A VEGETATION CLASSIFICATION AND MAP

FOR THE

SEVILLETA NATIONAL WILDLIFE REFUGE, NEW MEXICO

New Mexico Natural Heritage Program
and
Sevilleta Long Term Ecological Research Program

Biology Department, University of New Mexico
Albuquerque, NM 87131

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Final Report[1]

Esteban Muldavin, Greg Shore, Kimberly Taugher, and Bruce Milne[2]

Summary

The Sevilleta National Wildlife Refuge in central New Mexico is an important site for the maintenance of biodiversity in the Southwest, and a center for the study of the effects of global change on aridland ecosystems. To support management of these important biological resources, and effective design and implementation of scientific research, a vegetation classification and 1:70,000 scale map of actual vegetation was developed (Version 1.0). The map is based on an unsupervised classification of multi-temporal LANDSAT Thematic Mapper (TM) satellite imagery using a Normalized Difference Vegetation Index (NDVI) computed from 12 TM images that variously cover the April-to-October growing seasons from 1987 to 1993. Thirty-two spectral classes were derived from unsupervised classification and grouped into 13 map units based on similar vegetation composition and spatial relationships. A preliminary vegetation classification following the US National Vegetation Classification system was developed from extensive ground survey work (251 plots), and serves as a basis for defining map units. Eighty-seven plant associations were recognized among 27 Cover Types (Alliances). The targets for the mapping effort were 15 major Cover Types: Black Grama, Blue Grama, Galleta Grass, Indian Ricegrass, Alkali Sacaton, Giant Sacaton, Fourwing Saltbush, Broom Dalea, Creosotebush, Honey Mesquite, Oneseed Juniper, Pinyon Pine, Salt Cedar, and Rio Grande Cottonwood. Map units can reflect single cover types, or transitions that combine two or more. An annotated map legend provides details on species composition and structure along with known major inclusions of other types. This is the highest resolution and most accurate map yet developed for the Sevilleta, and is appropriate for use at 1:50,000 or greater scales. To meet future needs for even higher resolution maps in management and research, new approaches will be needed that take advantage of new technologies. For example, a technique is suggested that builds directly upon this map to increase accuracy and precision in a cost-effective manner by combining the TM imagery with aerial photography or high-resolution sensor data (the next generation -- Version 2.0). The Sevilleta Vegetation Map (Version 1.0) and this report will be made available in digital form on the web page of the Sevilleta Long Term Research Program at the University of New Mexico

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[1] submitted in partial fulfillment of grants from the Mary Flagler Cary Charitable Trust and The Nature Conservancy, New Mexico Chapter, Santa Fe, NM, and the Sevilleta National Wildlife Refuge, Socorro, NM to the New Mexico Natural Heritage Program, University of New Mexico, Albuquerque, NM.

[2]Esteban Muldavin, Ecologist and Senior Research Scientist, New Mexico Natural Heritage Program (NMNHP); Greg Shore, GIS Specialist Sevilleta Long Term Ecological Research Program (LTER); Kimberly Taugher, Biologist (LTER); Bruce Milne, Ecologist and LTER Principal Investigator.

(sevilleta.unm.edu).

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Introduction

The Sevilleta National Wildlife Refuge, at over 400 square miles (92,619 ha; 228,770 acres), is one of the largest reserves in the Southwest US, and one that is recognized as having an increasing importance in the maintenance of arid-land biodiversity in the region[3]. The US Fish and Wildlife Service with the assistance of The Nature Conservancy has inherited the role of stewardship for this globally important and diverse ecosystem. With that stewardship come many questions about the composition and status of the biota, and how to manage it and other natural resources of the refuge for long-term sustainability. In addition, and in keeping with the original tenets set out for the refuge, the site has become increasingly important for education and research on global change, culminating in the establishment of the Sevilleta Long Term Ecological Research Program (LTER) and the building of the Sevilleta Research Station[4]. One of the cornerstones of LTER research takes advantage the diversity of the refuge by focusing on the Sevilleta as a crossroads of four major biomes (Chihuahuan Desert, Great Basin, Rocky Mountains and the Great Plains), and framing many of its research questions on global change in the context of the nature and dynamics of these biomes and their boundaries.

In this setting there are a wide variety of management and research goals for the refuge, but what is held in common among the various groups is a need to identify and describe composition and map the pattern of the vegetation communities across the refuge. Thus, as a joint project involving the US Fish and Wildlife Service (FWS), the LTER, the New Mexico Natural Heritage Program (NMNHP) and the New Mexico Chapter of the Nature Conservancy (TNC), a vegetation classification and map of the major dominance types (cover types or alliances) was developed from satellite imagery and field sampling. The major objective for the map was to provide support for: 1) the habitat analysis of wildlife species, and other biodiversity inquiries on rare species and communities; 2) research on ecosystem structure and dynamics in the context of global change; and 3) natural resources planning to sustain the biological and other values of the refuge.

To meet this diversity of objectives required a vegetation map that was well defined and sufficiently detailed to meet most needs, yet relatively inexpensive to produce. Therefore, the map was developed using moderate resolution LANDSAT Thematic Mapper (TM) satellite imagery because it is relatively inexpensive to obtain, and because it is digital and thus lends itself to automated analysis and map production, further lowering costs. Yet with it comes inherent limitations on spatial resolution (28.5 meters), and spectral definition (seven limited-range bands of color), and hence a limit on the precision of any given map. But, even with these constraints, TM was still seen as meeting the goals most efficiently, and sufficient to produce a map of major dominance types at a 1:50,000 scale.

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[3] At the a joint workshop of the World Wildlife Fund, The Nature Conservancy, Pronotura, and Technologico de Monterrey on Biodiversity Conservation Priorities for the Chihuahuan Desert Ecoregion Complex, held in Monterrey, Mexico on Sept. 30, 1997, the Sevilleta National Wildlife Refuge was recognized as one of the most important and biologically significant sites in the Chihuahuan Desert Ecoregion .

