# UNITED STATES FISH AND WILDLIFE SERVICE
# MAXWELL NATIONAL WILDLIFE REFUGE
# VEGETATION MAP
# MAXWELL, NEW MEXICO

**Final Report**

Submitted to:

U.S. Fish & Wildlife Service
Region 2 Office
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## Introduction

A map of the current vegetation distribution of Maxwell National Wildlife Refuge (MNWR) was produced by Earth Data Analysis Center (EDAC) in association with the New Mexico Natural Heritage Program (NMNHP) at the University of New Mexico (UNM). The map was developed using computer analysis of high-resolution digital ortho-photography and Landsat Thematic Mapper (TM) satellite imagery.

Ground survey vegetation data were gathered in late summer and fall of 1999 and these data provided the basis for the development of map units appropriate for use at a 1:24,000 scale. The mapping methodology is described below along with brief descriptions of each map unit provided in Appendix A. The map is available in both digital and hard-copy format. The vegetation map provides a baseline on the spatial distribution of native vegetation communities and areas of potential concern where non-natives have increased. The mapped information can be used to assist in the principal objectives of the refuge, which are to: (1) provide feeding and resting area for wintering migratory waterfowl, (2) provide habitat for other migratory birds and non-migratory wildlife, and (3) allow for fish and wildlife oriented recreation (Bartolino et al. 1996).

## Study Area

### *Location & Landscape*

The Maxwell National Wildlife Refuge is located just outside of Maxwell, New Mexico, approximately 14 km (23 miles) south of Raton in Colfax County. The Canadian River lies to the east of the refuge and the Vermejo River is to the south. The refuge is managed by the U.S. Fish and Wildlife Service and was established by the Migratory Bird Conservation Commission on August 24, 1965. The refuge encompasses 6,000 ha (2,792 acres) of fee title land, 1,082 ha (438 acres) of leased land, and 2,241 ha (907 acres) that are managed under joint lease with the Bureau of Reclamation (BOR) and the Vermejo Conservancy District (Bartolino et al. 1996, Mobley 1990). The impoundments, Lakes 12, 13, and 14 are joint lease areas. The playas are filled by natural runoff from surrounding lands (Mobley 1990). State law specifies that these impoundments must be used for cropland irrigation, thereby precluding use for wetland development.

The refuge lies within the Raton Section of the Great Plains Province (Hawley 1986) that is largely known for short-grass prairies and deeply dissected canyons. The terrain within the refuge is an open, gently rolling plain with a mosaic of grasslands dotted by natural and modified playas and wetlands having an average elevation of 1,830 m. (6,000 ft.).

Soils within the refuge are deep to moderately well-drained soils derived from Cretaceous shale and deposited by alluvial-eolian processes. The Vermejo Series of soils lie within the more lowland areas while the Swastika Series are relatively upland in comparison. The silty clay loam soils of the Vermejo Series are easily erodible and often are high in salts. The Swastika Series are silty loams to silty clay loams are also high in salts, but slightly less erodible (Anderson et al. 1986).

This region receives an average annual precipitation of 400 mm (16 in), most of it from convective thundershowers during the summer (Bartolino 1996). Snow can occur from November to May with usually not more than 100 mm. (4 in.) of accumulation at any time. Snowmelt from the Sangre de Cristo Mountains, located to the northwest, provide most of the surface water for the refuge. Summer thunderstorms also contribute large volumes of runoff. Temperatures can range from as low as -23°C (-9°F) in the winter to as high as 33°C (92°F) in the summer.

Irrigation in this area has a long history beginning in 1888 (Bartolino et al. 1996). The refuge lies within the center of the Vermejo Project Area, which can provide water for about 2,997 ha. (7,400 acres) of irrigable land (Bartolino et al. 1996) with the Lake 13 being the largest impoundment on the refuge. Surface waters are diverted through a series of canals from the Vermejo diversion dam. Lakes 12, 13, and 14 provide irrigation water, under the jurisdiction of the Vermejo Conservancy District, to adjacent croplands (Mobley 1990). Additionally, several playa lakes depressions have been deepened to provide continuous supplies of water for wildlife.

## Materials and Methods

### *Data Sources*

#### Satellite Imagery

Landsat Thematic Mapper (TM) satellite imagery was one of the data sets used for mapping the natural vegetation cover for the study area. The TM scene used for the project was acquired over the area on 3 September, 1993, by the Landsat 5 platform. It was imported into ERDAS Imagine (Version 8.3) where all raster processing and analyses were accomplished. The TM scene was of good quality with no clouds, cirrus or scan line defects.

The satellite imagery, with its stable sensor platform, is relatively easy to geometrically correct to the known coordinate system of a base map. The height of the sensor above the earth (705 km. for Landsat) negates most parallax problems commonly found in aerial photography (parallax is the apparent change in positions of stationary objects affected by the viewing angle – creating greater distortions at greater distances from the center of an aerial photo). Also, satellite data do not have the radiometric problems of air photos, such as hot spots, dark edges, or different contrasts for each photo due to sun-angle changes during the overflight.

The quantitative spectral and spatial aspects of TM imagery add particularly important dimensions to the mapping process. Multi-spectral satellite imagery records the variable reflection of natural radiation of surface materials such as rocks, plants, soils, and water, differently. Variations in plant reflection and absorption due to biochemical composition will register distinct spectral "signatures" (Wickland 1991, Lillesand and Kiefer 1987). These signatures provide a quantitative measure of reflectance at specific wavelengths, which can then be statistically analyzed to develop a vegetation map of spectrally similar plant communities.

Landsat TM has the highest spectral discrimination, with six spectral bands and one thermal band, among commercially available space-based sensors. Each band represents a specific range of light wavelength (Table 1). For vegetation mapping, bands 2, 3, 4, and 5 are particularly useful. TM bands 3, 5, and 7 are useful for detecting variations in surface geology. Surface geology and soil discrimination are important in developing mapping units of the vegetation communities in sparsely vegetated areas that occur on the refuge.

TM integrates the spectral characteristics of each band over the Instantaneous Field of View (IFOV) of an area 28.5 m. x 28.5 m.; this is the smallest area resolvable by the sensor and is represented on the computer screen by individual "pixels" (picture elements). Individual occurrences of plants are not resolved by the sensor; therefore, TM is particularly suited for evaluating and quantitatively identifying more generalized vegetation "community" occurrence patterns and their associated surface substrate characteristics.

