Floristic Quality and Wildlife Habitat Assessment of Playas in Eastern Colorado

Final Report to the
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EXECUTIVE SUMMARY

This is the Final Report for the project entitled *Floristic Quality and Wildlife Habitat Assessment of Playas in Eastern Colorado*, funded by the United States Environmental Protection Agency (EPA), with matching funds provided by the Colorado Division of Wildlife (CDOW). This work builds on several years of playa research by Rocky Mountain Bird Observatory (RMBO) supported by EPA, CDOW, the Playa Lakes Joint Venture (PLJV), and the United States Fish and Wildlife Service (USFWS). This also builds on the work of the Colorado Natural Heritage Program (CNHP) to develop the Floristic Quality Assessment for Colorado (Rocchio 2007a).

Playa in native prairie in eastern Colorado

Playas are shallow, depressional wetlands fed exclusively by rainfall and runoff, and are found throughout much of the Great Plains. These wetlands are vital to biodiversity in this ecoregion, but are threatened by agriculture and development. Interest in conserving these wetlands is strong, but information about playa conditions is required to design appropriate conservation strategies.

Several multi-metric indices have been developed to evaluate the ecological condition of wetlands in response to human disturbance. One of most common biotic indices is the Floristic Quality Assessment (FQA), which involves ranking plant species according to indices of conservatism (C values) and estimating the number of native and non-native species from intensive vegetation sampling (Milburn et al. 2007; Rocchio 2007a). Indices of human disturbance are often calculated from measurements of impacts associated with hydrology, landuse and landscape context (Rocchio 2007a). Other indices such as the Ecological Integrity Assessment (EIA) are derived from both plant and human disturbance data (Faber-Landgendoen et al. 2006; Rocchio 2006). Although the multi-metric indices were not developed as measures of biodiversity, there is increased interest in evaluating the extent that ecological indicators pertain to species assemblages other than plants (Stapanian et al. 2004; Brazner et al. 2007).

To assess the condition of playas in eastern Colorado, we applied two tools created by the Colorado Natural Heritage Program: the FQA and the EIA. The FQA was developed for statewide application but has not yet been tested within the Central Shortgrass Prairie Ecoregion of eastern Colorado. The EIA was developed for Intermountain Basin playa wetlands in the Southern Rocky Mountains of Colorado, but could have application to the playas of the Central Shortgrass Ecoregion. The FQA, EIA Scorecard, and most wetland assessment tools are based on botanical and abiotic factors. However, the relationship between wetland condition as indicated by these metrics and wildlife habitat values has not been determined. In this report we applied the FQA, the EIA, and reported measures of avian use during migration for playa wetlands in eastern Colorado. We related avian use to human disturbance, floristic quality metrics, as well as the EIA Scorecard. We also

determine the sensitivity of FQA metrics to sampling effort, seasonality, and the application of restoration practices.

We studied playas in eastern Colorado from 2004-2007, collecting human disturbance, vegetation, and avian use data. For 109 playas with intensive vegetation assessments, we found that FQA metrics accurately responded to a multivariate Human Disturbance Index (HDI-2) constructed from 11 disturbance factors. This human disturbance gradient included a local landuse component and a landscape component. In particular, the count of native species, percent non-native species, and the floristic quality indices accounted for a relatively high proportion of the variation in human disturbance.

Blue-winged Teal use playas during migration

Adjacent agricultural land-use was the single most important human disturbance factor for predicting the floristic quality of playa wetlands. The floristic quality of playas with adjacent agriculture was considerably lower than playas with adjacent grassland. In addition, the percent of non-native species was greater in playas with adjacent cropland than in playas with surrounding grassland, decreased with increasing native prairie in the landscape, and was greater in playas with hydrological modifications than intact playas.

In the analysis of a smaller subset of these playas for which we collected human disturbance data for the Human Disturbance Index (HDI-1) as described in Rocchio (2007a), however, there was no association between the top four FQA metrics (Mean C, count of native species, FQI, percent non-native species) and HDI-1. Similarly, the EIA Scorecard developed for playas in the Intermountain Region was not associated with any of the top four FQA metrics in the Central Shortgrass playas.

We found no evidence for positive relationships between bird use and floristic quality. Waterfowl abundance and number of bird species per survey strongly declined with increasing Mean C, number of native plants, and FQI, and bird use increased with the percent of non-native species. This pattern could be due to an association of waterfowl with particular plants that provide rich seed resources but which otherwise have low C-values, or could be due to a positive association with adjacent cropland for foraging resources. There was some evidence for greater waterfowl abundance in landscapes dominated by cropland. However, in contrast to the above patterns, waterfowl abundance declined with increasing levels of the HDI-1 Human Disturbance Index. Surprisingly, the total number of bird species per survey was greater on playas with adjacent agriculture than playas with adjacent grassland. This pattern may be expected if several bird species use waste grain as a food resource during the autumn migration. Shorebird abundance was not associated with the top four floristic quality measures. Instead, shorebird numbers were much lower on playas with hydrological alterations than on intact playas. These findings were not surprising considering playas without pits provide important shallow water habitat and that shorebirds likely select habitat on the basis of sparse vegetation and the presence of mud flats.

When we examined the patterns of bird use in a larger study of 226 playa wetlands from 2004 to 2007, we found several relationships between bird use and human disturbance. The average number of species (all types of birds) was higher in playas with hydrological modifications. This is probably due to pits and other impoundments creating a different set of habitat types than are typically found in playas. As above, shorebirds were less abundant on playas with hydrological modifications. However, waterfowl abundance was unrelated to anthropogenic landuse. In addition to the above patterns, playa size and proximity to other playa wetlands also were important for the abundance of waterfowl and shorebirds. This suggests large playas in complexes may be more attractive than isolated playas for birds, perhaps offering increased foraging opportunities with relatively low search costs (Farmer and Parent 1997).

We evaluated several approaches for sampling vegetation, including season effects, sample pooling and the utility of opportunistic off-plot surveys. Mean C was lower in autumn than in the summer, and the percent of non-native species was greater in autumn than the summer. Nevertheless, seasonal variation in the estimates had no effect on the strength of association between floristic quality and human disturbance. Pooling counts of native species across two visits showed a stronger relationship to human disturbance than counts averaged across two visits, but the effect was not observed for Mean C, FQI, or percent non-native. We found no evidence that additional species observed in opportunistic off-plot surveys (species not detected during Daubenmire samples) improved the strength of the association between floristic quality and human disturbance.

Our analyses for the comparison of restored and control playas were unable to detect differences in the floristic quality metrics or EIA Scorecard. However, because the conservation projects were implemented beginning in 2005, there were a limited number of restoration projects (six groups) in place for a minimum of one full growing season.

In conclusion, our findings showed little redundancy in floristic and avian responses to human disturbance, which suggested that both metrics merit consideration when prioritizing the conservation of playa wetlands. For conservation of floristic values, one might prioritize playas in native grassland. For migratory birds, it might be best to conserve large playas in complexes that are inundated frequently. We did not measure occupancy by amphibian species or other wildlife. Indeed, using floristic data to represent biotic condition may not represent the full spectrum of biological values associated with playa wetlands. We recommend a holistic approach that takes into account the values of playas to a variety of taxa when assessing biotic condition data in a conservation framework.

TABLE OF CONTENTS

CHAPTER 1. INTRODUCTION

Playas are shallow depressional wetlands of the Great Plains that fill periodically from heavy rainfall (Smith 2003). Playas provide important wetland functions, such as the capture of surface runoff and aquifer recharge (Osterkamp and Wood 1987). In addition, playas contribute to biodiversity (Bolen et al. 1989), provide critical shorebird migration stopover habitat (Skagen and Knopf 1993; Davis and Smith 1998), and host high numbers of wintering waterfowl (Nelson et al. 1983). However, because they are imbedded in working landscapes, playas are also impacted extensively by disturbances including increased sedimentation rates, pit excavation, road construction, feedlot runoff, urban development, overgrazing, and deliberate filling (Haukos and Smith 2003).

Private landowner and NRCS biologist discussing conservation practices for a farmed playa

Interest in protecting these isolated, ephemeral wetlands is strong. In Colorado, wildlife conservation groups including the Colorado Division of Wildlife (CDOW), U.S. Fish and Wildlife Service (USFWS), Playa Lakes Joint Venture (PLJV), Colorado Wetland Partnership's (CWP) Prairie and Wetlands Focus Area (PWFA), and Rocky Mountain Bird Observatory (RMBO) have begun protecting, enhancing, and restoring playas through voluntary programs. Congress has also demonstrated its commitment to protect and restore this resource by creating the Wetlands Restoration Initiative (CP23a) of the USDA Farm Bill Conservation Reserve Program (USDA 2004). However, until now, little has been known about the conditions of the playas in Colorado, and these programs have had sparse information with which to guide their efforts.

Because reliable data on the quality of wetlands are required to guide informed management decisions, a number of approaches for evaluating wetlands have been developed (Karr 1981, 1991; Brinson 1993; U.S. EPA 2002; Bryce et al. 2002; DeKeyser et al. 2003). Several multi-metric indices have been developed to evaluate the ecological condition of wetlands. Their primary goal is to evaluate the influence of human disturbance on wetland ecosystems. Many indices use rapid assessment survey methodology but can also incorporate information from intensive local vegetation surveys and large-scale landscape data. Indices of biotic integrity use plant, invertebrate, fish, amphibian, or bird data to indicate wetland responses to human disturbance (Karr 1991; Bryce et al. 2002; Rocchio 2007b). One of most common biotic indices is the Floristic Quality Assessment (FQA). Based on the concept that plant species vary in their sensitivity to human disturbance (Swink and Wilhelm 1979, 1994), floristic quality assessment (FQA) indices have been implemented as measures of wetland condition in a number of ecoregions (e.g., Swink and Wilhelm 1979, 1994; Milburn et al. 2007; Rocchio 2007a). Indices of human disturbance are often calculated from measurements of impacts associated with hydrology, landuse and landscape context (Rocchio 2007a). Other indices such as the Ecological Integrity Assessment (EIA) are derived from both plant and human disturbance data (Faber-Landgendoen et al. 2006; Rocchio 2006). Although the multi-metric indices were not developed as measures of biodiversity, there is increased interest in evaluating the extent that ecological indicators pertain to species assemblages other than plants (Stapanian et al. 2004; Brazner et al. 2007).

A floristic tool has recently been developed by the Colorado Natural Heritage Program (CNHP) to assess the condition of wetlands for the state of Colorado: Floristic Quality Assessment Indices for Colorado Plant Communities (FQA: Rocchio 2007a). The FQA was developed for statewide application but has not yet been tested within the Central Shortgrass Prairie Ecoregion of eastern Colorado. In addition, CNHP drafted an Ecological Integrity Assessment Scorecard (EIA Scorecard) for playas in the Intermountain Basin Playas system (Rocchio 2006), which could be used to evaluate the condition of playas in the Central Shortgrass. The FQA, EIA Scorecard, and most wetland assessment tools are based on botanical and abiotic factors. However, the relationship between wetland condition as indicated by these metrics and wildlife habitat values has not been determined. In this report we apply the FQA, the EIA, and report measures of avian use during migration for playa wetlands in eastern Colorado to pursue the following objectives.

Plains coreopsis (*Coreopsis tinctoria*), a common plant of eastern Colorado playas.

1. Test the newly developed FQA tool for Colorado on playa wetlands in the Central Shortgrass Prairie Ecoregion, determining the correlation of various FQA indices to measures of human disturbance, including roads, land use practices within the wetland and in the surrounding landscape, and on-site disturbances such as hydrological manipulations.

2. Assess the effectiveness of the Intermountain Basins Playas EIA Scorecard for Central Shortgrass Prairie playas.

3. Determine the relatedness of floristic quality measures to wildlife habitat values of playas, as measured by migratory bird use.

4. Determine the correlation of migratory bird use to human disturbance factors.

5. Determine the sensitivity of FQA metrics to sampling effort and seasonality.

6. Test whether FQA indices or EIA Scorecard values distinguish among playas receiving restoration practices (such as managed grazing and pit removal) and nearby comparison, unrestored playas.

We test the FQA and EIA Scorecard using two primary sets of playas. The "focus group" includes playas selected specifically for the study of FQA, EIA Scorecard, and migratory bird use (n = 22). A "broad group" is comprised of playas that were sampled intensively for vegetation in the 2006 or 2007 field seasons and are then related to a human disturbance gradient but which are lacking intensive migratory bird data and formal EIA Scorecard rankings (n = 109).

This project directly builds upon several other Wetlands Program Development Grant projects supported by EPA Region 8, including *Survey and Assessment of Playas in Eastern Colorado, Phases I and II* (RMBO); *A Floristic Bioassessment Tool for Colorado Wetlands* (CNHP); and the *Ecological Integrity Assessment and Performance Measures for Wetland Mitigation* (CNHP), of which the *Intermountain Basins Ecological System Ecological Integrity Assessment* was a part. Please refer to the Final Report for the *Survey and Assessment of Playas* for background information on the playas of eastern Colorado (Cariveau and Pavlacky 2008).

CHAPTER 2. METHODS

Study Area

The study area encompasses 113,404 km^2 (43,786 mi^2) of eastern Colorado (102^{o}3'1"- 105^{o}16'15"W, 36^{o}59'34"- 41^{o}0'6"N) within the South-central Semi-arid Prairies Ecological Region (CEC 1997, Gauthier and Wilken 1998) and Shortgrass Prairie Bird Conservation Region 18 (US NABCI Committee 2000a, b). This region consists of flat to gently rolling topography, with occasional canyons and bluffs. The dominant native vegetation is shortgrass prairie composed of blue grama (*Bouteloua gracilis*), buffalo grass (*Buchloe dactyloides*) and western wheatgrass (*Pascopyrum smithii*). Livestock grazing and irrigated and dry-land agriculture are the primary land uses. Elevation ranges from 975 m (3,200 ft) to 1800 m (6,000 ft), mean monthly temperature from -12^{o}C (10^{o}F) to 38^{o}C (100^{o}F) and mean annual precipitation from 250 mm (10 in) to 750 mm (30 in).

Site Selection

The playas evaluated in this effort were selected from a GIS database containing potential playa locations. The GIS database was initially created by Ducks Unlimited, Inc. (DU) and was subsequently refined by Playa Lakes Joint Venture (PLJV) and RMBO through 2008. The GIS database was built from three primary sources: (1) DU's interpretation of LANDSAT satellite imagery (DU 2003), (2) the U.S. Geological Survey National Hydrography Database (NHD; USGS 2000), and (3) the Natural Resource Conservation Service's (NRCS) Soils Survey Geographic Database (SSURGO; USDA 1995). The LANDSAT dataset was developed to serve as a catalog of hydrologically functioning playa lakes present during periods of peak precipitation between 1986 and 2000 (DU 2003). The NHD layer was a subset of *lake/pond* and *playa* features extracted from the NHD comprehensive set of digital spatial data containing surface water features such as lakes, ponds, streams, rivers, springs, and wells. The model incorporated probable locations derived from SSURGO data for 23 counties in our study area. The dataset grew from containing approximately 2,500 potential playa locations in 2003 to over 8,300 locations in 2008 (Figure 1). Please see Cariveau and Pavlacky 2008 for a more thorough discussion of the GIS dataset and its characteristics.

Two primary sets of playas were evaluated in this project. The "focus group" was comprised of playas selected specifically for the study of FQA, EIA Scorecard, and migratory bird use. The pool of playas from which these were drawn included all playas providing wet conditions during the fall 2006 bird migration season. Those playas were located by our monitoring of daily rainfall (http://water.weather.gov/download.php) and visits to areas receiving rainfall sufficient to potentially pond water, which we defined as 2 inches within 24 hours or 4 inches within a week, as based on discussions with biologists familiar with playas. Because of the scarcity of rain events meeting these criteria and the low number of wet playas encountered in the field, the playas in our sample may be regarded as representative of all those wet within the study area in the fall of 2006. From this group, we selected only those that were wet long enough to provide at least six weekly bird surveys to be eligible for FQA and EIA Scorecard evaluation in the following field season of 2007 (n = 62). These playas were categorized into low, medium, and high bird use based upon numbers of birds divided by the acres flooded averaged across surveys. A random number was then assigned to each playa in each stratum; landowners were contacted for access to playas in random order until access was gained for at least six playas in each stratum. This yielded a total of 22 playas, with 7, 8, and 7 in each of low, medium, and high bird use categories, respectively.

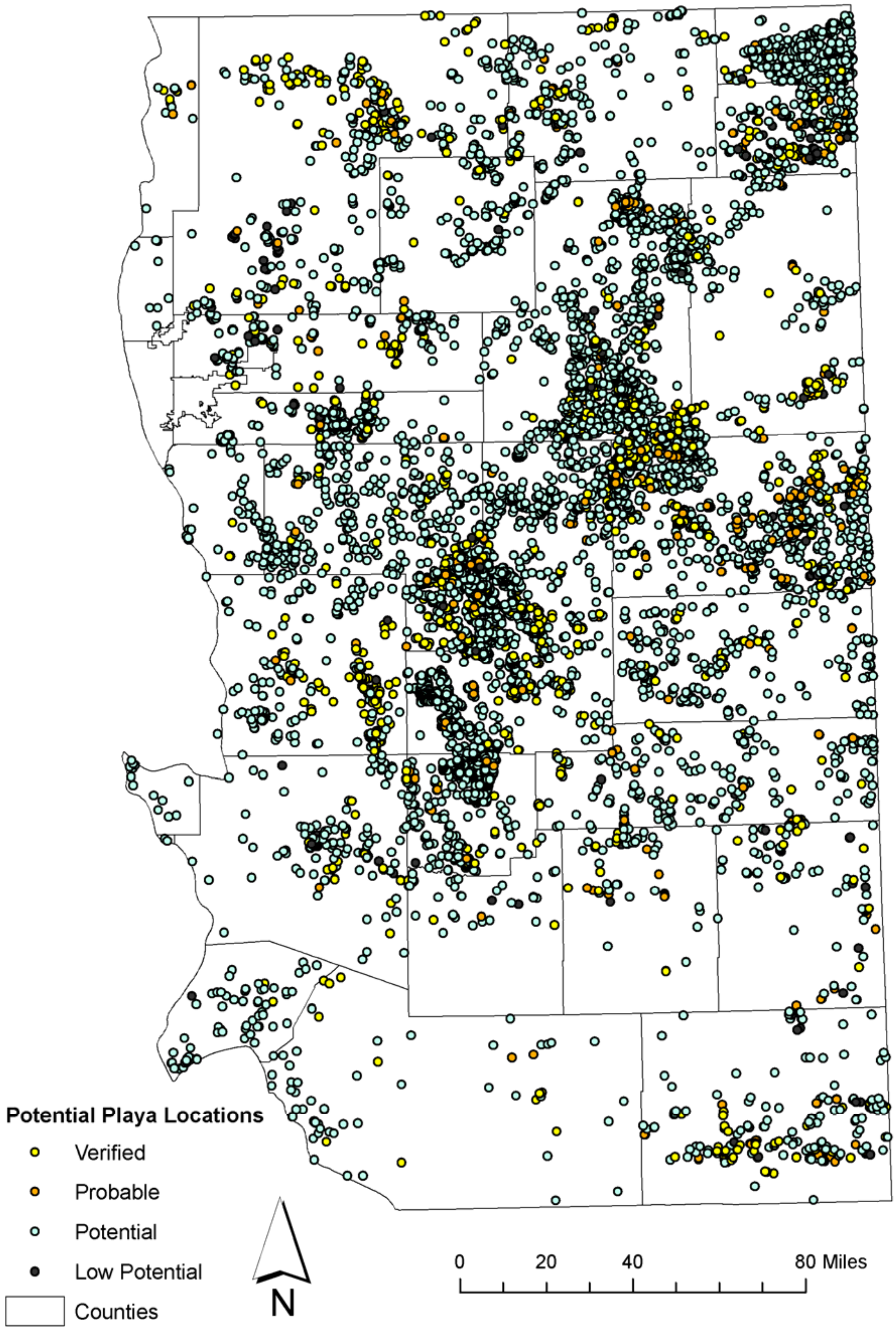


Figure 1. Potential playa locations (n = 8,347) in RMBO GIS database of BCR 18 in Colorado (12/2008).

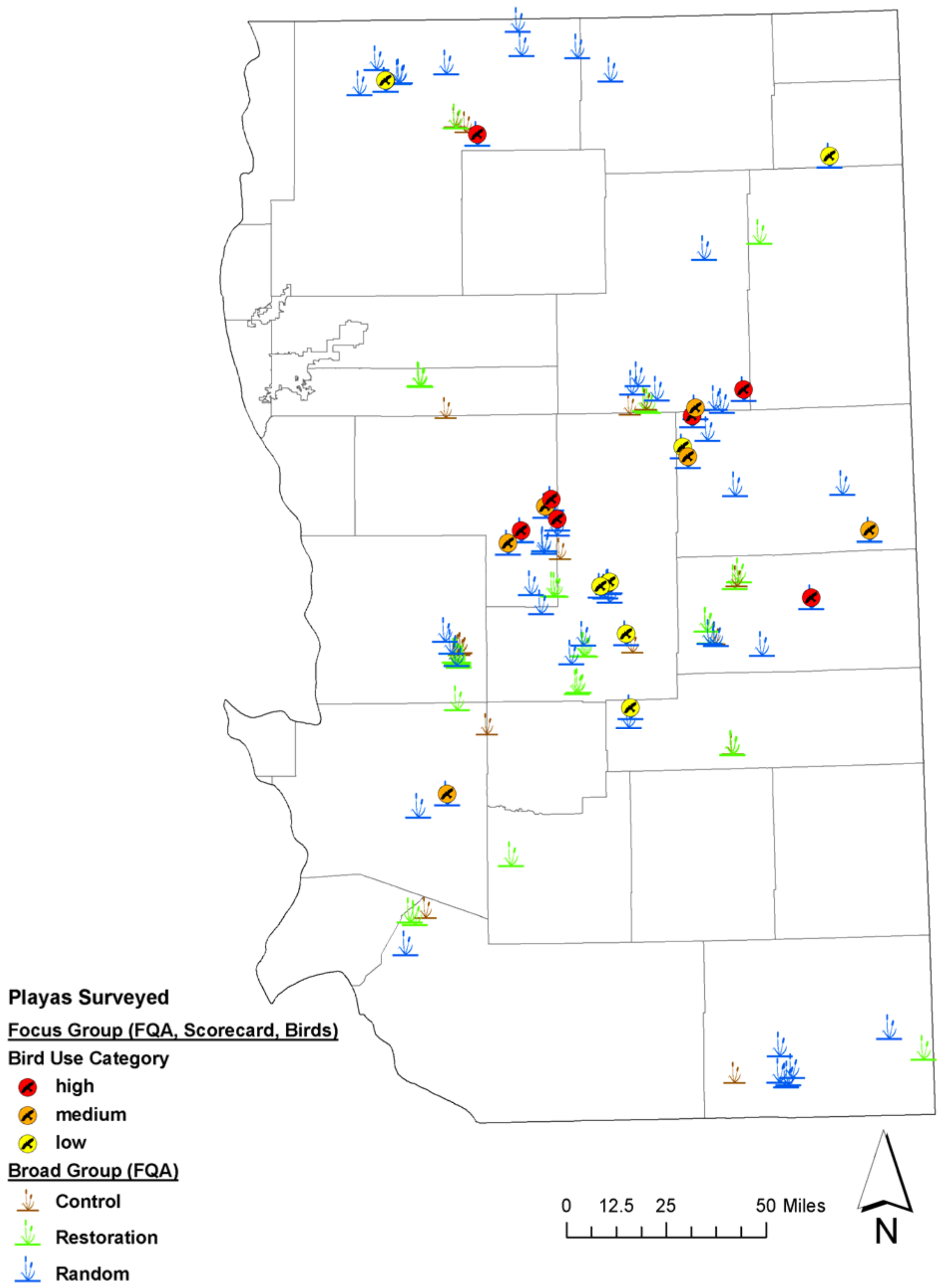


Figure 2. Playas surveyed for the FQA project 2006-2007. Focus group playas for which vegetation, EIA Scorecard, and bird use data were collected are shown with bird icons; the broad group of playas with floristic and human disturbance gradient (HDI-2) data are shown with vegetation icons.

The other primary set of playas in this analysis, the “broad group,” is comprised of a larger array of playas that were sampled intensively for vegetation in the 2006 or 2007 field seasons (n = 109). This includes the previous set of playas but also many lacking bird use and EIA Scorecard data. The group is comprised of 61 representative playas from sixteen counties throughout the study area (Table 1 and Figure 2); most were selected over several years by a stratified-random process, (see Cariveau and Pavlacky 2008), as well as playas being examined for their responses to restoration practices. The restoration group included 31 playas in restoration programs (entailing practices such as grazing management and pit removal) and 17 “control” (non-restored) wetlands to be compared with the restoration playas. Control playas were selected to match the conditions of the restored playa before the restoration occurred. Controls were either located by asking the landowner if he or she knew of any playas with appropriate conditions nearby or by consulting our GIS database of potential playa locations. Control playas were located as close to the restored playas as possible, usually within 30 miles.

Table 1. Numbers of playas sampled per county, 2006-2007.

County	Broad Group	Focus Group
Arapahoe	4	
Baca	7	
Cheyenne	11	1
Crowley	1	
El Paso	13	
Elbert	11	4
Kiowa	5	1
Kit Carson	7	4
Las Animas	4	
Lincoln	15	5
Logan	1	
Otero	1	
Phillips	1	1
Pueblo	2	1
Washington	12	2
Weld	14	3

Playa Conditional Assessment

For each playa, we collected the following information using a standardized field form:

- The Universal Transverse Mercator (UTM) coordinates of the playa center and marked them in a handheld Garmin eTrex® Global Positioning System (GPS) unit;
- Two photographs, and the location, bearing, and written description for each;
- The distance and compass bearing from the center to the playa edge, along the widest and narrowest axes of the playa, with edges determined by change in vegetation at the upland interface.
- The acreage of the playa was estimated as being one of three size class categories (<2 ac, 2-12 ac, or >12 ac).
- The relative wetness of playas by classifying the extent of standing water within the playa basin (> or <50% areal extent covered by standing water), indicators of

past wetness (dry with hydrophytes present, dry with cracks visible), or if the playa was dry (no hydrophytes or cracks visible);

- The following agricultural uses in the playa basin: farmed, grazed, or hayed;
- Hydrologic modifications to the playa: pitted/excavated, constructed inlet or outlet, impounded/bermed/terraced, and whether a well was present;
- If the playa basin was bisected by a road;
- Estimated average height of vegetation within the playa (<0.1 m, 0.1- <0.5 m, 0.5 – 1.0 m, and >1.0 m);
- The surrounding land use (to 100 m) as dryland agriculture (cropland), irrigated agriculture, USDA Conservation Reserve Program (CRP), and/or grassland;

Avian Use Surveys

We mapped possible playas in the high rainfall areas and surveyed all wet playas within a distance of the road from which waterfowl and shorebirds could be distinguished. Surveys were repeated every 7 to 10 days for as long as playas contained standing water or moist soil within the migratory season (the final survey was conducted November 17, 2006).

Surveyors used binoculars or a spotting scope placed along the roadside to visually identify and count all birds using the playa and the upland within 100 m of the playa edge; any aural detections also were recorded. We recorded the date, time of day, duration of survey, estimated temperature, estimated wind speed, and general weather categories. Bird data collected included species, number observed (or estimated), habitat, activity, and when known, sex and age class.

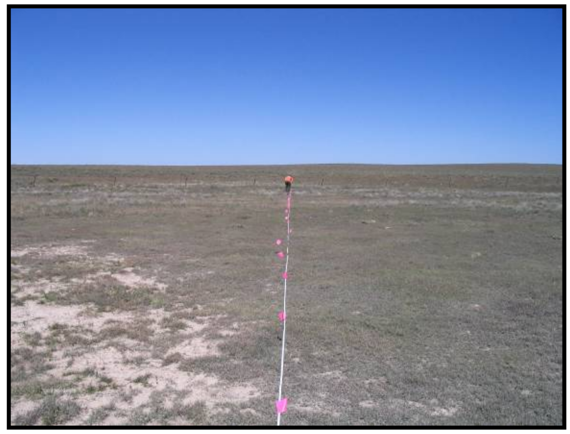
A biologist surveying birds from the roadside

To describe avian habitat availability for each survey we estimated the percent of the playa basin covered by the following categories: dry mud, dry mud vegetated, wet mud (saturated), wet mud vegetated, standing water (inundated), and water with emergent vegetation. Observers were trained to characterize areas as vegetated when they contained a canopy cover of at least 25% vegetation. Thus, areas very sparsely vegetated were contained within the “unvegetated” estimate of habitat. This corresponds to the preferences of shorebirds for open areas with less than 25% cover by vegetation (Burger et al. 1997, Colwell and Oring 1988, Hands 1988, and Helmers 1991 in Helmers 1993).

