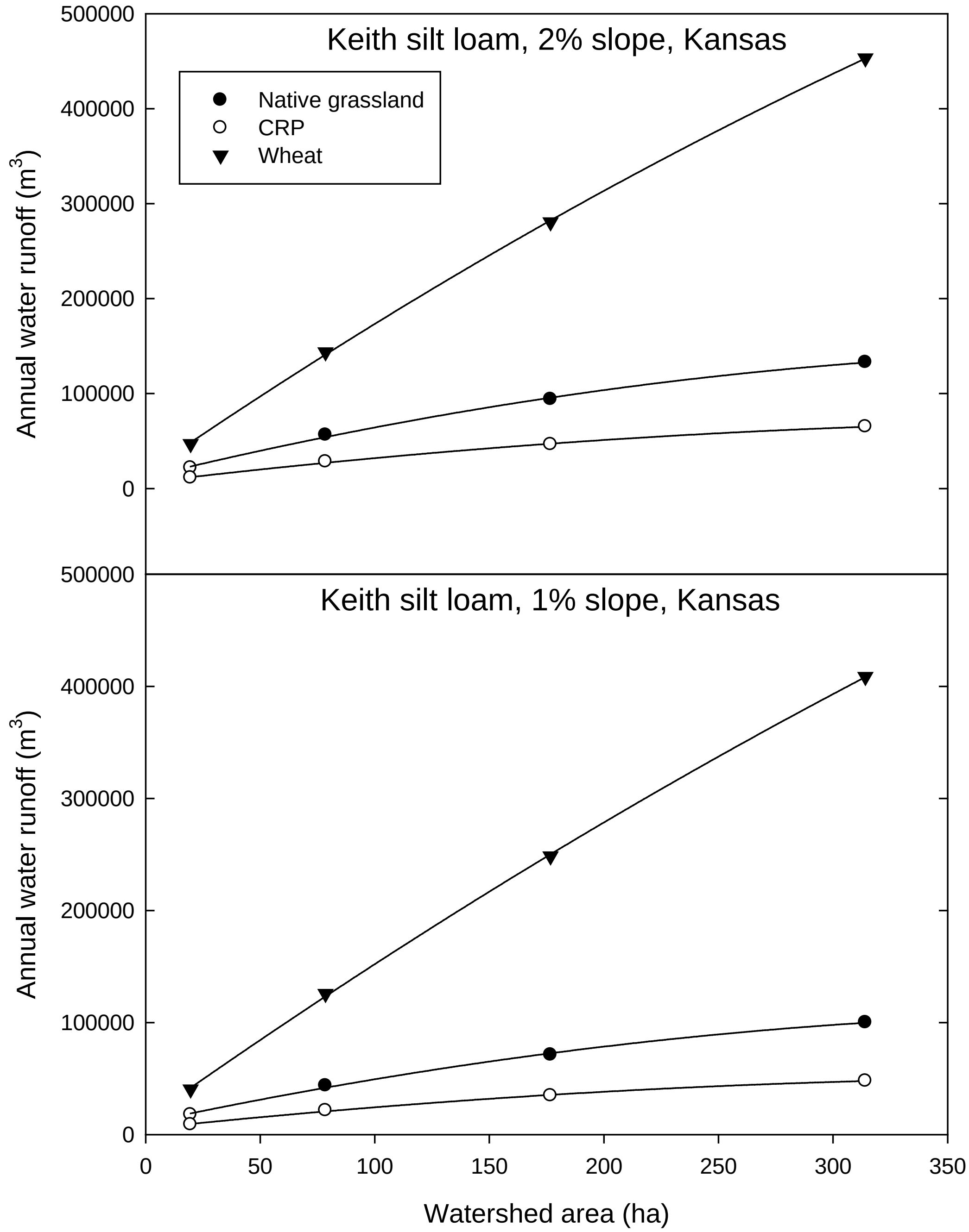


Fig. 6. See page 39 for legend.