[4] The Sevilleta LTER is part of the Biology Department at the University of New Mexico, Albuquerque, NM and is jointly funded by the National Science Foundation and the University of New Mexico.

Although the image analysis and initial map production from TM imagery is mostly automated, a map still requires ground validation, or "truthing." To define classes derived from the imagery requires extensive ground sampling in the context of a well-characterized vegetation classification. To this end, an extensive network of ground points was established with quantitative data on species composition and abundance along with site characteristics. A vegetation classification was developed to categorize and characterize the ground data and to define map classes. The classification not only serves in the development of the vegetation map, it also provides a structure for understanding the range of variability among vegetation communities with respect to composition and environmental setting.

In this report we present the classification and map with details on the methods used in their development, along with an assessment of the map's accuracy, its strengths and limitations. We also include in appendices dichotomous keys to aid in the identification of vegetation communities of the refuge, plant species lists derived from the ground data, and technical information on the image classification. This is the first iteration of the classification and map i.e., Version 1.0, but the map represents the most detailed vegetation map yet developed for the refuge.

Acknowledgements

We would like to thank the Mary Flagler Cary Charitable Trust for their generous financial support of this project through a grant to the New Mexico Chapter of The Nature Conservancy. The Sevilleta National Wildlife Refuge also made significant financial, logistical and personnel contributions, particularly with respect to the field work of Patty Hoban and Dennis McMahon. The Sevilleta LTER provided the extensive technical support for the map production and field work in cooperation with the New Mexico Natural Heritage Program. In addition, we wish to thank Denis Kearns, Troy Maddux, and Susan Gear, crew chiefs and the dedicated field biologist who made the project possible: Lisa Belden, Claire Carpenter, Kristy Giese, Nancy Monteith, Kelli Parker, Jennifer Payne, Richard Smith, and Linda Weiss.

Study Area

Landscape Setting

The Sevilleta National Wildlife Refuge is located in central New Mexico between Albuquerque and Socorro, and is part of a former Spanish land grant that spans the entire width of the Rio Grande Basin (Figure 1). The elevations range from 1,387m (4,550 feet) at the Rio Grande to 2,797m (8,953 feet) at Ladron Peak west of the river, and to 2,195m (7,201 feet) in the Los Pinos Mountains east of the river. The eastern boundary includes virtually the entire Los Pinos Mountain Range. This block-fault range is a southward extension of the Manzano Mountains. The west-facing scarp, composed primarily of Precambrian granite, is in strong contrast to the surrounding plains and hills. The overlying eastern slope is composed of Pennsylvanian and Madera limestone formations. Westward along the base of the scarp are many alluvial fans which overlie a more gently sloping bajada that extends to the Rio Grande. This gently sloping bajada becomes increasingly dissected near the Rio Grande (see Kelly 1977, Machette 1978).

West of the Rio Grande, the Ladron Mountains, providing both the highest elevation and the western boundary of the study area, rise abruptly from the surrounding alluvial fans and outwash plains. They exist as a discrete mountain range independent of nearby ranges. The northern extent of the mountains ends abruptly with precipitous Precambrian granitic cliffs. Steep pediments extend down to the surrounding plateau. The eastern side is a network of many small canyons that end among the rolling foothills. The Rio Salado enters the Sevilleta from the west side and joins the Rio Grande near the middle of Sevilleta. Its wide sandy river bottom is the source of sand forming extensive dunes near the Rio Grande. The southwest quarter of the Sevilleta has numerous low hills composed of basaltic and rhyolitic tuffs, aggraded valleys and dissected lowlands of recent alluvium. Detailed geology and GIS maps of the entire area are available from the LTER.

Variations in elevation, parent material and geomorphic setting have combined to produce a variety of soils within the Sevilleta ranging from thin and rocky residual souls to deep alluvium. Excluding the Rio Grande floodplain, there are 38 named series represented among four soil orders (Aridisols, Entisols, Alfisols and Mollisols). In the floodplain are additional Entisols and Vertisols (Johnson 1988). There is a wide range of variation in soil properties such as texture, depth, presence of and depth to argillic and calcic horizons, A-horizon organic matter content, temperature and moisture regimes and salinity. The variability attributed to topography, geology, and soils over a number of scales contributes directly to the variety of gradients in the Sevilleta.