Vegetation Sampling

We marked the playa center and established two transects originating from that point, the first extending along the longest axis of the playa and the second perpendicular to the first. For each transect, we measured the distance from the playa's center to the observable upland interface (Flowers 1996; Rivers 2003). This distance was divided by 20 to determine the spacing distance between 20 transect sample points. This method standardized the sampling effort among playas of different sizes. Another five sample points for each transect line were in upland vegetation.

To characterize vegetation, we used a 25 x 50 cm plot or Daubenmire frame (Daubenmire 1959). This frame was positioned at each of the 25 sample points, with the longer side parallel to the transect line. Plots were placed on alternating sides of the transect line to improve the probability of adequately sampling. Within each quadrat we estimated cover by plant species as well as four other cover types: bare ground, water, litter or duff. Percent canopy cover was recorded as one of six cover classes: 1=0–5%, 2=5–25%, 3=25–50%, 4=50–75%, 5=75–95%, 6=95–100% (Daubenmire 1959). Plant height was recorded using a meter stick. The plant that had the greatest height within each quadrant was measured to the nearest 0.5 cm. After completing the plot measurements, we surveyed the entire playa area in search of plant species that could have been missed within the quadrats. This additional survey allowed for a more complete plant list for each playa.



Transect for sampling vegetation

In 2006, if a plant species was not definitively identified in the field, a specimen was collected for subsequent identification. In 2007, a specimen of every plant found in each county was collected. All plant specimens from 2007 were identified by personnel from the Denver Botanic Gardens (Donald Hazlett) and voucher specimens for the quality specimens are archived at the Kathryn Kalmbach herbarium in Denver. The plant nomenclature used for plant species follows the online Catalogue of the Colorado Flora: A Biodiversity Baseline hosted by the Museum at the University of Colorado Boulder (http://cumuseum.colorado.edu/Research/Botany/Databases/catalog.html).

Using the USDA PLANTS database (http://plants.usda.gov/) we categorized each plant species according to wetland indicator status (obligate wetland, facultative wetland, facultative, facultative upland, upland) as defined in the 1987 *Wetland Delineation Manual* (Environmental Laboratory 1987) and listed in the *National List of Vascular Plant Species that Occur in Wetlands* (Reed 1988). We highlighted obligate wetland plants (99% probability of occurring in wetlands), facultative wetland plants (67-99% likely to occur in wetlands), and facultative plants (34-66% likely to occur in wetlands). First we included all plants with these statuses on either the national or Region 5 list, then we removed those that were classified as FACU on the Region 5 list. If available, we used the USDA Region 5 indicator status rather than the national status. We also used the USDA PLANTS Database to assign each plant to a life form (e.g. annual or perennial) and to determine origin as native or introduced. In addition,

Daubenmire frame for vegetation sampling

we related plants to the Colorado Department of Agriculture Noxious Weed List (www.colorado.gov/ag/csd).

Floristic Quality Assessment Indices

Floristic quality measures were calculated from our Daubenmire plot plant data following the CNHP report *Floristic Quality Assessment Indices for Colorado Plant Communities* (Rocchio 2007a). We specifically indicate when we included plants identified during the post-plot walk-around surveys. Plant species were assigned coefficients of conservatism (C-values) according to the CNHP database "FQASpeciesList_2008_03_25.dbf" provided by CNHP Wetland Ecologist Joanna Lemly. Generally, C-values are characterized as follows: 0-3, species very prevalent in non-natural areas, have wide ecological tolerance, do not show fidelity to natural areas; 4-6, species show a weak affinity to natural areas but provide no indication of quality, includes many dominant species; 7-9 species are obligate to natural areas but can sustain some level of habitat degradation; 10, species are obligate to high-quality natural areas without degradation (Rocchio 2007a).

Several species identified during our project lacked C-values in the original FQA report. Two species (*Amaranthus minimus,* slim amaranth, and *Critesion brachyantherum,* meadow barley) we determined to be non-native but were not marked as such in the database; these received zero for C-values. For nine species with missing values, we assigned the mean values from floristic quality assessments of Kansas and Nebraska (Table 2: Freeman and Morse 2002; Steinauer and Rolfsmeier 2003). Only one plant species remained for which were unable to assign a C-value: *Portulaca halimoides*, silkcotton purslane, which was only collected from one playa in our study and does not range into Kansas and Nebraska (USDA PLANTS database).

Table 2. C-values assigned to plants lacking C-values in the CO FQA Table.

Latin Name	Common Name	Kansas C	Nebraska C	New CO C
Ammannia robusta	grand redstem	2	4	3
Astragalus adsurgens	prairie milkvetch		5	5
Atriplex argentea	silverscale saltbrush	6	4	5
Bacopa rotundifolia	disk waterhyssop	4	4	4
Bergia texana	Texas bergia	2	3	3
Cyperus acuminatus	tapertip flatsedge	0	3	2
Heteranthera limosa	blue mud plantain	5	4	5
Heterotheca latifolia	camphorweed	2		2
Tithymalus spathulatus	warty spurge	5	2	4

Ten metrics were calculated for each playa per the FQA report (Table 3; Rocchio 2007a). For playas that were sampled more than once in 2006-2007, we averaged their FQA metrics across surveys.

Table 3. Terminology, description and calculation of the floristic quality metrics.

Indices	Description	Calculation
Species count	Number of plant species observed	N_a
Native species count	Number of native plant species observed	N_n
Mean C	Average C-value of all plants	$\sum_{i=1}^{n} C_i \Big/ N_a$
Mean C_{nat}	Average C-value of only the native plants	$\sum_{i=1}^{n} C_i \Big/ N_n$
Cover-weighted Mean C	Sum of the C-values multiplied by the cover values divided by the sum of the cover values for all species	$\sum_{i=1}^{n} x_i C_i \Big/ \sum_{i=1}^{n} x_i$
Cover-weighted Mean C_{nat}	Sum of the C-values multiplied by the cover values divided by the sum of the cover values for native species	$\sum_{i=1}^{n} x_i C_i \Big/ \sum_{i=1}^{n} x_i$
FQI	Mean C of all plants multiplied by the square-root of number of native plants	$\left(\sum_{i=1}^{n} C_i \Big/ N_a \right) \sqrt{N_n}$
FQI_{nat}	Mean C of native plants multiplied by the square-root of number of native plants	$\left(\sum_{i=1}^{n} C_i \Big/ N_n \right) \sqrt{N_n}$
Cover-weighted FQI	Cover-weighted Mean C for all species multiplied by the square-root of native species	$\left(\sum_{i=1}^{n} x_i C_i \Big/ \sum_{i=1}^{n} x_i \right) \sqrt{N_n}$
Cover-weighted FQI_{nat}	Cover-weighted Mean C for native plants multiplied by the square-root of native plants	$\left(\sum_{i=1}^{n} x_i C_i \Big/ \sum_{i=1}^{n} x_i \right) \sqrt{N_n}$
Adjusted FQI	Mean C of native plants divided by 10 multiplied by square-root of native plants divided by the square-root of number of all plants multiplied by 100	$\dfrac{\left(\sum_{i=1}^{n} C_i \Big/ N_n \right)}{10} \dfrac{\sqrt{N_n}}{\sqrt{N_a}} (100)$
Adjusted cover-weighted FQI	Cover-weighted Mean C for native plants divided by 10 multiplied by square-root of native plants divided by the square-root of number of all plants multiplied by 100	$\dfrac{\left(\sum_{i=1}^{n} x_i C_i \Big/ \sum_{i=1}^{n} x_i \right)}{10} \dfrac{\sqrt{N_n}}{\sqrt{N_a}} (100)$
Count of non-native species	Number of non-native plants	N_e
Percent non-native species	Number of native plants divided by the number of all plants multiplied by 100	$(N_n / N_a)(100)$

N_n = count of native species, N_a = count of all species, N_e = count of non-native species, C_i = index of conservatism for the i^{th} species, x_i = percent cover for the i^{th} species.

In addition to these metrics, we reported the number of rare or imperiled plant species found in playas according to the Conservation Status Ranking system of the Natural Heritage Network governed by NatureServe. The system provides a way to evaluate the relative imperilment of species at state and global levels. Conservation status ranks range from critically imperiled to demonstrably secure (Table 4). These status assessments are based on the best available information, and consider a variety of factors such as abundance, distribution, population trends, and threats. We included all species with state ranks 1-3 on the Colorado Natural Heritage Program state list of plants (http://www.cnhp.colostate.edu/tracking/vascular.html; updated 8-22-08).

Table 4. Conservation Status Rankings of plants, for either the state or global level, as modified from information provided by NatureServe via the CNHP website.

Rank	Status	Definition
1	Critically Imperiled	Extreme rarity (often 5 or fewer occurrences) or some factor(s) such as very steep declines make it especially vulnerable to extirpation
2	Imperiled	Rarity due to very restricted range, very few populations (often 20 or fewer), steep declines, or other factors make it very vulnerable to extirpation
3	Vulnerable	Restricted range, relatively few populations (often 80 or fewer), recent and widespread declines, or other factors make it vulnerable to extirpation
4	Apparently Secure	Uncommon but not rare; some cause for long-term concern due to declines or other factors.
5	Secure	Common; widespread and abundant.

Ecological Integrity Assessment (EIA) Scorecard

The EIA Scorecard of the *Intermountain Basins Playa System Ecological Integrity Assessment* (Rocchio 2006) incorporates measures of human disturbance as well as measures of biotic integrity to derive an overall rating of ecological integrity for each playa. Four main factors are considered: landscape context, biotic condition, abiotic condition, and wetland size. Each factor is approximated by “core” or “supplemental” metrics to be measured either by remote sensing (Tier 1), rapid assessment (Tier 2), or intensive field sampling (Tier 3). Supplemental metrics are not required but provide more in-depth assessment for particular factors. We collected data for all but two of the core metrics proposed by the EIA Scorecard, as detailed below.

Landscape Context

We collected data for all three of the core metrics for landscape context: adjacent landuse, buffer width, and percentage of unfragmented landscape within 1 km (Rocchio 2006).

To depict adjacent landuse, we noted in the field all landuses within 100 m of the playa edge. Later, using National Agricultural Inventory Photography aerial photography in GIS (NAIP 2005), we estimated the percent of the 100 m buffer area comprised by each landcover type. The coefficient for each of these landuse types (Table 5, from Rocchio 2006) was then multiplied by its estimated percentage of the adjacent landuse to create a sub-landuse score. Sub-landuse scores were then summed for each playa, and playas were categorized as follows: A = Excellent (landuse score 0.95-1.0); B = Good (0.8-0.94); C= Fair (0.4-0.79); and D = Poor (< 0.04).

Table 5. Surrounding landuses within 100 m of playa edge, from the EIA Scorecard.

Paved roads / parking lots / domestic or commercial buildings / gravel pit	0.001*
Unpaved roads (driveway or tractor trail) / Mining	0.1
Agriculture (tilled crop production)	0.2
Heavy grazing / intense recreation / ATV use / camping / fishing area	0.3
Hayed	0.5
Moderate grazing	0.6
Moderate recreation (high-use trail)	0.7
Light grazing / light recreation	0.9
Fallow with no history of grazing or human use during past 10 yrs.	0.95
Natural area / land managed for native vegetation	1.0

*This was listed as 0 in Rocchio 2005; we modified it to 0.001 for our calculations.

We estimated average buffer width of each playa to road or cropland in the field; these values were then reviewed when viewing playas in aerial photography in GIS. Playas with buffers greater than 100 m wide were classified as A; 50-100 m buffers were ranked B; 25-50 m buffers were ranked C; and buffers of less than 25 m were ranked D.

To characterize the degree of fragmentation in the surrounding landscape (out to 1 km beyond playa), we selected among four categories during the field visit. "Excellent" was selected if the playa was in a landscape of 90-100% unfragmented and roadless natural landscape with no internal fragmentation observed; "good" indicated that 60-90% of the landscape was in a natural, unfragmented condition with minimal internal fragmentation; "fair" indicated that 20-60% of the landscape was unfragmented with moderate internal fragmentation; and "poor" indicated less than 20% unfragmented natural landscape with high internal fragmentation.

The three metrics for Landscape Context were then combined by multiplying each metric's rating by its weight (Table 6) and summing across the three metrics. The overall Score was then assigned: Excellent (4.5-5.0); Good (3.5-4.4); Fair (2.5-3.4); Poor (1.0-2.4).

Table 6. Surrounding Landuse Metrics, Ratings, and Weights for calculating overall score.

Metric	Definition	A	B	C	D	Weight
Adjacent Land Use	Addresses the intensity of human dominated land uses within 100 m of the wetland.	5	4	3	1	0.40
Buffer Width	Wetland buffers are vegetated, natural (non-anthropogenic) areas that surround a wetland.	5	4	3	1	0.40
Percentage of unfragmented landscape within 1 km.	An unfragmented landscape has no barriers to the movement and connectivity of species, water, nutrients, etc. between natural ecological systems.	5	4	3	1	0.20

Biotic Condition

For biotic condition, we measured all of the core metrics: relative cover of native plant species, dominance by invasive species, and floristic quality index (mean C, native).

Relative cover of native plant species was derived from Daubenmire plots, in which we summed all of the cover of native plants and divided this by the summed cover of all plants and multiplied by 100. The playa was considered Excellent if 100% of the plant species cover was comprised of native species; Good if 85-99% of plant cover was native; Fair 50-84% cover by natives; and Poor if < 50% of the plant cover was native.

Invasive species in the Intermountain Basins Playa EIA was scored only for two invasive species, whitetop (*Cardaria* spp.) and Canada thistle (*Cirsium arvense*), neither of which were recorded on playas in the Central Shortgrass Ecoregion. However, we created our own index for this metric based upon the "invasiveness" variable within the CNHP FQA table. The FQA Panel assigned invasiveness scores of 1-4 from less invasive to highly invasive (FQASpeciesList_2008_03_25.dbf, as explained in Colorado Floristic Quality Assessment Database Manual, provided by CNHP biologist Joe Rocchio). From a list of species with invasiveness scores for each playa, we multiplied the number of species in each invasiveness category by its score, and then summed these for each playa. These values ranged from 12 – 61. We assigned those with scores less than 20 as Excellent, 20-39 as Good, 40-59 as Fair, and greater than 59 as Poor.

We calculated the mean C-value of the native plants per playa, and then categorized playas based upon those values: Excellent, >4.5; Good, 3.5 – 4.5; Fair, 3.0-3.5; and Poor, < 3.0.

Biotic condition subscores were rolled together by assigning the ratings and computing a weighted average score (Table 7). The overall Score was then assigned: Excellent (4.5-5.0); Good (3.5-4.4); Fair (2.5-3.4); Poor (1.0-2.4).

Table 7. Biotic Condition Categories, Ratings, and Weights for calculating overall score.

Metric	Definition	A	B	C	D	Weight
Percent of Cover of Native Plant Species	Percent of the plant species which are native to the Southern Rocky Mountains.	5	4	3	1	0.30
Invasive Species	Prevalence of invasive, aggressive plants.*	5	4	3	1	0.20
Floristic Quality Index (Mean C nat)	The mean conservatism of all the native species growing in the wetland.	5	4	3	1	0.50

Abiotic Condition

For abiotic condition, we measured two core metrics: landuse within the wetland and hydrological alterations. We did not measure water table depth because Central Shortgrass playas are recharge wetlands by definition and their function should therefore not relate to water table depths. During our field visit, landuses within the wetland were classified and scored in the same manner as surrounding landuse (see Table 3). We recorded all of the hydrological modifications observed to classify playas into four categories of hydrological alteration (Table 8).

Table 8. Hydrological Alterations on the EIA Scorecard, Categories, and Scores

Excellent (A) = 5	Good (B) = 4	Fair (C) = 3	Poor (D) = 1
__ (No) alterations __ No dikes or diversions. __No ditches__No fill __No flow additions	**__Low alteration** __Roads at or near __Sm. Ditches __Sm. Flow additions (< 1 ft. deep)	**__Moderate** __2-Lane Rd. __Low dikes __Rd. w/culverts __Med. Div./ditches (1-3 ft. deep) __Mod. Flow add.	**__High** __4 Lane Hwy. __Lg. dikes __Diversions__Ditches (>3 ft. deep) __Fill__Water pumps __Other flow additions

Abiotic condition scores were then rolled up with a modification of the original EIA Scorecard guidelines. The original weighted Landuse by .25, water table depth by.20, and hydrological alterations by .50. To maintain the heavier weighting on hydrological alterations, we used weights of .34 for landuse and .66 for hydrological alterations.

Playa Size

For the final factor of size, we used the acreage values represented in our GIS. We did not try to represent relative size as we did not feel confident we could accurately depict anthropogenic changes to wetland size using a single visit and without historical baseline data regarding wetland size.

Overall Integrity Rating
To derive an overall Integrity Ranking for each playa, we used the formulae provided by the EIA guidelines (Rocchio 2006):

- If Landscape Context = *A* then the Overall Ecological Integrity Rank = [Abiotic Condition Score *(0.35)] + [Biotic Condition Score *(0.25)] + [Landscape Context Score * (0.25)] + [Size Score * (0.15)]
- If Landscape Context is *B*, *C*, or *D* AND Size = *A* then the Overall Ecological Integrity Rank = [Abiotic Condition Score *(0.35)] + [Biotic Condition Score *(0.25)] + [Size Score * (0.25)] + [Landscape Context Score * (0.15)]
- If Landscape Context is *B*, *C*, or *D* AND Size = *B* then the Overall Ecological Integrity Rank = [Abiotic Condition Score *(0.35)] + [Biotic Condition Score *(0.25)] + [Landscape Context Score * (0.20)] + [Size Score * (0.20)]
- If Landscape Context is *B*, *C*, or *D* AND Size = *C* or *D* then the Overall Ecological Integrity Rank = [Abiotic Condition Score *(0.35)] + [Biotic Condition Score *(0.25)] + [Landscape Context Score * (0.25)] + [Size Score * (0.15)]

An Overall Ecological Integrity Rating was then assigned using the following criteria: Excellent, A = 4.5 - 5.0; Good, *B = 3.5 – 4.4;* Fair, *C = 2.5 – 3.4;* and Poor, *D = 1.0 – 2.4.*

Human Disturbance Index (HDI-1)

To test the Floristic Quality Assessment, we calculated a Human Disturbance Index (HDI) as described in the *HDI Form* of the *Floristic Quality Assessment Indices for Colorado Plant Communities* (Rocchio 2007a; Appendix A). To distinguish this from subsequent investigations of human disturbance, we call this “HDI-1.” HDI-1 in a semi-quantitative index used to describe the degree of divergence from reference condition (or minimum disturbed condition). HDI-1 is comprised of three main types of factors: alterations within buffers and surrounding landuse, hydrologic alterations, and physical/chemical disturbances.

It should be noted that we designed our field data collection of human disturbance factors to fit the *IB IEA* because that was available when we proposed our study. Subsequently, the Human Disturbance Index form became available in the Floristic Quality Assessment report (Rocchio 2007a). HDI-1 is more appropriate for testing the FQA because it includes only abiotic human disturbance factors; however, we did not collect all of the HDI-1data during fieldwork. We collected all of the metrics for surrounding landuse and hydrological alterations, but were lacking some for physical/chemical disturbances. Here we explain the derivation of scores for each category, noting when we diverged from the original HDI-1.

Alterations to Buffers and Surrounding Landuse
Three measures were combined to assess this factor.

First we estimated average buffer width of each playa to road or cropland. Playas with buffers of greater than 100 m were classified as Excellent and received 0 points; 50-100 m buffers were ranked Good (3 points); 25-50 m buffers were Fair (7 points); buffers of less than 25 m were ranked Poor (10 points).

Secondly, all landuses within 100 m of the playa edges were recorded and landuse scores were computed as described in *EIA Scorecard*: *Landscape Context* above. Playas were subsequently allocated points as follows: 0 points for Excellent (landuse scores 0.95-1.0); 3 points for Good (0.8-0.94); 7 points for Fair (0.4-0.79); and 10 points for Poor (< 0.04).

Third, we characterized the degree of fragmentation in the surrounding landscape (out to 1 km beyond playa). We selected among four categories during the field visit. "Excellent" was checked if the playa was in a landscape of 90-100% unfragmented and roadless natural landscape with no internal fragmentation observed; "good" indicated that 60-90% of the landscape was in a natural, unfragmented condition with minimal internal fragmentation. A "fair" rating indicated that 20-60% of the landscape was unfragmented with moderate internal fragmentation, and "poor" indicated less than 20% unfragmented natural landscape with high internal fragmentation. Excellent playas were awarded 0 points; good, 3 points; fair, 7 points; and poor, 10 points.

Subscores were combined by summing the two highest scores, dividing by 20, and multiplying by 100.

Hydrological Modifications
We recorded all of the hydrological modifications observed to classify playas into four categories of hydrological alteration (Table 9).

Table 9. Hydrological Alterations on the EIA Scorecard, Categories, and Scores

Excellent (0)	Good (4)	Fair (12)	Poor (20)
__ (No) alterations __ No dikes__divers. __No ditches__No fill __No flow additions	**__Low alteration** __Roads at or near __Sm. Ditches __Sm. Flow additions (< 1 ft. deep)	**__Moderate** __2-Lane Rd. __Low dikes __Rd. w/culverts __Med. Div./ditches (1-3 ft. deep) __Mod. Flow add.	**__High** __4 Lane Hwy. __Lg. dikes __Diversions__Ditches (>3 ft. deep) __Fill__Water pumps __Other flow additions

The hydrological alteration factor was calculated by using the categorical score (e.g., 0 for Excellent, 20 for Poor), dividing by 20 and multiplying by 100.

Physical/Chemical Disturbance
Onsite landuse was recorded and scored as described in *EIA Scorecard*: *Landscape Context* above. Substrate/soil disturbance, algae, cattail dominance, sediment and turbidity, and toxics and heavy metals metrics were not measured. The physical/chemical disturbance factor was calculated by using the categorical score (e.g., 0 for Excellent, 20 for Poor), dividing by 20 and multiplying by 100.

We calculated a Human Disturbance Index Final Score by averaging the three subscores. Scores range from 0 (reference condition) to 100 (highly impacted).

Human Disturbance Gradient (HDI-2) and Analysis

For the broad group of playas (n = 109), most of which were missing EIA Scorecard/HDI-1 data, we compiled eleven metrics to represent human disturbance (Table 10). We used these to understand what aspect(s) of human disturbance were most strongly related to floristic quality measures. To represent the proportion of the surrounding landscape that was in native prairie ("LaPr"), we buffered the playas in a doughnut configuration with a 2 km-radius from the edge of the playa polygons and overlaid this with the Playa Lakes Joint Venture landcover data, ArcGIS (ESRI 2005). This was a distance that we felt would depict the landscape pertinent to waterbirds during migration stopover. The proportion of native prairie in the surrounding landscape was calculated by summing the area covered by shortgrass prairie, mixed-grass prairie, and sand-sage, and then divided by the total area of the buffer. To represent the proportion of the landscape that was unfragmented ("LaUn"), we calculated the proportion of the 2 km radius that was composed by the largest block of native prairie, unfragmented by roads, development, or cropland, FRAGSTATS (McGarigal et al. 2002). To represent the roadedness of the area surrounding each playa, we calculated road density (km^{-1}) within the 2 km buffers for each playa ("RdDe") by dividing the total road length (km) by the area (km^2) of the buffer. We calculated the distance from playa center to nearest road using the TIGER roads GIS layer (US Census Bureau 2007; "RdDi"). Based on field visits, we coded as 0 or 1 if a playa was tilled or not, grazed or not, impounded or bermed, dug out or pitted, or if a playa was split or bordered by a road. Playas were given a 1 for grassland if adjacent landuse (out to 100 m beyond playa edges) included grassland and a 1 for surrounding landuse of cropland; several playas with split landuse contexts (such as on the edge of a cropfield) were coded as a one for each surrounding landuse type.

Table 10. Human Disturbance factors used in HDI-2 and their weightings in principal components 1 and 2. Human Landuse factors included in models predicting floristic quality and avian use metrics.

Factor	Definition
LaPr	proportion of 2 km surrounding playa in native prairie
LaUn	proportion of surrounding 2 km that is unfragmented
RdDe	length of roads in surrounding 2 km of playa
RdDi	distance from playa center to nearest road
Gras	surrounding landuse was grassland
Ag	surrounding landuse was cropland
Plow	if a playa was tilled or not
Graz	if a playa was grazed or not
Impo	if a playa was impounded or bermed
Pit	if a playa was dug out or pitted
Rdlm	if a playa was split or bordered by a road

The 11 human disturbance factors listed above were combined to represent one or more gradients of human disturbance (HDI-2). The data used for this analysis was composed of 109 playas and associated measures of human disturbance. We used Principle Components Analysis (PCA) of qualitative, quantitative, or mixed data (PROC PRINQUAL, SAS Institute 2008) to develop one or more principle components represented by linear combinations of the variables that maximized the proportion variation explained. We transformed the variables prior to conducting the PCA using optimal scoring for continuous variables and monotonic transformations for categorical variables (SAS Institute 2008). The structure loadings for the linear combinations of the variables were estimated using Factor Analysis (PROC FACTOR, SAS Institute 2008). The principal component scores from the PCA were used to represent gradients human disturbance and evaluate the relative strength of association for the various FQA indices.

We evaluated the strength of association between the 14 floristic quality metrics and gradients of human disturbance (HDI-2) for 109 playas using a general linear model (PROC GLM, SAS Institute 2008). The coefficient of determination (R^2) was estimated for each of the 14 floristic quality models and 95% confidence intervals for R^2 were calculated using effect size measures (PROC GLM, SAS Institute 2008). The beta coefficients and associated standard errors for PCA1 and PCA2 were used to evaluate the effects of human disturbance on the floristic quality metrics.

To better understand the effects of human disturbance on floristic quality, we conducted a model selection analysis to evaluate the predictive ability of the 11 human disturbance factors on the four floristic quality metrics with the strongest association with human disturbance [Mean C (all species), Species Count (native), FQI (all species), Exotic Species (%)]. We used a generalized linear model (Nelder and Wedderburn 1972) with the normal distribution and identity link function to model floristic quality as a function of the human disturbance variables (PROC GENMOD, SAS Institute 2008). Because several of the human disturbance variables were highly correlated ($r > 0.6$), we selected variables with the largest effect size from groups of variables defined by landscape context, wetland proximity, road prevalence and adjacent landuse. This resulted in a set of seven predictor variables including playa size, landscape context, wetland proximity, road prevalence, road bisection, hydrological modification and adjacent landuse. The four floristic quality metrics were modeled using all subsets of three variable models for a total of 63 models per floristic quality metric. We used information-theoretic model selection to evaluate the likelihood of the models given the parameters and to estimate the amount of Kullback-Liebler Information lost when models are used to approximate reality (Burnham and Anderson 2002). Akaike's Information Criteria corrected for sample size (AICc) was used to rank the set of candidate models (Burnham and Anderson 2002). The AICc weights (w_i) and evidence ratios were used as strength of evidence for the competing models (Burnham and Anderson 2002). We used cumulative AICc weights [$w_{i+}(j)$] to evaluate the importance of each predictor variable (Burnham and Anderson 2002). The 95% confidence intervals for the beta parameters were used to evaluate the effect size of the variables and beta parameters exhibiting coefficient variation less than 0.6 provided evidence for the effects.