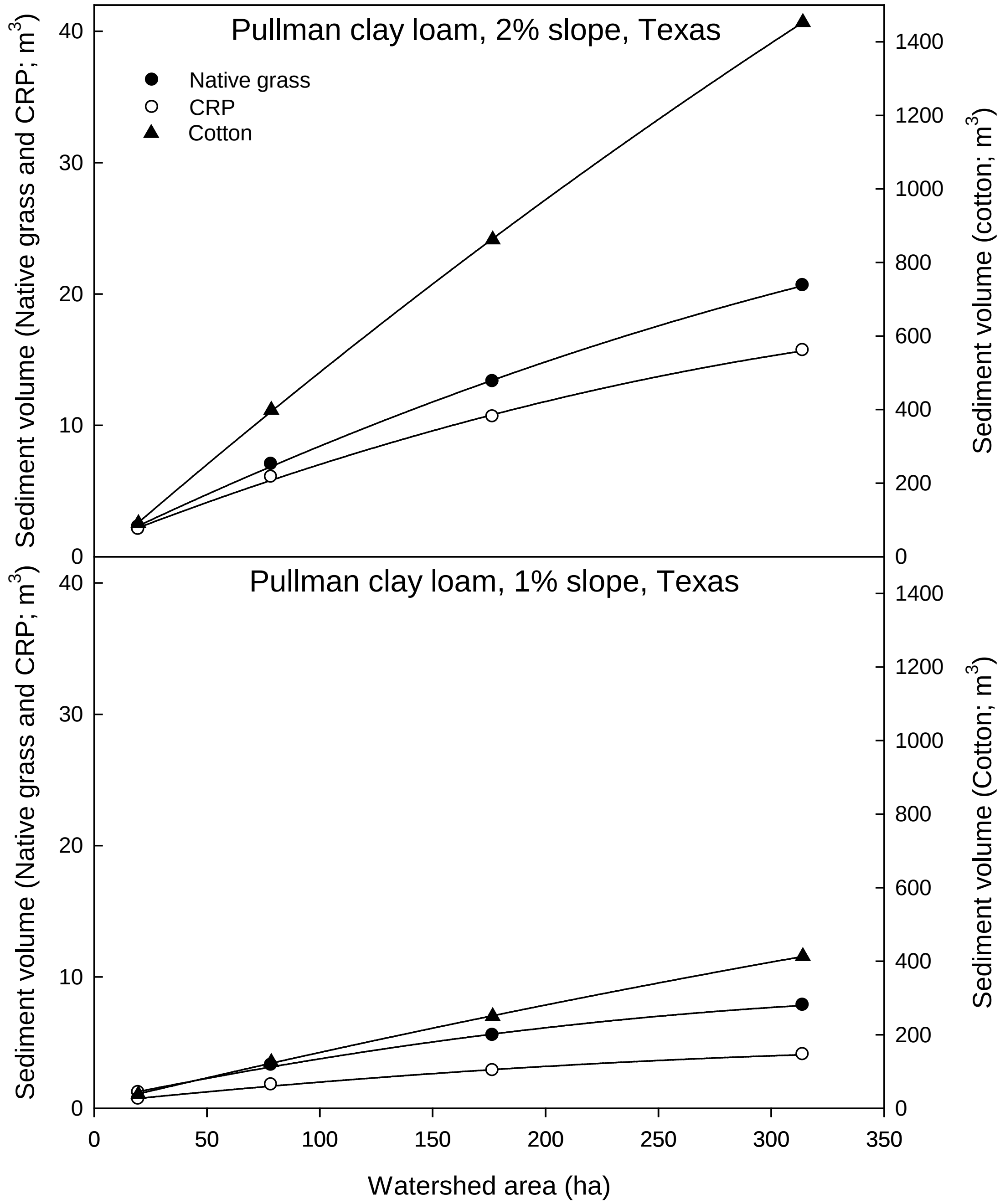
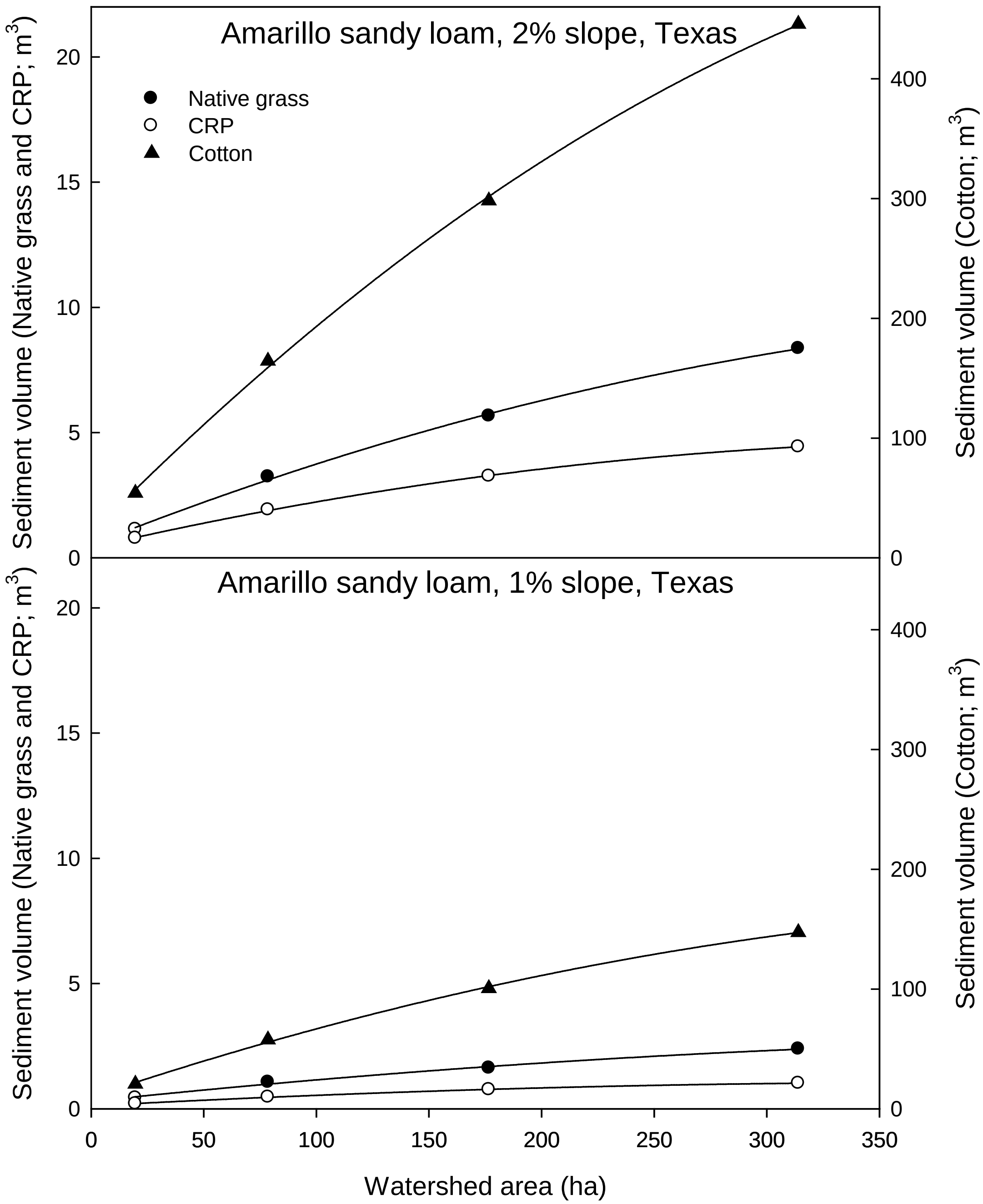