**Table 1. Landsat Thematic Mapper bands, their spectral ranges, and principal remote sensing applications for earth research (derived from Lillesand and Kiefer 1987).**

| Band | Wavelength (microns) | Spectral Location |
|---|---|---|
| **1** | 0.45-0.52 | Blue visible |
| **2** | 0.52-0.60 | Green visible |
| **3** | 0.63-0.69 | Red visible |
| **4** | 0.76-0.90 | Near-infrared |
| **5** | 1.55-1.75 | Mid-infrared |
| **6** | 10.4-12.5 | Thermal Infrared |
| **7** | 2.08-2.35 | Mid-infrared |

Aerial Photography

Black and white aerial photographs were acquired over this area under the National Aerial Photography Program (NAPP) on 29 September, 1997. The photographs were ortho-rectified and used in an analysis of spatial variability in the landscape (explained below).

Ancillary Map Coverages

In addition to the above data sources, four vector files in ARC/INFO (7.2.1) format were created to aid map development. These include coverages for boundaries, roads, elevation contours, and landuse.

The boundary coverage was digitized using a combination of the U.S. Geological Survey (USGS) 1:24,000 Digital Raster Graphics (DRG) and map sheets provided by the Maxwell NWR office. Tract boundaries within the refuge were digitized from map sheets provided by the refuge office. The roads were digitized principally using the aerial photography since the USGS Digital Line Graphs (DLG) did not sufficiently represent the current road network. Drainages and irrigation canals were also digitized using air photos.

A USGS Digital Elevation Model (DEM) with a spatial resolution of 30m x 30m was processed and geometrically referenced to the coordinate system listed above. These data were used to ortho-rectify the aerial photography and processed to create elevation contours to identify geomorphic position and provide general terrain reference.

The refuge office also provided a map of the land ownership prior to acquisition by the U.S. Fish and Wildlife Service. Land ownership is useful in determining past land uses, such as grazing or agriculture, which can influence the composition and structure of present plant communities. Agricultural fields were digitized based on the aerial photograph. Agricultural fields, roads, and past landuse designations were used to fine-tune the vegetation classification since misclassification can result in areas that are not considered a 'vegetation class'.

## ***Image Processing***

### Geometric Correction

The TM scene was rectified to a map-based coordinate system using a nearest-neighbor interpolation. This process makes the image planimetric so that area, direction, and distance measurements can be performed. The image-to-map rectification process involves selecting a point on the map with its coordinate and the same point on the image with its x and y coordinate. The root mean square error ($RMS_{error}$) is computed to determine how well the map and image coordinates fit in a least-squares regression equation. The $RMS_{error}$ for these images was 0.98 pixel error (or approximately 28 m). The images were projected into the New Mexico State Plane, Zone 4726, using the 1983 North American Datum and the Geodetic Reference Spheroid 1980.

### Radiometric Correction

A radiometric correction was performed on all TM bands to account for the systematic signal distortion of the sensor. One major source of distortion that occurs is the sensor offset, the residual "black noise" that is recorded by the sensor when there is no input signal (Lillesand and Kiefer 1987). The other major distortion is from the channel gain, which is the slope transfer relation between the signal received and the sensor's response. Differential offsets and gains between bands will cause problems when comparing their responses to a certain feature, so it is necessary to calibrate all the bands to each other. Gain and offset coefficients for each band are provided for by EOSAT for Landsat TM5 in the original header. The effect of these deviations on the original data can be modeled as:

$$L = (DN * Gain) + Offset \quad (Eq. 1)$$

where **L** is the radiometrically corrected signal and **DN** is the input digital number value. The gains and offsets shown in Table 2 were used to transform the image DN values.

**Table 2. Gains and offsets used to radiometrically calibrate the image data.**

| | TM1 | TM2 | TM3 | TM4 | TM5 | TM7 |
|---|---|---|---|---|---|---|
| **OFFSET** | -0.15 | -0.280487 | -0.119403 | -0.15 | -0.014999 | -0.014999 |
| **GAIN** | 0.0602436 | 0.1175036 | 0.0805971 | 0.0815399 | 0.0108074 | 0.0056984 |

Normalized Difference Vegetation Index

The Normalized Difference Vegetation Index (NDVI) enhances vigorous vegetation over other major surface features. It is believed that this enhancement helps to emphasize vegetation response patterns in the classification over soil responses. The NDVI also allows quick assessment of class signatures: for example, riparian areas should have a higher NDVI response than senescent grasslands.

The Normalized Difference Vegetation Index (NDVI) was created using Equation 2 and added to the file.

$$NDVI = (TM4 - TM3) / (TM4 + TM3) \quad (Eq. 2)$$

Where **TM4** is the near infrared TM band and **TM3** is the visible red TM band.

Panchromatic Aerial Photo Processing

One NAPP air photo was scanned at 1 meter (3 ft.) pixel resolution and ortho-rectified using the USGS DEM for elevation control and the USGS DRG for ground reference. Ortho-rectification is a process that uses a terrain model to take out parallax and other distortions to correct the photos to a planimetric grid[1]. Specifically, ortho-rectification takes the known geometry of the lens and camera system and compares these to the known geometry on the ground based on the DEM and DRG through a set of co-linear equations. Once a set of co-linear

[1] New Mexico State Plane projection, Zone 4726, using the 1983 North American Datum and the 1980 Geodetic Reference Spheroid.

equations fall within a small enough $RMS_{Error}$, the resulting equation is used to model the geometric distortion in the x, y, and z plane. This results in a photo that is planimetrically correct even across severe terrain changes. The obvious advantage to using this data in the classification procedure is the one-meter spatial resolution. Additionally, the photography enhanced the differences between native vegetation and highly disturbed sites.

## Variance Filter

It is expected that different vegetation types will have different spatial patterns. For example, a fourwing saltbush/blue grama shrubland community might have high spatial variation due to changes in image response representing the mixed shrub, and sparse grass components of this landscape, whereas a cattail wetland community, with its nearly closed canopy will have less variation in response. Variance filters enhance different variance responses on different landscapes with little discernable evidence of the photograph frame boundaries.

A variance filter was applied to the aerial photographs using the below equation:

$$V = \sum(DN - \mu)^2 / 9 \quad \text{(Eq. 3)}$$

where **V** is the resulting variance, **DN** is the image value, and $\mu$ is the average value for the 3 x 3 filter kernel.

## Software and Hardware Used

ERDAS Imagine, Version 8.3, was the principal software used throughout the mapping process. All digital imagery and GIS coverages were processed, manipulated, and used as overlays for analysis within the Imagine environment. The ERDAS Imagine software was loaded on a PC using an NT operating system. Arc/Info, Version 7.2.1, and ArcView 3.1 were used to create, import, and manipulate vector coverages. Microsoft Excel, Version 2.0 was used to store and manipulate all field data. Trimble's GeoExplorers were used to collect GPS data in the field.