Sampling Effects on FQI Performance

The effect of season on the estimated floristic quality metrics was investigated for 16 playas sampled during the spring and summer of 2007. We used a linear mixed model (PROC MIXED, SAS institute 2008) to evaluate the effects of season and human disturbance on the top four floristic quality metrics. This model assumed a normal distribution for the random effects of playa ID and included a block covariance structure for the categories of playa ID (PROC MIXED, SAS institute 2008). We analyzed models containing the categorical fixed effect of season, the continuous fixed effects of HD1-1, PCA1 and PCA2, each continuous variable with an additive effect of season, and the interaction between each human disturbance variable and season. Interaction effects were interpreted as evidence for differences in the association with human disturbance attributed to season. We used information-theoretic model selection to evaluate the models as in the above section (Burnham and Anderson 2002). The 95% confidence intervals for the beta parameters were used to evaluate the effect sizes and beta parameters exhibiting coefficient variation less than 0.6 provided evidence for the effects. Second, we investigated the effects of pooling the data across two samples *versus* taking the mean from the two samples for the same 16 playas. We used a linear mixed model as above to assess the effects of sample pooling and human disturbance on the top four floristic quality metrics (PROC MIXED, SAS institute 2008). We analyzed models containing the categorical fixed effect of data pooling, the continuous fixed effects of HD1-1, PCA1 and PCA2, each continuous variable with an additive effect of data pooling, and the interaction between each human disturbance variable and data pooling. As above, interaction effects were interpreted as different associations with human disturbance attributed to sample pooling. We used information-theoretic model selection to evaluate the models as in the Human Disturbance Gradient section (Burnham and Anderson 2002). The 95% confidence intervals for the beta parameters were used to evaluate the effect sizes and beta parameters exhibiting coefficient variation less than 0.6 provided evidence for the effects.

Next, we investigated the effects of incorporating additional off-plot data *versus* data from the Daubenmire samples for the 16 playas. Again, we used a linear mixed model to evaluate the effects of off-plot sampling, human disturbance and playa area on the top four floristic quality metrics (PROC MIXED, SAS institute 2008). We analyzed models containing the categorical fixed effect of data pooling, the continuous fixed effects of HD1-1, PCA1, PCA2 and playa area, each continuous variable with an additive effect of off-plot sampling, and the interaction between each continuous variable and off-plot sampling. As above, interaction effects were interpreted as different associations with human disturbance or playa area attributed to sample pooling. As in the Human Disturbance Gradient section, we used information-theoretic model selection to assess the models (Burnham and Anderson 2002). The 95% confidence intervals for the beta parameters were used to evaluate the effect sizes and beta parameters exhibiting coefficient variation less than 0.6 provided evidence for the effects.

Avian Abundance Analyses

To relate bird use to human disturbance broadly, we use analyses completed under *Assessment and Conservation of Playas in Eastern Colorado* (Cariveau and Pavlacky 2008), which we explain again here. To depict avian use of wet playas during migration, the counts of all birds as well as individual birds within landbird, shorebird and waterfowl groups were modeled as a function of covariates (Table 11) using a generalized linear mixed model (McCulloch 2003). This model assumed a normal distribution for the random effects of playa ID and included a block covariance structure for the categories of playa ID (PROC GLIMMIX, SAS Institute 2008). We investigated the suitability of the Poisson and negative binomial family distributions for each response variable by fitting the full model and examining the quasi-likelihood over-dispersion parameter (McCullagh and Nelder 1989; Pearson X^2 statistic / degrees of freedom). We used the over-dispersion parameter as an indication of variation in excess of the mean and we selected the negative binomial distribution when the over-dispersion parameter was > 1.2 (Anderson et al. 1994). All models used the log link function and the parameters were estimated using maximum likelihood with Adaptive Quadrature (SAS Institute 2008).

We followed a sequential model building strategy that first determined the structure for the migratory chronology (Group A), then established the dimensions of the local-scale ecological model, including human disturbance factors (Group B) and then determined the inclusion of landscape-scale factors (Group C; Table 11). The time chronology part of the model was built using all subsets of the Season, Year, Date, Season*Date, and Year*Date covariates (Table 11). In addition, we evaluated the threshold ($\log_e$*Date) and quadratic (Date + Date^2) functional forms of the Date covariate. The migration chronology covariates were forced into the full model containing all seven covariates in Table 11. After arriving at the migration chronology part of the model, the ecological model was constructed using all subsets of the Group B covariates in Table 11. In addition to the linear effect of playa size, we evaluated the threshold functional form ($\log_e$*Size) to evaluate the evidence for curvilinear relationships between the response variables and playa size. After determining the best model composed of ecological covariates, we evaluated the best subsets of the landscape-scale Area and Wetland covariates.

Table 11. Human disturbance, ecological, and seasonal covariates tested in the full models of avian use of playa wetlands in eastern Colorado, 2004-2007.

Group	Variable	Description	Range and Levels
A	Date	Ordinal date of the survey from 1 Jan. – 1 July or from 1 July – 31 Dec.	1 - 182
A	Year	Year of the survey	2004 - 2007
A	Season	Season of the survey, divided at July 1	Spring, Fall
B	Size	Playa area (ha) from the GIS database	0.13 - 26.02 ha
B	Wetness	Hydrologic condition of the playa during survey;(≥ 1% mud or standing water=wet)	Dry, Wet
B	Landcover	Dominant landcover type of playa from field surveys	Grass, Agriculture
B	Hydro	Hydrologic modification of playa	Altered, Not Altered
B	Road	Distance (km) from playa center to nearest road	0.01 - 5.05 km
C	Area	Area (%) within 2 km from playa edge comprised by other playas	0.0 - 6.3 %
C	Wetland	Distance (km) from playa center to nearest non-playa wetland in NHD	0.30 – 23.19 km

Finally, we used information-theoretic model selection to evaluate the likelihood of the models given the parameters and to estimate the amount of information lost when models are used to approximate reality (Burnham and Anderson 2002). Akaike's Information Criteria corrected for sample size (AICc) was used to rank the set of candidate models (Burnham and Anderson 2002). The AICc weights and evidence ratios were used as strength of evidence for the competing models (Burnham and Anderson 2002). The estimates for the mean and standard errors of the response variables were estimated using the exponential transformation of the least squares means (SAS Institute 2008) and the delta method (Powell 2007), respectively.

We used a similar approach for analyzing the effects of human disturbance and floristic quality on shorebird and waterfowl abundance in the focus group of playas (n = 22). This dataset included 164 surveys from August 30 to November 11 2006, including 6 - 9 repeat visits to each playa. Shorebird and waterfowl counts during migration were modeled as a function of fixed effects of floristic quality and human disturbance using a generalized linear mixed model (McCulloch 2003) with the negative binomial distribution and log link function. This model assumed a normal distribution for the random effects of playa ID and the parameters were estimated using maximum likelihood, adaptive quadrature (PROC GLIMMIX, SAS Institute 2008). To improve the optimization of the parameters, the survey date covariate was standardized using the z-transformation (Sokal and Rohlf 1981). As above, we used a sequential model building strategy that (1) determined the effect of survey date to define the migration chronology, (2) determined the inclusion of important ecological covariates such as playa area, and proximity to playas and other wetlands and (3) added each of the floristic quality and human disturbance covariates, including HDI-1, HDI-2 and ecological integrity, to the model one at a time. As above, we used information-theoretic model selection to evaluate the likelihood of the models given the parameters (Burnham and Anderson 2002). The 95% confidence intervals for the beta parameters were used to evaluate the effect sizes and beta parameters exhibiting coefficient variation less than 0.6 provided evidence for the effects.

CHAPTER 3. RESULTS

General Playa Characteristics

Playas in the broad group (n =109) ranged in size from 0.14 ha to 26.02 ha, with a mean of 3.50 ha (SE = 0.38; 8.34 ac). The focus group (n = 22) included playas from 0.84 – 18.90 ha, averaging 4.61 ha (SE = 0.51; 11.38 ac) in size.

In the broad group, 82 of the playas were surrounded by grassland, 16 by cropland, 8 by a combination of grassland and cropland, and 3 by CRP and grassland. In the focus group, 8 playas were in cropland, 8 were in grassland, 1 was surrounded by grass and CRP, and 5 were surrounded by both cropland and grassland.

Twenty-three (21%) of the playas in the broad group were hydrologically modified by pits (n = 7), impoundments/berms (n = 1), constricted inlet/outlets (n = 1) or a combination of these impacts (n = 9). The focus group included four playas with on-site hydrological modifications.

Playa Vegetation

We identified 245 non-crop plant species in the vegetation of the sampled playas. A list of all plant species and genera documented during surveys is presented in Appendix A.

The most commonly encountered plant species were buffalograss, western wheatgrass, and Russian thistle (Table 12). In terms of cover, the most prevalent species were buffalograss (36% of all plant species cover), western wheatgrass (7%), and common spikerush, needle spikerush, and kochia (each comprising 5%).

Table 12. Plant species found in at least one fourth of playas sampled in eastern Colorado.

Scientific Name	Common Name	Region 5 Wetland Indicator Status	Nativity	% Playas Occupied
Buchloe dactyloides	buffalograss		Native	71
Pascopyrum smithii	western wheatgrass		Native	65
Salsola australis	Russian thistle		Exotic	61
Bassia sieversiana	kochia		Exotic	53
Eleocharis palustris	common spikerush	OBL	Native	46
Verbena bracteata	prostrate vervain		Exotic	43
Ratibida tagetes	short-ray prairie coneflower		Native	43
Eleocharis acicularis	needle spikerush	OBL	Native	38
Oenothera canescens	spotted evening primrose	FACW-	Native	36
Phyla cuneifolia	frogfruit	FAC	Native	36
Portulaca oleracea	common purslane		Exotic	36
Ambrosia tomentosa	skeletonleaf bursage/bur ragweed		Native	31
Grindelia squarrosa	curlycup gumweed		Native	30
Plantago patagonica	wooly plantain		Native	29
Chondrosum gracile	blue grama		Native	29
Iva axillaris	poverty sumpweed	FAC	Native	28
Polygonum ramosissimum	bushy knotweed	FAC	Native	27
Vulpia octoflora	sixweeks fescue		Native	27

Wetland plants comprised 35% of the species list (85 species with wetland indicator statuses of facultative, facultative wet, or wetland obligate according to either the Region 5 or national list; Appendix A and Table 12). Fifty-six of these species were facultative wet or wetland obligate; 28 species were obligates. We detected a number of rarer wetland species as well (Don Hazlett, personal comm.), including *Ammannia robusta* (grand redstem), *Bacopa rotundifolia* (disk waterhyssop), *Bergia texana* (Texas bergia), *Portulaca halimoides* (silkcotton purslane), *Heteranthera limosa* (blue mud plantain), *Cyperus acuminatus* (tapertip flatsedge), *Marsilea mucronata* (western water clover, pepperwort), and *Myosurus minimus* (bristly mousetail).

Twenty-six percent of the plant species we identified in playas were non-native to Colorado. The most dominant of these in terms of cover are noted in Table 12. Ten plants were on the Colorado noxious weed list (Table 13).

Table 13. Noxious weeds found in playas in eastern Colorado

Scientific Name	Common Name	Level of Concern	% Playas Occupied
Convolvulus arvensis	field bindweed	C	11
Anisantha tectorum	cheatgrass	C	9
Tribulus terrestris	puncturevine	C	8
Breea arvensis	canada thistle	B	3
Panicum miliaceum	wild proso millet	C	3
Tamarix ramosissima	saltcedar, tamarisk	B	2
Cardaria latifolia	tall whitetop	B	1
Cirsium vulgare	bull thistle	B	1
Erodium cicutarium	redstem stork's bill	B	1
Verbascum thapsus	common mullein	C	1

The greatest number of species in the study had C-values of zero because they were non-native; the next most common C-values were 4 and 5, indicating a neutral response to disturbance, not particularly tolerant or intolerant.

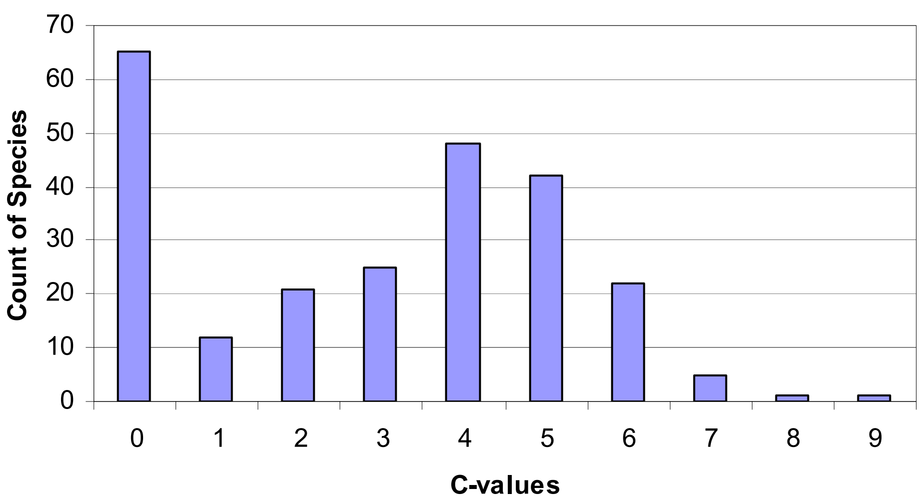


Figure 3. Numbers of plants with Coefficients of Conservatism (C-values) from all playas sampled in this study in eastern Colorado. No plants had C-value = 10.

Seven plant species in the study had C-values of greater than six, indicating fidelity to undisturbed natural areas (Table 14). One species, *Marsilea mucronata*, was quite prevalent in 29% of the playas studied.

Table 14. Plants with C-values greater than six and their frequency of occurrence.

Latin Name	Common Name	C-Value	# Playas
Chenopodium cycloides	sandhill goosefoot	9	1
Krascheninnikovia lanata	winterfat	8	2
Chamaesyce lata	hoary sandmat	7	1
Carex stenophylla	needleleaf sedge	7	1
Chondrosum barbatum	sixweeks grama	7	1
Marsilea mucronata	western water clover, pepperwort	7	32
Packera tridenticulata	threetooth ragwort	7	5

We detected five plant species tracked by CNHP as imperiled (state ranks S1-S3; Table 15). One species, *Ambrosia linearis*, was found in 19% of the playas we surveyed; it is ranked as “vulnerable to extinction” both statewide and globally. The other four species are “critically imperiled” within Colorado; three are considered “secure” globally and one vulnerable to extinction at the global level. These plants were found at a total of 28 playas in our study; no playas contained more than one species of concern.

Table 15. State-ranked plant species documented in playas in eastern Colorado 2006-2007.

Latin Name	Common Name	State Rank	Global Rank	# of Playas
Ambrosia linearis	streaked burr ragweed	S3	G3	21
Chenopodium cycloides	sandhill goosefoot	S1	G3G4	1
Heterotheca latifolia	camphorweed	S1	G5	1
Oxybaphus decumbens	narrowleaf four o'clock	S1	G5	4
Portulaca halimoides	silkcotton purslane	S1	G5	1

Average plant heights per playa ranged from 8.62 to 58.94 cm, averaging 26.85 cm (SE = 1.33) overall.

Floristic Quality Indices and Associated Metrics

The ranges, averages, and standard errors for the floristic quality metrics (values averaged for playas surveyed multiple times) are reported in Table 16. The metrics for the broad group (n = 109) showed a greater range of values than those of the focus group (n = 22). The means for the focus group were slightly lower (or higher in the case of percent non-native) than the means of the broad group. Average C-values were low, even when calculated from native species only (Table 16).

Table 16. Ranges, means, and standard errors for FQA metrics of playas in eastern Colorado.

Metric	Group	Range	Mean	SE
Total plant species count	Broad	1 - 23	12.30	0.37
	Focus	1 - 18	10.64	1.10
Native species count	Broad	1 - 15	8.42	0.33
	Focus	1 - 13.5	6.20	0.83
Percent non-native species	Broad	0 - 80	29.80	1.67
	Focus	0 - 72	39.73	4.80
Mean C	Broad	0.04 - 4.00	2.52	0.07
	Focus	0.82 - 3.33	2.01	0.17
Mean C_{nat}	Broad	2.00 - 7.00	3.56	0.05
	Focus	2.35 - 4.00	3.30	0.09
Cover-weighted Mean C	Broad	0.003 - 4.93	2.99	0.11
	Focus	0.29 - 4.32	2.20	0.26
Cover-weighted Mean C_{nat}	Broad	1.05 - 7.00	3.61	0.09
	Focus	1.05 - 4.50	3.00	0.18
FQI	Broad	0.40 - 12.39	7.31	0.27
	Focus	1.42 - 10.90	4.96	0.64
FQI_{nat}	Broad	2.00 - 14.72	10.03	0.25
	Focus	3.00 - 14.03	7.78	0.64
Cover-weighted FQI	Broad	0.003 - 15.36	8.66	0.38
	Focus	0.46 - 14.74	5.51	0.87
Cover-weighted FQI_{nat}	Broad	1.81 - 15.69	10.30	0.33
	Focus	1.81 - 15.69	7.27	0.82
Adjusted FQI	Broad	8.94 - 42.16	29.67	0.58
	Focus	14.23 - 35.78	25.32	1.30
Adjusted cover-weighted FQI	Broad	5.46 - 43.21	30.29	0.82
	Focus	5.46 - 39.33	23.40	1.90

Human Disturbance Index (HDI-1)

The focus group playas scored from 40-100, with an average score of 70 (SE = 2.74) in terms of human disturbance, measured as HDI-1. Half of the playas (n = 11) had scores exceeding 67 and could be characterized as highly disturbed; half were between 33 and 67, representing moderate disturbance levels. According to this scheme, none of the playas were in the group closer to reference condition. The component scores were as follows. The playas scored 65 – 100 for disturbance to buffer and surrounding landuse (mean = 97.05, SE = 1.79). These scores were high in part due to all playas scoring the maximum for habitat fragmentation (estimated as embedded within a landscape with less than 20% unfragmented, roadless natural area). Scores for hydrological disturbance ranged from 20-100, with an average of 41.82 (SE = 5.08). Physical or chemical disturbance scores as measured by onsite landuse ranged from 0 to 100, with a mean of 70.45 (SE = 4.68).

Human Disturbance Gradient (HDI-2)

For the broad group of playas, the percent of landscape surrounding playas (2 km radius) in native prairie ranged from 1.51 – 96.08, with a mean of 50.82 (SE = 2.82). The percent of unfragmented landscape ranged from 0.53 – 96.01, with a mean of 34.76 (SE = 2.52). Road density metrics varied from no roads to 2.49 km of road per km^2, with an average of 0.79 (SE = 0.03) km/ km^2. Distance from playa center to nearest road ranged from 12.18 – 5,059.20 m, with a mean of 450.49 m (SE = 67.12). Fifteen playas were plowed, 84 grazed; 23 were within cropland and 88 were within grassland. Fifteen playas were impounded, and sixteen were pitted. Seventeen were directly impacted by roads.

For the focus group of playas, the percent of landscape surrounding playas in native prairie ranged from 1.51 – 70.51, with a mean of 34.60 (SE = 5.15). The percent of unfragmented landscape ranged from 1.51 – 63.95, with a mean of 21.95 (SE = 4.03). Road density metrics varied from 0.03 – 1.40 km of road per km^2, with an average of 0.79 (SE = 0.06) km/ km^2. Distance from playa center to nearest road ranged from 12.18 – 345.09 m, with a mean of 147.17 m (SE = 21.40). Ten playas were plowed, 13 grazed; 13 were within cropland and 14 were within grassland. Two playas were impounded, and three were pitted. Seven were directly impacted by roads.

The multivariate analysis distilled the eleven human disturbance factors into two principal components (Table 14, Figure 4). Component 1 captured variation (50.4%) due to landscape composition. Component 2 accounted for 24.8% of the variation and was strongly related to adjacent and onsite landuse (see factor weights in Table 14).

Table 14. Human Disturbance factors used in HDI-2 and their weightings in principal components 1 and 2.

Factor	Definition	Component 1	Component 2
LaPr	proportion of 2 km surrounding playa in native prairie	0.9964	-0.0850
LaUn	proportion of surrounding 2 km that is unfragmented	0.9997	0.0234
RdDe	length of roads in surrounding 2 km of playa	-0.7724	-0.5688
RdDi	distance from playa center to nearest road	0.8349	0.5504
Gras	surrounding landuse was grassland	0.5808	-0.6293
Ag	surrounding landuse was cropland	-0.5288	0.6802
Plow	if a playa was tilled or not	-0.6109	0.6260
Graz	if a playa was grazed or not	0.5089	-0.6766
Impo	if a playa was impounded or bermed	0.6990	0.3850
Pit	if a playa was dug out or pitted	0.7194	0.4802
RdIm	if a playa was split or bordered by a road	-0.0314	0.0099

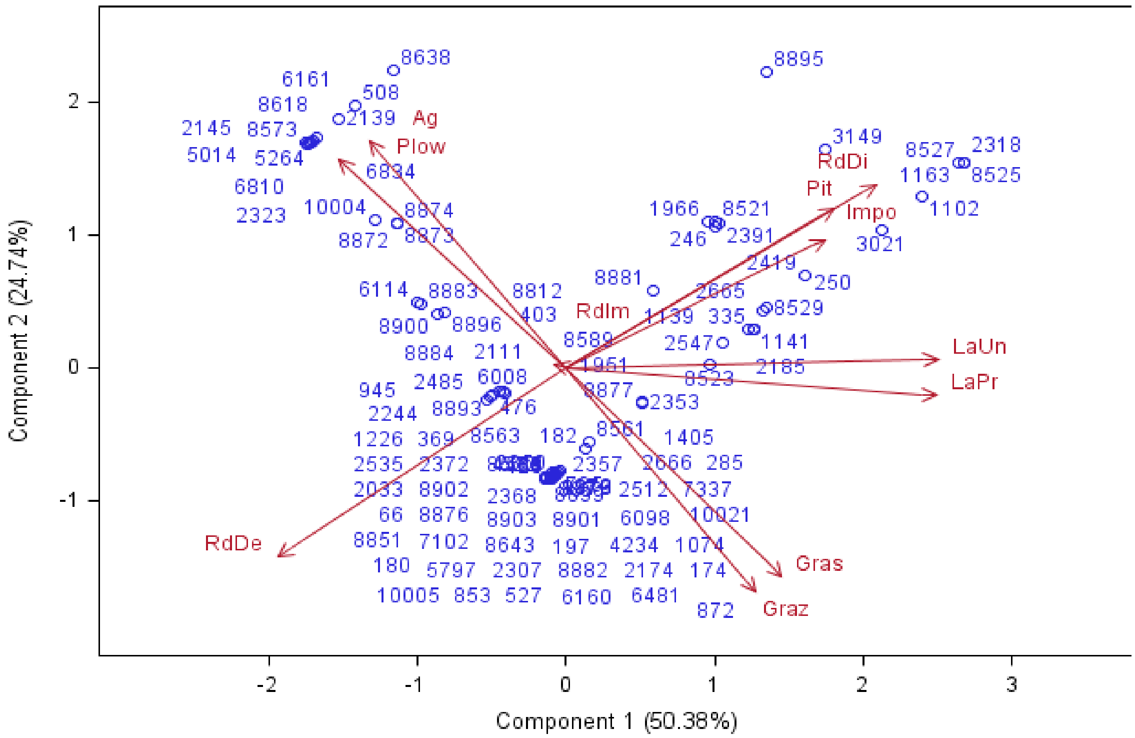


Figure 4. Multimensional Preference Analysis reducing eleven human disturbance variables into two Principal Components.

Playas in the focus group appeared to be arrayed across the same range of variation represented by playas in the broad group (Figure 5).

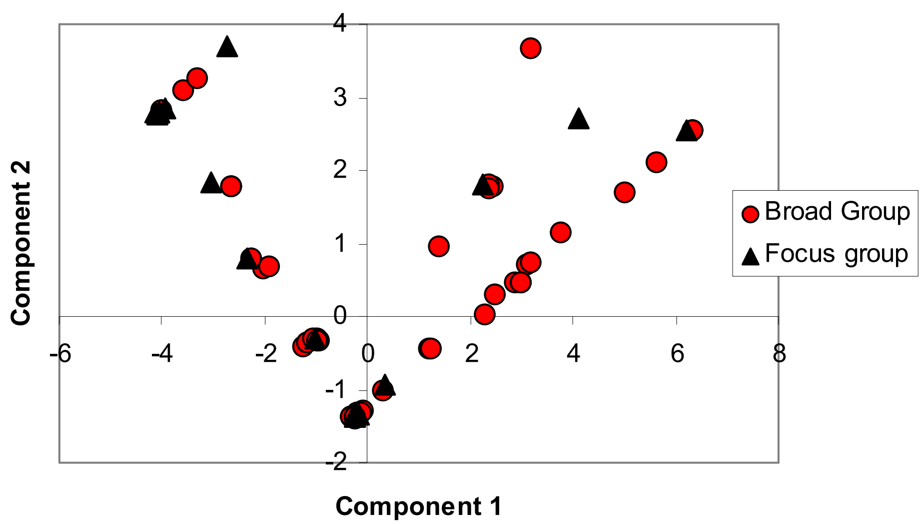


Figure 5. Figure indicating the dispersion of playas within the focus group relative to those in the broad group with respect to human disturbance component axes 1 and 2.

Ecological Integrity Assessment Scorecard

For landscape context, the focus group playas mostly scored “poor;” three scored “fair.” For biotic condition, which was based upon floristic data, 5 playas were scored as poor, 5 fair, and 12 good. Abiotic condition (hydrological modifications and onsite landuse) was similar, with 3 playas in poor condition, 8 fair, and 11 good. Playas varied in size from less than a hectare to nearly 19 hectares, classified as poor (1), fair (14), good (4), and excellent (3). Overall Ecological Integrity Scores classified 8 playas as poor, 9 as fair, 5 as good, and none as excellent.

Ecological Integrity scores were weakly related to HDI-1 scores with a Spearman correlation r = -0.33 (Figure 6). HDI-1 explained 11% of the variation in Ecological Integrity scores (r^2 = 0.11; F-ratio = 2.48, p = 0.13).

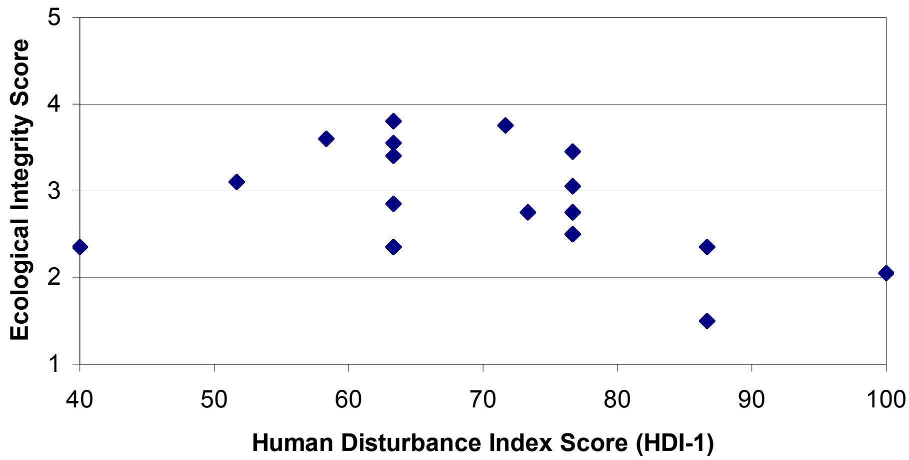


Figure 6. Relationship between Ecological Integrity Scores and Human Disturbance Index scores.

FQI relationships to Human Disturbance

We assessed the relative strength of association for the various FQI scores to human disturbance (HDI-2). We found that native species count, percent exotic species, and FQI scores (FQI_{all}, FQI_{nat}, cover-weighted FQI_{all}, cover-weighted FQI_{nat}) were most strongly related to HDI-2 (Figure 7). The percent of exotic species declined with PCA1 and increased with PCA2, while the other floristic quality metrics were positively related to PCA 1 and negatively related to PCA 2 of HDI-2. (Appendix B, Section 1, Table 1).