Fig. 6. See page 39 for legend.



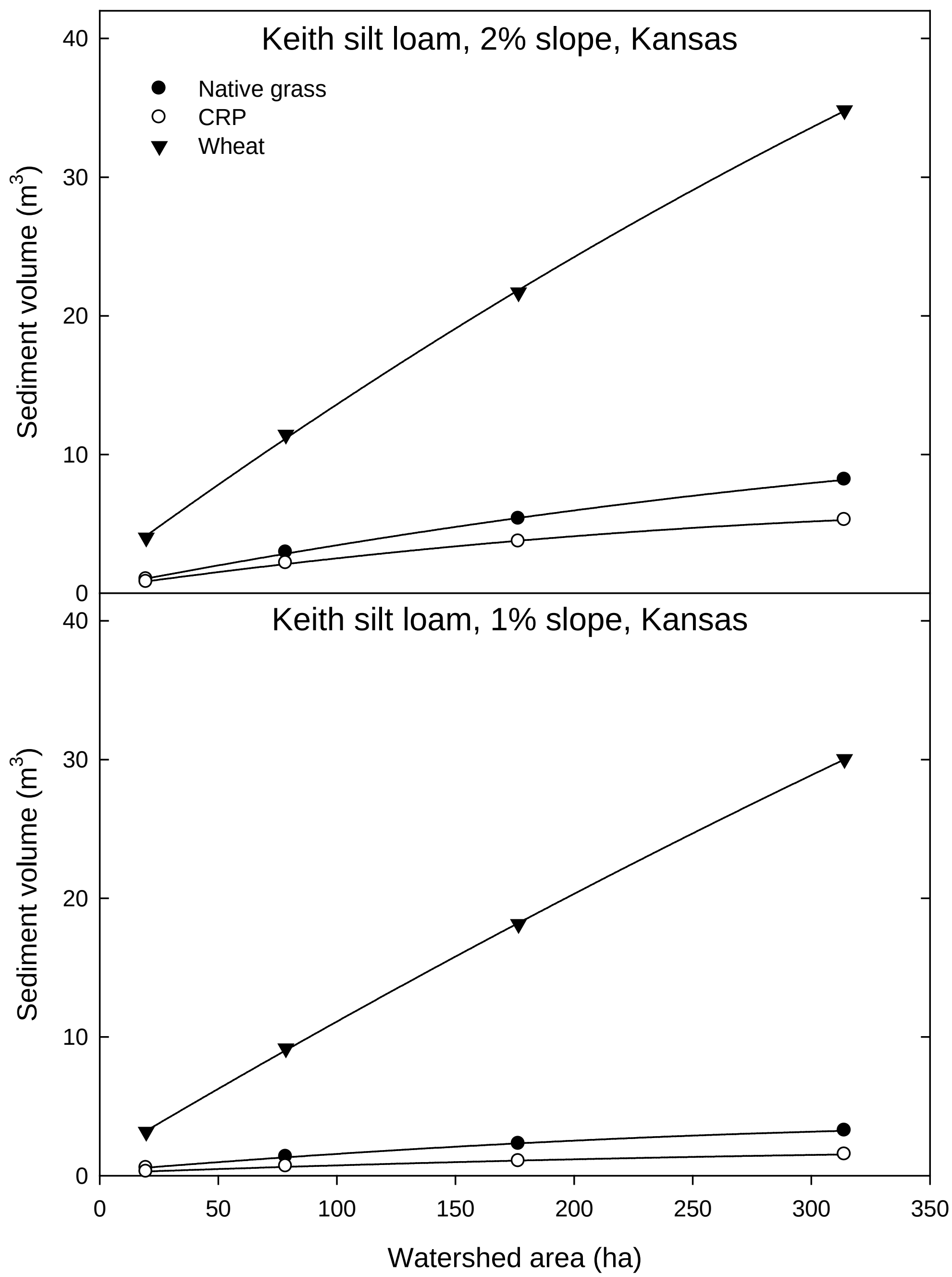


Figure 6. Model simulation results of annual water runoff and annual sediment runoff from watersheds composed of native grassland, cropland (cotton or wheat), and Conservation Reserve Program (CRP). Four watershed areas, two slopes, and three soil types are included in various combinations. WEPP (cropland) and RHEM (native grassland and CRP) were used to model water and sediment runoff. See methods for details.

Appendix 1. Plant species list and classification for the western High Plains. Wetland status codes indicate species that are restricted to upland (UPL), more often in the upland (FACU— i.e. facultative upland), in uplands and wetlands equally (FAC—i.e. facultative), more often in wetlands (FACW—i.e. facultative wetland), or wetland obligate (OBL). NS is nonsufficient data to classify.

Scientific Name	Wetland Status	Life History	Distribution
Acacia angustissima	NS	Perennial	Native
Achillea millefolium	FACU	Perennial	Native
Aegilops cylindrica	NS	Annual	Introduced
Agropyron cristatum	NS	Perennial	Introduced
Agropyron smithii	FAC-	Perennial	Native
Amaranthus blitoides	FACW	Annual	Introduced
Amaranthus retroflexus	FACU	Annual	Native
Ambrosia artemisiifolia	FACU-	Annual	Native
Ambrosia grayi	FACW	Perennial	Native
Ambrosia psilostachya	FAC	Annual	Native
Ammannia auriculata	OBL	Annual	Native
Andropogon gerardii	FAC-	Perennial	Native
Andropogon scoparius	FACU	Perennial	Native
Aristida oligantha	NS	Annual	Native
Aristida purpurea	NS	Perennial	Native
Aristida sp	NS	Perennial	Native
Artemisia filifolia	NS	Perennial	Native
Artemisia ludoviciana	FACU-	Perennial	Native

Scientific Name	Wetland Status	Life History	Distribution
Asclepias engelmanniana	NS	Perennial	Native
Asclepias latifolia	NS	Perennial	Native