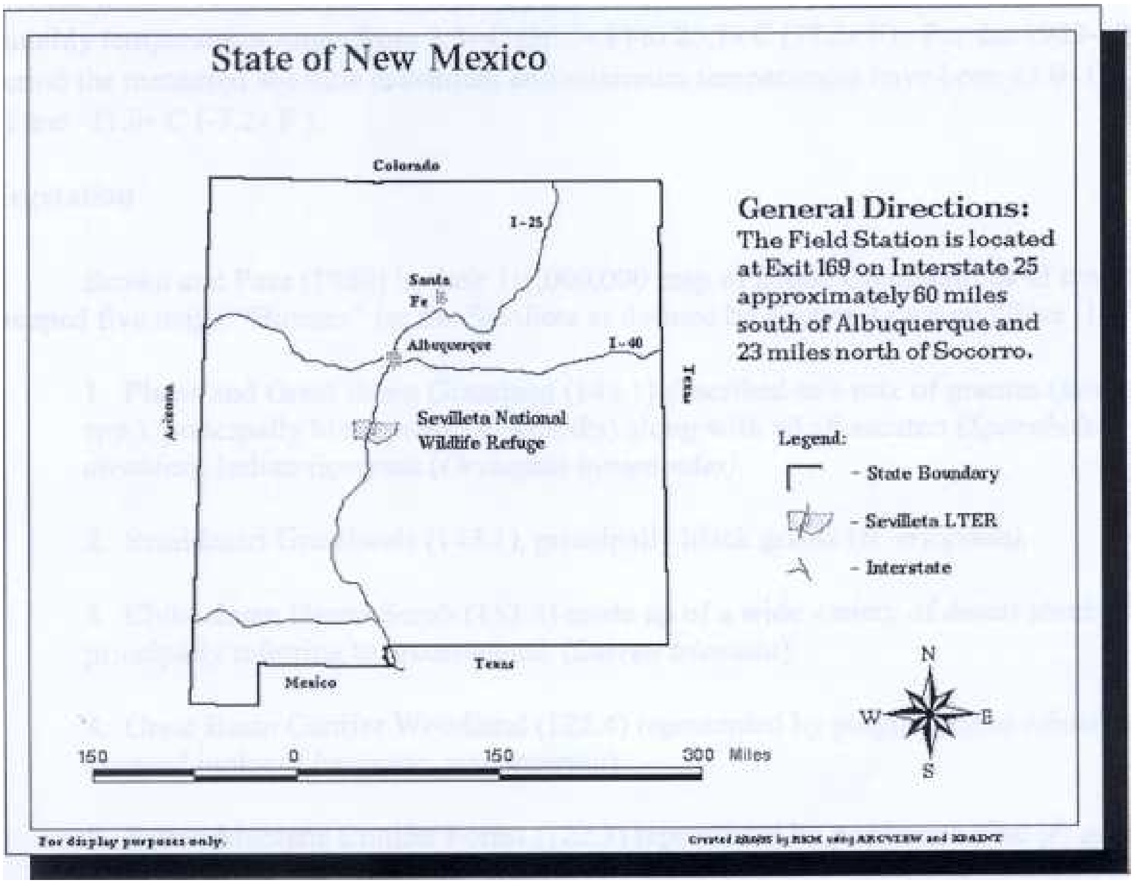


Figure 1. Location of the Sevilleta National Wildlife Refuge

Climate

The Sevilleta climate is characterized by a combination of abundant sunshine, low humidity, and high variability in most meteorological factors. The site exists in the boundary between several major air mass zones, which contributes to the dynamics of the local climate. The annual temperature/precipitation cycle of the Sevilleta is characterized by the dry, cold, winter months of December through February with a transition into the warmer, windy, but still generally dry, spring period of March through May. Spring is followed by a hot, dry June and then a hot but wetter summer "monsoon" period of July and August. This summer precipitation occurs as intense thunderstorms often accounting for over half of the annual moisture. Subsequent to the monsoons, fall is characterized by moderate temperatures with drying from October through November. Importantly, El Niño and La Niña events strongly influence non-monsoon precipitation. The weather of the Sevilleta National Wildlife Refuge is monitored by eight meteorological stations which cover the latitudinal and elevational gradient of the refuge. "Met Alley" located at the Sevilleta Research Station includes a sun photometer, an evaporation dish, a precipitation collector, and a meteorological monitoring station. For the period 1989-1998, mean annual precipitation using all stations was 255 mm (9.95 in) with an annual range of 144 mm (5.6 in) in 1995 to 326 mm (14.2) in 1991. A long-term record (80 years) from a station at Socorro, NM, shows annual values ranging from <100 mm (<3.9 in) to >500 mm (>19.5 in) with a mean of 244 mm (9.5 in). The highest-elevation meteorological site (1975 m) had an annual average of 349 mm (13.6 in) while four lower elevation sites had annual averages ranging from 205 to 255 mm (8.0 to 10.0 in). Temperatures for the eight stations range from mean monthly lows of -4.9° C (23.2° F) and -5.0° C (41° F) during December and January respectively to mean monthly highs of 32.6°C (90.7°F) and 33.1° C (91.6° F) in June and July. Mean monthly temperatures range from 2.5° C (36.5° F) to 25.1° C (77.2° F). For the 1989-1995 period the measured absolute maximum and minimum temperatures have been 43.0° C (109.4° F) and -21.8° C (-7.2° F).

Vegetation

Brown and Pase (1980) in their 1:1,000,000 map of Biotic Communities of the Southwest mapped five major "Biomes" for the Sevilleta as defined by Brown, Lowe and Pase (1979):

1. Plains and Great Basin Grassland (142.1) described as a mix of gramas (*Bouteloua* spp.), principally blue grama (*B. gracilis*) along with alkali sacaton (*Sporobolus airoides*), Indian ricegrass (*Oryzopsis hymenoides).*