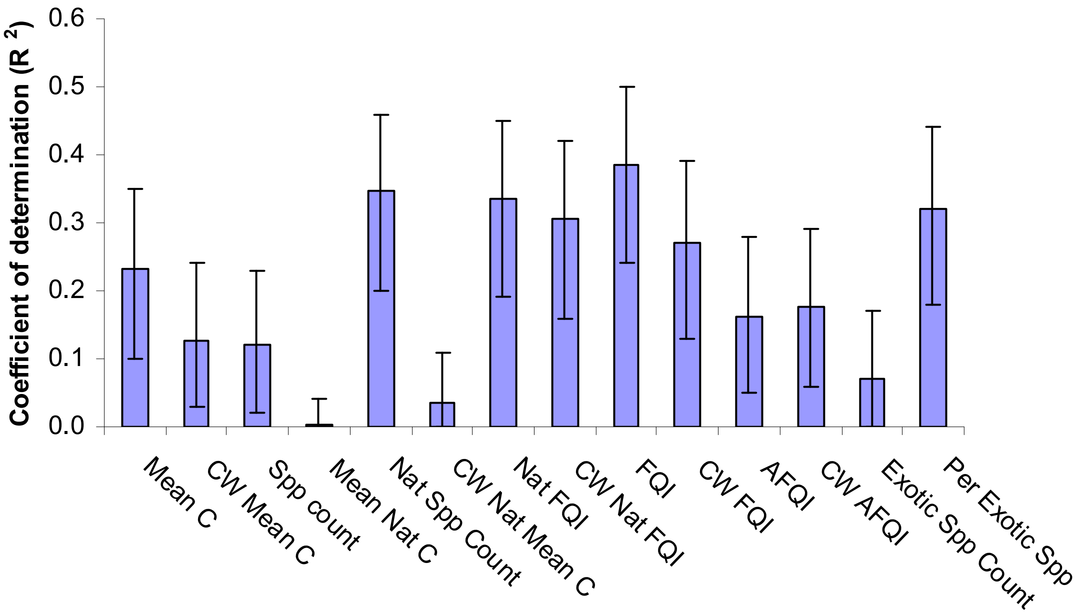


Figure 7. Coefficients of determination (R^2) for the relationship of various FQI metrics to human disturbance, as represented by components 1 and 2 (HDI-2). "CW" represents cover-wieghted metrics.

FQI_{all}, FQI_{nat}, cover-adjusted FQI_{all}, and cover-adjusted FQI_{nat} showed relatively high coefficients of determination (R^2 = 0.27 – 0.39). All four indices showed floristic quality increased with PCA1 and declined with PCA2 and the magnitude of the effects were not appreciably different. The effect of PCA2 on FQI_{all} (β = -0.91, SE = 0.130) was substantially larger than for FQI_{nat} (β = -0.74, SE = 0.126) suggesting FQI_{all} outperformed FQI_{nat}, but there were few differences among the regression coefficients for the other indices (Appendix B.1, Table 1). We selected FQI_{all} to represent the group of floristic quality indices in subsequent analyses. In addition, Mean C accounted for a relatively high proportion of variation (R^2 = 0.23) and was included in subsequent analyses because of its central role in the theory of floristic indices.

When we examined each floristic quality metric in relation to the different components of human disturbance, we found that species count of native plants was best predicted by a model containing the effects of adjacent grassland and playa size (Figure 8; Appendix B.2, Table 2). The model accounted for 29.1 % of the variation in native species count (R^2 = 0.291). The count of native species was greater in playas with adjacent grassland than playas with adjacent agriculture (β = 5.04, SE = 0.78), while the number of native species showed a slight decline with increasing playa size (β = -0.11, SE = 0.070). The second-best model contained only the effect of adjacent grassland (Appendix B.2, Table 2, 4) and accounted for 27.4 % of the variation in native species count (R^2 = 0.274). To see the statistical tables, please refer to Appendix B.2, Tables 2 - 4.

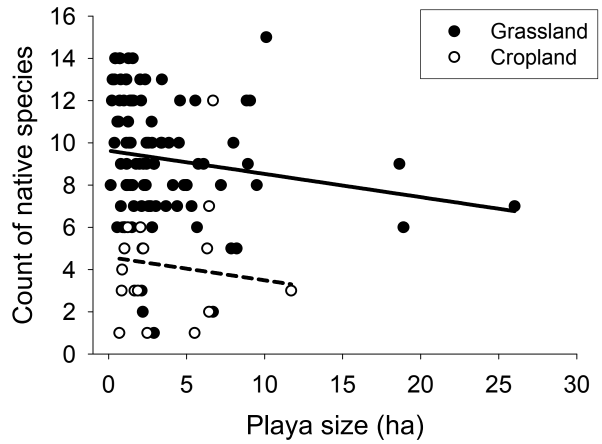


Figure 8. The effects of adjacent grassland and playa size on the count of native species. The trend lines represent the predicted count of native species as a function adjacent land use and playa size from the best approximating model. The solid line represents predicted values for grassland playas and the dashed line represents predicted values for playas in cropland.

Mean C was lower in playas with adjacent agriculture than in playa with surrounding grassland **(**β = -0.79, SE = 0.15; Figure 9). The best model containing the effect of adjacent agriculture accounted for 21.4 % of the variation in Mean C (R^2 = 0.214; Appendix B.2, Tables 5 - 7).

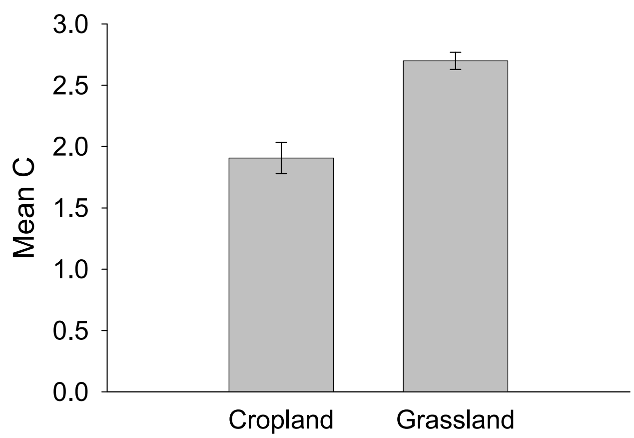


Figure 9. The effect of adjacent agriculture on Mean C from the best approximating model. The error bars represent one standard error.

FQI_{all} was greater in playas with adjacent grassland than in playas with surrounding cropland (Figure 10; β = 4.29, SE = 0.639; see also Appendix B.2, Tables 8 - 10). The model containing the effect of adjacent grassland accounted for 29.3 % of the variation in FQI_{all} (R^2 = 0.293).

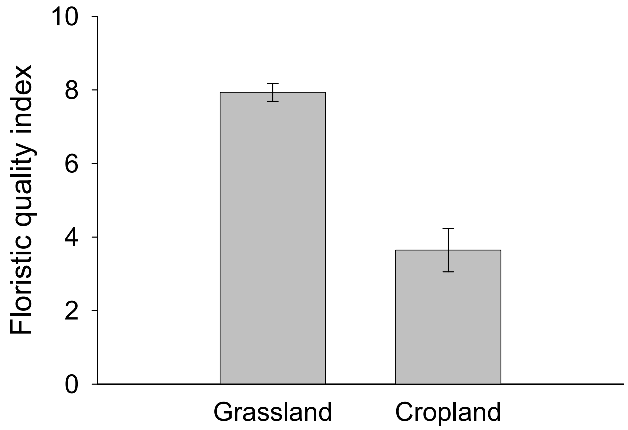


Figure 10. The effect of adjacent grassland on FQI_{all} from the best approximating model. The error bars represent one standard error.

The percent of non-native species was best predicted by a model containing the effects of adjacent cropland, native prairie in the landscape, and hydrological modifications (Figures 11 and 12). This model accounted for 29.8 % of the variation in the percentage of non-native species (R^2 = 0.298). The percent of non-native species was greater in playas with adjacent cropland than in playas with surrounding grassland (β = 18.19, SE = 3.853), decreased with increasing native prairie at the landscape level (β = -0.10, SE = 0.056), and was greater in playas with hydrological modifications than intact playas (β = 5.40, SE = 3.408). There was nearly equal support for a competing model containing the effects of adjacent cropland and native prairie in the landscape (Appendix B.2, Tables 11 - 13). This model accounted for 28.2 % of the variation in percent non-native species (R^2 = 0.282). There was also considerable support for the third best model containing the effect of adjacent cropland, which accounted for 26.7 % of the variation in the percent of non-native species (R^2 = 0.267).

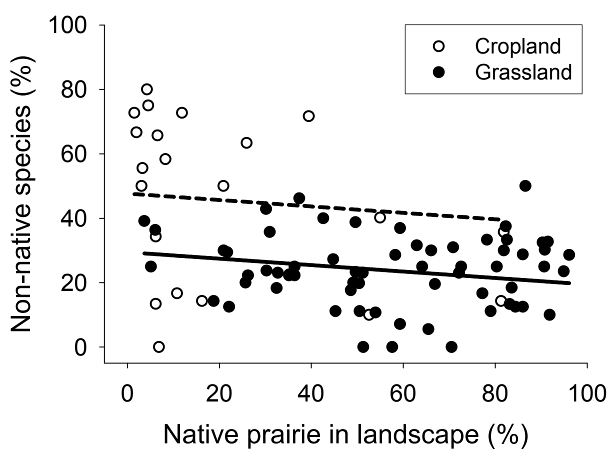


Figure 11. The effects of adjacent grassland and native prairie in the surrounding landscape on the percent of exotic species. The trend lines represent predicted percent of exotic species as a function of adjacent land use and native prairie in the surrounding landscape from the best approximating model. The dashed line represents predicted values for playas in cropland and solid line represents predicted values for grassland playas.

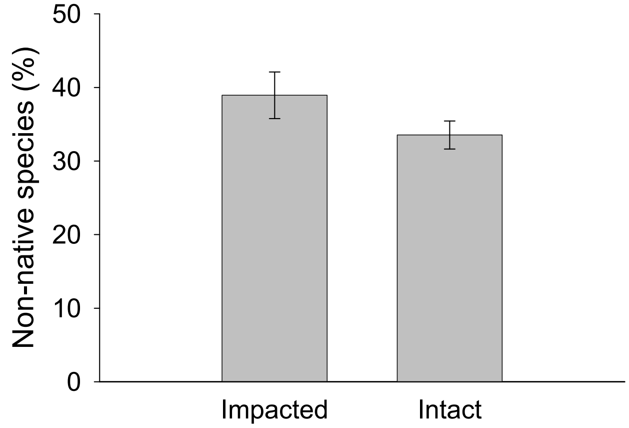


Figure 12. The effects of hydrological alteration on the percent of exotic species from the best approximating model. The error bars are one standard error.

Native species count, Mean C, FQI_{all}, and percent non-native species were not related to the human disturbance HDI-1 within the focus group. The 95% confidence intervals for the effects of HDI-1 on the floristic quality metrics comfortably covered zero (see Appendix B, Section II, Table 14).

The occurrence of imperiled plant species (five species listed in Table 15) was best predicted by a model containing hydrological modifications, distance to nearest non-playa wetland, and distance to road. The occurrence of the rare plants was positively related to hydrological modifications, distance to nearest non-playa wetland, and was negatively related to distance to road (see Appendix B, Section II, Tables 15 - 17). While hydrological modification was 1.8 times more important than adjacent grassland in predicting the occurrence of imperiled plant species, the second best model containing the effect of adjacent grassland had nearly equal support (ΔAICc = 0.47). The second best model showed the occurrence of imperiled plants was greater in playas with adjacent grassland than in playas with surrounding cropland (Table 17). Only two occurrences were within our focus group where we could report the Ecological Integrity Assessment (EIA) and Human Disturbance Index scores (HDI-1). One playa had an EIA rank of Good and a HDI-1 of highly disturbed; the second playa had an EIA rank of Fair and was ranked as moderately disturbed on HDI-1.

Sampling Effects on FQI Performance

When comparing the top four floristic metrics from early in the season (summer) to later (fall) within 2007, we found no differences between the sampling periods for Native Species Count and FQI_{all}. The percentage of non-native species was higher during the summer than the fall, and there was also evidence that Mean C was lower during the summer than the fall. There was no evidence for interactions between season and human disturbance, indicating the association between the floristic metrics and human disturbance was similar in both seasons (Appendix B, Section III, Tables 18-25).

When we compared the averaged FQI scores to HDI-2 to scores obtained by pooling across both surveys (i.e., compiling a single species list from the two surveys), we found that as expected, species counts were higher from pooled data than the means. In addition, the count of native species exhibited an interaction between the effect of sample pooling and human disturbance (HDI-2), which indicated the pooled counts had a stronger association with human disturbance (steeper slope) than the counts averaged across the surveys. FQI was also higher in the pooled dataset, but there was very little evidence for an interaction, indicating FQI had no difference in its relationship to human disturbance with respect to sample pooling. While Mean C and the percent of non-native species declined with human disturbance, we detected no effect of sample pooling for these metrics. Please see Appendix B, Section IV, Tables 26-33 for statistics.

When off-plot (walking around after the Daubenmire samples) data were included for the broad group, the number of all plant species reported per survey ranged from 1-47, more than doubling the species count for some playas. The mean number of all species per playa survey increased by 6.14 species to 18.44 species (SE = 0.72). For the focus group, the number of all plant species per survey ranged from 12-36, with an average of 23.5 (SE = 1.24) species, up from the plot-only average of 10.64 (SE = 1.10). One playa notably increased from detection of one species in the plot data to twelve found when including the walk-around surveys. This playa was plowed, planted with corn, and non-crop plants were noted as covering only a very small portion of the basin.

Adding the walkaround surveys to the plot data for the broad group had no effect on Mean C: the range was 0.40 – 4.08 and average was 2.48 (SE = 0.07).

When we considered inclusion of species discovered during the post-plot walkaround period, there was no difference between Mean C for the plot and off-plot data. Conversely, we found the count of native species, FQI, and percentage of non-native species were higher when walkaround plants were included, but the lack of interaction effects indicated their relationship to human disturbance was similar for both the plot-only and the plot/off-plot data combined (Appendix B, Section V, Tables 34-41). At the same time, the second best model provided some evidence for an interaction between the effects of off-plot sampling and human disturbance (PCA2; Tables 34, 35), which suggested the strength of association between the number of native species and human disturbance differed for the plot and the walkaround data. The second best model showed the count of native species for the off-plot data declined with increasing disturbance (PCA2, β = -0.48, SE = 0.250), but the interaction (Plot*PCA2, β = -0.50, SE = 0.279) indicated the effect of human disturbance on number native species was more pronounced for the plot data (PCA2, β = -0.98, SE = 0.375). The confidence interval for the interaction between off-plot sampling and PCA2 comfortably covered zero, which suggested there was little evidence for this effect.

FQI and Restoration

We found no difference in Mean C, native species count, FQI_{all}, or percent non-native species for restored vs. unrestored control playas (statistics or refer to Appendix B, Table 42). However, sample sizes were small (six restored and unrestored pairs).

Avian Use

We documented use of playas by 48,830 birds of 148 species during the course of the larger study 2004-2007 (see Appendix C for a complete list). This included 22 species of waterfowl, 27 species of shorebird, 12 species of other waterbirds (e.g., cranes, gulls, and herons), 6 other species of wetland dependent birds (e.g., Yellow-headed Blackbird, Marsh Wren) and 81 species of landbird. The average number of all birds detected on each wet playa per survey was 25.52 (SE = 3.729). The mean number of shorebirds detected on wet playas per survey was 4.10 (SE = 0.707). The mean number of waterfowl observed on each wet playa per survey was 4.43 (SE = 1.720).

In the focus group of wet playas in fall 2006, we observed 20,615 birds of 70 species, including 17 species of waterfowl, 16 species of shorebird, 8 species of other waterbirds, 3 species of other wetland dependent birds, and 26 species of landbird. On average waterfowl were most abundant, with an average count of 58.78 +/- 21.35 birds per playa survey. Landbirds were next most abundant (X = 24.75 +/- 5.13), followed by other waterbirds (21.98 +/- 19.22). Shorebirds were least numerous with an average abundance of 5.85 +/- 1.36 birds per survey. The average species count per survey was 4.77+/- 0.41 species.

Bird use of the wet playas in fall 2006 ranged from no birds to a high count of 4,435 birds on one survey. This survey included 2,400 Sandhill Cranes, 1,450 Canada Geese, and six other species of waterfowl and waterbird. Three other surveys exceeded 1,000 birds, two of which were dominated by waterfowl and the third by Sandhill Cranes. The most abundant waterfowl, in descending order, were Green-winged Teal, Cinnamon/Blue-winged Teal, Canada Goose, Mallard, and Northern Pintail. The most abundant shorebirds were Killdeer, Long-billed Dowitcher, Lesser Yellowlegs, Baird’s Sandpiper, and Least Sandpiper. Sandhill Crane and American Coot were the most abundant other waterbirds. The most abundant landbirds were Horned Lark, McCown’s Longspur, Red-winged Blackbird, Lapland Longspur, and Chestnut-collared Longspur.

Avian Use Models

The analysis of shorebirds in the focus group of playas showed that shorebird numbers followed a quadratic trend through time, indicating peak shorebird counts during migration on 19 September 2006. After accounting for migration chronology, hydrological modification of the playas was the human disturbance factor that best predicted shorebird abundance (Appendix B, Section VI, Table 43). The parameter estimate from the best model (β = -1.40, SE = 0.657) indicated shorebirds were less abundant in playas with hydrological modifications than intact playas (Figure 13). Shorebird abundance was not predicted by the Human Disturbance Index (HDI-1), Ecological Integrity scores, native plant species count, Mean C, FQI_{all}, percent non-native plant species, or any other human disturbance metric (Appendix B, Section VI, Tables 43 and 44).

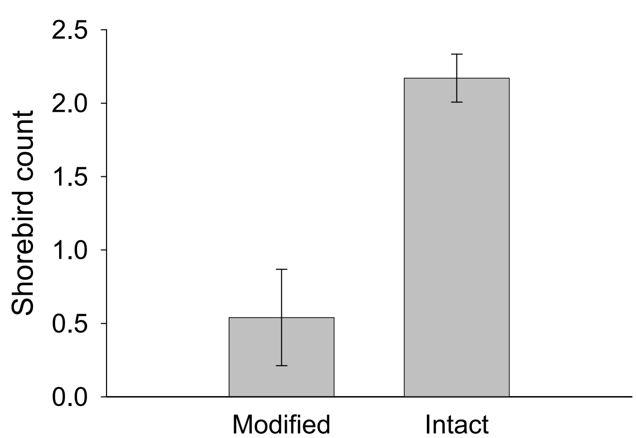


Figure 13. The fixed effect of hydrological modification on shorebird abundance from the best approximating model. The vertical bars represent the predicted mean shorebird count and the error bars are one standard error.

The analysis of waterfowl abundance in the focal group of playas indicated that waterfowl abundance declined through the autumn and increased with playa size. After accounting for date and playa size, waterfowl abundance in the focus group of playas was negatively associated with several floristic quality metrics (Appendix B, Section VI, Tables 45, 46). Waterfowl abundance was negatively related to Mean C (Figure 14), FQI_{all}, and native plant species count, and positively related to the percent of non-native plant species (Appendix B, Section VI, Tables 45, 46). Waterfowl numbers were also negatively related to Human Disturbance Index (HDI-1); suggesting waterfowl abundance declined with increasing disturbance (Figure 15, Appendix B, Section VI, Tables 45, 46). Among the human disturbance factors, there was some evidence for a small negative effect of the percent of the landscape in unfragmented prairie on waterfowl abundance (CV = 0.58, Figure 16). Waterfowl abundance was not predicted by Ecological Integrity (Appendix B, Section VI, Tables 3 and 4).

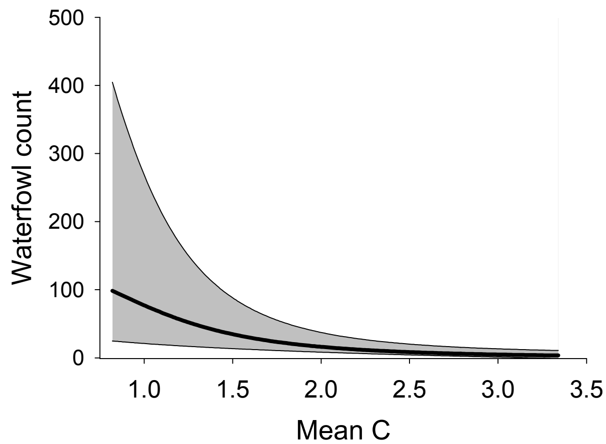


Figure 14. The fixed effect of Mean C on waterfowl abundance from the best approximating floristic quality model. The bold line represents predicted waterfowl counts and the shaded area represents the 95% confidence interval for the prediction.

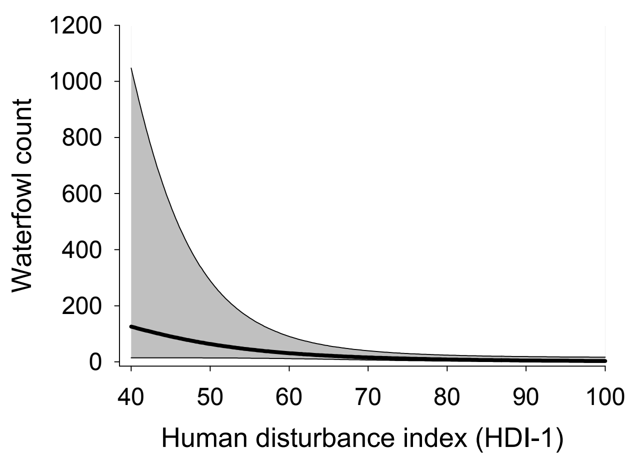


Figure 15. The fixed effect of human disturbance (HDI-1) on waterfowl abundance. The bold line represents predicted waterfowl counts and the shaded area represents the 95% confidence interval for the prediction.

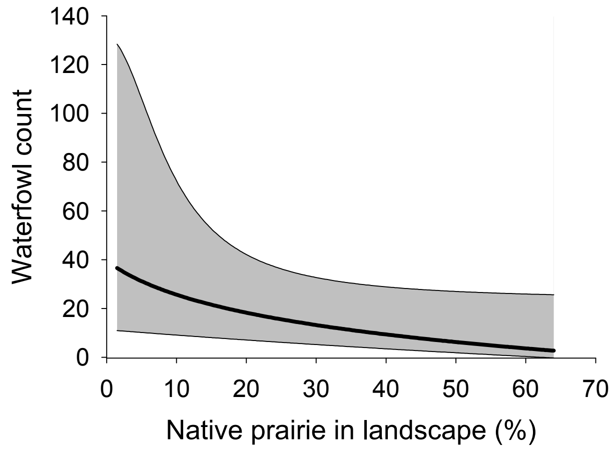


Figure 16. The fixed effect of percent unfragmented native prairie in the landscape on waterfowl abundance. The bold line represents predicted waterfowl counts and the shaded area represents the 95% confidence interval for the prediction.

The analysis for the number of avian species in the focal group of playas showed that the number of bird species followed a quadratic trend through time, and the species count increased with the area of playa cover in the surrounding landscape (Appendix B, Section VI, Table 48). After accounting for the effects of date and playa cover in the landscape, the count of avian species in the focus group of playas was negatively associated with floristic quality (Appendix B, Section VI, Tables 47, 48). The number of bird species was negatively related to the count of native plant species (Figure 17), FQI_{all}, and Mean C, and positively related to the percent of non-native plant species (Appendix B, Section VI, Tables 47, 48). Among the human disturbance factors, the count of avian species was higher in playas with adjacent cropland than in playas with adjacent grassland (Appendix B, Section VI, Figure 17, Tables 47, 48). There was also some evidence for the effects of increasing number of bird species with increasing distance from the road (CV = 0.58), increasing species counts with increasing disturbance as measured by PCA2 (CV = 0.60), and declining bird numbers as a function of increasing percent of unfragmented prairie in the landscape (CV = 0.60, Appendix B, Section VI, Figure 18, Table 47).

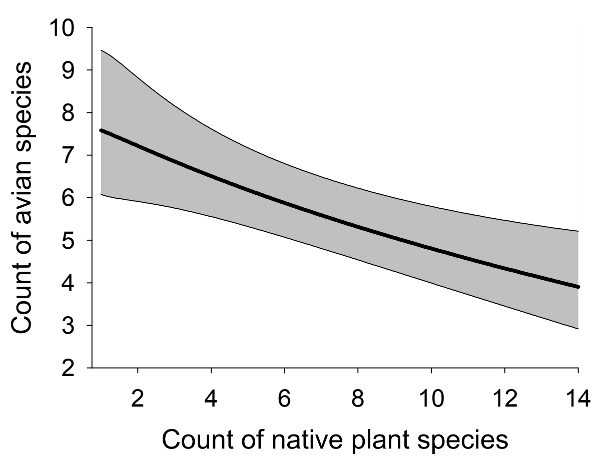


Figure 17. The fixed effect of the number of native plant species on the count of avian species from the best approximating model. The bold line represents predicted waterfowl counts and the shaded area represents the 95% confidence interval for the prediction.

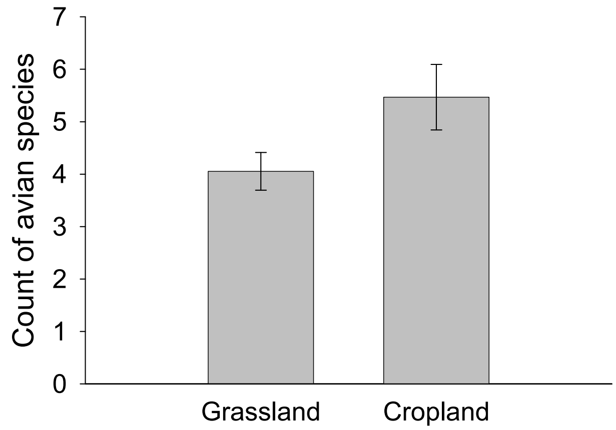


Figure 18. The fixed effect of adjacent grassland on the number of bird species. The vertical bars represent the predicted mean count of bird species and the error bars are one standard error.

For the full dataset, the best model for shorebird use of wet playas included the effects of playa size, hydrological modification, and area of playa cover in the surrounding landscape, and was 9.8 times more probable than the next best competing model (Appendix B, Section VII, Tables 49, 50). Shorebird numbers were greater in playas without hydrological modifications and during the spring, and were also positively related to the $\log_e$*area of playas and the percent of playa cover in the surrounding landscape (Appendix B, Section VII, Table 50). Although the 95% confidence interval for the effect of hydrological modification included zero (Appendix B, Section VII, Table 50), this covariate had a high probability of occurring in the top model (cumulative AIC weight = 0.63) and was present in the four of the five highest ranking models prior to fitting the proximity to wetland covariates. The relationship between shorebird numbers and playa size increased non-linearly such that shorebird numbers increased sharply with playa area up to approximately 5 ha (12.4 ac) after which the relationship between shorebird numbers and playa area was less pronounced (not shown).

For waterfowl, the best model included the effects of playa size and the percent of playa cover in the landscape, but none of the human disturbance factors. The model was 13.1 times more probable than the next best competing model (Appendix B, Section VII, Tables 51, 52). Waterfowl abundance was greater during the spring and increased with playa size and percent of playa cover in the surrounding landscape (Appendix B, Section VII, Table 52).

The best model for the number of avian species included the effects of playa size, hydrological modifications and playa cover in the surrounding landscape (Appendix B, Section VII, Table 53). This model was 9.9 time more likely than the next best competing model and showed the number of bird species was greater on playas with hydrological modifications (Appendix B, Section VII, Table 54), The count of avian species also increased with playa size and the percent of playa cover in the surrounding landscape (Appendix B, Section VII, Table 54).

CHAPTER 4. DISCUSSION

Playa Vegetation

In terms of vegetation cover, native grasses dominated the vegetation of playas, as has been found by other observers (Hoagland and Collins 1997). However, playas also provided habitat for 85 wetland plant species, including some rarer ones: *Ammannia robusta* (grand redstem), *Bacopa rotundifolia* (disk waterhyssop), *Bergia texana* (Texas bergia), *Portulaca halimoides* (silkcotton purslane), *Heteranthera limosa* (blue mud plantain), *Cyperus acuminatus* (tapertip flatsedge), *Marsilea mucronata* (western water clover, pepperwort), and *Myosurus minimus* (bristly mousetail). Based on our previous work, we found that playa vegetation composition differed from the surrounding upland (Cariveau and Pavlacky 2008; see also Reed 1930). We found that forbs and annuals were more abundant, while grasses were less abundant in playas than in the surrounding uplands. Furthermore, a high proportion of playa plants were not found in adjacent uplands (55%), while only 12% of the upland plants were not found in playas. This supports the assertion that playas do indeed increase local and regional biodiversity in the shortgrass prairie (Hoagland and Collins 1997).