Asclepias pumila	NS	Perennial	Native
Asclepias sp	NS	Perennial	Native
Asclepias subverticillata	FACU-	Perennial	Native
Asclepias verticillata	NS	Perennial	Native
Asclepias viridiflora	NS	Perennial	Native
Aster subulatus	OBL	Annual	Native
Astragalus lindheimeri	NS	Annual	Native
Astragalus mollissimus	NS	Perennial	Native
Baccharis sp	FAC	Perennial	Native
Bacopa rotundifolia	OBL	Perennial	Native
Baptisia australis	NS	Perennial	Native
Bothriochloa ischaemum	NS	Perennial	Introduced
Bothriochloa laguroides	NS	Perennial	Native
Bouteloua curtipendula	NS	Perennial	Native
Bouteloua gracilis	NS	Perennial	Native
Bouteloua hirsuta	NS	Perennial	Native
Bouteloua sp	NS	Perennial	Native
Bromus japonicus	FACU	Annual	Introduced
Bromus tectorum	NS	Annual	Introduced
Bromus unioloides	NS	Annual	Introduced
Buchloe dactyloides	FACU-	Perennial	Native

Scientific Name	Wetland Status	Life History	Distribution
Callirhoe involucrata	NS	Perennial	Native
Carduus nutans	NS	Annual	Introduced
Carex sp	unknown	unknown	unknown
Castilleja purpurea	NS	Perennial	Native
Cenchrus longispinus	NS	Annual	Native
Chamaesaracha coniodes	NS	Perennial	Native
Chamaesyce serpens	UPL	Annual	Native
Chenopodium album	FAC	Annual	Native
Chenopodium leptophyllum	FACU	Annual	Native
Chloris verticillata	NS	Perennial	Native
Chloris virgata	NS	Annual	Native
Cirsium arvense	FACU	Perennial	Introduced
Cirsium ochrocentrum	NS	Perennial	Native
Cirsium sp	unknown	unknown	unknown
Cirsium undulatum	FACU	Perennial	Native
Cirsium vulgare	FACU	Annual	Introduced
Convolvulus arvensis	NS	Perennial	Introduced
Convolvulus equitans	NS	Perennial	Native
Conyza canadensis	FACU-	Annual	Native
Coreopsis tinctoria	FAC	Annual	Native
Croton capitatus	NS	Annual	Native
Croton dioicus	NS	Perennial	Native
Croton texensis	NS	Annual	Native