### *Mapping Strategy*

### *Ground Survey Data*

The mapping process used here is dependent on ground vegetation survey data to develop the map. A set of sixty-three (63) vegetation plots was collected from the study area on September 23-24 and November 18, 1999. To ensure a wide coverage of the study area for mapping purposes, potential field plot locations were initially determined using aerial photography interpretation and an unsupervised image classification (see Image Classification below) of the range of patch types. Sampling was directed towards large polygons of uniform spectral characteristics distributed throughout the study area.

Plot data includes noting the major vegetation community, collection of unidentified plants, general comments that include qualitative condition of the plant community, regularly repeated forbs, geomorphic position, and aspect, where relevant. Plots were placed in the center of stands of more or less uniform vegetation representing the dominant vegetation type of the selected polygon. Stands were a minimum of 1 ha in size, with the exception of stands that are limited in size such as disturbances along drainages.

A Global Positioning System (GPS) was used to record the plot locations necessary for use in the image analysis. GPS positions were collected using Trimble Geoexplorers. No attempt was made to differentially correct the data since a ± accuracy of 100 meters (300 feet) was considered acceptable for plant community typing.

### *Image Classification*

Supervised Strategy and Seeding

The image classification procedure synthesizes satellite image data with field plot data and ancillary data derived principally from Geographic Information System (GIS) coverages. A supervised classification strategy was adopted to create the vegetation map based on vegetation community types of Maxwell NWR. This strategy develops spectral classes based on ground locations with known characteristics such as vegetation composition and landscape context.

In a supervised classification strategy, the field data is applied to the image data through an interactive process called "seeding." In the seeding process, a pixel at the field plot location was selected in the imagery and its spectral characteristics were used to gather other similar contiguous pixels to create a statistical model or “seed” of the field plot. The seeding algorithm searches around that point within user-defined parameters which contain a seed within: 1) a certain distance, 2) a certain area, and 3) a certain spectral distance defined as:

$$SD = \sqrt{\sum(\mu - X)^2}$$

where **SD** is the spectral distance between a new pixel and the mean of the current seed group pixels across all bands, $\mu$ is the mean of the seed pixel group for each image band, and $\mathbf{X}$ is the spectral value of the new pixel for each band.

In an iterative process, the best seed models were constructed by adjusting the parameters and comparing the resulting pixel distributions against the terrain models and the original imagery. A seed was developed for each field plot using the plot GPS location and associated field information. The seed’s maximum area was initially defined by the size of the vegetation community occurrence as determined in the field. The actual seed was then defined by increasing the spectral distance iteratively until the spectral signature collected within the seed generated a covariance matrix which could be inverted, a requirement for the maximum likelihood decision rule used later in the actual classification.

The seed shape and location was checked against field notes and maps, and by direct interpretation of the seed in the image on the screen in conjunction with the terrain models. Each seed is saved in a signature file with its field plot number, mean values for each image band, variance, number of pixels that were used to create the seed, and minimum and maximum values.

## Supervised Classification

Statistics gathered in the seeding process were used to perform a supervised classification. Supervised classifications are based on a maximum likelihood decision rule which contains a Bayesian classifier that uses probabilities to weight the classification towards particular classes. In this study the probabilities were unknown, so the maximum likelihood equation for each of the classes is given as:

$$D = [0.5\ln(cov_c)]-[0.5(X-M_c)^T * (cov_c^{-1})*(X-M_c)]$$

where **D** is the weighted distance, $\mathbf{cov_c}$ is the covariance matrix for a particular class, $\mathbf{X}$ is the measurement vector of the pixel, $\mathbf{M_c}$ is the mean vector of the class and $^{\mathbf{T}}$ is the matrix transpose function (ERDAS 1997). Each pixel is then assigned to the class with the lowest weighted distance. This technique assumes the statistical signatures have a normal distribution.

This decision rule is considered the most accurate, because it not only uses a spectral distance (as the minimum distance decision rule), but it also takes into account the variance of each of the signatures. The variance is important when comparing a pixel to a signature representing, for example, a blue grama/buffalo grass community which might be fairly heterogeneous, to a water class, which is more homogeneous.

To locate problems, informal accuracy checking was used based on field data, air photos, personal knowledge of a site and other ancillary data. If a distribution problem with a seed was detected, the seed was rechecked to insure it was properly modeling the vegetation type and landscape. This preliminary map had as many map classes as seeds used to develop it.

## RESULTS

### *Map Units*

The seed map classes were aggregated into a limited number of Mapping Units (MU's) for the final map (Figure 1). Mapping Units are grouped together based on floristic composition, landscape position, spatial contiguity and spectral similarity, i.e. floristically similar seed classes, which had similar landscape positions, and were spatially near each other, were grouped into a mapping unit. This was an iterative process based on informal accuracy checking that was continued until all seed classes were grouped into the most consistent and accurate mapping units.

Nineteen map units were defined (Table 3) that include nine grasslands, two wetlands and three shrublands, all which represent a general vegetation community type. For the most part, these community types correspond to the New Mexico Natural Heritage's (NMNHP) plant community classification database. The NMNHP classifies communities based on a combination of the dominant perennial vegetation, substrate and landscape position. There are also five miscellaneous cover classes which represent planted vegetation (Agricultural Fields and Tree Groves classes) or non-vegetative land cover types (Barren and Surface Water classes). A 'Herbaceous Disturbance' class was created to identify the distribution of disturbance-dependent plants such as sweetclover, sunflower, thistle, and bindweed and other weedy vegetation of interest to the refuge.

Detailed descriptions of each map unit are provided in Appendix A. The dominant plant communities included within the map unit are provided as well as communities that are considered *inclusions* within the mapping unit. The communities designated as *inclusions* were either too small to differentiate into separate mapping units or are considered to have enough similar elements of the dominant plant communities represented by the mapping unit.

### *Final Vegetation Map*

To create the final map, a filtering process was applied to create a minimum map unit polygon size of 40 square meters (0.004 ha.). The procedure eliminates the “speckle” created by spatially solitary mapping units, which have less than six contiguous pixels. The eliminated areas are then filled in by the majority of surrounding pixels using a 3-pixel x 3- pixel majority filter (a majority filter replaces the middle pixel of a 3 x 3 kernel with the class which is the majority within that kernel). The filtered file was substituted into the map wherever there were clusters of pixels of a particular class, which covered less than 40 square meters.

No attempt was made to classify buildings, pavement, concrete, or lawns due to the heterogeneity of reflecting surfaces. A few seeded classes did map features such as roadside trees very well and were used. Roads, water, and agricultural GIS coverages in vector format were placed directly onto the map to provide for their classification.