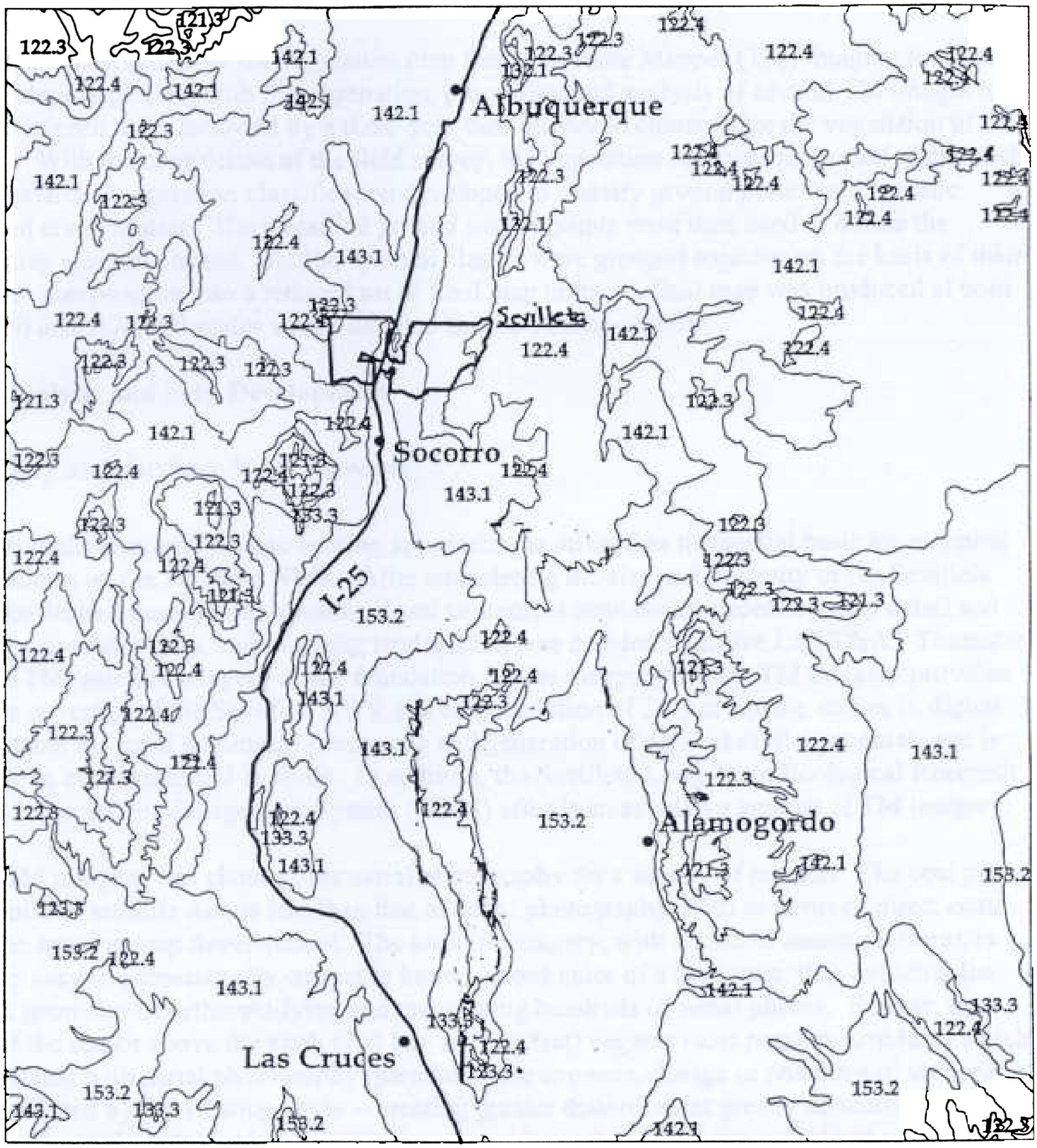
2. Semidesert Grasslands (143.1), principally black grama (*B. eriopoda)*.

3. Chihuahuan Desert Scrub (153.2) made up of a wide variety of desert shrubs, but principally referring to creosotebush (*Larrea trientata*).

4. Great Basin Conifer Woodland (122.4) represented by pinyon (*Pinus edulis*) and oneseed juniper (*Juniperus monosperma*).

5. Petran Montane Conifer Forest (122.3) represented by ponderosa pine (*P. ponderosa*)

With the exception of Petran Montane Conifer Forest, these biomes are well-represented on the Sevilleta and served to help define many of the questions posed by the LTER (Figure 2).



121.3	Rocky Mountain Subalpine Conifer Forest	132.1	Great Basin Montane Scrub
122.3	Rocky Mountain Montane Conifer Forest	133.3	Interior Chaparral
122.4	Great Basin Conifer Woodland	142.1	Plains and Great Basin Grassland
123.3	Madrean Evergreen Forest and Woodland	143.1	Scrub-Grassland (Semi-Desert Grassland)
		153.2	Chihuahuan Desertscrub

Figure 2. The relation of the Sevilleta National Wildlife Refuge to the major biomes as mapped by Brown, Lowe and Pase (1979).

Materials and Methods

The development of the vegetation map from Thematic Mapper (TM) imagery involved a series of steps beginning with the acquisition, processing and analysis of several TM images to create an interim map, followed by a three-year field survey to characterize the vegetation of the Sevilleta. With the completion of the field survey, the vegetation data was processed, databased, and a provisional vegetation classification developed to classify ground points into specific vegetation communities. The classified ground survey points were then used to define the interim map spectral classes. Similar spectral classes were grouped together on the basis of their vegetation composition into a reduced set of final map units. A final map was produced at both 1:250,000 and 1:70,000 scales with a detailed annotated map legend.

Image Analysis and Map Development

TM Imagery and Ancillary Map Coverages

A multi-temporal remote-sensing approach was utilized as the spatial basis for mapping the vegetation on the Sevilleta NWR. After considering the size and diversity of the Sevilleta NWR, the desired time frames, personnel and equipment limitations, necessary map detail and flexibility, available data, and mapping strategies, it was decided to utilize LANDSAT Thematic Mapper (TM) satellite imagery as the foundation for the mapping effort. TM imagery provides complete coverage of the Sevilleta NWR at a cell resolution of 28.5 m square, comes in digital form suitable for rapid automated processing and generation of derived digital products, and is amenable to multi-temporal analysis. In addition, the Sevilleta Long Term Ecological Research (LTER) Information Management System (SIMS) affords an extensive archive of TM imagery.

TM imagery was chosen over aerial photography for a variety of reasons. The cost per-square-mile of satellite data is less than that of aerial photography, both in terms of direct costs and in the ensuing map development. The satellite imagery, with its stable sensor platform, is relatively easy to geometrically correct to known coordinates of a base map, thus avoiding the complex geometry of orthorectifying and mosaicking hundreds of aerial photos. Further, the height of the sensor above the earth (705 km. for Landsat) negates most parallax problems which are associated with 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.

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. 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. Table 1 summarizes the function of each band.

TM integrates the spectral characteristics of each band over the Instantaneous Field of View (IFOV) of an area of 28.5m x 28.5m; 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.