Scientific Name	Wetland Status	Life History	Distribution
Cryptantha crassisepala	NS	Annual	Native
Cucurbita foetidissima	NS	Perennial	Native
Cuscuta squamata	NS	Annual	Native
Cynodon dactylon	FACU	Perennial	Introduced
Cyperus acuminatus	OBL	Annual	Native
Cyperus esculentus	FACW	Perennial	Introduced
Cyperus schweinitzii	FAC	Perennial	Native
Dalea enneandra	NS	Perennial	Native
Dalea formosa	NS	Perennial	Native
Dalea purpurea	NS	Perennial	Native
Delphinium carolinianum	NS	Perennial	Native
Descurainia pinnata	NS	Annual	Native
Desmanthus illinoensis	FACU	Perennial	Native
Distichlis spicata	FACW+	Perennial	Native
Echinocactus texensis	NS	Perennial	Native
Echinochloa colona	FACW	Annual	Introduced
Echinochloa crus-galli	FACW-	Annual	Introduced
Echinochloa muricata	OBL	Annual	Native
Eleocharis atropurpurea	FACW	Annual	Native
Eleocharis macrostachya	OBL	Perennial	Native
Eleocharis parvula	OBL	Perennial	Native
Elymus canadensis	FAC+	Perennial	Native
Engelmannia pinnatifida	NS	Perennial	Native

Scientific Name	Wetland Status	Life History	Distribution
Eragrostis cilianensis	FACU	Annual	Introduced
Eragrostis curvula	NS	Perennial	Introduced
Eragrostis intermedia	NS	Perennial	Native
Eragrostis secundiflora	FACU-	Perennial	Native
Eragrostis sp	unknown	unknown	unknown
Eragrostis spectabilis	FACU-	Perennial	Native
Eragrostis trichodes	NS	Perennial	Native
Erigeron divergens	NS	Annual	Native
Erigeron modestus	NS	Perennial	Native
Erigeron strigosus	FAC-	Annual	Native
Eriochloa contracta	FAC+	Annual	Native
Eriogonum annuum	NS	Annual	Native
Erodium cicutarium	NS	Annual	Introduced
Erodium sp	NS	Annual	Introduced
Erodium texanum	NS	Annual	Native
Erysimum asperum	NS	Perennial	Native
Escobaria vivipara	NS	Perennial	Native
Euphorbia albomarginata	NS	Perennial	Native
Euphorbia dentata	NS	Annual	Native
Euphorbia marginata	FACU	Annual	Native
Evolvulus nuttallianus	NS	Perennial	Native
Gaillardia pulchella	NS	Annual	Native
Galium aparine	FAC-	Annual	Native

Scientific Name	Wetland Status	Life History	Distribution
Gaura coccinea	NS	Perennial	Native
Gaura mollis	NS	Annual	Native
Geranium carolinianum	NS	Annual	Native
Glandularia bipinnatifida	NS	Perennial	Native
Grindelia squarrosa	FACU-	Perennial	Native
Gutierrezia dracunculoides	NS	Annual	Native
Gutierrezia sarothrae	NS	Perennial	Native
Haplopappus ciliatus	FACU	Annual	Native
Helenium amarum	FACU	Annual	Native
Helenium microcephalum	FACW-	Annual	Native
Helianthus annuus	FAC	Annual	Native
Helianthus ciliaris	FAC	Perennial	Native
Helianthus maximiliani	FACU-	Perennial	Native
Helianthus petiolaris	NS	Annual	Native
Hesperostipa comata	NS	Perennial	Native
Heteranthera limosa	OBL	Annual	Native
Heteranthera mexicana	OBL	Annual	Native
Heterotheca latifolia	FACU	Annual	Native
Heterotheca villosa	NS	Perennial	Native
Hoffmannseggia glauca	FAC	Perennial	Native
Hordeum pusillum	FACU	Annual	Native
Hymenopappus filifolius	NS	Perennial	Native
Hymenoxys odorata	NS	Annual	Native

Scientific Name	Wetland Status	Life History	Distribution
Ipomoea leptophylla	NS	Perennial	Native
Iva axillaris	FAC	Perennial	Native
Juglans nigra	FACU	Perennial	Native
Juncus sp	FACW	Perennial	Native
Juniperus coahuilensis	NS	Perennial	Native
Kochia scoparia	FACU	Annual	Introduced
Krascheninnikovia lanata	NS	Perennial	Native
Lactuca serriola	FAC	Annual	Introduced
Lactuca tatarica	FAC	Perennial	Native
Lepidium densiflorum	FAC	Annual	Native
Lepidium sp	unknown	unknown	unknown
Lepidium virginicum	FAC-	Annual	Native
Leptochloa dubia	NS	Perennial	Native
Leptochloa fascicularis	OBL	Annual	Native
Lippia cuneifolia	FAC	Perennial	Native
Lippia nodiflora	FAC	Perennial	Native
Lygodesmia juncea	NS	Perennial	Native
Lythrum californicum	OBL	Perennial	Native
Machaeranthera pinnatifida	NS	Perennial	Native
Machaeranthera tanacetifolia	NS	Annual	Native
Malva neglecta	NS	Annual	Introduced
Malvella leprosa	FACW	Perennial	Native
Marsilea vestita	OBL	Perennial	Native