**Table 3. Maxwell NWR vegetation mapping units.**[2]

| MU# | MU Description | Ha | Ac |
|---|---|---|---|
| 1 | Cattail Wetland | 27.9 | 69.1 |
| 2 | Rushes & Sedges Wetlands | 17.5 | 43.4 |
| 3 | Fourwing Saltbush/Blue Grama Shrubland | 34.0 | 84.2 |
| 4 | Fourwing Saltbush/Alkali Sacaton Shrubland | 5.2 | 12.9 |
| 5 | Rubber Rabbitbrush/Blue Grama Shrubland | 2.7 | 6.7 |
| 6 | Blue Grama/Buffalograss Grasslands | 91.6 | 226.4 |
| 7 | Blue Grama/Bottlebrush Squirreltail Grasslands | 11.1 | 27.4 |
| 8 | Blue Grama/Western Wheatgrass Grasslands | 29.8 | 73.6 |
| 9 | Blue Grama/Alkali Sacaton Grasslands | 56.0 | 138.4 |
| 10 | Alkali Sacaton Grassland | 264.8 | 654.5 |
| 11 | Western Wheatgrass Grassland | 30.6 | 75.6 |
| 12 | Smooth Brome Grassland | 60.4 | 149.2 |
| 13 | Alkali Muhly Grassland | 47.5 | 117.4 |
| 14 | Inland Saltgrass Grassland | 6.9 | 17.1 |
| 15 | Herbaceous Disturbance | 254.9 | 629.9 |
| 16 | Agricultural Fields | 198.8 | 491.4 |
| 17 | Tree Groves | 15.6 | 38.6 |
| 18 | Surface Water | 257.4 | 636.2 |
| 19 | Barren or Sparsely Vegetated | 55.6 | 137.6 |

[2] Area was calculated using a Geographic Information System (GIS).

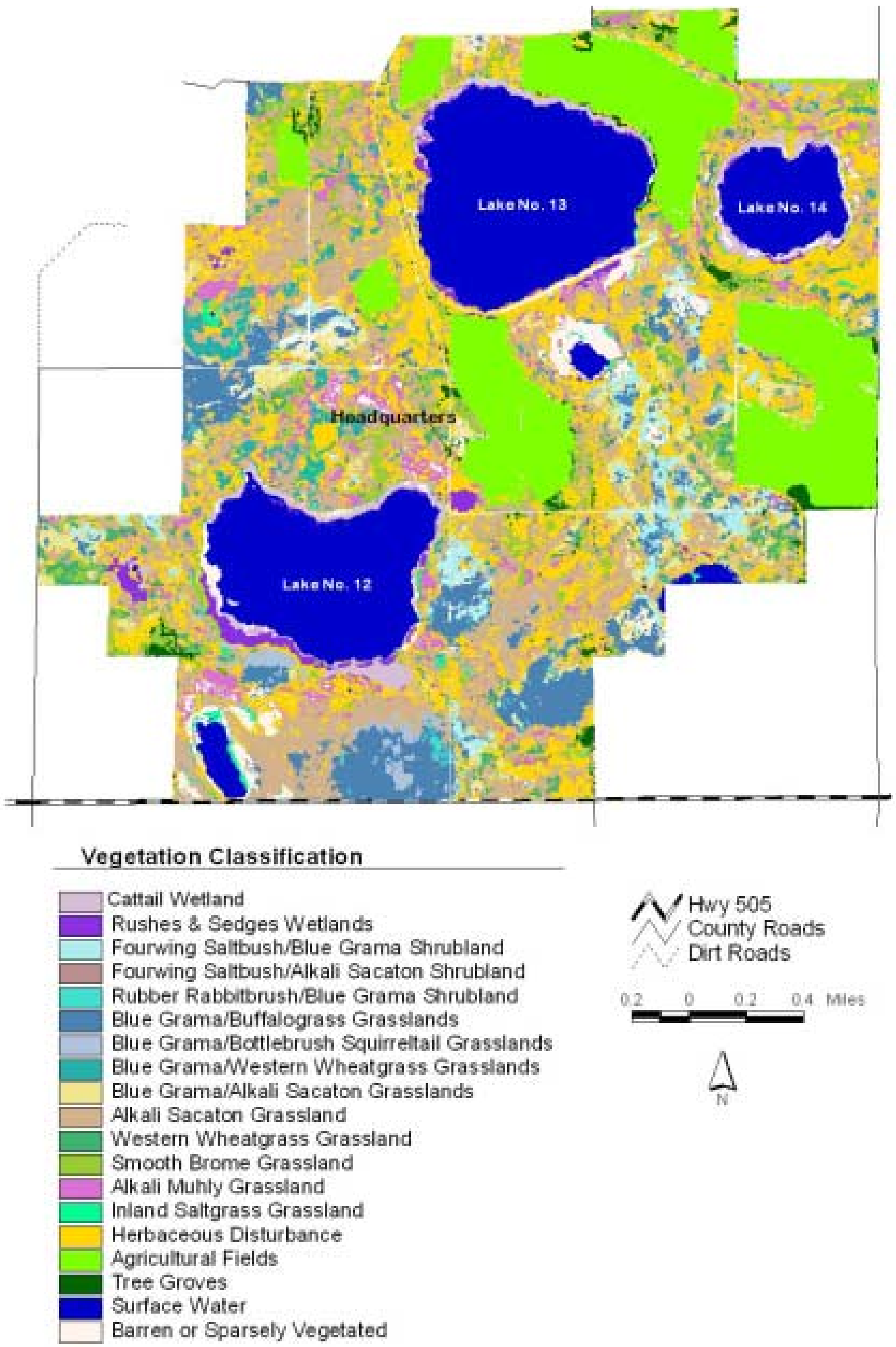


**Figure 1. Map of Vegetation Classification**

## DISCUSSION

Maxwell NWR is within the Plains-Mesa-Foothill Grassland complex of North America (New Mexico Natural Heritage Program Community classification database, Brown & Lowe 1982, Dick-Peddie 1993) that is composed almost entirely of grasses with shrubs and forbs constituting less than ten percent. These grasslands once spread nearly uninterrupted over the vast rolling plains of eastern New Mexico and adjacent Texas, Oklahoma, Kansas and Nebraska, but have been greatly reduced due to dryland and irrigated farming (Haukos and Smith 1992, Dick-Peddie 1993). Little is known of the extent, distribution and condition of Plains-Mesa Grassland in New Mexico, and for this reason, mapping the plant communities within the refuge will contribute to the knowledge base of this important group.