There are constraints to using TM imagery. Some of the principal problems occur when vegetation is not the major cover type and differential reflectances of various geologic substrates dominate. As with aerial photography, topographic effects creating shadows within narrow valleys and steep escarpments can also cause problems. A proper combination of field sampling and image processing techniques helps to alleviate many problems. Furthermore, the sensor cannot penetrate clouds or snow, but other TM images covering the same area free of clouds or snow can be acquired to fill these "gaps" in coverage. Finally, because of edge effects among a small number of spatially contiguous pixels, small occurrences of vegetation types are difficult to reliably map. Hence the minimum mapping unit polygon size is normally 0.5 ha or larger.

Other ancillary GIS layers used in the sampling and evaluation process were: a surface terrain model created by acquiring and stitching (mosaicking) together the 15 US Geological Survey (USGS) 7.5 minute Digital Elevation Models (DEMs) that cover the study area. The DEMs were further processed to create slope and aspect images. Digital Line Graphs (DLGs) of road and drainage networks were compiled for the study area in Arc/Info (7.03) by the LTER.

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	Principal applications
1	0.45-0.52	Blue	Designed for water body penetration, making it useful for coastal water mapping. Also useful for soil/vegetation discrimination, forest type mapping, and cultural feature identification.
2	0.52-0.60	Green	Designed to measure green reflectance peak of vegetation for vegetation discrimination and vigor assessment. Also useful for cultural feature identification.
3	0.63-0.69	Red	Designed to sense in a chlorophyll absorption region aiding in plant species differentiation. Also useful for cultural feature identification.
4	0.76-0.90	Near-infrared	Useful for determining vegetation types, vigor, and biomass content, for delineating water bodies, and for soil moisture discrimination.
5	1.55-1.75	Mid-infrared	Indicative of vegetation moisture content and soil moisture. Also useful for differentiation of snow from clouds.
6	10.4-12.5	Thermal infrared	Useful in vegetation stress analysis, soil moisture discrimination, and thermal mapping applications.
7	2.08-2.35	Mid-infrared	Useful for discrimination of mineral and rock types. Also sensitive to vegetation moisture content.

Multi-temporal Image Analysis

Due to the difficulty of separating closely allied taxa, such as grasses, from one another in a single satellite image, it was decided to exploit the seasonal phenological behavior of contrasting species (e.g., cool-season versus warm-season grasses) to improve the image classification work. A multi-temporal stack of TM images provides the time component in the analysis. A transformation of the TM images to Normalized Difference Vegetation Index (NDVI) images provides the phenological "greenness" measure. In essence, image pixels that exhibit similar "greenness" spectral behavior through time should cluster together during image classification, and these clusters in turn should theoretically be associated with some definable vegetation classes on the ground. Furthermore, a sufficiently long multi-temporal stack should yield classes that reflect plant responses not only to seasonal but to climate fluctuations such as El Nino as well. Finally, due to an initial lack of well-distributed field plots, an unsupervised approach to image classification was employed in this project.

Twelve of the available 21 TM scenes were selected out of the SIMS archive, spanning the period 1987 - 1993, and including the following scene dates:

10 September 87, 28 September 88, 19 May 89, 10 October 89
06 May 90, 11 September 90, 23 April 91, 09 April 92
04 June 92, 02 October 92, 30 May 93, 19 September 93

Selections were made to include seasonal and annual variation, eliminate cloud cover, minimize topographic shadow, and minimize satellite path edge data loss.

Image preparation consisted of geometric rectification to the UTM (NAD-27 datum) coordinate system to less than 28.5 m RMS error, utilizing ground control points identifiable in the imagery. Radiometric calibration and subsequent transformation to at-satellite reflectance was performed by utilizing standard procedures published in Markham and Barker (1986), with required parameters generated from various orbital and astronomical software packages such as SatTrack, SkyMap, and Xephem. Finally, images were converted to NDVI representations using the standard formula for TM data:

$$NDVI = (TMband4 - TMband3) / (TMband4 + TMband3)$$

and then composited into a single 12-layer image file.

In order to train the computer to recognize the spectral characteristics of the diverse plant communities represented in the satellite imagery, an unsupervised training algorithm (ERDAS Imagine ISODATA) was run on the 12-layer image to generate 32 spectral clusters and corresponding signatures. This number represented a three-fold increase over the final expected number of classes, which provides for a finer partitioning of the imagery and subsequent regrouping into major classes. Evaluation of signatures utilizing a Jeffries-Matusita Signature Separability Analysis indicated good separation among the clusters. These 32 signatures were then used along with a Maximum Likelihood Classifier to produce a classified image containing 32 image classes. A follow-up Chi-square threshold test of potential pixel misclassification indicated good classification results for most classes of substantial area. One notable exception to the above procedure occurred in the northwest corner (Ladron Peak) and far east (Los Pinos) border of the Sevilleta NWR where satellite data are occasionally missing due to variations in the orbits of the Landsat satellites. As mentioned above, scene selection attempted to minimize these regions of data loss, but in the worst case, only 7 of the 12 scenes had overlapping coverage for some pixels. In those regions, each pixel was evaluated for exact satellite coverage and assigned an image class based on its closest (Euclidean) spectral distance to a respective class signature (subsetted to eliminate appropriate signature axes or dimensions).

An interim map based on the 32 image classes was developed as foundation for the development of the final map. Final map development was a two-fold process of characterizing and developing a classification of the vegetation communities based on ground survey data, and then relating specific vegetation communities to the image classes of the interim map to form final map units.

Field Surveys

Field surveys were conducted over a three-year period during the growing seasons of 1994 through 1996 to gather data on the vegetation composition of the 32 spectral classes and to develop a provisional vegetation classification for the Sevilleta. Two sampling strategies were used: a *directed* sampling network based on the distribution of TM class patches in the preliminary vegetation map to ensure adequate evaluation of all spectral classes of the map, and a *reconnaissance* sampling network based on vegetation pattern discerned on the ground to ensure adequate coverage of the range of variability among vegetation communities.