Wetland-dependent plants dominating an eastern Colorado playa

A fourth of the plant species found in playas were non-native to Colorado, including ten species on the Colorado noxious weed list. This rate of exotic species was similar to that encountered in an assessment of prairie pothole wetlands in a mix of cropland, native prairie, and restored watersheds (23%; Gleason et al. 2008). We found strong relationships of percent non-native species to human disturbance; the proportion of exotic specieds was higher for playas in cropland, in playas with hydrological modifications, and in landscapes with less native prairie.

Even though non-native species were prevalent, we did find some imperiled species, including four species with State Rank = 1, indicating special vulnerability to extirpation within the state. These species were detected only on playas located within native prairie.

Grass-dominated playa in native prairie

Ambrosia linearis occurred in 19% of the playas we studied. Only two occurrences were within our focus group where we could report the Ecological Integrity Assessment (EIA) and Human Disturbance Index scores (HDI-1). One playa had an EIA rank of Good and a HDI-1 of highly disturbed; the second playa had an EIA rank of Fair and was ranked as moderately disturbed on HDI-1. When we investigated the relationship of these plants to human disturbance in the broad group of playas, the imperiled plants occurred more often in playas with adjacent grassland, in playas with onsite hydrological modifications, and occurrence increased at greater distances from other wetlands. Thus, playas with surrounding grassland, with or without impoundments, and playas further from other wetland types appear important for the occurence of these species. We speculate that imperiled species occurring in playas near other wetland types may be more likely to be colonised and outcompeted by exotic species. Fourteen of the fifteen impoundments were found within grassland, so it is difficult to say if the species truly were positively associated with impoundments or were just associated with grasslands and not avoiding impounded wetlands.

Floristic Quality

In general, the native vegetation associated with the playa wetlands of eastern Colorado had lower coefficients of conservatism (Mean C_{nat} = 3.30 +/- 0.09) than vegetation statewide (Mean C_{nat} = 6.31 +/- 0.04; Rocchio 2007a). In addition, 33% of the native plants in playas had C-values of three or less, indicating species with wide ecological tolerance. This is much greater than the 8% of the statewide flora falling into this category (Rocchio 2007a). Perhaps because of similar agricultural landscapes, the prevalence of lower C-values in playa wetlands was more like the values in Nebraska and North and South Dakota, where 21% and 23% of their species had C-values of 3 or less, respectively (Nebraska Game and Parks Commission 2003; Northern Great Plains Floristic Quality Assessment Panel 2001). These C-values indicate that playa vegetation in general is typically tolerant of disturbance, which might be predicted for a temporary wetland type subject to pronounced wet-dry cycles. This is similar to findings in the prairie pothole ecoregion in which temporary wetlands had lower modified FQI scores and fewer native species than semi-permanent wetlands (Gleason et al. 2008). Other observers have noted how floristic characteristics vary among wetland types and that effective flora quality assessment must be restricted to within wetland types (Rocchio 2007a).

Most of the floristic quality metrics we investigated did not appear responsive to playa size. However, we found declining number of native species with increasing playa size, which may indicate inadequate sampling of the large playas. This is similar to the findings of another large-scale study of playas, in which plant species richness and diversity did not relate strongly to area (Haukos and Smith 2004). While playa size accounted for a small percentage of variation, the count of native species was positively associated with the size of playa wetlands in northern New Mexico and southern Colorado (Smith and Haukos 2002). Nevertheless, studies using the partial count of species as an estimator of species richness are not expected to accurately demonstrate the species-area relationship (Cam et al. 2002).

Human Disturbance

Playas in our focus group were generally found to be moderately to heavily impacted according to the Human Disturbance Index (HDI-1) employed for the statewide FQA (Rocchio 2007). In fact, the HDI-1 did not perform well in describing variation among playas in our focus group; half were considered highly disturbed, half moderately disturbed, and none were classified as less disturbed. All of the playas scored in the maximum impact category for landscape fragmentation, for instance. The lack of variation in the focus group could be due to several factors. First, eastern Colorado is a landscape heavily modified by agriculture. Accordingly, human disturbance scores might be expected to be below the state average. Secondly, the focus group of playas were selected to be near roads to faciliate bird surveys, so this is biased with respect to distance to road. Proximity to roads influenced the landscape fragmentation score, the buffer width score, as well as the hydrological modification score when the playas were directly bounded by or bisected by the road. Our ability to make recommendations regarding improvement of the HDI-1 is impaired by sample size and by our method of locating this group of playas near roads, but see below.

Non-native plants along the roadside edge of a pitted playa

Ecological Integrity

Ecological Integrity scores did not correlate strongly with the HDI-1 for the focus group of playas as might have been expected. This is particularly surprising because some components of Ecological Integrity Assessment were built from the same data as HDI-1 (e.g., landscape context, onsite landuse, hydrological modifications). However, we found some limitations with the application of these human disturbance factors to the playas of eastern Colorado, as noted above. The factors driving the divergence were likely the two components of Ecological Integrity that were not in HDI-1: wetland size and biotic integrity. For instance, two playas received Ecological Integrity scores of Good, despite having ranked as highly disturbed according to HDI-1. These two were both large and had high floral quality. This suggests wetland size perhaps can ameliorate the effects of human disturbance, but our sample sizes are low. Future studies could pursue this question. The Ecological Integrity Assessment Scorecards were developed primarily to help establish performance measures for wetlands mitigation and also for applications to monitoring and assessment (Faber-Langendoen et al. 2006). In that context, then, perhaps a greater weight by size and biotic condition might be appropriate. It should be noted that we did not appear to have had sites representing reference conditions. However, with a sample size of 109, including those in restoration programs and some far from roads in native prairie, we expected a good array of conditions. It may be that the "least disturbed condition" is a more appropriate scale for playas in the Central Shortgrass Prairie Ecoregion (Stoddard et al 2006).

The EIA Scorecard we employed was developed for use on the playas of the Intermountain Basins (IB). The primary difference between IB playas and those of the Central Shortgrass Ecoregion is that shortgrass playas are strictly recharge wetlands that do not receive groundwater inputs (Smith 2003). Therefore, they respond only to rainfall and surface flow for their hydrological cycling. This made metrics in the IB EIA Scorecard such as Water Table Depth irrelevant. In addition, approximately half of the native prairie in the Central Shortgrass has been converted to agriculture (Neely et al. 2006), and few areas may be regarded as representing of natural, pristine conditions. For this reason, Central Shortgrass playas consistently ranked low on measures related to landscape conditions. We found that many of the metrics included in the scorecard did not yield a good spread of rankings among the playas in our broad sample. Here we give some recommendations for converting the IB Playa scorecard for application in the Central Shortgrass Ecoregion.

Based on our observations of the range and variablility of the scores when applied to playas in eastern Colorado, we can suggest some revisions to the EIA Scorecard if it were to be applied to the Central Shortgrass Ecoregion. We would recommend broadening the consideration of landscape fragmentation to a radius of 2 km from wetlands to better depict a range of values. For comparison, we also consulted the *Interim Functional Assessment Model for Playa Wetlands*, a Hydrogeomorphic (HGM) model developed in Kansas (NRCS 1999); it used 1 mile as a buffer for depicting landscape condition. Alternatively or in addition, the categories for landscape fragmentation could be modified for the Central Shortgrass Ecoregion to something like: < 15%, Poor; 16-40% Fair; 41-74% Good; > 75%, Excellent. This would have improved the distribution of scores considerably for our broad sample of playas.

There is a growing interest in the characteristics of buffers directly surrounding playas (such as is within 100 m) and their potential effects on playa hydroperiods and sedimentation rates (e.g., Skagen et al. 2008). For instance, in playas in southwestern Nebraska, we found that playas in surrounding landuse of CRP were less likely to become inundated following a heavy rain event than playas in native grassland or cropland (Cariveau et al. 2007). This is the scale at which the current Surrounding Landuse scores are calculated. However, most playas are not in specific buffer programs and are subject to runoff from the entirety of their watersheds (or those areas not impeded by roads or other hydrological alterations to runoff). For these playas, we would recommend another broader radius of consideration for surrounding landuse, one that depicts the playa watershed, the area which directly affects the inputs of water, sediments, and potentially pollutants to playas. Playa watersheds are typically much greater than 100 m beyond the edge of the playa basin. For a sample of playas (*n* = 48) in southwest Nebraska, the mean watershed size was 34.6 ac after accounting for areas of watersheds that were blocked by roads or other modifications (85.5 ha; Cariveau and Pavlacky, unpublished data). We developed a predictive model that showed watershed size scaled with playa size. Using the average size of Colorado playas, 2.7 ha (Cariveau and Pavlacky 2008), we predicted the mean watershed size would have a raidius of approximately 316 m, assuming a circular watershed. While this is a limited sample size, it suggests that on average a much larger area is affecting the hydrology of playas. We recommend using 300 m to depict the landuses surrounding the playa and reduce the redundancy of this score with that of on-site landuse (variation explained R^2 = 0.54 in our broad sample). Alternatively, one could allow the investigator to tailor the watershed depiction to the proper scale for each wetland, as was done in the *Interim Functional Assessment Model for Playa Wetlands* (NRCS 1999) and the Rainwater Basin HGM model (Stutheit et al. 2004).

Similarly, for the same reasons elaborated upon above, we would recommend that the buffer width categories be liberalized for this wetland type in this ecoregion. Computing buffer distances out to 200 or 300 m would probably give a more meaningful spread in the categorization of playas for an agricultural landscape with a high prevalence of cropland and unpaved roads.

For the biotic condition portion of the EIA Scorecard, we recommend using the FQI_{all}, pooling data for multiple visits when available. It is important that the metric be calculated including non-native species, because we found the Mean C and FQI when calculated from native species to be much less responsive to human disturbance. Alternatively, we feel that the count of native species and the percent non-native species could also similarly represent response to human disturbance.

To depict abiotic condition, we used only the score for on-site landuse, because the water table depth categories were not relevant and the other metrics were all classified as supplemental. For Central Shortgrass playas, the incorporation of the Sediment Loading Index and the Surface Water Runoff Index scores as core metrics could strengthen the abiotic condition scores. These two metrics were designed to predict sediment loading and runoff based upon the landuse in the wetland and surrounding watershed, using coefficients for runoff and sediment loads developed in a HGM model developed for the Great Salt Lake area (Keate 2005 in Rocchio 2006). The other two HGM models we consulted, *Interim Functional Assessment Model for Playa Wetlands* (NRCS 1999) and the HGM Assessment for Rainwater Basins (Stutheit et al. 2004) used more direct measures of sedimentation within the basins. In either case, attempting to relate condition to runoff and sediment loading would strengthen the abiotic assessment. Future investigations by RMBO and others will help to better elucidate playa hydrologic responses to rainfall and sedimentation in relation to watershed level landuses.

Relationship of Floristic Quality to Human Disturbance

In playas, it seems that the nativity of the vegetation was a significant factor in describing the variation among playas and response to human disturbance. Mean C and FQI metrics were more strongly related to human disturbance when calculated on all species rather than just native species. And, the count of native species and percent non-native also strongly related to human disturbance. In a study of ecosystem services of wetlands in the prairie pothole region, Gleason and others (2008) similarly chose an FQI index that incorporated native and non-native species.

If one wanted to narrow down the list of floristic quality metrics, we would recommend using these four: native species count, mean C, FQI_{all}, and percent non-native species. Native species count, mean C, and FQI_{all} were most strongly predicted by adjacent landuse, positively associated with grassland or negatively with cropland. Percent exotic species were higher on playas in cropland and with hydrological modifications and lower in areas with higher percent native prairie in the landscape. Haukos and Smith (2004) and Smith and Haukos (2002) similarly found that the number of exotic species was greater for playas in cropland watersheds than those surrounded by grassland. A study of wet meadows in Minnesota investigating the relative effects of on-site human disturbances and landscape-level conditions found that percent native graminoid and herbaceous perennial responded to on-site human disturbances (if a wetland was cultivated or received stormwater runoff) as well as the percent of the surrounding landscape within a radius of 500 m that was disturbed by either agriculture or urban development (Galatowitsch et al. 2000). They did not find that overall plant species richness responded to human disturbance, which they attributed to the possibility that species richness could reach high levels at intermediate levels of disturbance, representing both more conservative as well as more disturbance-adapted species. They found an interaction between local and landscape factors in that ditches were detrimental to the percent of native graminoid or herbaceous perennial only when a high percent of the landscape was disturbed; this supports the idea that a disturbed landscape would support a greater source of weeds for dispersal than a largely intact landscape. Our findings corroborate this finding, with the percentage of non-native species being higher on playas in landscape with a lower percentage of native prairie.

We found that rare plants were not good indicators of low human disturbance. While all of the occurrences of the five state-listed imperiled plants were in grassland, they were also positively associated with hydrological modifications and proximity to roads. Our results suggest that farming playas provides no habitat for these species, but also that the distribution of these species may actually be increased due to pitting and impounding practices in grassland playas.

Floristic Quality and Sampling Effort

We found that the count of native species and FQI were not dependent upon the season of sampling. Conversely, Mean C was lower in autumn than in the summer growing season. This pattern was further illustrated by our finding that the percent of non-native species was greater in autumn than the summer. This contrasts with Matthews' (2003) findings that variation in FQI was primarily due to seasonal variation in the estimated number of species. Nevertheless, seasonal variation in the estimates had no effect on the strength of association of the floristic quality metrics to human disturbance. Pooling the counts of non-native species across two visits showed a stronger relationship to human disturbance than counts averaged across the two sampling periods, suggesting this would be a strong approach to assessing playas. However, while estimates of FQI were inflated by additional species observed in the pooled data, the strength of association between FQI and human disturbance was not affected by sample pooling. In addition, the added cost of a second site visit might not warrant the additional weight of the relationship to human disturbance. If sites are visited multiple times, for instance as part of an annual visit, then perhaps pooling the data may be an effective strategy.

As above, we found no evidence that additional species observed in the opportunistic off-plot surveys improved the strength of the association between floristic quality and human disturbance. There was no difference in Mean C when additional off-plot species were included in the calculations. Therefore, the high estimates of FQI observed for the off-plot data were likely due to the additional number of off-plot species observed (effect for native species = 4.04, SE = 0.649). However, the inclusion of additional species observed in the off-plot surveys did not increase the strength of association between the floristic quality metrics and human disturbance. Instead, we observed a stronger relationship between the number of native species and human disturbance for the plot data than the data including off-plot species. The systematic sampling design (Daubenmire plots) seemed to generate more reliable indices than those calculated with plot and off-plot additional species combined. One explanation for this is that in playas largely dominated by agricultural land use, sometimes there are very small amounts of native vegetation present, which could be detected only during the walkaround surveys. Another possible explanation is that hydrological modifications such as pits, impoundments, and road impacts create microenvironments that increase plant species richness in those areas, and because they are typically limited to a small part of the playa basin, their effects are not detected in the plot data but only in the walkaround surveys. Most applications of the floristic quality assessment confine the opportunistic search for additional species to large randomly located plots within the relevé sample design (Peet et al. 1998). As mentioned above, the playa-wide opportunistic search for additional species did not improve the ability of the floristic quality metrics to predict human disturbance. In fact, our results indicated the count of native species declined with increasing playa size, which is contrary to expectations from the species-area relationship and suggests that we undersampled large playas. Studies using incomplete counts of species as an estimator of species richness are not expected to accurately demonstrate the species-area relationship (Cam et al. 2002). We recommend using an estimator that accounts for variation in species detection probabilities for accurate estimates of species richness (Colwell and Coddington 1994). Accurate estimation of species richness would be expected to enhance the response of FQA metrics to human disturbance and would likely reduce problems associated with seasonal variation in the detection of plant species.

We found the cover-weighted floristic measures did not out-perform the non cover-weighted indices, suggesting that the effort required for estimating cover would be unnecessary for future investigations of playa floristic quality.

Floristic Quality and Restoration

At the inception of this project in 2004, there were virtually no conservation projects on playas within eastern Colorado. Through the course of this project, playas became recognized as a valued resource by a variety of conservation partners, including the Colorado Division of Wildlife, USFWS Partners for Wildlife, the USDA Natural Resources Conservation Service, and Rocky Mountain Bird Observatory's (RMBO) Stewardship Division. These entities and others began delivering playa conservation projects including retirement from farming, buffer strip plantings, filling pits, and managed grazing.

Because conservation projects were only implemented starting in 2005, we had a very limited sample size of projects (six groups) that had been in place for at least one full growing season to study. We did find an effect of restored playas providing greater cover by forbs than paired comparison playas with similar land use and human modifications (Cariveau and Pavlacky 2008). We did not find any differences in the FQA metrics, which could be because of low sample sizes and/or limited time for the vegetation to change. Other studies typically wait five to fifteen years to see the effects of restoration on vegetative communities. We recommend that the fuller set of 33 playas for which we collected baseline data be re-visited in five or more years to better determine if FQA indices might be suitable for measuring playa responses to restoration practices.

Relationship of Avian Use to Human Disturbance, Ecological Integrity, and Floristic Quality

Shorebirds that use playas for migratory stopover habitat

Playas have been noted as important stopover wetlands for transcontinental migrant shorebirds (Haukos and Smith 1994, Skagen and Knopf 1993, Skagen and Knopf 1994) and for providing important wintering and migration habitat for waterfowl (Nelson et al. 1983, Haukos and Smith 1994, Smith 2003). Our findings corroborate these assertions. Colorado playas have greater cover values of bare ground, forbs, and annuals than adjacent uplands (Cariveau and Pavlacky 2008). When inundated, playas provide open water and nutritious seeds from annual plants for foraging waterfowl and shorebirds (Anderson and Smith 1999; Sheeley and Smith 1989; Baldassarre and Fisher 1984). In addition, the playas we sampled generally lacked dense vegetation, with bare ground accounting for nearly 50% (Cariveau and Pavlacky 2008). This open habitat is favored by migrating shorebirds, which select shallow, sparsely vegetated wetlands with substantial mudflats (Colwell and Oring 1998) with vegetative cover less than 25% (Helmers 1993). Indeed, we found high levels of use by waterfowl and shorebirds during the course of our study: playas hosted 67 wetland-dependent species and numbers in excess of 4,000 birds were found in surveys of wet playas.

In our focus group of playas, there was no evidence for positive relationships between bird use and floristic quality indices, or bird use and Ecological Integrity values. Instead, waterfowl abundance was negatively associated with Mean C, native species count, and FQI_{all}, and positively associated with the percent of non-native species. This could be due to an association of waterfowl with particular plants that provide rich seed resources but which have low C-values (T. LaGrange, personal communication; J. Gammonley, personal communication). For example, non-native playa species such as barnyard grass (*Echinochloa crus-galli*), spotted lady's thumb (*Persicaria maculata*), redroot pigweed (*Amaranthus retroflexus*) and curly dock (*Rumex crispus*) are important forage plants for waterfowl. In addition, native plants with low C-values, such as pale dock (*Rumex altissimus*), Pennsylvania smartweed (*Persicaria bicornis*) and disk waterhyssop (*Bacopa rotundifolia*) also provide important waterfowl food resources (unpublished data; T. LaGrange, L. Smith, L. Fredrickson, and R. Cox).

A playa dominated by smartweed (*Persicaria* sp.), a plant considered to have high waterfowl forage value

Waterfowl numbers exhibited a small negative trend with increasing percent of the landscape in unfragmented prairie. This suggested waterfowl numbers were greater in landscapes dominated by cropland. Others have found that waste grains are an important source of energy for migrating waterfowl (Gruenhagen and Fredrickson 1990). Higher abundance of waterfowl in agricultural landscapes may partially explain the negative association of waterfowl abundance to the floristic quality metrics, as we found that floristic quality metrics were much lower in playas with adjacent agricultural landuse. We did not find waterfowl abundance to increase with distance from the road, as others have (LaGrange and Dinsmore 1989).

In the smaller group of playas, we found waterfowl abundance was negatively related to human disturbance as measured by HDI-1. This finding indicated waterfowl favored less disturbed sites along the composite human disturbance gradient. This effect was difficult to interpret for several reasons. This result contrasts with the strong negative association of waterfowl abundance with floristic quality. Floristic quality was negatively related to human disturbance (HDI-2) in our broad group, although we found no such relationship between floristic quality metrics and HDI-1. Secondly, when we considered the broad avian dataset, where our sample sizes were better, no effects of human disturbance were evident. It is possible that waterfowl were responding to the suite of human disturbance factors acting in concert within HDI-1 that we could not detect when testing various other human disturbance metrics alone. Finally, sample sizes were very limited in this analysis, HDI-1 scores were poorly distributed (heaping at several values), and few large flocks of waterfowl created an uneven distribution of waterfowl numbers. The relationship of migrating waterfowl abundance on playas to floristic quality and human disturbance likely requires additional study.

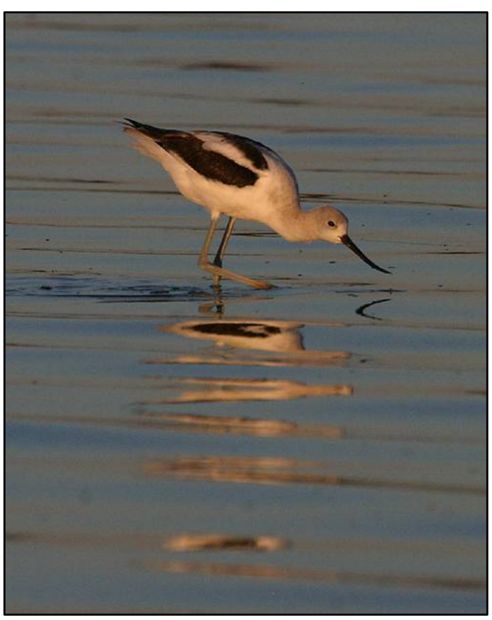
A tilled playa with *Persicaria* species on edge

We found no relationship between shorebird abundance and the floristic quality metrics.

This finding is not surprising considering shorebirds are likely to select habitat on the basis of sparse vegetation and the presence of mud flats (Colwell and Oring 1998) rather than on floristics. However, shorebird abundance was much lower on playas impacted by pits or impoundments. The abundance of migrant shorebirds during spring was also lower on wetlands with hydrological modification in agricultural field wetlands in North Dakota (Neimuth et al. 2006). It is likely that shorebirds prefer unmodified playas because the natural slope in unmodified playas steep creates the gentlest gradient for shallow foraging habitat conditions. In addition, these playas may be superior for visibility which allows shorebirds to scan for predators, as pits often create spoil piles which would create visual obstruction. Also, the longer hydroperiods of pitted playas are associated with lower invertebrate abundances (Smith 2003), which may reduce food resources for migrating shorebirds.

The analysis for the count of bird species showed that the number of bird species declined with increasing floristic quality of the playas. In addition, we observed more species in playas with adjacent agriculture than in playas with adjacent grassland. This contrasts with findings of Stapanian *et al*. (2004) where the total count of avian species increased with a multi-metric indicator of ecological integrity, including a cursory assessment of floristic quality. However, the number of wetland dependent species was not strongly associated with the ecological integrity of the wetlands (Stapanian et al. 2004). In a study of wetlands along the shore of the Great Lakes, the functional indicators for wetland vegetation showed the largest response to human disturbance (Brazner et al. 2007). Conversely, avian abundance and species richness showed low concordance with functional indicators for the quality of wetland vegetation (Brazner et al. 2007).

When we examined all of the playas in the full study, we found several relationships of bird use to human disturbance. Average number of bird species was higher in playas with hydrological modifications. This is probably due to pits and other impoundments creating a different set of habitat types than are typically found in playas. As above, shorebirds were less abundant on hydrologically modified playas. However, waterfowl abundance was unrelated to anthropogenic landuse. In addition, the size and proximity to other playas were important for the abundance of waterfowl and shorebirds, also found by Neimuth et al. (2006). This suggests that large playas in complexes are more attractive than isolated playas for birds, perhaps offering increased foraging opportunities with relatively low search costs (Farmer and Parent 1997).



American Avocet, a common playa migrant

The importance of natural hydrological profiles for shorebirds provides support for the conservation practice of filling pits. In the past, many livestock producers have used heavy equipment to deepen playas or parts of playas so that they hold water for their livestock to use over a longer period of time. In wetter regions, pits were dug to drain agricultural fields. Re-filling excavated pits to restore the natural soil gradient is a restoration practice that restores hydrologic function, re-distributing shallower water over a larger area for a shorter period of time. This provides shallow foraging habitat for shorebirds and waterfowl, as well as more appropriate conditions for many wetland-dependent plants, especially annuals that provide important seed resources for migratory waterbirds. In return for diminishing their opportunity to water their livestock within the playa basin, many restoration projects also provide a clean, reliable water source for the producer. This alleviates the need to water the cattle in the playa and also adds flexibility to the livestock producer's grazing operation as they can now graze the pasture when they want without having to be dependent on the unreliable and erratic availability of water in the playa.

Conclusions

Our results indicated the floristic quality assessment accurately reflected the extent of human disturbance for playas in eastern Colorado, when we used the broad group of playas and a composite gradient composed of eleven human disturbance factors. An analysis of a smaller focus group of playas did not find associations of FQA metrics with the Human Disturbance Gradient from the Colorado FQA project (HDI-1). This may have been due to limitations in HDI-1, a smaller sample size in that analysis, or the proximity of playas in that group to roads. We recommend modifications to the human disturbance index that may improve its function in the heavily modified landscape of eastern Colorado.

In particular, the count of native species, percent non-native species, and the floristic quality indices (unadjusted) were effective for detecting responses to anthropogenic land use. Adjacent cropland had the largest impact on the floristic quality of playa wetlands, and hydrological modifications and percent of the landscape in native prairie were also important for describing the percent of non-native species. Rare species were found exclusively in grassland playas. A simplistic representation of these findings is that playas in native grassland have higher floristic quality.

Although the floristic metrics corresponded to human disturbance, bird use showed different responses to human disturbance. Shorebirds responded negatively to hydrological alterations, but otherwise avian use did not decline with the human disturbance factors we measured. In contrast, species counts were higher on cropland playas than on grassland playas and were negatively related to FQA metrics. Waterfowl numbers were negatively related to floristic quality measures and were more abundant in cropland-dominated landscapes. Counts of all birds were higher in playas with hydrological modifications. Migratory bird use of playas wetlands is best predicted by playa size, the extent of flooding, and proximity to other wetlands.

Our findings showed little redundancy in floristic and avian responses to human disturbance, which suggested that both metrics merit consideration when prioritizing the conservation of playa wetlands. For conservation of floristic values, one might prioritize playas in native grassland. For migratory birds, it might be best to conserve large playas in complexes that are inundated frequently. We did not measure occupancy by amphibian species or other wildlife and would encourage such studies. Indeed, using floristic data to represent biotic condition may not represent the full spectrum of biological values associated with playa wetlands. We recommend a holistic approach that takes into account the values of playas to a variety of taxa when assessing biotic condition in a conservation framework.