During field surveys, an attempt was made to identify patterns of affinities for some forbs and shrubs to consistently occur within plant communities. Our field surveys concur with previous work by Brown and Lowe (1982), Dick-Peddie (1993) and Parmenter et al. (1994) that specific forbs appear consistently that are indicative of the plains-mesa-foothill grassland type. Common forbs include globemallow (*Sphaeralcea* spp.), curly cup gumweed (*Grindelia squarrosa*) and coneflower (*Ratibida tagetes*). Common shrubs found scattered throughout the plains-mesa grasslands are rubber rabbitbrush (*Chrysothamnus nauseosus*), fourwing saltbush (*Atriplex canescens*), and soapweed yucca (*Yucca glauca*), found in the upland grasslands and shrublands within the refuge. The lowland grasslands, dominated by dropseed (*Sporobolus* spp.) were often associated with fourwing saltbush. Broom snakeweed (*Gutierrezia microcephala*), a disturbance indicator shrub is also found in some of the more degraded grasslands on the refuge.

An attempt was also made to identify areas that had a high occurrence of non-native plants, with particular attention to noxious weeds, as designated by the New Mexico Department of Agriculture (NMDA) in 1999. The NMDA has classified noxious weeds into three divisions. *Class A* are species not yet present in New Mexico or have a limited distribution and prevention of infestation is the highest priority. *Class B* are species limited to portions of the state, and should be treated as Class A weeds in areas where they have not yet reached infestation level. We found no Class A or Class B weeds on the refuge; however, it is possible they exist as vegetation surveys were toward the end of the growing season, making positive identification of some species difficult. *Class C* weeds are those that are widespread in New Mexico, with management decisions for these species to be determined at the local level. Bindweed, *Convolvulus arvensis*, a Class C weed, is ubiquitous throughout the western wheatgrass monotypic and buffalograss grasslands on the refuge. This may be due to past grazing practices on these lands. Cattle will ignore bindweed in favor of the grasses, leaving these invasive plants to increase. Another Class C noxious weed found on the refuge is the Siberian elm (*Ulmus pumila*). This tree appears to have been planted along roadsides and old home sites, but spreads easily through vigorous vegetative reproduction. It appears to be increasing within the refuge, especially near the southwest corner of the refuge (see Figure 1).

Other weedy species are also present at high densities on the refuge. Many of the blue grama grasslands are thick with bottlebrush squirreltail (*Elymus elymoides*), sleepygrass (*Stipa robusta*) or poverty three-awn (*Aristida divaricata*). These species are disturbance increasers, and usually occur in rangelands subjected to heavy grazing. Once established, these grasses are difficult to eradicate. Because they are unpalatable to livestock, grazing only leads to further increase of these species since grazers avoid them, creating new seedbeds. Seed dispersal is enhanced by awns that cling to animals that disperse the seed widely.

In disturbed bottomlands with intermittent standing water, Canadian wildrye (*Elymus canadensis*) is found along with horseweed (*Conyza canadensis*), cocklebur (*Xanthium strumarium*), Mexican dock (*Rumex salicifolia* var. *mexicana*) and rabbitfoot grass (*Polypogon monspeliensis*). These areas are certainly used by birds, and some of the plants, particularly Mexican dock, are eaten and may be spread by birds. Weedy species, such as sunflower (*Helianthus annuus*), sweetclover (*Melilotus alba/M. officinalis*), pigweed (*Amaranthus hybridus*) and kochia (*Kochia scoparia*) are abundant along drainages and irrigation canals which are probably subject to regular mowing, clearing, and fluctuating water levels.

The map presented here is the most accurate and detailed map developed to date for the vegetation of Maxwell National Wildlife Refuge. The intended scale for use of the map is 1:24,000 (7.5' USGS quadrangle size). The map units were designed to both accurately reflect the vegetation composition of the area, but also to be a optimally useful for natural resources management at that scale. Use of the map at finer scales is not recommended without review (additional ground truthing). Future refinement of map unit categories and the scale of use might be possible, but not necessarily appropriate for most natural resources management applications. The map has been made available both in hard copy form and in a digital format suitable for integration into a GIS.

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## Appendix A.  Map Unit Descriptions

**MAXWELL NATIONAL WILDLIFE REFUGE**
**MAPPING UNIT DESCRIPTIONS**

| MU# | MU DESCRIPTION | AC | HA |
|---|---|---|---|
| 1 | Cattail Wetland | 69.1 | 27.9 |

These wetlands are dominated by stands of monotypic cattail (*Typha latifolia*). Cattail is an obligate wetland plant species that forms dense colonies in standing water along the shore margins of lakes and ponds on the refuge. It is also found on the mud banks of some canals and drainages. Rushes, sedges, and inland saltgrass (*Distichlis spicata*) are locally dominant.

| MU# | MU DESCRIPTION | AC | HA |
|---|---|---|---|
| 2 | Rush and Sedge Wetland | 43.4 | 17.5 |

Rushes and sedges are principally found at the margins of the lakes, drainages, and wet, lowland depressions where water levels are shallow or fluctuating. American bulrush (*Scirpus pungens*), three-square sedge (*Schoenoplectus americanus*), Baltic rush (*Juncus balticus*), common spikerush (*Eleocharis* spp.) and Mexican dock (*Rumex salicifolius var. mexicanus*) are the most common species within this map unit. Highly disturbed sites along canals may be mixed with weedy species such as broadleaf milkweed (*Asclepias latifolia*) and western whorled milkweed (*Asclepias subverticillata*).

| MU# | MU DESCRIPTION | AC | HA |
|---|---|---|---|
| 3 | Fourwing Saltbush/Blue Grama Shrubland | 84.2 | 34.0 |

This shrubland is dominated by fourwing saltbush (*Atriplex canescens*) with an understory of blue grama (*Bouteloua gracilis*). This community has a high diversity of regularly occurring forb species that include cluster aster (*Aster falcatus* var. *commutatus*), broom groundsel (*Senecio spartioides*), poverty sumpweed (*Iva axillaris*) and clover (*Melilotus alba, M. officinalis*). This community is found on moderate slopes with a silty clay loam substrate. Prickly pear (*Opuntia phaeacantha*) and winterfat (*Krascheninnikovia lantana*) are also abundant. This community has a highly disturbed phase where disturbance indicators including broom snakeweed (*Gutierrezia microcephala*), black medic (*Medicago lupulina*), poverty sumpweed (*Iva axillaris*), and common sunflower (*Helianthus annuus*) are common.

| MU# | MU DESCRIPTION | AC | HA |
|---|---|---|---|
| 4 | Fourwing Saltbush/Alkali Sacaton Shrubland | 12.9 | 5.2 |