Directed Sampling Network

This was an extensive sampling network developed primarily to ensure the vegetation variation was sampled among all spectral mapping units developed from the unsupervised classification of the TM imagery. A stratified random sampling design was adopted for this purpose, with an equal number of plots randomly chosen from each image class. The network was designed to maximize acquisition of as many ground points as possible among all spectral units. To improve field efficiency, Arc/Info GRID tools were used to restrict sample selection to sample buffer corridors paralleling existing roads. Eligible polygons were required to be at least 4 x 4 contiguous pixels in size (approximately 120 m x 120 m) to accommodate image rectification and GPS (Global Positioning Systems) navigation errors. Working field maps containing target plot coordinates were provided to field crews, along with GPS units, for locating and installing plots. Field crews were directed to points on the ground representing the polygons using GPS (global positioning systems). Sampling points were established as close to the center of the delineation as possible, with obvious minor inclusions avoided (if the delineation appears to be mostly grassland, then a shrubland inclusion was avoided).

Sample plots were 400 sq. meters in size, and circular with a radius of 11.3 meters. A list of all vascular plant species within the plot, stratified by lifeform (shrub, grass and forb layers), was compiled and cover estimated for each species using a modified Krajina Scale. Because we are working in arid and semi-arid environments, the Krajina scale is optimal because it has finer gradation at lower levels of cover than other scales such as the Braun-Blanquet scale, but not so highly refined that estimates cannot be made quickly. Along with abundance estimate, the average height of the species was estimated. Site attributes evaluated include: percent slope, shape and aspect, surface soil texture and color, ground cover (percent rock, gravel, bare soil and litter), parent material and erosion type. Plant vouchers specimens were collected as necessary and confirmed at the University of New Mexico Herbarium. Species names follow Kartesz (1994) and a species list derived from the plot data is provided in Appendix A.

Environmental information to be collected is also constrained by time factors and available expertise. Soil surface horizon (epipedon) color and texture, including coarse fraction on site are proposed, or alternatively, collecting a sufficient sample in a bag and/or box for later analysis (color, texture, structure, pH, OM etc.). Landform identification into relatively straight forward categories following Gile, Hawely and Grossman (1981) is also included, along with rock type. Other information will include slope, elevation and aspect.

A total of 119 plots were collected in this way in the Fall of 1995 and 1996 by LTER field teams. Locations for each plot were determined using GPS with differential post-processing to +/- 5 meters precision. Each plot was staked with rebar covered with PVC and tagged. The distribution of sample points is shown in Figure 3.

Due to procedural errors (e.g., entering wrong target coordinates, or improper configuration of GPS unit before entering coordinates) and GPS navigation errors (e.g., due to poor GPS conditions or activation of DOD Selective Availability), plots were occasionally installed in incorrect locations, the result being possible shifts in image class and/or polygon sampling, leading to possible violations of plot suitability criteria. As a consequence, all field plots (including reconnaissance type plots) were subjected to a final plot suitability analysis. Plots were deemed suitable for use in image class labeling if they satisfied the following criteria: 1) fell outside a 50-meter road exclusion buffer, 2) fell within a polygon of minimum 3 x 3 pixel core region, 3) occurred in a region with complete 12-scene satellite data, and 4) did not fall in an image class outlier pixel as determined by the above mentioned Chi-square threshold test (95% C.L.) of Mahalanobis Distances, by signature.

Reconnaissance Sampling Network

To characterize as fully as possible the characteristics and range of variation among vegetation communities, a network of more intensively sampled reconnaissance vegetation plots was established that was independent of the above directed sampling. Based on extensive field reconnaissance, plots were established in replicate stands of homogeneous vegetation representing the major dominance types (alliances) of the refuge. The same basic data was collected on these plots, but with added information on soils (full soil profile description with sampling for physical/chemical analysis by soil horizon), and species lists that recorded not only species within the plot, but also in the surrounding stand.

A total of 132 plots were collected in this manner in the Fall of 1994 and 1995 by field teams composed of NMNHP, LTER and US Fish and Wildlife Service personnel (Figure 3). Of these plots, 47 have full soil profile descriptions with analyses performed at New Mexico Tech University. All plots were also located with GPS and monumented with rebar and PVC. Although these plot were not part of the stratified random design above, they were tested for suitability for defining image classes in the same manner of the directed sample. Those that met the requirements were also used to define image classes. All plots, both directed and reconnaissance, were used for developing the vegetation classification.

Provisional Vegetation Classification Development

All plot data was processed following quality control procedures of the LTER and NMNHP. Species names were confirmed, and a database constructed containing all floristic and site information for each plot. Agglomerative cluster analyses using the floristic data were used to group plots into vegetation associations based on overall floristic similarity. These associations were named based on the overstory dominant species (Alliance species) and a co-dominant or associated indicator species. Plant associations were organized into a hierarchical vegetation classification following the structure and guidelines of the United States National Vegetation Classification (Federal Geographic Data Committee 1996). The definitions for each level of this hierarchy are presented in Table 3.

Based on these guidelines, a hierarchical dichotomous decision key to the alliances of the Sevilleta was developed which outlines the specific rules for defining particular vegetation types (Appendix B). The efficacy of the decision rules was tested using canonical discriminant analysis within and among the major formations. The plant associations were also compared with associations for the Southwest that have previously been identified in the NMNHP communities list of the Biological and Conservation Database (BCD).