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APPENDIX A

PLANT SPECIES DOCUMENTED ON EASTERN COLORADO PLAYAS, 2007

Latin Name[1]	Common Name	% Playas Occupied	C-Value[2]	Nativity[3]	Wetland Status[4]	Invasiveness[5]
Acanthoxanthium spinosum (L.) Fourreau	spiny cocklebur	6	0	Exotic	FACU	
Achnatherum hymenoides - (Roemer & J.A. Schultes) Barkworth	Indian ricegrass	1	5	Native	FACU	
Agaloma marginata (Pursh) Loeve & Loeve	snow-on-the-mountain	8	1	Native	FACU	
Agropyron cristatum (L.) Gaertner (sensu lato)	crested wheatgrass	4	0	Exotic		4
Amaranthus albus L.	prostrate pigweed	25	0	Exotic	FACU	2
Amaranthus blitoides S. Watson	mat amaranth	2	4	Native	FACW	
Amaranthus hybridus L.	slim amaranth	1	0	Native		
Amaranthus retroflexus L.	redroot pigweed	31	0	Exotic	FACU	
Amaranthus sp.	Amaranth sp.	4				
Ambrosia acanthicarpa Hooker	slimleaf bursage	1	4	Native		
Ambrosia artemisiifolia L. var. elatior (L.) Descourtils	annual ragweed, common ragweed	10	0	Exotic	FACU	
Ambrosia grayi (A. Nelson) Shinners	woollyleaf bursage, woollyleaf burr ragweed	16	1	Native	FAC	
Ambrosia linearis (Rydberg) Payne	streaked burr ragweed	19	4	Native		
Ambrosia psilostachya De Candolle var. coronopifolia (Torrey & Gray) Farwell	western ragweed	9	3	Native	FAC	
Ambrosia sp.	ragweed sp.	19				
Ambrosia tomentosa Nuttall	skeletonleaf bursage, skeletonleaf burr ragweed	36	3	Native		
Ambrosia trifida L.	great ragweed	1	0	Exotic	FACW	
Ammannia robusta Heer & Regel	grand redstem	1	3	Native	OBL	
Anisantha tectorum (L.) Nevski	cheatgrass	8	0	Exotic		4
Argemone polyanthemos (Fedde) G. Ownbey	crested pricklypoppy	1	3	Native		
Aristida divaricata Humboldt & Bonpland ex Willdenow	poverty threeawn	1	5	Native		
Aristida purpurea Nuttall	purple threeawn	27	3	Native		
Aristida sp.	threeawn sp.	3				
Artemisia carruthii Wood {ex} Carruth	Carruth's sagewort	2	5	Native		
Artemisia frigida Willdenow	fringed sagebrush	13	4	Native		

Latin Name[1]	Common Name	% Playas Occupied	C-Value[2]	Nativity[3]	Wetland Status[4]	Invasiveness[5]
Artemisia ludoviciana Nuttall	white sagebrush	2	4	Native	FACU-	
Artemisia sp.	sagebrush sp.	6				
Asclepias viridiflora Rafinesque	green comet milkweed	1	6	Native		
Aster sp.	aster sp.	6				
Astragalus adsurgens Pallas var. robustior Hooker	prairie milkvetch	1	3	Native		
Astragalus bisulcatus (Hooker) A. Gray	two grooved milkvetch	1	5	Native		
Astragalus mollissimus Torrey	woolly locoweed	14	5	Native		
Astragalus sp.	milkvetch sp.	4				
Astragalus tenellus Pursh	looseflower milkvetch	3	6	Native		
Atriplex argentea Nuttall	silverscale saltbrush	2	5	Native	FAC	
Atriplex gardneri (Moquin) Standley	Gardner's saltbush	1	6	Native		
Bacopa rotundifolia (Michaux) Wettstein in Engler & Prantl	disk waterhyssop	2	4	Native	OBL	
Bassia sieversiana (Pallas) W. A. Weber	kochia	65	0	Exotic	FACU	4
Bergia texana (Hooker) Seubert ex Walpers	Texas bergia	1	3	Native	OBL	
Bolboschoenus maritimus (L.) Palla subsp. paludosus (A. Nelson) Loeve & Loeve	cosmopolitan bulrush	3	5	Native	NI	
Bouteloua curtipendula (Michaux) Torrey	sideoats	1	6	Native		
Bouteloua curtipendula (Michaux) Torrey var. curtipendula	sideoats grama	1	5	Native		
Breea arvensis (L.) Lessing	Canada thistle	3	0	Exotic	FACU	4
Brickellia eupatorioides (L.) Shinners	false boneset	1	6	Native		
Bromopsis inermis (Leysser) Holub	smooth brome	1	0	Exotic		4
Bromus japonicus Thunberg	Japanese brome	9	0	Exotic	FACU	4
Bromus sp.	brome sp.	1				
Buchloe dactyloides (Nuttall) Engelmann	buffalograss	77	4	Native	FACU	
Caesalpinia jamesii (Torrey & Gray) Fisher	James' holdback	1	6	Native		
Camelina microcarpa Andrzejowski ex De Candolle	little false flax	1	0	Exotic	NI	3
Cardaria latifolia (L.) Spach	tall whitetop, broadleaved pepperweed	1	0	Exotic	FACW	4
Carex aquatilis Wahlenberg	water sedge	4	6	Native	OBL	

Latin Name[1]	Common Name	% Playas Occupied	C-Value[2]	Nativity[3]	Wetland Status[4]	Invasiveness[5]
Carex sp.	sedge sp.	28				
Carex stenophylla Wahlenberg subsp. eleocharis (L. H. Bailey) Hulten	needleleaf sedge	1	7	Native		
Cenchrus longispinus (Hackel in Kneucker) Fernald	mat sandbur	11	1	Native		
Chamaesaracha coronopus (Dunal) A. Gray	greenleaf five eyes	1	5	Native		
Chamaesyce glyptosperma (Engelmann) Small	ribseed sandmat	9	2	Native		
Chamaesyce lata (Engelmann) Small	hoary sandmat	1	7	Native		
Chamaesyce sp.	sandmat sp.	8				
Chenopodium berlandieri Moquin	netseed lambsquarters, pitseed goosefoot	13	2	Native		
Chenopodium cycloides A. Nelson	sandhill goosefoot	1	9	Native		
Chenopodium desiccatum A. Nelson	aridland goosefoot, desert goosefoot	8	3	Native		
Chenopodium incanum (S. Watson) Heller	mealy goosefoot	9	5	Native		
Chenopodium leptophyllum (Nuttall ex Moquin) S. Watson	narrowleaf goosefoot	24	5	Native	NI	
Chenopodium sp.	goosefoot sp.	61				
Chenopodium watsonii A. Nelson	Watson's goosefoot	1	4	Native		
Chloris verticillata Nuttall	tumble windmill grass	2	1	Native		
Chondrosum barbatum (Lagasca) Clayton	sixweeks grama	1	7	Native		
Chondrosum gracile Humboldt, Bonpland, & Kunth	blue grama	34	4	Native		
Chondrosum prostratum (Lagasca) Sweet	matted grama	2	0	Exotic		4
Chrysothamnus nauseosus (Pallas ex Pursh) Britton	rubber rabitbrush	7	3	Native		
Cirsium flodmanii (Rydberg) Arthur	Flodman's thistle	1	3	Native	NI	
Cirsium ochrocentrum A. Gray	yellowspine thistle	1	4	Native		
Cirsium sp.	thistle sp.	1				
Cirsium undulatum (Nuttall) Sprengel	wavyleaf thistle	31	5	Native	FACU	
Cirsium vulgare (Savi) Tenore	bull thistle	1	0	Exotic	UPL	4
Cleome serrulata Pursh	Rocky Mountain beeplant	1	2	Native	FACU	

Latin Name[1]	Common Name	% Playas Occupied	C-Value[2]	Nativity[3]	Wetland Status[4]	Invasiveness[5]
Convolvulus arvensis L.	field bindweed	11	0	Exotic		4
Conyza canadensis (L.) Cronquist	marestail, horseweed	46	0	Exotic	FACW	3
Coreopsis sp.	coreopsis sp.	5				
Coreopsis tinctoria Nuttall	plains coreopsis	20	3	Native	FAC	
Corydalis curvisiliqua Engelmann subsp. occidentalis (Engelmann ex A. Gray) W. A. Weber	curved fumewort	1	5	Native		
Critesion jubatum (L.) Nevski	foxtail barley	16	2	Native	FACW	
Critesion pusillum (Nuttall) Loeve	little barley	22	1	Native	FAC	
Croton texensis (Klotsch) Muller-Argoviensis in De Candolle	Texas croton	1	2	Native		
Cryptantha crassisepala (Torrey & Gray) Greene	thick sepal cryptantha	2	3	Native		
Cryptantha crassisepala (Torrey & Gray) Greene var. elachantha I.M. Johnston	thicksepal cryptantha	9	1	Native		
Cryptantha minima Rydberg	little cryptantha	6	3	Native		
Cryptantha sp.	cryptantha sp.	5				
Cuscuta sp.	dodder sp.	1				
Cylindropuntia imbricata (Haworth) Knuth	tree cholla	3	4	Native		
Cyperus acuminatus Torrey & Hooker	tapertip flatsedge	1	2	Native	OBL	
Cyperus aristatus Rottboel	bearded flatsedge	1	5	Native	OBL	
Descurainia pinnata (Walter) Britton	paradise tansymustard	11	2	Native		
Descurainia sophia (L.) Webb ex Prantl	herb sophia	2	0	Exotic		3
Descurainia sp.	tansymustard sp.	9				
Diplachne fascicularis (Lamarck) P. Beauvois	bearded spangletop	1	4	Native	OBL	
Distichlis stricta (Torrey) Rydberg	inland saltgrass	14	4	Native	NI	
Dyssodia papposa (Ventenat) A. S. Hitchcock	fetid marigold	4	2	Native		
Echinochloa crus-galli (L.) P. Beauvois	barnyard grass	28	0	Exotic	FACW	3
Eleocharis acicularis (L.) Roemer & Schultes	needle spikerush	39	5	Native	OBL	
Eleocharis palustris (L.) Roemer & Schultes	common spikerush	50	3	Native		

Latin Name[1]	Common Name	% Playas Occupied	C-Value[2]	Nativity[3]	Wetland Status[4]	Invasiveness[5]
Eleocharis sp.	spikerush sp.	14				
Elymus canadensis L.	Canada wildrye	3	4	Native	FACU	
Elymus elymoides (Rafinesque) Swezey	squirreltail	17	4	Native	FACU	
Eragrostis cilianensis (Allioni) F. T. Hubbard	stinkgrass	16	0	Exotic	FACU	2
Eragrostis curvula (Schrader) Nees	weeping lovegrass	1	0	Exotic		
Eragrostis pilosa (L.) P. Beauvois	Indian lovegrass	5	0	Exotic	FACU	
Eragrostis sp.	lovegrass sp.	7				
Erigeron bellidiastrum Nuttall	western daisy fleabane	2	4	Native		
Erigeron colo-mexicanus A. Nelson	running fleabane	2	6	Native		
Erigeron divergens Torrey & Gray	spreading fleabane, spreading daisy	7	4	Native		
Erigeron pumilus Nuttall	Navajo fleabane	1	5	Native		
Erigeron sp.	fleabane sp.	5				
Eriogonum annuum Nuttall	annual buckwheat	2	4	Native		
Eriogonum effusum Nuttall	spreading buckwheat	6	5	Native		
Eriogonum microthecum Nuttall	slender buckwheat	4	6	Native		
Erodium cicutarium (L.) L'Heritier	redstem stork's bill	1	0	Exotic		4
Erysimum asperum (Nuttall) De Candolle	western wallflower	6	4	Native		
Euphorbia sp.	sandmat sp.	2				
Evolvulus nuttallianus Schultes	shaggy dwarf morning-glory	2	6	Native		
Fallopia convolvulus (L.) Loeve	black bindweed	5	0	Exotic	FACU	
Ferocactus sp.	barrel cactus sp.	5				
Fragaria sp.	strawberry sp.	1				
Froelichia gracilis (Hooker) Moquin	slender snakecotton	1	4	Native		
Gaillardia pinnatifida Torrey	red dome blanket flower	5	6	Native		
Galinsoga parviflora Cavanilles	galliant soldier	4	0	Exotic		
Gaura coccinea Nuttall ex Pursh	scarlet beeblossom	4	5	Native		
Gaura mollis James	velvety guara, velvetweed	1	1	Native	NI	
Gaura sp.	beeblossom sp.	1				
Glandularia bipinnatifida (Nuttall) Nuttall	showy vervain, Dakota mock vervain	3	3	Native		
Glycyrrhiza lepidota Pursh	wild licorice	1	3	Native	FACU	
Gnaphalium palustre Nuttall	western marsh cudweed	4	5	Native	OBL	

Latin Name[1]	Common Name	% Playas Occupied	C-Value[2]	Nativity[3]	Wetland Status[4]	Invasiveness[5]
Grammica indecora (Choisy) W. A. Weber var. neuropetala (Engelmann) W. A. Weber	bigseed dodder	3	4	Native		
Grindelia inornata Greene	Colorado gumweed	1	3	Native		
Grindelia sp.	gumweed sp.	1				
Grindelia squarrosa (Pursh) Dunal	curlycup gumweed	39	1	Native	FACU-	
Gutierrezia sarothrae (Pursh) Britton & Rusby	broom snakeweed	6	3	Native		
Hedeoma hispidum Pursh	rough false pennyroyal	3	5	Native		
Helianthus annuus L.	common sunflower	13	1	Native	FACU	
Helianthus petiolaris Nuttall	prairie sunflower	5	2	Native		
Helianthus sp.	sunflower sp.	5				
Heliotropium curassavicum L. subsp. oculatum (Heller) Thorne	seaside heliotrope	3	0	Exotic	OBL	
Hesperostipa comata (Trinius & Ruprecht) Barkworth	needle and thread	1	6	Native		
Heteranthera limosa (Swartz) Willdenow	blue mud plantain	2	5	Native	OBL	
Heterotheca latifolia Buckley	camphorweed	1	2	Native	FACU	
Heterotheca sp.	goldenaster sp.	1				
Heterotheca villosa (Pursh) Shinners	hairy false golden aster	19	3	Native		
Hymenopappus filifolius Hooker	fineleaf hymenopappus	2	6	Native		
Hymenopappus filifolius Hooker var. polycephalus (Osterhout) B. Turner	manyhead hymenopappus	1	5	Native		
Hymenopappus tenuifolius Pursh	Chalk Hill hymenopappus	1	6	Native		
Ipomoea leptophylla Torrey	bush morning glory	2	6	Native		
Ipomopsis laxiflora (Coulter) V. Grant	iron ipomosis	7	3	Native		
Iva axillaris Pursh	poverty sumpweed	29	2	Native	FAC	
Juncus sp.	rush sp.	1				
Koeleria macrantha (Ledebour) Schultes	prairie Junegrass	2	6	Native		
Krascheninnikovia lanata (Pursh) Meeuse & Smit	winterfat	2	8	Native		
Lactuca serriola L.	prickly lettuce	21	0	Exotic	FAC	3
Lappula redowskii (Hornemann) Greene	flatspine stickseed	5	2	Native		
Lepidium densiflorum Schrader	common pepperweed	29	0	Exotic	FAC	3

Latin Name[1]	Common Name	% Playas Occupied	C-Value[2]	Nativity[3]	Wetland Status[4]	Invasiveness[5]
Leptochloa sp.	sprangletop sp.	4				
Leucanthemum vulgare Lamarck	oxeye daisy	1	0	Exotic	NI	4
Liatris punctata Hooker	dotted blazing star	1	6	Native		
Lygodesmia juncea (Pursh) D. Don	skeletonweed	12	4	Native		
Machaeranthera pinnatifida (Hooker) Shinners	lacy tansyaster	6	4	Native		
Machaeranthera pinnatifida (Hooker) Shinners var. pinnatifida	lacy tansyaster	2	4	Native		
Machaeranthera sp.	tansyaster sp.	4				
Machaeranthera tanacetifolia (Humboldt, Bonpland, & Kunth) Nees	tansyleaf tansyaster	1	2	Native		
Mammillaria sp.	cactus sp.	2				
Mariscus schweinitzii (Torrey) Koyama	Schweinitz's flatsedge	1	6	Native	FACU	
Marsilea mucronata A. Braun	western water clover, pepperwort	29	7	Native	OBL	
Marsilea sp.	waterclover sp.	2				
Medicago sativa L.	alfalfa	7	0	Exotic	NI	3
Melilotus albus Medicus	yellow sweetclover	2	0	Exotic	FACU	3
Melilotus officinale (L.) Pallas	yellow sweetclover	14	0	Exotic		3
Mollugo verticillata L.	green carpetweed	1	0	Exotic	FAC	
Monolepis sp.	povertyweed sp.	1				
Monroa squarrosa (Nuttall) Torrey	false buffalograss	5	4	Native		
moss sp.	moss sp.	3				
Muhlenbergia asperifolia (Nees & Meyen ex Trinius) Parodi	scratchgrass muhly	1	4	Native	FACW	
Muhlenbergia torreyi (Kunth) A. S. Hitchcock ex Bush	ring muhly	3	5	Native		
Myosurus minimus L.	bristly mousetail	7	5	Native		
Oenothera albicaulis Pursh	whitest evening primrose	1	6	Native		
Oenothera canescens Torrey & Fremont	spotted evening primrose	46	4	Native	FACW-	
Oenothera sp.	primrose sp.	6				
Oenothera villosa Thunberg subsp. strigosa (Rydberg) Dietrich & Raven	hairy evening primrose	1	4	Native	FACU	

Latin Name[1]	Common Name	% Playas Occupied	C-Value[2]	Nativity[3]	Wetland Status[4]	Invasiveness[5]
Oligosporus caudatus (Michaux) Poljakov	field sagewort	1	5	Native		
Oligosporus dracunculus (L.) Poljakov	terragon	1	3	Native		
Oligosporus filifolius (Torrey) Poljakov	sand sagebrush	3	5	Native		
Oonopsis foliosa (A. Gray) Greene	leafy false goldenweed	1	6	Native		
Opuntia sp.	cactus sp.	40				
Oxybaphus decumbens (Nuttall) Sweet	narrowleaf four o'clock	4	5	Native	NI	
Oxytropis lambertii Pursh	Lambert crazyweed, purple locoweed	3	5	Native	FACU	
Oxytropis sericea Nuttall	white locoweed	1	5	Native		
Oxytropis sp.	locoweed	6				
Packera tridenticulata (Rydberg) Weber & Loeve	threetooth ragwort	5	7	Native		
Panicum capillare L.	witchgrass	23	0	Exotic	FAC	2
Panicum miliaceum L.	wild proso millet, broomcorn millet	3	0	Exotic		4
Panicum obtusum Humboldt, Bonpland, & Kunth	vine mesquite	2	4	Native	FACW	
Panicum virgatum L.	switchgrass	1	5	Native	FAC	
Pascopyrum smithii (Rydberg) Loeve	western wheatgrass	72	5	Native	FACU	
Pectis angustifolia Torrey	lemonscent	1	4	Native		
Penstemon albidus Nuttall	white penstemon	2	5	Native		
Penstemon angustifolius Nuttall ex Pursh subsp. Angustifolius	broadbeard beardtongue	1	5	Native		
Penstemon sp.	penstemon sp.	1				
Persicaria amphibia (L.) S. Gray	water smartweed	1	4	Native	OBL	
Persicaria bicornis (Rafinesque) Nieuwland	Pennsylvania smartweed	6	4	Native	FACW+	
Persicaria lapathifolia (L.) S. Gray	curlytop knotweed	3	0	Exotic	OBL	4
Persicaria maculata (L.) S. Gray	spotted ladysthumb	1	0	Exotic	OBL	4
Persicaria sp.	smartweed sp.	14				
Phyla cuneifolia (Torrey) Greene	frog-fruit, fogfruit	42	4	Native	FAC	
Physalis heterophylla Nees	clammy groundcherry	2	5	Native		
Physalis virginiana P. Miller	prairie groundcherry	1	4	Native		
Picradenia odorata (De Candolle) Britton	bitter rubberweed	1	4	Native	NI	

Latin Name[1]	Common Name	% Playas Occupied	C-Value[2]	Nativity[3]	Wetland Status[4]	Invasiveness[5]
Picradeniopsis oppositifolia (Nuttall) Rydberg	oppositeleaf bahia	4	2	Native		
Picradeniopsis woodhousei (A. Gray) Rydberg	Woodhouse's bahia	1	4	Native		
Plantago patagonica Jacquin	woolly plantain	41	2	Native	UPL	
Plantago sp.	plantain sp.	3				
Poa sp.	grass sp.	2				
Poinsettia dentata (Michaux) Klotsch & Garcke	toothed spurge	2	1	Native		
Polygonum arenastrum Boreau	oval-leaf knotweed	3	0	Exotic	NI	3
Polygonum aviculare L. var. aviculare	prostrate knotweed	27	0	Exotic		3
Polygonum ramosissimum Michaux	bushy knotweed	39	2	Native	FAC	
Polygonum sp.	Polygonum sp.	8				
Populus deltoides H. Marshall subsp. wislizenii (S. Watson) Eckenwalder	eastern cottonwood	3	4	Native	FAC	
Populus sp.	cottonwood sp.	1				
Portulaca halimoides L.	silkcotton purslane	1		Native	NI	
Portulaca oleracea L.	common purslane	41	0	Exotic	FAC	3
Portulaca sp.	purslane sp.	6				
Potentilla rivalis Nuttall ex Torrey & Gray	brook cinquefoil	7	5	Native	FACW+	
Potentilla sp.	cinquefoil sp.	2				
Proboscidea louisianica (P. Miller) Thellung	ram's horn, devil's claw	5	1	Native	FACU	
Proboscidea sp.	devil's claw sp.	1				
Psoralidium lanceolatum (Pursh) Rydberg	lemon scurfpea	2	5	Native		
Psoralidium sp.	scurfpea sp.	11				
Psoralidium tenuiflorum (Pursh) Rydberg	slimflower scurfpea	13	5	Native		
Quincula lobata (Torrey) Rafinesque	Chinese lantern	2	3	Native		
Ratibida columnifera (Nuttall) Wooton & Standley	prairie coneflower	16	4	Native		
Ratibida sp.	prairie coneflower sp.	10				
Ratibida tagetes (James) Barnhart	short-ray prairie coneflower	52	4	Native		
Rorippa sinuata (Nuttall in Torrey & Gray) A. S. Hitchcock	spreading yellowcress	29	4	Native	FACW	

Latin Name[1]	Common Name	% Playas Occupied	C-Value[2]	Nativity[3]	Wetland Status[4]	Invasiveness[5]
Rumex altissimus Wood	pale dock	5	1	Native	FAC	
Rumex crispus L.	curly dock	9	0	Exotic	FACW	3
Rumex stenophyllus Ledebour	narrowleaf dock	1	0	Exotic	FACW+	
Rumex triangulivalvis (Danser) Rechinger f.	Mexican dock	2	4	Native	FAC	
Rumex utahensis Rechinger	toothed willow dock	1	4	Native		
Salsola australis R. Brown	tumbleweed, Russian thistle	72	0	Exotic	FACU	4
Salsola collina Pallas	slender Russian thistle	1	0	Exotic		
Salvia reflexa Hornemann	lanceleaf sage	5	2	Native		
Sanguisorba minor Scopoli	small burnet	1	0	Exotic	NI	2
Schedonnardus paniculatus (Nuttall) Trelease	tumblegrass	24	2	Native		
Schoenoplectus lacustris (L.) Palla subsp. creber (Fernald) Loeve & Loeve	softstem bulrush	5	3	Native	OBL	
Schoenoplectus pungens (M. Vahl) Palla	common threesquare	1	4	Native	OBL	
Schoenoplectus sp.	bulrush sp.	1				
Scorzonera sp.	Scorzonera sp.	2				
Senecio sp.	Senecio sp.	1				
Setaria glauca (L.) P. Beauvois	yellow foxtail	5	0	Exotic		
Setaria sp.	bristlegrass or panicgrass sp.	3				
Setaria viridis (L.) P. Beauvois	green bristlegrass	4	0	Exotic		2
Sisymbrium altissimum L.	tumble mustard	17	0	Exotic	FACU	4
Solanum rostratum Dunal	buffalobur nightshade	19	0	Exotic		2
Solanum triflorum Nuttall	cutleaf nightshade	5	2	Native		
Solidago sp.	goldenrod sp.	1				
Solidago velutina De Candolle	threenerve goldenrod	1	6	Native		
Sorghastrum sp.	Indiangrass sp.	1				
Sorghum vulgare Persoon	grain sorghum	1	0	Exotic		2
Spergula arvensis L.	corn spurry	1	0	Exotic		
Sphaeracea sp.		1				
Sphaeralcea angustifolia (Cavanilles) G. Don var. cuspidata A. Gray	copper globemallow	1	5	Native		

Latin Name[1]	Common Name	% Playas Occupied	C-Value[2]	Nativity[3]	Wetland Status[4]	Invasiveness[5]
Sphaeralcea coccinea (Pursh) Rydberg	scarlet globemallow	28	4	Native		
Sphaeralcea sp.	globemallow sp.	1				
Sporobolus airoides (Torrey) Torrey	alkali sacaton	5	5	Native	FAC	
Sporobolus cryptandrus (Torrey) A. Gray	sand dropseed	28	2	Native	FACU-	
Sporobolus sp.	grass sp.	2				
Suaeda calceoliformis (Hooker) Moquin	Pursh seepweed	1	3	Native	FACW	
Suckleya suckleyana (Torrey) Rydberg	poison suckleya	16	4	Native	FACW	
Symphyotrichum sp.	aster sp.	2				
Talinum parviflorum Nuttall ex Torrey & Gray	sunbright	10	6	Native		
Talinum sp.	flameflower sp.	3				
Tamarix ramosissima Ledebour	saltcedar, tamarisk	2	0	Exotic	FACW	4
Taraxacum officinale G. H. Weber ex Wiggers	common dandelion	10	0	Exotic	FACU	3
Thelesperma filifolium (Hooker) A. Gray var. intermedium (Rydberg) Shinners	stiff greenthread	7	5	Native		
Thelesperma megapotamicum (Sprengel) Kuntze	Colorado greenthread	5	5	Native		
Thelesperma sp.	greenthread sp.	5				
Thlaspi arvense L.	field pennycress	4	0	Exotic	NI	3
Tithymalus spathulatus (Lamarck) W. A. Weber	warty spurge	1	4	Native	FACU	
Tragopogon dubius Scopoli subsp. major (Jacquin) Vollmann	yellow salisfy	15	0	Exotic		2
Tribulus terrestris L.	puncturevine	8	0	Exotic		4
Trifolium repens L.	white clover	1	0	Exotic	FACU	3
Triticum aestivum L.	common wheat	8	0	Exotic		3
Triticum sp.	wheat sp.	3				
Typha angustifolia L.	narrowleaf cattail	3	0	Exotic	OBL	
Typha latifolia L.	broadleaf cattail	2	2	Native	OBL	
Typha sp.	cattail sp.	1				
Unknown Forb		6				
Unknown Grass		10				

Latin Name[1]	Common Name	% Playas Occupied	C-Value[2]	Nativity[3]	Wetland Status[4]	Invasiveness[5]
Unknown plant sp.		21				
Unknown Shrub		1				
Verbascum thapsus L.	common mullein	1	0	Exotic	NI	4
Verbena bracteata Lagasca & Rodriguez	prostrate vervain,bigtract verbena	56	0	Exotic	FACU	2
Veronica peregrina L. subsp. xalapensis (Humboldt, Bonpland, & Kunth) Pennell	speedwell purslane	19	0	Exotic	OBL	
Vexibia nuttalliana (B. Turner) W. A. Weber	silky sophora	8	5	Native		
Vicia sp.	vetch sp.	2				
Virgulus ericoides (L.) Reveal & Keener	manyflowered aster	5	4	Native	FACU	
Vulpia octoflora (Walter) Rydberg	sixweeks fescue	32	3	Native	UPL	
Xanthisma sp.	sleepydaisy sp.	1				
Xanthium strumarium L.	rough cockleburr	15	0	Exotic	FAC	4
Xanthoparmelia sp.	lichen sp.	2				
Ximenesia encelioides Cavanilles	golden crownbeard/goldweed	4	0	Exotic	FAC	
Yucca glauca Nuttall in Fraser	soapweed yucca	5	4	Native		
Zea mays L.	corn	3				

1. Scientific names follow those of the University of Colorado at Boulder Herbarium, based upon those of Weber, as provided by Colorado Natural Heritage Program, Floristic Quality Assessment Database (March 2008).
2. C-values are Coefficient of conservativism, ranging from 0 (not conservative) to 10 (extremely conservative or fidelitous to natural areas); from CNHP FQA Database and explained in Rocchio 2007.
3. Native or exotic (non-native) to Colorado as provided by CNHP FQA database from USDA PLANTS database.
4. Wetland Indicator Status from CNHP FQA Database; OBL=Obligate, FACW=Facultative Wetland, FAC=Facultative, FACU=Facultative Upland, UPL=Obligate Upland, from US Fish and Wildlife Service. Reed, PB. 1988. National List of Plant Species That Occur in Wetlands -- Central Plains (Region 5). National Wetland Inventory, U.S. Department of the Interior, Fish and Wildlife Service, St. Petersburg, FL. 90 pp. Blank indicates species was not on list.
5. Degree of invasiveness from CNHP FQA Database, ranged from 1 = less invasive to 4 = highly invasive as described in Rocchio (2007).