This fourwing saltbush (*Atriplex canescens*)/alkali sacaton (*Sporobolus airoides*) shrubland is found in swales and highly alkaline areas that interfinger with alkali sacaton grasslands (MU #19). Some of the weedy species, such as Canadian horseweed (*Conyza canadensis*), sunflower (*Helianthus annuus*), pitseed goosefoot (*Chenopodium berlandieri*), field bindweed (*Convolvulus arvensis*), and poverty sumpweed (*Iva axillaris*) are typically found in this community.

| MU# | MU DESCRIPTION | AC | HA |
|---|---|---|---|
| 5 | Rubber Rabbitbrush/Blue Grama Shrubland | 6.7 | 2.7 |

The rubber rabbitbrush (*Chrysothamnus nauseosus*) shrublands have grassy understories dominated by blue grama (*Bouteloua gracilis*). Buffalograss (*Buchloe dactyloides*) and ring muhly (*Muhlenbergia torreyi*) are also common. Winterfat (*Krascheninnikovia lantana*) patches are found throughout this community. This diverse community also has an assortment of forbs that include curlycup gumweed (*Grindelia squarrosa*), fetid marigold (*Dyssodia papposa*), plantain (*Plantago* spp.) and broom groundsel (*Senecio spartioides*).

| MU# | MU DESCRIPTION | AC | HA |
|---|---|---|---|
| 6 | Blue Grama/Buffalograss Grasslands | 226.4 | 91.6 |

This grassland unit, typically found on gently sloping silty loam soils, includes several community types, all of which are dominated by blue grama (*Bouteloua gracilis*). These grasslands include blue grama/galleta (*B. gracilis*/*Hilaria jamesii*), blue grama/winterfat (*B. gracilis*/*Krascheninnikovia lanata*), blue grama/buffalograss *(B. gracilis/Buchloe dactyloides*), and blue grama/sleepygrass (*B. gracilis*/*Stipa robusta*). The blue grama/galleta grasslands are typically in very good condition although with rubber rabbitbrush (*Chrysothamnus nauseosus*) increasing at some sites. Indicator plains mesa forbs representative of these grasslands include fetid marigold (*Dyssodia papposa*) and broom groundsel (*Senecio multicapitatus*). Weedy indicator plants in blue grama grasslands typically include prickly lettuce *(Lactuca serriola*), Canadian horseweed (*Conyza canadensis)*, common kochia (*Kochia scoparia*), common sunflower (*Helianthus annuus*), wavyleaf thistle (*Cirsium undulatum*), snakeweed (*Gutierrezia microcephala*), prickly pear (*Opuntia phaeacantha*), poverty sumpweed (*Iva axillaris*), and purple aster (*Machaeranthera canescens*). Prairie dog towns occur within buffalograss dominated grasslands of the refuge. Surrounding the towns, vegetation is cropped very low, due to the activities of the prairie dogs.

*Inclusions:* buffalograss monotypic
blue grama/galleta
blue grama/winterfat
blue grama/sleepygrass

| MU# | MU DESCRIPTION | AC | HA |
|---|---|---|---|
| 7 | Blue Grama/ Bottlebrush Squirreltail Grasslands | 27.4 | 11.1 |

This is a grassland community dominated by blue grama (*Bouteloua gracilis*), with bottlebrush squirreltail locally co-dominant (*Elymus elymoides*). Trailing fleabane (*Erigeron flagellaris*) frequently occurs in the understory, and sweetclover (*Melilotus spp*.), black medic (*Medicago lupulina*), alfalfa (*Medicago sativa*) and snakeweed (*Gutierrezia microcephala*) are found at varying densities.

| MU# | MU DESCRIPTION | AC | HA |
|---|---|---|---|
| 8 | Blue Grama/Western Wheatgrass Grasslands | 73.6 | 29.8 |

This grassland is co-dominated by blue grama (*Bouteloua gracilis*) with western wheatgrass (*Pascopyrum smithii*). Patches of fourwing saltbush (*Atriplex canescens*) may be found at some sites. Short ray coneflower (*Ratibida tagetes*), plains bahia (*Bahia oppositifolia*), and poverty sumpweed (*Iva axillaris*) are typically found in high densities throughout this community.

| MU# | MU DESCRIPTION | AC | HA |
|---|---|---|---|
| 9 | Blue Grama/ Alkali Sacaton Grasslands | 138.4 | 56.0 |

Alkali sacaton (*Sporobolus airoides*) and blue grama (*Bouteloua gracilis*) are co-dominants in this mapping unit. This is a transitional community between the upland grasslands and more alkaline, lowland depressions. These sites have plains-mesa indicator forbs, such as fetid marigold (*Dyssodia papposa*) and shortray coneflower (*Ratibida tagetes*), throughout. In more disturbed sites, poverty three-awn (*Aristida divaricata*) increases.

| MU# | MU DESCRIPTION | AC | HA |
|---|---|---|---|
| 10 | Alkali Sacaton Grassland | 654.5 | 264.8 |

Alkali sacaton grasslands typically occupy broad expanses on silty clay loams within playa depressions. These grasslands also occupy hummocky landscapes southeast of Lake 13. This mapping unit includes several alkali sacaton dominated communities due principally to the microtopography in these lowland swales. Fluctuating water levels in these heavy soils create a mosaic of grasses interrupted by barren or sparse areas where poverty sumpweed (*Iva axillaris*) increases. Although alkali sacaton (*Sporobolus airoides*) is dominant, sand dropseed (*Sporobolus cryptandrus*) occurs in lenses of coarser soils. Some swales are co-dominated with inland saltgrass (*Distichlis spicata*) or alkali muhly (*Muhlenbergia asperifolia*). Weedy species that increase in this community are typically netleaf lambsquarters (*Chenopodium berlandieri*), common kochia (*Kochia scoparia*), Canadian horseweed (*Conyza canadensis*) and poverty sumpweed (*Iva axillaris*).

When alkali sacaton occurs with sleepygrass (*Stipa robusta*), buffalograss (*Buchloe dactyloides*) often occurs within the understory. These sites were probably agricultural areas due to the high density of field bindweed (*Convolvulus arvensis*) and alfalfa (*Medicago sativa*) and as yet have not recovered from its past landuse. Alkali sacaton, when co-dominant with spike dropseed (*Sporobolus contractus*), covers more upland areas.