Scientific Name	Wetland Status	Life History	Distribution
Melilotus alba	NS	Annual	Introduced
Melilotus officinalis	FACU	Annual	Introduced
Mentha arvensis	FACW	Perennial	Native
Mimosa microphylla	NS	Perennial	Native
Mimosa nuttallii	NS	Perennial	Native
Monolepis nuttalliana	FACW	Annual	Native
Oenothera canescens	FACW-	Perennial	Native
Opuntia imbricata	NS	Perennial	Native
Opuntia phaeacantha	NS	Perennial	Native
Panicum capillare	FAC	Annual	Native
Panicum sp	unknown	unknown	unknown
Panicum obtusum	FACW	Perennial	Native
Panicum virgatum	FACW	Perennial	Native
Paspalum paspaloides	OBL	Perennial	Native
Pediomelum argophyllum	NS	Perennial	Native
Phalaris caroliniana	FACW	Annual	Native
Physalis heterophylla	NS	Perennial	Native
Physalis viscosa	NS	Perennial	Native
Plantago patagonica	FACU-	Annual	Native
Poa arachnifera	NS	Perennial	Native
Poa pratensis	FACU+	Perennial	Native
Polygonum amphibium	OBL	Perennial	Native
Polygonum aviculare	FACW	Annual	Introduced

Scientific Name	Wetland Status	Life History	Distribution
Polygonum erectum	OBL	Annual	Native
Polygonum lapathifolium	OBL	Annual	Native
Polygonum pensylvanicum	FACW-	Annual	Native
Polygonum persicaria	OBL	Annual	Introduced
Polygonum ramosissimum	FACW	Annual	Native
Polygonum striatulum	FACW	Annual	Native
Portulaca mundula	NS	Annual	Native
Portulaca oleracea	FAC	Annual	Introduced
Potamogeton nodosus	OBL	Perennial	Native
Potentilla paradoxa	FACW+	Annual	Native
Proboscidea louisianica	FAC-	Annual	Native
Prosopis glandulosa	FACU-	Perennial	Native
Psoralidium tenuiflorum	NS	Perennial	Native
Quincula lobata	NS	Perennial	Native
Ranunculus macounii	OBL	Perennial	Native
Ratibida columnifera	NS	Perennial	Native
Ratibida tagetes	NS	Perennial	Native
Rorippa sinuata	FACW	Perennial	Native
Rumex altissimus	FACW+	Perennial	Native
Rumex crispus	FACW	Perennial	Introduced
Ruppia maritima	OBL	Perennial	Native
Sagittaria calycina	OBL	Annual	Native
Sagittaria latifolia	OBL	Perennial	Native

Scientific Name	Wetland Status	Life History	Distribution
Sagittaria longiloba	OBL	Perennial	Native
Salix nigra	OBL	Perennial	Native
Salsola iberica	FACU	Annual	Introduced
Salvia azurea	NS	Perennial	Native
Schedonnadrus paniculatus	NS	Perennial	Native
Scirpus maritimus	OBL	Perennial	Native
Scutellaria drummondii	NS	Annual	Native
Scutellaria lateriflora	OBL	Perennial	Native
Senecio douglasii	NS	Perennial	Native
Setaria pumila	FAC	Annual	Introduced
Setaria viridis	NS	Annual	Introduced
Setaria vulpiseta	NS	Perennial	Native
Sisymbrium altissimum	FACU+	Annual	Introduced
Sitanion hystrix	FACU-	Perennial	Native
Solanum elaeagnifolium	NS	Perennial	Native
Solanum rostratum	NS	Annual	Native
Sonchus asper	FACW	Annual	Introduced
Sorghastrum nutans	FACU	Perennial	Native
Sorghum halepense	FACU	Perennial	Introduced
Sphaeralcea coccinea	NS	Perennial	Native
Sporobolus compositus	FACU	Perennial	Native
Sporobolus cryptandrus	FACU-	Perennial	Native
Suckleya suckleyana	FACW	Annual	Native