Final Map Unit Development and Map Production

Final Map Units

All field plots were evaluated and assigned to a plant association according to the vegetation classification. However, only suitable replicate field plots were utilized to describe each image class, and the classification was used only down to the Alliance level for map units. These labeled image classes were then aggregated into higher level vegetation groups, typically at the Alliance Group/Regional Biome levels. In an attempt to clean up obvious disparities in the map resulting from cross-classifications and excessive class variability, a final visual inspection was conducted utilizing 1:6000 scale aerial photos, and expert knowledge from various Sevilleta NWR-familiar personnel, to split, resort, and regroup some image classes based primarily on a spatial context.

Using only the suitable plots, the vegetation composition of each of the 32 spectral classes was defined in terms of the vegetation classification. Similar spectral classes were then grouped based on vegetation similarity and spatial relationships into final Map Units (MU) representing the major vegetation types of Sevilleta. Descriptions for each MU were developed which provide brief summaries of the vegetation composition of each unit along with the list of the subset of spectral classes that are included in each unit.

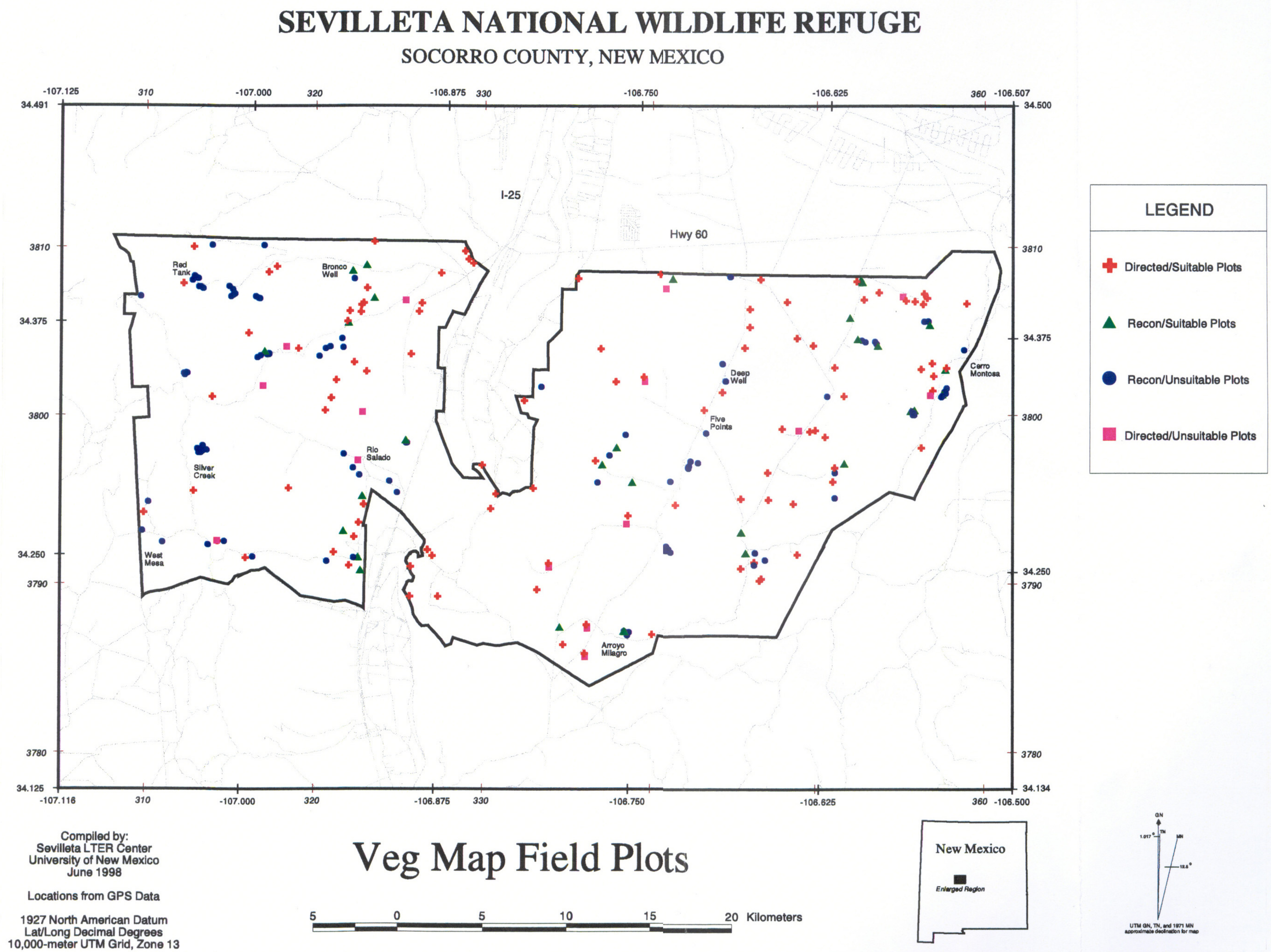


Figure 3. Sample locations for the Sevilleta National Wildlife Refuge Vegetation Map (see text for details on plot types).

Final Map Production

To create the final map, a filtering process was applied to create a minimum mapping unit size of 0.5 hectares. The procedure first eliminates 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 0.5 hectares. In addition, based on informal accuracy assessment using aerial photos, a small number of obvious errors were detected and addressed through a direct editing process.

Hardcopy map production was accomplished within the ArcView environment, with colors selected to enhance contrast between contiguous vegetation classes. Hard copies of the final map were then plotted at 1:250,000 for the report, and as a 1:70,000 scale wall map. The digital map products are being documented and readied for archival within the Sevilleta Information Management System SIMS for easy access via the WWW.

Map Validation

No formal validation of the map units has been performed at this time. A systematic random sampling along roads would be most efficient and cost effective, but was beyond the resources of this project. Informally, the map was accuracy "checked" using aerial photos and other available ground data.