*Inclusions:* alkali sacaton/monotypic
alkali sacaton/inland saltgrass
alkali sacaton/spike dropseed
alkali sacaton/sleepygrass

| MU# | MU DESCRIPTION | AC | HA |
|---|---|---|---|
| 11 | Western Wheatgrass Grassland | 75.6 | 30.6 |

This is a grassland community dominated by western wheatgrass (*Pascopyrum smithii*). This mesic grassland includes areas of where wheatgrass forms a dense, monotypic cover as well as areas with a significant understory of bindweed. Other grasses are seldom found in this community; however, there may be inclusions of forbs such as sweetclover, prickly lettuce (*Lactuca serriola*), and common sunflower (*Helianthus annuus*).

| MU# | MU DESCRIPTION | AC | HA |
|---|---|---|---|
| 12 | Smooth Brome Grassland | 149.2 | 60.4 |

Smooth brome (*Bromus inermis*) typically occurs in monotypic stands or in association with blue grama. It is a non-native that was planted in the old agricultural fields and contains a significant amount of alfalfa (*Medicago sativa*). Some of the more disturbed sites have high densities of field bindweed (*Convolvulus arvensis*), poverty sumpweed (*Iva axillaris*), netleaf lambsquarters (*Chenopodium berlandieri*), and showy milkweed (*Asclepias speciosa*).

| MU# | MU DESCRIPTION | AC | HA |
|---|---|---|---|
| 13 | Alkali Muhly Grassland | 117.4 | 47.5 |

Alkali muhly dominates wet, lowland depressions throughout the refuge in nearly monotypic stands. Alkali muhly is also found along roadsides and ditches with other grasses, such as alkali sacaton (*Sporobolus airoides*), mat muhly (*Muhlenbergia richardsonii*), or western wheatgrass (*Pascopyrum smithii*) in a highly disturbed matrix that include weedy species such as western whorled milkweed (*Asclepias subverticillata*), prickly lettuce (*Lactuca serriola*), barnyard grass(*Echinochloa crus-galli*), common cocklebur (*Xanthium strumarium*) and poverty sumpweed (*Iva axillaris*).

| MU# | MU DESCRIPTION | AC | HA |
|---|---|---|---|
| 14 | Inland Saltgrass Grassland | 17.1 | 6.9 |

Inland saltgrass (*Distichlis spicata*) is a wetland community found throughout the refuge in swales, playas, ditches, and at the margins of waterbodies. This grass typically forms a thick mat interspersed with occasional forbs on saturated, usually saline soils. In some areas, western wheatgrass is found within this community. Along ditches weedy species increase and include western whorled milkweed and broadleaf milkweed.

| MU# | MU DESCRIPTION | AC | HA |
|---|---|---|---|
| 15 | Herbaceous Disturbance | 629.9 | 254.9 |

Herbaceous disturbance covers areas that are dominated by 'early colonizers' such as poverty sumpweed (*Iva axillaris*), common sunflower (*Helianthus annuus*), sweetclover (*Melilotus spp*.), thistle (*Cirsium spp*.), common kochia (*Kochia scoparia*), and prickly lettuce (*Lactuca serriola*). These plants are quick to invade areas that have been disturbed by surface blading, fire, or overgrazing. Many of these areas follow the canals and ditches. Also, some of the margins of the wetlands that extend into the plains are infested with these plants and eventually colonize adjacent grasslands. Some of this may be due to seeds being introduced into the area from the irrigation canals. Many of the playa depressions are dominated by these herbaceous disturbance plants.

| MU# | MU DESCRIPTION | AC | HA |
|---|---|---|---|
| 16 | Agricultural Fields | 491.4 | 198.8 |

This mapping unit represents fields that were in production or fallow at the time of image acquisition.

| MU# | MU DESCRIPTION | AC | HA |
|---|---|---|---|
| 17 | Tree Groves | 38.6 | 15.6 |

Usually near old homesteads or along roads are areas dominated by groves of trees that can be combinations of any of the following: Siberian elm (*Ulmus pumila*), cottonwood (*Populus deltoides*), Russian olive (*Elaeagnus angustifolia*), or juniper (*Juniperus* spp.). The understory grasses and forbs are diverse.

| MU# | MU DESCRIPTION | AC | HA |
|---|---|---|---|
| 18 | Surface Water | 636.2 | 257.4 |

This mapping unit represents the surface water extent as a combination of 3 September, 1993, the acquisition date of the satellite image and the aerial photography dated 29 September, 1997.

| MU# | MU DESCRIPTION | AC | HA |
|---|---|---|---|
| 19 | Barren or Sparsely Vegetated | 137.6 | 55.6 |

Barren ground, little to no cover of vegetation.

## Appendix B. Preliminary Species List

The species list is grouped into lifeforms and arranged within groups alphabetically first by family and second by genus. Species names follow Kartesz (1994). The “Origin” column indicates whether a species is a native (N) or introduced (I). This list is not intended to be a complete list of all species found within the refuge, but a preliminary account of species identified under this contract.

| Common Name | **Family** | **Scientific Name** | **Origin** |
|---|---|---|---|
| **TREES** | | | |
| Alligator juniper | Cupressaceae | *Juniperus deppeana* Steud. | N |
| One-seed juniper | Cupressaceae | *Juniperus monosperma* (Engelm.) Sarg. | N |
| New Mexico locust | Fabaceae | *Robinia neomexicana* Gray | N |
| Cottonwood | Salicaceae | *Populus deltoides* Bartr. ex Marsh. | N |
| Siberian elm | Ulmaceae | *Ulmus pumila* L. | I |
| **SHRUBS** | | | |
| Soaptree yucca | Agavaceae | *Yucca glauca* Nutt. | N |
| Rubber rabbitbrush | Asteraceae | *Chrysothamnus nauseosus* (Pallas ex.Prush) Britt. | N |
| Snakeweed | Asteraceae | *Gutierrezia microcephala* (DC.) Gray | N |
| Prickly pear | Cactaceae | *Opuntia phaeacantha* Engelm. | N |
| Fourwing saltbush | Chenopodiaceae | *Atriplex canescens* (Pursh) Nutt. | N |
| Winterfat | Chenopodiaceae | *Krascheninnikovia lanata* (Pursh) Guldenstaedt | N |
| Coyote willow | Salicaceae | *Salix exigua* Nutt. | N |
| Pale wolfberry | Solanaceae | *Lycium pallidum* Miers | N |
| Saltcedar | Tamaricaceae | *Tamarix ramosissima* Ledeb. | I |
| **GRAMINOIDS** | | | |
| Three-square sedge | Cyperaceae | *Schoenoplectus americanus* (Pers.) Volk. Ex Schinz & R. Keller | N |
| American bulrush | Cyperaceae | *Scirpus acutus* Muhl. ex Bigelow | N |
| Spike rush | Cyperaceae | *Eleocharis* spp. | |
| Baltic rush | Juncaceae | *Juncus balticus Willd.* | N |
| Rush | Juncaceae | *Juncus* spp. L. | N |