Scientific Name	Wetland Status	Life History	Distribution
Symphyotrichum divaricatum	NS	Annual	Native
Symphyotrichum lanceolatum	OBL	Perennial	Native
Tamarix gallica	FACW-	Perennial	Introduced
Taraxacum officinale	FACU+	Perennial	Native
Tetraneuris scaposa	NS	Perennial	Native
Thelesperma filifolium	NS	Annual	Native
Thelesperma megapotamicum	NS	Perennial	Native
Thelesperma simplicifolium	NS	Perennial	Native
Thinopyrum ponticum	NS	Perennial	Introduced
Thlaspi arvense	NS	Annual	Introduced
Tradescantia occidentalis	UPL	Perennial	Native
Tragopogon dubius	NS	Annual	Introduced
Tribulus terrestris	NS	Annual	Introduced
Trifolium repens	FACU+	Perennial	Introduced
Typha latifolia	OBL	Perennial	Native
Typha sp	OBL	Perennial	Native
Ulmus pumila	NS	Perennial	Introduced
Verbascum thapsus	NS	Annual	Introduced
Verbena bracteata	FAC	Annual	Native
Verbena hastata	FACW	Perennial	Native
Verbesina encelioides	FAC	Annual	Native
Vernonia marginata	FAC	Perennial	Native
Veronica arvensis	NS	Annual	Introduced

Scientific Name	Wetland Status	Life History	Distribution
Veronica peregrina	OBL	Annual	Native
Vicia villosa	NS	Annual	Introduced
Xanthium strumarium	FAC	Annual	Native
Yucca glauca	NS	Perennial	Native

Appendix 2. Plant species list and classification scheme for the Rainwater Basin. Wetland status codes indicate species that are restricted to upland (UPL), more often in the upland (FACU— i.e. facultative upland), in uplands and wetlands equally (FAC—i.e. facultative), more often in wetlands (FACW—i.e. facultative wetland), or wetland obligate (OBL). NS is nonsufficient data to classify.

Scientific Name	Wetland Indicator	Life History	Distribution
Abutilon theophrasti	UPL	Annual	Introduced
Achillea millefolium	FACU	Perennial	Native
Agrostis hyemalis	FACU	Perennial	Native
Alisma triviale	OBL	Perennial	Native
Alopecurus carolinianus	FACW	Annual	Native
Amaranthus retroflexus	FACU	Annual	Native
Ambrosia artemisiifolia	FACU	Annual	Native
Ambrosia grayi	FAC	Perennial	Native
Ambrosia psilostachya	FAC	Perennial	Native
Ambrosia trifida	FACW	Annual	Native
Ammannia robusta	NS	Annual	Native
Andropogon gerardii	FAC-	Perennial	Native
Apocynum cannabinum	FAC	Perennial	Native
Arctagrostis latifolia	NS	Perennial	Native
Artemisia ludoviciana	FACU-	Perennial	Native
Aruncus dioicus	NS	Perennial	Native
Asclepias incarnata	OBL	Perennial	Native
Asclepias syriaca	NS	Perennial	Native
Asclepias verticillata	NS	Perennial	Native

Scientific Name	Wetland Indicator	Life History	Distribution
Aster ericoides	FACU	Perennial	Native
Aster lanceolatus	OBL	Perennial	Native
Bacopa rotundifolia	OBL	Perennial	Native
Bidens aristosa	NS	Annual	Native
Bidens frondosa	FACW	Annual	Native
Bidens vulgata	NS	Annual	Native
Boltonia asteroides	FACW	Perennial	Native
Bromus inermis	NS	Perennial	Introduced
Bromus japonicus	FACU	Annual	Introduced
Bromus tectorum	NS	Annual	Introduced
Calystegia sepium	FAC	Perennial	Native
Cannabis sativa	FACU-	Annual	Introduced
Capsella bursa-pastoris	FACU	Annual	Introduced
Carduus nutans	NS	Annual	Introduced
Carex blanda	FAC	Perennial	Native
Carex brevior	FAC	Perennial	Native
Carex cristatella	FACW	Perennial	Native
Carex gravida	NS	Perennial	Native
Carex laeviconica	OBL	Perennial	Native
Carex pellita	OBL	Perennial	Native
Carex vulpinoidea	OBL	Perennial	Native
Ceratophyllum demersum	OBL	Perennial	Native
Chenopodium album	FAC	Annual	Native

Scientific Name	Wetland Indicator	Life History	Distribution
Chenopodium pratericola	NS	Annual	Native
Cirsium altissimum	NS	Annual	Native
Cirsium arvense	FACU	Perennial	Introduced
Cirsium vulgare	NS	Annual	Introduced
Conyza canadensis	FACU-	Annual	Native
Coreopsis tinctoria	FAC	Annual	Native
Cuscuta campestris	NS	Perennial	Native
Cyperus esculentus	FACW	Perennial	Introduced
Digitaria cruciata	NS	Annual	Introduced
Echinacea purpurea	NS	Perennial	Native
Echinochloa crus-galli	FACW	Annual	Introduced
Eleocharis acicularis	OBL	Perennial	Native
Eleocharis compressa	FACW	Perennial	Native
Eleocharis erythropoda	OBL	Perennial	Native
Eleocharis palustris	OBL	Perennial	Native
Elymus canadensis	FACU	Perennial	Native
Erechtites hieraciifolia	FAC	Annual	Native
Erigeron strigosus	FAC	Annual	Native
Euphorbia esula	NS	Perennial	Introduced
Galium aparine	FACU	Annual	Native
Glycine max	NS	Annual	Introduced
Hedeoma hispida	NS	Annual	Native
Helianthus annuus	FACU	Annual	Native