APPENDIX B

STATISTICAL TABLES

Section I. All FQI metrics in relation to human disturbance gradient (HDI-2)

Table 1. Model parameters for the effect of human disturbance (HDI-2) as measured by principle component 1 (PCA1) and 2 (PCA2) on metrics of floristic quality.

Section Parameter	Estimate	SE	Lower 95% CL	Upper 95% CL
Mean C (all)				
Intercept	2.52	0.061	2.39	2.64
PCA1	0.07	0.026	0.02	0.13
PCA2	-0.18	0.037	-0.26	-0.11
Standard deviation	0.64			
Cover-weighted Mean C (all)				
Intercept	2.99	0.105	2.78	3.20
PCA1	0.12	0.045	0.02	0.21
PCA2	-0.19	0.064	-0.32	-0.06
Standard deviation	1.10			
Species Count (all)				
Intercept	12.11	0.383	11.35	12.88
PCA1	0.44	0.164	0.11	0.77
PCA2	-0.63	0.233	-1.10	-0.16
Standard deviation	4.00			
Mean C (native)				
Intercept	3.56	0.053	3.45	3.67
PCA1	0.01	0.023	-0.04	0.06
PCA2	0.01	0.032	-0.06	0.08
Standard deviation	0.55			
Species Count (native)				
Intercept	8.50	0.268	7.97	9.04
PCA1	0.52	0.114	0.29	0.76
PCA2	-0.98	0.163	-1.31	-0.65
Standard deviation	2.80			
Cover-weighted Mean C (native)				
Intercept	3.61	0.085	3.44	3.79
PCA1	0.05	0.036	-0.03	0.12
PCA2	-0.07	0.052	-0.18	0.03
Standard deviation	0.89			
FQI (native)				
Intercept	10.03	0.206	9.62	10.45
PCA1	0.39	0.088	0.21	0.57
PCA2	-0.74	0.126	-0.99	-0.48
Standard deviation	2.16			
Cover-weighted FQI (native)				
Intercept	10.30	0.280	9.74	10.86
PCA1	0.47	0.119	0.23	0.71
PCA2	-0.96	0.170	-1.30	-0.61
Standard deviation	2.92			
FQI (all)				
Intercept	7.31	0.214	6.88	7.73
PCA1	0.38	0.091	0.20	0.57
PCA2	-0.91	0.130	-1.17	-0.65
Standard deviation	2.23			
Cover-weighted FQI (all)				
Intercept	8.66	0.326	8.01	9.32

PCA1	0.51	0.139	0.23	0.79
PCA2	-1.01	0.199	-1.41	-0.61
Standard deviation	3.40			
Adjusted FQI (all)				
Intercept	29.67	0.532	28.61	30.73
PCA1	0.57	0.227	0.12	1.03
PCA2	-1.22	0.324	-1.86	-0.57
Standard deviation	5.56			
Cover-weighted Adjusted FQI (all)				
Intercept	30.29	0.752	28.79	31.78
PCA1	0.83	0.321	0.19	1.48
PCA2	-1.84	0.458	-2.75	-0.93
Standard deviation	7.85			
Species Count (exotic)				
Intercept	3.70	0.212	3.27	4.12
PCA1	-0.09	0.090	-0.27	0.10
PCA2	0.34	0.129	0.08	0.60
Standard deviation	2.21			
Exotic Species (%)				
Intercept	29.80	1.385	27.05	32.55
PCA1	-1.95	0.591	-3.13	-0.78
PCA2	5.30	0.844	3.62	6.97
Standard deviation	14.46			

Section II. Top four FQI metrics in relation to human disturbance factors

Table 2. Model selection results for the effects of human disturbance on count of native plant species.

Model	K	log(*L*)	AICc	ΔAICc	w_i
Grass Size	4	-270.0	217.34	0.00	0.141
Grass	3	-271.3	218.79	0.35	0.118
Grass Size Wetland	5	-269.2	218.91	0.69	0.099
Grass Wetland	4	-270.5	218.92	1.02	0.085

Table 3. Importance of variables for predicting count of native plant species.

Variable	$w_+(j)$
Grass	1.000
Size	0.432
Wetland	0.300
Distance	0.163
Prairie	0.162
Hydro	0.159
Bisect	0.158

Table 4. Parameter estimates, standard errors (SE) and 95% confidence limits (CL) from the best approximating and competing models for the effects of human disturbance on count of native plant species.

Parameter	Estimate	SE	Lower 95% CL	Upper 95% CL
Best model				
Intercept	4.59	0.764	3.08	6.11
Grass	5.04	0.780	3.50	6.59

Other	-	-	-	-
Size	-0.11	0.070	-0.25	0.03
Standard deviation	2.88	0.195	2.53	3.32
Competing model				
Intercept	4.19	0.729	2.74	5.63
Grass	5.06	0.789	3.50	6.62
Other	-	-	-	-
Standard deviation	2.91	0.197	2.56	3.35

Table 5. Model selection results for the effects of human disturbance on Mean C.

Model	K	log(*L*)	AICc	ΔAICc	w_i
Ag	3	-105.7	217.34	0.00	0.166
Ag Prairie	4	-105.2	218.79	1.44	0.081
Ag Hydro	4	-105.3	218.91	1.57	0.076
Ag Bisect	4	-105.3	218.92	1.58	0.076

Table 6. Importance of variables for predicting Mean C.

Variable	$w_+(j)$
Ag	1.000
Prairie	0.262
Hydro	0.243
Bisect	0.241
Area	0.191
Distance	0.175
Size	0.165

Table 7. Parameter estimates, standard errors (SE) and 95% confidence limits (CL) from the best approximating model for the effects of human disturbance on Mean C.

Parameter	Estimate	SE	Lower 95% CL	Upper 95% CL
Intercept	2.70	0.070	2.56	2.84
Ag	-0.79	0.145	-1.09	-0.50
Other	-	-	-	-
Standard deviation	0.64	0.043	0.56	0.74

Table 8. Model selection results for the effects of human disturbance on FQI_{all}.

Model	K	log(*L*)	AICc	ΔAICc	w_i
Grass	3	-248.2	502.65	0.00	0.138
Grass Bisect	4	-247.4	503.12	0.47	0.109
Grass Hydro	4	-247.7	503.88	1.22	0.075
Grass Wetland Area	5	-246.8	504.16	1.51	0.065
Grass Bisect Hydro	5	-246.8	504.27	1.61	0.061

Table 9. Importance of variables for predicting FQI_{all}.

Variable	$w_+(j)$
Grass	1.000
Bisect	0.326
Hydro	0.266
Wetland Area	0.217
Size	0.178
Prairie	0.173
Distance	0.167

Table 10. Parameter estimates, standard errors (SE) and 95% confidence limits (CL) from the best approximating model for effects of human disturbance on FQI_{all}.

Parameter	Estimate	SE	Lower 95% CL	Upper 95% CL
Intercept	3.64	0.590	2.47	4.81
Grass	4.29	0.639	3.02	5.56
Other	-	-	-	-
Standard deviation	2.36	0.160	2.07	2.72

Table 11. Model selection results for the effects of human disturbance on percent non-native species.

Model	K	log(*L*)	AICc	ΔAICc	w_i
Ag Prairie Hydro	5	-446.2	903.02	0.00	0.125
Ag Prairie	4	-447.5	903.30	0.28	0.108
Ag	3	-448.6	903.40	0.37	0.104
Ag Prairie Area	5	-446.6	903.85	0.83	0.083
Ag Hydro	4	-447.7	903.87	0.85	0.082
Ag Area	4	-448.2	904.84	1.81	0.050

Table 12. Importance of variables for predicting percent non-native species.

Variable	$w_+(j)$
Ag	1.000
Prairie	0.432
Hydro	0.336
Area	0.228
Size	0.155
Distance	0.148
Bisect	0.142

Table 13. Parameter estimates, standard errors (SE) and 95% confidence limits (CL) from the best approximating and competing models for the effects of human disturbance on percent non-native species.

Parameter	Estimate	SE	Lower 95% CL	Upper 95% CL
Best model				
Intercept	29.45	3.641	22.24	36.65
Ag	18.19	3.853	10.56	25.81
Other	-	-	-	-
Prairie	-0.10	0.056	-0.21	0.02
Hydro altered	5.40	3.408	-1.35	12.14
Intact				
Standard deviation	14.51	0.983	12.77	16.68
Competing model				
Intercept	29.90	3.672	22.63	37.16
Ag	18.27	3.897	10.56	25.98
Other	-	-	-	-
Prairie	-0.08	0.056	-0.20	0.03
Standard deviation	14.68	0.994	12.92	16.87
Competing model				
Intercept	24.92	1.618	21.71	28.12
Ag	21.29	3.378	14.60	27.97
Other	-	-	-	-
Standard deviation	14.83	1.004	13.05	17.04

Table 14. Parameter estimates, standard errors (SE) and 95% confidence limits (CL) for the effects of human disturbance index 1 (HDI-1) on the floristic quality metrics.

Parameter	Estimate	SE	Lower 95% CL	Upper 95% CL
Mean C (all)				
Intercept	1.20	0.924	-0.70	3.10
HDI-1	0.01	0.013	-0.02	0.04
Standard deviation	0.77	0.116	0.58	1.07
Species Count (native)				
Intercept	9.55	4.693	-0.07	19.17
HDI-1	-0.05	0.066	-0.19	0.10
Standard deviation	3.90	0.587	2.97	5.41
FQI (all)				
Intercept	5.29	3.550	-1.99	12.57
HDI-1	-0.01	0.050	-0.11	0.10
Standard deviation	2.95	0.444	2.25	4.09
Non-native (%)				
Intercept	54.91	26.292	1.04	108.78
HDI-1	-0.22	0.371	-0.98	0.55
Standard deviation	21.82	3.290	16.67	30.29

Table 15. Model selection results for the effects of human disturbance on Rare Species.

Model	K	log(*L*)	AICc	ΔAICc	w_i
Hydro Wetland Distance	5	-52.7	113.87	0.00	0.153
Hydro Distance Grass	5	-53.0	114.33	0.47	0.121
Hydro Distance Prairie	5	-53.2	114.85	0.98	0.094
Wetland Distance Grass	5	-53.4	115.21	1.34	0.078
Hydro Wetland Grass	5	-53.6	115.58	1.71	0.065

Table 16. Importance of variables for predicting Rare Species.

Variable	$w_+(j)$
Hydro	0.693
Wetland	0.628
Distance	0.618
Grass	0.383
Prairie	0.251
Size	0.088
Bisect	0.083

Table 17. Parameter estimates, standard errors (SE) and 95% confidence limits (CL) from the best approximating and competing models for the effects of human disturbance on Rare Species.

Parameter	Estimate	SE	Lower 95% CL	Upper 95% CL
Best model				
Intercept	-1.89	0.530	-3.00	-0.89
Hydro altered	1.39	0.548	0.32	2.50
Intact	-	-	-	-
Wetland	0.11	0.052	0.009	0.22
Road distance	-0.0011	0.0007	-0.0028	-0.0001
Competing model				
Intercept	-2.65	1.063	-5.58	-0.97
Hydro altered	1.60	0.535	0.56	2.69
Intact	-	-	-	-
Road distance	-0.0012	0.0007	-0.0028	-0.0002
Grass	1.79	1.084	0.05	4.75
Other	-	-	-	-

Section III. Top four FQI metrics in relation to season of sampling and human disturbance

Table 18. Model selection results for the effects of season and human disturbance on native species count.

Model	K	log(*L*)	AICc	ΔAICc	w_i
PCA2	4	-73.4	156.2	0.0	0.463
Season PCA2	5	-72.8	157.8	1.6	0.208
PCA1 PCA2	5	-73.2	158.7	2.5	0.133

Table 19. Model parameters from the best approximating model for the effects of season and human disturbance on native species count.

Parameter	Estimate	SE	Lower 95% CL	Upper 95% CL
Intercept	8.17	0.739	6.58	9.76
PCA2	-1.25	0.375	-2.05	-0.45
Playa ID	6.83	2.809	3.49	18.79
Residual error	2.09	0.740	1.16	4.85

Table 20. Model selection results for effects of season and human disturbance on Mean C.

Model	K	log(*L*)	AICc	ΔAICc	w_i
Season PCA2	5	-28.6	69.5	0.0	0.330
PCA2	4	-30.4	70.2	0.7	0.232
Season*PCA2	6	-27.6	70.5	1.0	0.200
Season PCA1 PCA2	6	-28.6	72.5	3.0	0.074
PCA1 PCA2	5	-30.3	72.9	3.4	0.060

Table 21. Model parameters from the best approximating and competing models for the effects of season and human disturbance on Mean C.

Parameter	Estimate	SE	Lower 95% CL	Upper 95% CL
Best model				
Intercept	2.34	0.171	1.97	2.71
Summer	-	-	-	-
Fall	0.30	0.150	-0.03	0.62
PCA2	-0.23	0.078	-0.40	-0.06
Playa ID	0.39	0.174	0.19	1.20
Residual error	0.18	0.064	0.09	0.42
Competing model				
Intercept	2.19	0.154	1.86	2.53

Table 22. Model selection results for the effects of season and human disturbance on FQI_{all}.

Model	K	log(*L*)	AICc	ΔAICc	w_i
PCA2	4	-67.8	145.0	0.0	0.505
Season PCA2	5	-67.3	146.9	1.9	0.195
PCA1 PCA2	5	-67.8	147.9	2.9	0.119
Season*PCA2	6	-66.5	148.4	3.4	0.092

Table 23. Model parameters from the best approximating model for the effects of season and human disturbance on FQI_{all}.

Parameter	Estimate	SE	Lower 95% CL	Upper 95% CL
Intercept	6.30	0.571	5.07	7.52

PCA2	-1.03	0.290	-1.65	-0.41
Playa ID	3.84	1.692	1.88	11.59
Residual error	1.74	0.616	0.96	4.04

Table 24. Model selection results for the effects of season and human disturbance on percent non-native species.

Model	K	log(*L*)	AICc	ΔAICc	w_i
Season PCA2	5	-128.8	269.8	0.0	0.470
PCA2	4	-131.1	271.7	1.9	0.182
Season*PCA2	6	-128.3	271.9	2.1	0.164
Season PCA1 PCA2	6	-128.6	272.6	2.8	0.116

Table 25. Model parameters from the best approximating and competing models for the effects of season and human disturbance on percent non-native species.

Parameter	Estimate	SE	Lower 95% CL	Upper 95% CL
Best model				
Intercept	39.32	3.889	30.97	47.66
Fall	-8.09	3.457	-15.47	-0.72
Summer	-	-	-	-
PCA2	6.98	1.768	3.21	10.75
Playa ID	127.37	64.201	57.81	474.03
Residual error	95.62	33.808	53.04	221.49
Competing model				
Intercept	35.27	35.269	27.79	42.75
PCA2	6.98	1.768	3.23	10.73
Playa ID	111.00	65.962	45.18	574.15
Residual error	128.37	45.385	71.20	297.34

Section IV. Top four FQI metrics in relation to pooling samples across seasons and human disturbance

Table 26. Model selection results for the effects of sample pooling and human disturbance on native species count.

Model	K	log(*L*)	AICc	ΔAICc	w_i
Pooled*PCA2	6	-69.7	154.6	0.0	0.468
Pooled PCA2	5	-71.6	155.4	0.8	0.314
Pooled PCA1 PCA2	6	-71.3	158.0	3.4	0.086

Table 27. Parameter estimates, standard errors (SE) and 95% confidence limits (CL) from the best approximating and competing models for the effects of sample pooling and human disturbance on native species count.

Parameter	Estimate	SE	Lower 95% CL	Upper 95% CL
Best model				
Intercept	11.30	0.922	9.32	13.29
Mean	-2.91	0.348	-3.66	-2.16
Pooled	-	-	-	-
PCA2	-1.61	0.468	-2.62	-0.60
Mean*PCA2	0.37	0.177	-0.02	0.75
Pool*PCA2	-	-	-	-

Playa ID	11.40	4.187	6.20	27.49
Residual error	0.87	0.309	0.48	2.03
Competing model				
Intercept	11.19	0.924	9.20	13.18
Mean	-2.69	0.372	-3.49	-1.89
Pooled	-	-	-	-
PCA2	-1.43	0.460	-2.41	-0.44
Playa ID	11.28	4.189	6.10	27.52
Residual error	1.107	0.392	0.61	2.57

Table 28. Model selection results for the effects of sample pooling and human disturbance on Mean C.

Model	K	log(*L*)	AICc	ΔAICc	w_i
PCA2	4	-16.3	42.0	0.0	0.414
Pooled PCA2	5	-15.5	43.2	1.2	0.227
PCA1 PCA2	5	-16.2	44.7	2.7	0.107
Pooled*PCA2	6	-14.9	45.2	3.2	0.084

Table 29. Parameter estimates, standard errors (SE) and 95% confidence limits (CL) from the best approximating and competing models for the effects of sample pooling and human disturbance on Mean C.

Parameter	Estimate	SE	Lower 95% CL	Upper 95% CL
Best model				
Intercept	2.14	0.147	1.82	2.46
PCA2	-0.21	0.074	-0.38	-0.05
Playa ID	0.29	0.110	0.15	0.73
Residual error	0.04	0.015	0.02	0.10
Competing model				
Intercept	2.09	0.151	1.76	2.42
Mean	0.09	0.069	-0.06	0.24
Pool	-	-	-	-
PCA2	-0.21	0.074	-0.38	-0.05
Playa ID	0.29	0.110	0.15	0.73
Residual error	0.04	0.013	0.02	0.09

Table 30. Model selection results for the effects of sample pooling and human disturbance on FQI_{all}.

Model	K	log(*L*)	AICc	ΔAICc	w_i
Pooled PCA2	5	-56.3	124.9	0.0	0.617
Pooled*PCA2	6	-56.2	127.8	2.9	0.145
Pooled PCA1 PCA2	6	-56.3	128.0	3.1	0.131

Table 31. Parameter estimates, standard errors (SE) and 95% confidence limits (CL) from the best approximating model for the effects of sample pooling and human disturbance on FQI_{all}.

Parameter	Estimate	SE	Lower 95% CL	Upper 95% CL
Intercept	7.08	0.624	5.73	8.42
Mean	-0.77	0.211	-1.22	-0.31
Pool	-	-	-	-

PCA2	-1.06	0.312	-1.73	-0.39
Playa ID	5.28	1.931	2.87	12.67
Residual error	0.36	0.127	0.19	0.83

Table 32. Model selection results for the effects of sample pooling and human disturbance on Exotic Species (%).

Model	K	log(*L*)	AICc	ΔAICc	w_i
PCA2	4	-119.3	248.1	0.0	0.441
Pooled PCA2	5	-118.5	249.2	1.1	0.254
PCA1 PCA2	5	-119.1	250.5	2.4	0.133
Pooled*PCA2	6	-118.0	251.4	3.3	0.085
Pooled PCA1 PCA2	6	-118.3	251.9	3.8	0.066

Table 33. Parameter estimates, standard errors (SE) and 95% confidence limits (CL) from the best approximating and competing models for the effects of sample pooling and human disturbance on Exotic Species (%).

Parameter	Estimate	SE	Lower 95% CL	Upper 95% CL
Best model				
Intercept	36.78	3.418	29.44	44.11
PCA2	6.52	1.735	2.84	10.21
Playa ID	153.45	59.871	80.87	395.81
Residual error	30.42	10.753	16.87	70.45
Competing model				
Intercept	38.00	3.541	30.40	45.60
Mean	-2.46	1.851	-6.40	1.49
Pool	-	-	-	-
PCA2	6.52	1.735	2.82	10.23
Playa ID	154.96	59.826	82.13	394.83
Residual error	27.40	9.688	15.19	63.47

Section V. Top four FQI metrics in relation to inclusion of off-plot plants detected on walk-around surveys and human disturbance

Table 34. Model selection results for the effects of off plot sampling, human disturbance and playa size on native species count.

Model	K	log(*L*)	AICc	ΔAICc	w_i
Plot PCA1 PCA2	6	-619.7	1251.8	0.0	0.436
Plot*PCA1 Plot*PCA2	8	-618.0	1252.6	0.8	0.292
Plot PCA1 PCA2 Size	7	-619.5	1253.5	1.7	0.186
Plot*PCA1 Plot*PCA2 Plot*Size	10	-617.2	1255.3	3.5	0.076

Table 35. Parameter estimates, standard errors (SE) and 95% confidence limits (CL) from the best approximating and competing models for the effects of off plot sampling, human disturbance and playa size on native species count.

Parameter	Estimate	SE	Lower 95% CL	Upper 95% CL
Best model				
Intercept	12.54	0.412	11.72	13.36
Plot	-4.04	0.465	-4.96	-3.11
Off	-	-	-	-
PCA1	0.57	0.145	0.28	0.86

PCA2	-0.73	0.207	-1.14	-0.31
Playa ID	6.71	1.885	4.14	12.73
Residual error	11.79	1.597	9.19	15.67
Competing model				
Intercept	12.54	0.410	11.72	13.36
Plot	-4.04	0.458	-4.95	-3.12
Off	-	-	-	-
PCA1	0.62	0.175	0.27	0.97
PCA2	-0.48	0.250	-0.98	0.02
Plot*PCA1	-0.09	0.195	-0.49	0.30
Off*PCA1	-	-	-	-
Plot*PCA2	-0.50	0.279	-1.06	0.06
Off*PCA2	-	-	-	-
Playa ID	6.89	1.875	4.30	12.77
Residual error	11.43	1.548	8.91	15.19

Table 36. Model selection results for the effects of off plot sampling, human disturbance and playa size on Mean C.

Model	**K**	**log(*L*)**	**AICc**	**ΔAICc**	***w_i***
PCA1 PCA2	5	-142.5	295.1	0.0	0.332
Plot PCA1 PCA2	6	-141.9	296.2	1.1	0.192
Plot*PCA1 Plot*PCA2	8	-139.8	296.2	1.1	0.192
PCA1 PCA2 Size	6	-142.4	297.2	2.1	0.116
Plot*PCA1 Plot*PCA2 Plot*Size	10	-138.3	297.6	2.5	0.095
Plot PCA1 PCA2 Size	7	-141.9	298.3	3.2	0.067

Table 37. Parameter estimates, standard errors (SE) and 95% confidence limits (CL) from the best approximating model for the effects of off plot sampling, human disturbance and playa size on Mean C.

Parameter	**Estimate**	**SE**	**Lower 95% CL**	**Upper 95% CL**
Intercept	2.50	0.054	2.39	2.61
PCA1	0.08	0.023	0.03	0.13
PCA2	-0.20	0.033	-0.27	-0.13
Playa ID	0.28	0.043	0.20	0.39
Residual error	0.07	0.010	0.05	0.10

Table 38. Model selection results for the effects of off plot sampling, human disturbance and playa size on FQI_{all}.

Model	K	log(*L*)	AICc	ΔAICc	*w_i*
Plot PCA1 PCA2	6	-475.0	962.4	0.0	0.580
Plot PCA1 PCA2 Size	7	-474.8	964.1	1.7	0.248
Plot*PCA1 Plot*PCA2	8	-474.2	965.1	2.7	0.150

Table 39. Parameter estimates, standard errors (SE) and 95% confidence limits (CL) from the best approximating model for the effects of off plot sampling, human disturbance and playa size on FQI_{all}.

Parameter	**Estimate**	**SE**	**Lower 95% CL**	**Upper 95% CL**
Intercept	8.61	0.233	8.14	9.08
Plot	-1.30	0.199	-1.70	-0.90
Off	-	-	-	-

PCA1	0.43	0.090	0.25	0.61
PCA2	-0.87	0.128	-1.13	-0.61
Playa ID	3.77	0.672	2.73	5.53
Residual error	2.16	0.292	1.68	2.87

Table 40. Model selection results for the effects of off plot sampling, human disturbance and playa size on percent non-native species.

Model	K	log(*L*)	AICc	ΔAICc	w_i
Plot PCA1 PCA2	6	-829.8	1672.0	0.0	0.372
Plot*PCA1 Plot*PCA2	8	-828.5	1673.7	1.7	0.159
PCA1 PCA2	5	-831.8	1673.9	1.9	0.144
Plot*PCA1 Plot*PCA2 Plot*Size	10	-826.4	1673.9	1.9	0.144
Plot PCA1 PCA2 Size	7	-829.8	1674.1	2.1	0.130

Table 41. Parameter estimates, standard errors (SE) and 95% confidence limits (CL) from the best approximating and competing models for the effects of off plot sampling, human disturbance and playa size on percent non-native species.

Parameter	Estimate	SE	Lower 95% CL	Upper 95% CL
Intercept	31.75	1.221	29.33	34.18
Plot	-1.95	0.971	-3.88	-0.027
Off	-	-	-	-
PCA1	-2.28	0.478	-3.23	-1.33
PCA2	5.39	0.682	4.03	6.75
Playa ID	111.13	18.854	81.77	159.78
Residual error	51.34	6.955	40.03	68.25

Table 42. Parameter estimates, standard errors (SE) and 95% confidence limits (CL) for the effects of playa restoration on the floristic quality metrics.

Parameter	Estimate	SE	Lower 95% CL	Upper 95% CL
Mean C				
Intercept	2.58	0.214	2.02	3.13
Restored	-0.13	0.233	-0.64	0.39
Control	-	-	-	-
Region	0.07	0.090	0.01	13.66
Residual error	0.23	0.091	0.12	0.60
Species Count (native)				
Intercept	9.63	1.049	6.93	12.33
Restored	0.44	1.051	-1.85	2.74
Control	-	-	-	-
Region	2.51	2.460	0.69	87.09
Residual error	4.65	1.846	2.42	12.25
FQI				
Intercept	8.05	0.879	5.78	10.31
Restored	-0.34	0.961	-2.44	1.75
Control	-	-	-	-
Region	1.21	1.538	0.26	346.93
Residual error	3.92	1.553	2.05	10.29
Non-native species (%)				
Intercept	21.59	3.899	11.56	31.61
Restored	6.48	4.675	-3.71	16.67
Control	-	-	-	-

Region	9.12	25.473	1.01	>999.99
Residual error	94.91	37.209	49.89	246.19

Section VI. Wetland-dependent bird abundance on wet playas as measured in fall 2006 in relation to human disturbance factors, floristic quality, and ecological integrity within the focus group of playas

Table 43. Model selection results for the effects of human disturbance, ecological integrity, human disturbance index 1 and floristic quality on shorebird abundance, in descending order of model fit. The best model for each type is flagged with an asterisk.

Model	Type	K	log(*L*)	AICc	ΔAICc	w_i
Hydro*	human disturbance factor	6	-336.5	685.46	0	0.231
Road distance	human disturbance factor	6	-337.2	686.87	1.41	0.114
PCA1	human disturbance factor	6	-337.3	687.04	1.58	0.105
Grass	human disturbance factor	6	-337.7	687.91	2.45	0.068
Road density	human disturbance factor	6	-338	688.49	3.03	0.051
Integrity*	Ecological Integrity	6	-338	688.5	3.04	0.051
Cropland	human disturbance factor	6	-338.1	688.79	3.33	0.044
HDI-1*	Human Disturbance Index	6	-338.2	688.84	3.38	0.043
Count native spp*	FQA index	6	-338.2	689	3.54	0.039
Road bisection	human disturbance factor	6	-338.2	689	3.54	0.039
Mean C (all)	FQA index	6	-338.3	689.09	3.63	0.038
Prairie (%)	human disturbance factor	6	-338.3	689.16	3.7	0.036
PCA2	human disturbance factor	6	-338.3	689.21	3.75	0.035
Percent non-native spp.	FQA index	6	-338.4	689.23	3.77	0.035
FQI_{all}	FQA index	6	-338.4	689.24	3.78	0.035
Unfragmented Prairie	human disturbance factor	6	-338.4	689.24	3.78	0.035

Table 44. Parameter estimates, standard errors (SE) and 95% confidence limits (CL) from the best approximating models for the effects of human disturbance, ecological integrity, human disturbance index 1 and floristic quality on shorebird abundance.