| Common Name | **Family** | **Scientific Name** | **Origin** |
|---|---|---|---|
| **GRAMINOIDS, cont.** | | | |
| Big bluestem | Poaceae | *Andropogon gerardii* Vitman | N |
| Povery three-awn | Poaceae | *Aristida divaricata* Humb. & Bonpl. ex Willd. | N |
| Blue grama | Poaceae | *Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths | N |
| Smooth brome | Poaceae | *Bromus inermis* Leyss. | I |
| Buffalograss | Poaceae | *Buchloe dactyloides* (Nutt.) Engelm. | N |
| Inland saltgrass | Poaceae | *Distichlis spicata* (L.) Greene | N |
| Barnyard grass | Poaceae | *Echinochloa crus-galli* (L.) Beauv. | I |
| Bottlebrush squirreltail | Poaceae | *Elymus elymoides* (Raf.) Swezey | N |
| Plains lovegrass | Poaceae | *Eragrostis intermedia* Hitchc. | N |
| Galleta | Poaceae | *Hilaria jamesii* (Torr.) Benth. | N |
| Common wolfstail | Poaceae | *Lycurus phleoides Kunth* | N |
| Alkali muhly | Poaceae | *Muhlenbergia asperifolia* (Nees & Meyen ex Trin.) Parodi | N |
| Mat muhly | Poaceae | *Muhlenbergia richardsonis* (Trin.) Rydb. | N |
| Ring muhly | Poaceae | *Muhlenbergia torreyi* (Kunth) Hitch. ex Bush | N |
| Western wheatgrass | Poaceae | *Pascopyrum smithii* (Rydb.) Love | N |
| Little bluestem | Poaceae | *Schizachyrium scoparium* (Michx.) Nash | N |
| Plains bristlegrass | Poaceae | *Setaria leucopila* (Scrib. & Merr.) K. Schum. | N |
| Alkali sacaton | Poaceae | *Sporobolus airoides* (Torr.) Torr. | N |
| Spike dropseed | Poaceae | *Sporobolus contractus* Hitchc. | N |
| Sleepygrass | Poaceae | *Stipa robusta* (Vasey) Scribn. | N |
| **FORBS** | | | |
| Pigweed | Amaranthaceae | *Amaranthus hybridus* L. | N |

| Common Name | **Family** | **Scientific Name** | **Origin** |
|---|---|---|---|
| **FORBS, cont.** | | | |
| Broadleaf milkweed | Asclepiadaceae | *Asclepias latifolia* (Torr.)Raf. | N |
| Showy milkweed | Asclepiadaceae | *Asclepias speciosa* Torr. | N |
| Western whorled milkweed | Asclepiadaceae | *Asclepias subverticillata* (Gray) Vail | N |
| Common ragweed | Asteraceae | *Ambrosia artemisiifolia* L. | N |
| Giant ragweed | Asteraceae | *Ambrosia trifida* L. | N |
| Wild tarragon | Asteraceae | *Artemisia dracunculus* L. | N |
| Fringed sage | Asteraceae | *Artemisia frigida* Willd. | N |
| Heath aster | Asteraceae | *Aster falcatus* var *commutatus* (Torr. & Gray) A.G. Jones | N |
| Wavyleaf thistle | Asteraceae | *Cirsium undulatum* (Nutt.) Spreng. | N |
| Canadian horseweed | Asteraceae | *Conyza canadensis* (L.) Cronq. | N |
| Fetid marigold | Asteraceae | *Dyssodia papposa* (Vent.) Hitchc. | N |
| Trailing fleabane | Asteraceae | *Erigeron flagellaris* Gray | N |
| Curlycup gumweed | Asteraceae | *Grindelia squarrosa* (Pursh) Dunal | N |
| Common sunflower | Asteraceae | *Helianthus annuus* L. | N |
| Poverty sumpweed | Asteraceae | *Iva axillaris* Pursh | N |
| Prickly lettuce | Asteraceae | *Lactuca serriola* L. | I |
| Dotted gayfeather | Asteraceae | *Liatris punctata* Hook. | N |
| Purple aster | Asteraceae | *Machaeranthera canescens* (Pursh) Gray | N |
| Plains bahia | Asteraceae | *Picradeniopsis oppositifolia* (Nutt.) Rydb. ex Britt. | N |
| Short ray coneflower | Asteraceae | *Ratibida tagetes* (James) Barnh. | N |
| Broom groundsel | Asteraceae | *Senecio multicapitatus*Torr. & Gray | N |
| Common cocklebur | Asteraceae | *Xanthium strumarium* L. | N |

| Common Name | **Family** | **Scientific Name** | **Origin** |
|---|---|---|---|
| **FORBS, cont.** | | | |
| Pitseed goosefoot | Chenopodiaceae | *Chenopodium berlandieri* Moq. | N |
| Common Kochia | Chenopodiaceae | *Kochia scoparia* L. Schrad | I |
| Russian thistle | Chenopodiaceae | *Salsola kali* L. | I |
| Field bindweed | Convolvulaceae | *Convolvulus arvensis* L. | I |
| Locoweed | Fabaceae | *Astragalus* spp. L. | N |
| Black medic | Fabaceae | *Medicago lupulina* L. | I |
| Alfalfa | Fabaceae | *Medicago sativa* L. | I |
| White sweetclover | Fabaceae | *Melilotus albus* Medik. | I |
| Yellow sweetclover | Fabaceae | *Melilotus officinalis* (L.) Lam | I |
| Bugleweed | Lamiaceae | *Lycopus americanus* Muhl. ex Bart. | N |
| Venice mallow | Malvaceae | *Hibiscus trionum* L. | I |
| Common mallow | Malvaceae | *Malva neglecta* Wallr. | N |
| Globemallow | Malvaceae | *Sphaeralcea* spp. St.-Hil. | N |
| Velvety gaura | Onagraceae | *Gaura parviflora* Dougl. ex Lehm. | N |
| Plantain | Plantaginaceae | *Plantago* spp. L. | |
| Buckwheat spp. | Polygonaceae | *Eriogonum* spp. Michx. | |
| Knotweed | Polygonaceae | *Polygonum* spp. L. | U |
| Mexican dock | Polygonaceae | *Rumex salicifolius* var. *mexicanus* (Meisn.) C.L. Hitchc. | N |
| Common purslane | Portulacaceae | *Portulaca oleracea* L. | I |
| Clematis | Ranunculaceae | *Clematis* spp. L. | |
| Common mullein | Scrophulariaceae | *Verbascum thapsus* L. | I |
| Common cattail | Typhaceae | *Typha latifolia* L. | N |