Scientific Name	Wetland Indicator	Life History	Distribution
Helianthus grosseserratus	FACW	Perennial	Native
Helianthus maximilianii	UPL	Perennial	Native
Heteranthera limosa	OBL	Annual	Native
Heteranthera reniformis	OBL	Perennial	Native
Hordeum jubatum	FACW	Perennial	Native
Hordeum pusillum	FAC	Annual	Native
Juncus dudleyi	NS	Perennial	Native
Juncus interior	FAC	Perennial	Native
Lactuca ludoviciana	FAC	Annual	Native
Lactuca serriola	FAC	Annual	Introduced
Leersia oryzoides	OBL	Perennial	Native
Lepidium densiflorum	FAC	Annual	Native
Lepidium latifolium	FACW	Perennial	Introduced
Lepidium perfoliatum	FAC	Annual	Introduced
Lepidium virginicum	FACU	Annual	Native
Leptochloa fascicularis	OBL	Annual	Native
Lotus corniculatus	FACU	Perennial	Introduced
Lycopus americanus	OBL	Perennial	Native
Marsilea vestita	OBL	Perennial	Native
Medicago sativa	NS	Perennial	Introduced
Melilotus alba	FACU	Annual	Introduced
Melilotus officinalis	FACU	Annual	Introduced
Mentha arvensis	FACW	Perennial	Native

Scientific Name	Wetland Indicator	Life History	Distribution
Mollugo verticillata	FAC	Annual	Native
Nepeta cataria	FACU	Perennial	Introduced
Nulumbo lutea	OBL	Perennial	Native
Oxalis stricta	FACU	Perennial	Native
Panicum capillare	FAC	Annual	Native
Panicum virgatum	FAC	Perennial	Native
Pascopyrum smithii	FACU	Perennial	Native
Phalaris arundinacea	FACW+	Perennial	Native
Phleum pratense	FACU	Perennial	Introduced
Physalis virginiana	NS	Perennial	Native
Poa pratensis	FACU	Perennial	Native
Polygonum amphibium	OBL	Perennial	Native
Polygonum arenastrum	NS	Annual	Introduced
Polygonum bicorne	FACW+	Annual	Native
Polygonum pensylvanicum	FACW+	Annual	Native
Polygonum ramosissimum	FAC	Annual	Native
Populus deltoides	FAC	Perennial	Native
Portulaca oleracea	FAC	Annual	Introduced
Potamogeton nodosus	OBL	Perennial	Native
Potamogeton pectinatus	OBL	Perennial	Native
Potentilla norvegica	FAC	Annual	Native
Ratibida columnaris	NS	Perennial	Native
Rorippa palustris	OBL	Annual	Native

Scientific Name	Wetland Indicator	Life History	Distribution
Rorippa sinuata	FACW	Perennial	Native
Rudbeckia hirta	FACU	Perennial	Native
Rumex altissimus	FAC	Perennial	Native
Rumex crispus	FACW	Perennial	Introduced
Sagittaria brevirostra	OBL	Perennial	Native
Sagittaria calycina	OBL	Perennial	Native
Sagittaria graminea	OBL	Perennial	Native
Salix interior	NS	Perennial	Native
Schizachyrium scoparium	FACU	Perennial	Native
Schoenoplectus heterochaetus	OBL	Perennial	Native
Schoenoplectus tabernaemontani	OBL	Perennial	Native
Scirpus fluviatilis	OBL	Perennial	Native
Setaria pumila	FAC	Annual	Introduced
Solanum ptychanthum	NS	Annual	Native
Solanum rostratum	NS	Annual	Native
Solidago altissima	FACU	Perennial	Native
Solidago canadensis	FACU	Perennial	Native
Solidago missouriensis	NS	Perennial	Native
Sorghastrum nutans	FACU	Perennial	Native
Sorghum bicolor	NS	Annual	Introduced
Sparganium eurycarpum	OBL	Perennial	Native
Spartina pectinata	FACW	Perennial	Native
Taraxacum officinale	FACU	Perennial	Native

Scientific Name	Wetland Indicator	Life History	Distribution
Thlaspi arvense	NS	Annual	Introduced
Tragopogon dubius	NS	Annual	Introduced
Trifolium pratense	FACU	Perennial	Introduced
Trifolium repens	FACU	Perennial	Introduced
Typha angustifolia	OBL	Perennial	Introduced
Vernonia fasciculata	FAC	Perennial	Native
Veronica arvensis	NS	Annual	Introduced
Veronica peragrina	OBL	Annual	Native
Zea mays	NS	Annual	Introduced