Parameter	Estimate	SE	Lower 95% CL	Upper 95% CL
Best human disturbance model				
Intercept	1.51	0.302	0.88	2.15
Date	-2.03	0.272	-2.57	-1.49
$Date^2$	-0.74	0.173	-1.09	-0.39
Hydro altered	-1.40	0.657	-2.70	-0.09
Intact	-	-	-	-
Playa ID	0.65	0.445	0.15	1.97
Dispersion	2.86	0.531	2.02	4.06
Ecological Integrity model				
Intercept	0.11	1.369	-2.74	2.96
Date	-2.07	0.277	-2.62	-1.51
$Date^2$	-0.77	0.176	-1.12	-0.42
Integrity	0.41	0.477	-0.54	1.36
Playa ID	0.981	0.544	0.33	2.60
Dispersion	2.79	0.513	1.97	3.98
HDI-1 model				
Intercept	1.94	1.663	-1.53	5.42

Date	-2.06	0.278	-2.61	-1.51
$Date^2$	-0.75	0.177	-1.11	-0.40
HDI-1	-0.01	0.024	-0.06	0.04
Playa ID	1.03	0.569	0.35	2.73
Dispersion	2.79	0.513	1.97	3.98
Best floristic quality model				
Intercept	1.52	0.733	-0.01	3.05
Date	-2.05	0.277	-2.61	-1.50
$Date^2$	-0.75	0.177	-1.10	-0.39
Mean C	-0.13	0.336	-0.80	0.54
Playa ID	0.99	0.560	0.33	2.66
Dispersion	2.79	0.516	1.97	3.99

Table 45. Model selection results for the effects of human disturbance, ecological integrity, human disturbance index 1 and floristic quality on waterfowl abundance, in descending order of model fit. The best model for each type is flagged with an asterisk.

Model	Type	K	log(*L*)	AICc	ΔAICc	w_i
Mean C*	FQA index	6	-529.9	1072.32	0	0.343
Percent non-native spp.	FQA index	6	-530.1	1072.78	0.46	0.272
FQI_{all}	FQA index	6	-530.7	1073.93	1.61	0.153
HDI-1*	Human Disturbance Index	6	-531.9	1076.2	3.91	0.049
Count native spp	FQA index	6	-531.9	1076.3	3.98	0.047
Unfragmented Prairie*	human disturbance factor	6	-532.6	1077.72	5.4	0.023
Road bisection	human disturbance factor	6	-532.7	1077.98	5.66	0.02
Cropland	human disturbance factor	6	-532.8	1078.09	5.77	0.019
Hydro	human disturbance factor	6	-532.9	1078.31	5.99	0.017
Prairie (%)	human disturbance factor	6	-533.5	1079.43	7.11	0.01
Integrity*	Ecological Integrity	6	-533.5	1079.48	7.16	0.01
Road distance	human disturbance factor	6	-533.6	1079.76	7.44	0.008
PCA2	human disturbance factor	6	-533.7	1079.96	7.64	0.008
PCA1	human disturbance factor	6	-533.7	1080.02	7.7	0.007
Road density	human disturbance factor	6	-533.8	1080.06	7.74	0.007
Grass	human disturbance factor	6	-533.8	1080.08	7.76	0.007

Table 46. Parameter estimates, standard errors (SE) and 95% confidence limits (CL) from the best approximating models for the effects of human disturbance, ecological integrity, human disturbance index 1 and floristic quality on waterfowl abundance.

Parameter	Estimate	SE	Lower 95% CL	Upper 95% CL
Mean C				
Intercept	4.85	1.048	2.66	7.05
Date	-1.05	0.284	-1.62	-0.49
Size	0.21	0.077	0.05	0.37
Mean C	-1.50	0.513	-2.52	-0.48
Playa ID	2.04	0.976	0.83	4.90
Dispersion	5.77	0.857	4.37	7.73
Non-native species (%)				
Intercept	-0.29	1.010	-2.41	1.83
Date	-1.08	0.285	-1.65	-0.51
Size	0.22	0.078	0.06	0.38
Non-native	0.05	0.018	0.01	0.09
Playa ID	2.01	1.011	0.77	4.95

Dispersion	5.81	0.869	4.40	7.78
FQI				
Intercept	3.93	0.764	2.32	5.53
Date	-0.95	0.298	-1.54	-0.35
Size	0.17	0.066	0.03	0.31
FQI	-0.36	0.118	-0.60	-0.13
Playa ID	1.46	1.103	0.37	4.27
Dispersion	6.06	0.980	4.58	8.09
Species count (native)				
Intercept	4.50	0.860	2.69	6.30
Date	-0.81	0.306	-1.42	-0.20
Size	0.11	0.054	0.00	0.22
Native species	-0.28	0.085	-0.46	-0.11
Playa ID	0.48	0.859	0.00	3.12
Dispersion	6.83	1.152	5.25	8.99
HDI-1				
Intercept	6.81	2.349	1.89	11.73
Date	-1.07	0.294	-1.65	-0.48
Size	0.17	0.079	0.00	0.33
HDI1	-0.07	0.034	-0.14	0.00
Playa ID	2.48	1.165	1.05	5.90
Dispersion	5.82	0.872	4.39	7.80
Human disturbance factor				
Intercept	2.95	0.750	1.37	4.53
Date	-0.99	0.298	-1.58	-0.39
Size	0.15	0.079	-0.01	0.31
Unfragmented	-0.04	0.023	-0.09	0.01
Playa ID	2.52	1.278	0.99	6.11
Dispersion	5.89	0.900	4.44	7.90
Ecological integrity				
Intercept	0.17	2.528	-5.11	5.45
Date	-1.06	0.297	-1.65	-0.47
Size	0.09	0.111	-0.14	0.31
Integrity	0.80	0.999	-1.18	2.78
Playa ID	3.01	1.373	1.28	6.99
Dispersion	5.83	0.879	4.40	7.83

Table 47. Model selection results for the effects of human disturbance, ecological integrity, human disturbance index 1 and floristic quality on the count of avian species, in descending order of model fit. The best model for each type is flagged with an asterisk.

Model	Type	K	log(*L*)	AICc	ΔAICc	w_i
Count native spp.*	FQA index	7	-388.7	792.17	0.00	0.399
FQI_{all}	FQA index	7	-389.3	793.27	1.10	0.230
Mean C	FQA index	7	-390.6	796.00	3.83	0.059
Grassland*	Human disturbance factor	7	-390.8	796.28	4.11	0.051
Percent non-native spp.	FQA index	7	-390.8	796.41	4.24	0.048
Cropland	Human disturbance factor	7	-391.1	797.01	4.84	0.035
Road distance	Human disturbance factor	7	-391.4	797.50	5.33	0.028
PCA2	Human disturbance factor	7	-391.4	797.60	5.43	0.026
Unfragmented Prairie	Human disturbance factor	7	-391.5	797.64	5.47	0.026
HDI1*	Human disturbance index	7	-391.7	798.13	5.96	0.020
Prairie (%)	Human disturbance factor	7	-391.9	798.49	6.32	0.017
PCA1	Human disturbance factor	7	-391.9	798.54	6.37	0.017

Road bisection	Human disturbance factor	7	-392.1	798.97	6.80	0.013
Integrity*	Ecological Integrity	7	-392.2	799.08	6.91	0.013
Hydro	Human disturbance factor	7	-392.5	799.61	7.44	0.010
Road density	Human disturbance factor	7	-392.6	799.91	7.74	0.008

Table 48. Parameter estimates, standard errors (SE) and 95% confidence limits (CL) from the best approximating models for the effects of human disturbance, ecological integrity, human disturbance index 1 and floristic quality on the count of avian species.

Parameter	Estimate	SE	Lower 95% CL	Upper 95% CL
Species count (native)				
Intercept	1.95	0.154	1.62	2.27
Date	-0.33	0.054	-0.44	-0.22
$Date^2$	-0.25	0.046	-0.34	-0.15
Area	0.07	0.042	-0.01	0.16
Species count	-0.05	0.016	-0.09	-0.01
Playa ID	0.04	0.026	0.00	0.12
Dispersion	0.12	0.040	0.05	0.22
FQI				
Intercept	1.95	0.164	1.60	2.30
Date	-0.33	0.054	-0.44	-0.22
$Date^2$	-0.24	0.046	-0.34	-0.15
Area	0.07	0.044	-0.02	0.16
FQI	-0.06	0.022	-0.11	-0.01
Playa ID	0.04	0.027	0.00	0.13
Dispersion	0.12	0.039	0.05	0.21
Mean C				
Intercept	1.99	0.219	1.53	2.45
Date	-0.34	0.053	-0.45	-0.23
$Date^2$	-0.24	0.046	-0.33	-0.14
Area	0.08	0.047	-0.02	0.17
FQI	-0.19	0.087	-0.37	-0.01
Playa ID	0.06	0.030	0.01	0.15
Dispersion	0.12	0.039	0.05	0.21
Non-native species (%)				
Intercept	1.35	0.160	1.01	1.69
Date	-0.34	0.053	-0.45	-0.23
$Date^2$	-0.24	0.046	-0.33	-0.14
Area	0.07	0.047	-0.02	0.17
Non-native species	0.01	0.003	0.00	0.02
Playa ID	0.06	0.031	0.01	0.16
Dispersion	0.12	0.039	0.05	0.21
Grassland				
Intercept	1.75	0.138	1.45	2.04
Date	-0.33	0.054	-0.44	-0.22
$Date^2$	-0.24	0.046	-0.34	-0.15
Area	0.11	0.047	0.01	0.20
Grassland	-0.30	0.144	-0.59	-0.01
Other	-	-	-	-
Playa ID	0.06	0.031	0.01	0.16
Dispersion	0.12	0.039	0.05	0.21
HDI-1				
Intercept	2.18	0.411	1.31	3.04
Date	-0.34	0.054	-0.45	-0.22
$Date^2$	-0.25	0.046	-0.34	-0.15

Area	0.11	0.049	0.01	0.21
HDI-1	-0.01	0.006	-0.03	0.01
Playa ID	0.06	0.033	0.01	0.17
Dispersion	0.12	0.039	0.05	0.21
Ecological integrity				
Intercept	1.20	0.365	0.43	1.96
Date	-0.34	0.054	-0.45	-0.22
$Date^2$	-0.25	0.046	-0.34	-0.15
Area	0.09	0.049	-0.01	0.19
Integrity	0.14	0.124	-0.11	0.39
Playa ID	0.07	0.035	0.02	0.18
Dispersion	0.12	0.039	0.05	0.22

Section VII. Wetland-dependent bird abundance on wet playas as measured 2004-2007 in relation to ecological and human disturbance factors

Table 49. Model selection statistics for shorebirds

Model	K	Log(L)	AICc	ΔAICc	w_i
log_e*Size Hydro Area	10	-1223.12	2466.60	0.00	0.438
log_e*Size Hydro Area Wetland	11	-1222.50	2467.43	0.83	0.289

Table 50. Model parameters for the best approximating model for shorebirds

Effect	Parameter	Estimate	SE	Lower 95% CL	Upper 95% CL
Intercept		-0.88	2.459	-5.724	3.967
Season	Fall	1.50	2.466	-3.351	6.346
Season	Spring	-	-	-	-
Date		-2.22	0.286	-2.780	-1.655
$Date^2$		1.49	0.714	0.089	2.896
$Date^2$*Season	Fall	-2.88	0.760	-4.374	-1.386
$Date^2$*Season	Spring	-	-	-	-
log_e*Size		0.59	0.163	0.271	0.912
Hydro	Altered	-0.52	0.369	-1.248	0.204
Hydro	Not Altered	-	-	-	-
Playa Area-Landscape		0.31	0.129	0.059	0.565
Playa ID [a]		1.00	0.385	0.543	1.709
Scale [b]		4.38	0.461	3.668	5.251

[a] Covariance parameter for the random effect of Playa ID.
[b] Dispersion parameter for the negative binomial distribution.

Table 51. Model selection statistics for waterfowl

Model	K	Log(L)	AICc	ΔAICc	w_i
Size Area	8	-1528.00	3072.24	0.00	0.569
Size Area Wetland	9	-1527.84	3073.97	1.73	0.240

Table 52. Model parameters for the best approximating model for waterfowl

Effect	Estimate	SE	Lower 95% CL	Upper 95% CL
Intercept	0.61	0.593	-0.559	1.779
Date	0.05	0.230	-0.406	0.501
$Date^2$	-0.81	0.183	-1.166	-0.447
Playa Size	0.21	0.068	0.073	0.341
Playa Area-Landscape	0.55	0.233	0.091	1.007
Playa ID [a]	5.13	1.524	3.339	7.905
Scale [b]	7.28	0.816	6.088	8.747

[a] Covariance parameter for the random effect of Playa ID.
[b] Dispersion parameter for the negative binomial distribution.

Table 53. Model selection statistics for the count of bird species

Model	K	Log(L)	AICc	ΔAICc	w_i
Size Hydro Area	12	-1446.52	2917.55	0.00	0.412
Size Hydro Area Road	13	-1446.26	2919.14	1.59	0.186
Size Hydro Area Wetland	13	-1446.51	2919.64	2.09	0.145
Size Hydro Area Road Wetland	14	-1446.26	2921.23	3.68	0.065

Table 54. Model parameters for best approximating model for the count of bird species

Effect	Parameter	Estimate	SE	Lower 95% CL	Upper 95% CL
Intercept					
Year	2004	-0.31	0.809	-1.91	1.29
Year	2005	1.17	0.471	0.24	2.10
Year	2006	1.18	0.449	0.29	2.07
Year	2007	1.44	0.426	0.59	2.28
Season	Fall	-	-	-	-
Season	Spring	-0.19	0.690	-1.56	1.17
Date		-	-	-	-
$Date^2$		-0.33	0.082	-0.50	-0.17
$Date^2$*year	2004	0.60	0.325	-0.04	1.25
$Date^2$*year	2005	-0.46	0.267	-0.99	0.07
$Date^2$*year	2006	-0.38	0.268	-0.91	0.15
$Date^2$*year	2007	-0.70	0.272	-1.24	-0.16
$Season^2$*year	Fall	-	-	-	-
$Season^2$*year	Spring	-0.44	0.214	-0.87	-0.01
Playa Size		-	-	-	-
Hydro	Altered	0.05	0.015	0.01	0.08
Hydro	Not Altered	-	-	-	-
Area	Ag	0.28	0.143	-0.01	0.56
Playa ID [a]		0.29	0.071	0.19	0.43
Scale [b]		0.29	0.045	0.21	0.39

[a] Covariance parameter for the random effect of Playa ID.
[b] Dispersion parameter for the negative binomial distribution.

APPENDIX C

BIRD SPECIES DOCUMENTED ON PLAYAS THROUGHOUT THE STUDY 2004-2007

Common Name	***Scientific Name***	CO Sp. of Concern	Guild	Number Playas Occupied	Percent Playas Occupied	Number Observed
American Avocet	*Recurvirostra americana*		Shorebird	37	3.41	250
American Coot	*Fulica americana*		Waterbird	26	2.39	654
American Crow	*Corvus brachyrhynchos*		Landbird	4	0.37	8
American Golden-Plover	*Pluvialis dominica*		Shorebird	2	0.18	2
American Goldfinch	*Carduelis tristis*		Landbird	6	0.55	8
American Kestrel	*Falco sparverius*		Landbird	15	1.38	16
American Pipit	*Anthus rubescens*		Landbird	40	3.68	257
American Robin	*Turdus migratorius*		Landbird	4	0.37	9
American Tree Sparrow	*Spizella arborea*		Landbird	1	0.09	1
American White Pelican	*Pelecanus erythrorhynchos*	Tier 2	Waterbird	3	0.28	93
American Wigeon	*Anas americana*		Waterfowl	48	4.42	1135
Baird's Sandpiper	*Calidris bairdii*		Shorebird	45	4.14	328
Baird's Sparrow	*Ammodramus bairdii*		Landbird	1	0.09	3
Bald Eagle	*Haliaeetus leucocephalus*	Tier 1, ST	Other Wetland Dep.	2	0.18	2
Barn Swallow	*Hirundo rustica*		Landbird	36	3.31	178
Black Tern	*Chlidonias niger*		Waterbird	1	0.09	1
Black Vulture	*Coragyps atratus*		Landbird	1	0.09	1
Black-bellied Plover	*Pluvialis squatarola*		Shorebird	4	0.37	9
Black-billed Magpie	*Pica hudsonia*		Landbird	5	0.46	6
Black-necked Stilt	*Himantopus mexicanus*		Shorebird	2	0.18	7
Blue-winged Teal	*Anas discors*		Waterfowl	54	4.97	1422
Brewer's Blackbird	*Euphagus cyanocephalus*		Landbird	5	0.46	157
Brewer's Sparrow	*Spizella breweri*	Tier 1	Landbird	2	0.18	5
Brown-headed Cowbird	*Molothrus ater*		Landbird	11	1.01	93
Bufflehead	*Bucephala albeola*		Waterfowl	3	0.28	15
Bullock's Oriole	*Icterus bullockii*		Landbird	1	0.09	1
Burrowing Owl	*Athene cunicularia*	Tier 1, ST	Landbird	21	1.93	43
Cackling Goose	*Branta hutchinsii*		Waterfowl	4	0.37	250
Canada Goose	*Branta canadensis*		Waterfowl	8	0.74	1686

Common Name	***Scientific Name***	**CO Sp. of Concern**	**Guild**	**Number Playas Occupied**	**Percent Playas Occupied**	**Number Observed**
Canvasback	*Aythya valisineria*		Waterfowl	2	0.18	2
Cassin's Kingbird	*Tyrannus vociferans*		Landbird	1	0.09	1
Cassin's Sparrow	*Aimophila cassinii*	Tier 1	Landbird	11	1.01	13
Chestnut-collared Longspur	*Calcarius ornatus*	Tier 2	Landbird	115	10.59	2098
Chihuahuan Raven	*Corvus cryptoleucus*		Landbird	6	0.55	9
Chimney Swift	*Chaetura pelagica*		Landbird	1	0.09	1
Chipping Sparrow	*Spizella passerina*		Landbird	6	0.55	15
Cinnamon Teal	*Anas cyanoptera*		Waterfowl	6	0.55	80
Clay-colored Sparrow	*Spizella pallida*		Landbird	4	0.37	7
Cliff Swallow	*Petrochelidon pyrrhonota*		Landbird	5	0.46	15
Common Grackle	*Quiscalus quiscula*		Other Wetland Dep.	23	2.12	59
Common Nighthawk	*Chordeiles minor*		Landbird	6	0.55	7
Common Raven	*Corvus corax*		Landbird	5	0.46	6
Dark-eyed Junco	*Junco hyemalis*		Landbird	2	0.18	3
Eared Grebe	*Podiceps nigricollis*	Tier 2	Waterbird	8	0.74	25
Eastern Bluebird	*Sialia sialis*		Landbird	1	0.09	2
Eastern Kingbird	*Tyrannus tyrannus*		Landbird	7	0.64	16
Eastern Meadowlark	*Sturnella magna*		Landbird	1	0.09	1
Eurasian Collared-Dove	*Streptopelia decaocto*		Landbird	3	0.28	24
European Starling	*Sturnus vulgaris*		Landbird	25	2.3	194
Ferruginous Hawk	*Buteo regalis*	Tier 1, SC	Landbird	14	1.29	15
Franklin's Gull	*Larus pipixcan*		Waterbird	1	0.09	4
Gadwall	*Anas strepera*		Waterfowl	33	3.04	1220
Golden Eagle	*Aquila chrysaetos*	Tier 1	Landbird	1	0.09	1
Grasshopper Sparrow	*Ammodramus savannarum*		Landbird	10	0.92	12
Great Blue Heron	*Ardea herodias*		Waterbird	23	2.12	38
Great Horned Owl	*Bubo virginianus*		Landbird	2	0.18	2
Greater White-fronted Goose	*Anser albifrons*		Waterfowl	3	0.28	22
Greater Yellowlegs	*Tringa melanoleuca*		Shorebird	38	3.5	140
Great-tailed Grackle	*Quiscalus mexicanus*		Landbird	2	0.18	3
Green-winged Teal	*Anas crecca*		Waterfowl	69	6.35	7374

Common Name	***Scientific Name***	**CO Sp. of Concern**	**Guild**	**Number Playas Occupied**	**Percent Playas Occupied**	**Number Observed**
Hooded Merganser	*Lophodytes cucullatus*		Waterfowl	3	0.28	4
Horned Lark	*Eremophila alpestris*		Landbird	445	40.98	11473
House Finch	*Carpodacus mexicanus*		Landbird	5	0.46	8
House Sparrow	*Passer domesticus*		Landbird	6	0.55	19
Indigo Bunting	*Passerina cyanea*		Landbird	1	0.09	1
Killdeer	*Charadrius vociferus*		Shorebird	217	19.98	2453
Lapland Longspur	*Calcarius lapponicus*		Landbird	51	4.7	789
Lark Bunting	*Calamospiza melanocorys*	Tier 1	Landbird	122	11.23	561
Lark Sparrow	*Chondestes grammacus*		Landbird	14	1.29	32
Least Sandpiper	*Calidris minutilla*		Shorebird	21	1.93	123
Lesser Nighthawk	*Chordeiles acutipennis*		Landbird	2	0.18	3
Lesser Scaup	*Aythya affinis*	Tier 2	Waterfowl	4	0.37	23
Lesser Yellowlegs	*Tringa flavipes*		Shorebird	37	3.41	351
Light Goose (Ross's and Snow Goose)			Waterfowl	8	0.74	3049
Lincoln's Sparrow	*Melospiza lincolnii*		Landbird	1	0.09	1
Loggerhead Shrike	*Lanius ludovicianus*	Tier 1	Landbird	6	0.55	9
Long-billed Curlew	*Numenius americanus*	Tier 1, SC	Shorebird	9	0.83	30
Long-billed Dowitcher	*Limnodromus scolopaceus*		Shorebird	33	3.04	699
Mallard	*Anas platyrhynchos*		Waterfowl	86	7.92	4530
Marsh Wren	*Cistothorus palustris*		Other Wetland Dep.	1	0.09	2
McCown's Longspur	*Calcarius mccownii*	Tier 1	Landbird	103	9.48	2028
Merlin	*Falco columbarius*		Landbird	11	1.01	11
Mottled Duck	*Anas fulvigula*		Waterfowl	2	0.18	3
Mountain Bluebird	*Sialia currucoides*		Landbird	8	0.74	41
Mountain Plover	*Charadrius montanus*	Tier 1, SC	Shorebird	5	0.46	13
Mourning Dove	*Zenaida macroura*		Landbird	90	8.29	368
Northern Bobwhite	*Colinus virginianus*		Landbird	1	0.09	1
Northern Flicker	*Colaptes auratus*		Landbird	2	0.18	3
Northern Harrier	*Circus cyaneus*	Tier 2	Landbird	89	8.2	138
Northern Mockingbird	*Mimus polyglottos*		Landbird	4	0.37	4

Common Name	***Scientific Name***	**CO Sp. of Concern**	**Guild**	**Number Playas Occupied**	**Percent Playas Occupied**	**Number Observed**
Northern Pintail	*Anas acuta*	Tier 2	Waterfowl	45	4.14	2353
Northern Rough-winged Swallow	*Stelgidopteryx serripennis*		Landbird	2	0.18	3
Northern Shoveler	*Anas clypeata*		Waterfowl	59	5.43	1949
Northern Shrike	*Lanius excubitor*		Landbird	2	0.18	2
Orchard Oriole	*Icterus spurius*		Landbird	1	0.09	4
Pectoral Sandpiper	*Calidris melanotos*		Shorebird	25	2.3	106
Peregrine Falcon	*Falco peregrinus*	Tier 1, SC	Landbird	1	0.09	1
Pied-billed Grebe	*Podilymbus podiceps*		Waterbird	19	1.75	56
Pine Siskin	*Carduelis pinus*		Landbird	1	0.09	2
Prairie Falcon	*Falco mexicanus*	Tier 1	Landbird	16	1.47	23
Redhead	*Aythya americana*		Waterfowl	12	1.1	91
Red-necked Phalarope	*Phalaropus lobatus*		Shorebird	2	0.18	2
Red-tailed Hawk	*Buteo jamaicensis*		Landbird	14	1.29	15
Red-winged Blackbird	*Agelaius phoeniceus*		Other Wetland Dep.	69	6.35	888
Ring-billed Gull	*Larus delawarensis*		Waterbird	2	0.18	3
Ring-necked Duck	*Aythya collaris*		Waterfowl	6	0.55	20
Ring-necked Pheasant	*Phasianus colchicus*		Landbird	4	0.37	5
Rock Pigeon	*Columba livia*		Landbird	5	0.46	50
Ross's Goose	*Chen rossii*		Waterfowl	4	0.37	14
Rough-legged Hawk	*Buteo lagopus*		Landbird	1	0.09	1
Ruddy Duck	*Oxyura jamaicensis*		Waterfowl	10	0.92	138
Ruff	*Philomachus pugnax*		Shorebird	1	0.09	1
Sage Thrasher	*Oreoscoptes montanus*		Landbird	1	0.09	1
Sanderling	*Calidris alba*		Shorebird	1	0.09	2
Sandhill Crane	*Grus canadensis*	Tier 1, SC	Waterbird	42	3.87	6791
Savannah Sparrow	*Passerculus sandwichensis*		Landbird	28	2.58	84
Say's Phoebe	*Sayornis saya*		Landbird	5	0.46	5
Scaled Quail	*Callipepla squamata*	Tier 1	Landbird	2	0.18	2
Semipalmated Plover	*Charadrius semipalmatus*		Shorebird	3	0.28	5
Semipalmated Sandpiper	*Calidris pusilla*		Shorebird	1	0.09	1

Common Name	*Scientific Name*	CO Sp. of Concern	Guild	Number Playas Occupied	Percent Playas Occupied	Number Observed
Sharp-shinned Hawk	*Accipiter striatus*		Landbird	1	0.09	1
Snow Goose	*Chen caerulescens*		Waterfowl	7	0.64	123
Solitary Sandpiper	*Tringa solitaria*		Shorebird	6	0.55	8
Song Sparrow	*Melospiza melodia*		Other Wetland Dep.	1	0.09	2
Sora	*Porzana carolina*		Waterbird	1	0.09	1
Spotted Sandpiper	*Actitis macularia*		Shorebird	8	0.74	8
Sprague's Pipit	*Anthus spragueii*		Landbird	3	0.28	4
Stilt Sandpiper	*Calidris himantopus*		Shorebird	4	0.37	5
Swainson's Hawk	*Buteo swainsoni*	Tier 1	Landbird	41	3.78	79
Townsend's Solitaire	*Myadestes townsendi*		Landbird	1	0.09	1
Tree Swallow	*Tachycineta bicolor*		Landbird	6	0.55	15
Turkey Vulture	*Cathartes aura*		Landbird	11	1.01	16
Upland Sandpiper	*Bartramia longicauda*	Tier 1	Shorebird	4	0.37	10
Vesper Sparrow	*Pooecetes gramineus*	Tier 2	Landbird	34	3.13	127
Western Grebe	*Aechmophorus occidentalis*	Tier 2	Waterbird	2	0.18	2
Western Kingbird	*Tyrannus verticalis*		Landbird	45	4.14	72
Western Meadowlark	*Sturnella neglecta*		Landbird	253	23.3	912
Western Sandpiper	*Calidris mauri*		Shorebird	1	0.09	1
White-crowned Sparrow	*Zonotrichia leucophrys*		Landbird	6	0.55	10
White-faced Ibis	*Plegadis chihi*	Tier 2	Waterbird	11	1.01	23
White-rumped Sandpiper	*Calidris fuscicollis*		Shorebird	1	0.09	1
Wild Turkey	*Meleagris gallopavo*		Landbird	2	0.18	3
Willet	*Tringa semipalmata*		Shorebird	5	0.46	10
Wilson's Phalarope	*Phalaropus tricolor*	Tier 2	Shorebird	15	1.38	212
Wilson's Snipe	*Gallinago delicata*		Shorebird	22	2.03	71
Wood Duck	*Aix sponsa*		Waterfowl	2	0.18	3
Yellow Warbler	*Dendroica petechia*		Landbird	1	0.09	1
Yellow-headed Blackbird	*Xanthocephalus xanthocephalus*		Other Wetland Dep.	6	0.55	167
Yellow-rumped Warbler	*Dendroica coronata*		Landbird	2	0.18	2