Results

Vegetation Classification

A provisional, hierarchical vegetation classification for the Sevilleta National Wildlife Refuge is presented in Table 2. There were 87 Plant Associations (PA's) recognized among 27 Alliances (cover types). Of the 87 PA's, 40 are considered established types with at least five plots from New Mexico, or well documented in the literature. The remaining 47 are provisional and need further confirmation, but were still used to define mapping units.

The alliances, because they were the fundamental target of the mapping, are the focus here. As a whole, the range of variability among alliances reflects the high diversity of the Sevilleta, from the Pinyon (*Pinus edulis*) and Oneseed Juniper (*Juniperus monosperma*) woodland Alliances of the highest elevations in the Los Pinos and Sierra Ladrones, to the lowland and swale grasslands of the Alkali Sacaton (*Sporobolus airoides*) and Giant Sacaton (*Sporobolus wrightii*) Alliances. At low elevations are also found the desert shrublands: the Creosotebush (*Larrea tridentata*), Honey Mesquite (*Prosopis glandulosa)* and Broom Dalea (*Psorothamnus scoparius*) Alliances of Chihuahuan Desert affinity from the south, and the Fourwing Saltbush (*Atriplex canescens*), and Shadscale (*Atriplex confertifolia*) Alliances extending southward form the cold desert of the Great Basin in Utah.

Table 2. Provisional Vegetation Classification for the Sevilleta National Wildlife Refuge.

Hierarchy follows the US National Vegetation Classification system (Federal Geographic Data Committee, 1996). Hierarchical levels are as follows: I= Class, II=Subclass, III= Group, IV=Formation, V. Regional Biome Type, VI= Alliance with implied level VII Plant Associations (PA's). Regional Biome Type is not a formal part of the National Classification, but is a part of the New Mexico GAP classification and map (Thompson et al. 1986).

I. Woodland
  II. Evergreen woodland
    III. Temperate or subpolar needle-leaved evergreen woodland
      IV. Rounded-crown temperate or subpolar needle-leaved evergreen woodland
        V. Rocky Mountain Lower Montane Conifer Woodland
          VI. Ponderosa Pine (*Pinus ponderosa*) Woodland Alliance

        V. Rocky Mountain/Great Basin Conifer Woodland
          VI. Pinus edulis (Pinyon Pine) Woodland Alliance
            Pinus edulis/Bouteloua gracilis PA
            Pinus edulis/Stipa comata PA
            Pinus edulis-Quercus turbinella PA
            Pinus edulis/Muhlenbergia montana PA
            Pinus edulis/Yucca baccata PA

          VI. Oneseed Juniper (*Juniperus monosperma*) Woodland Alliance
            Juniperus monosperma/Bouteloua eriopoda PA
            Juniperus monosperma/Bouteloua gracilis PA
            Juniperus monosperma/Quercus turbinella PA
            Juniperus monosperma/Stipa neomexicana PA
            Juniperus monosperma/Muhlenbergia montana PA
            Juniperus monosperma/Bouteloua hirsuta PA

  II. Deciduous Woodland
    III. Cold-deciduous woodland
      IV. Seasonally/temporarily flooded cold-deciduous woodland
        V. Lowland Broad-leaved Deciduous Forested Wetland
          VI. Rio Grande or Plains Cottonwood (*Populus deltoides*) Woodland Alliance
            Populus deltoides/Distichlis spicata PA

Shrubland
  II. Deciduous shrubland (scrub)
    III. Cold-deciduous shrubland
      IV. Temperate cold-deciduous shrubland
        V. Rocky Mountain Montane Scrub
          VI. Mountain Mahogany (*Cercocarpus montanus*) Shrubland Alliance
            Cercocarpus montanus/Bouteloua curtipendula PA
            Cercocarpus montanus/Bouteloua gracilis PA
            Cercocarpus montanus/Stipa neomexicana PA

      IV. Seasonally/temporarily flooded cold-deciduous shrubland
        V. Lowland Broad-leaved Deciduous Scrub-shrub Wetland
          VI. Salt Cedar (*Tamarix ramosissima*) Shrubland Alliance
            Tamarix ramosissima/Sporobolus airoides PA
            Tamarix ramosissima/Sparse PA

III. Extremely xeromorphic deciduous shrubland (subdesert)
  IV. Extremely xeromorphic deciduous shrubland with succulents
    V. Chihuahuan Deciduous Desert Scrub
      VI. Broom Dalea (*Psorothamnus scoparius*) Shrubland Alliance
        Psorothamnus scoparius/Oryzopsis hymenoides PA
        Psorothamnus scoparius/Sporobolus flexuosus PA

      VI. Ocotillo (*Fouquieria splendens*) Shrubland Alliance
        Fouquieria splendens/Sparse PA

      VI. Honey Mesquite (*Prosopis glandulosa*) Shrubland Alliance
        Prosopis glandulosa-Atriplex canescens Sparse PA
        Prosopis glandulosa/Bouteloua eriopoda PA
        Prosopis glandulosa/Sporobolus flexuosus PA
        Prosopis glandulosa-Gutierrezia sarothrae PA

II. Evergreen Shrubland
  III. Temperate broad-leaved evergreen shrubland
    IV. Sclerophyllous temperate broad-leaved evergreen shrubland
      V. Interior Chaparral
        VI. Shrub Live Oak (*Quercus turbinella*) Shrubland Alliance
          Quercus turbinella/Bouteloua curtipendula PA

  III. Microphyllous evergreen shrubland
    IV. Undefined microphyllous evergreen shrubland)
      V. Plains-Mesa Microphyllous Sand Scrub
        VI. Sandsage (*Artemisia filifolia*) Shrubland Alliance
          Artemisia filifolia/Sporobolus flexuosus PA

  III. Extremely xeromorphic (subdesert)
    IV. Facultatively deciduous extremely xeromorphic subdesert shrubland
      V. Great Basin Desert Scrub
        VI. Fourwing Saltbush (*Atriplex canescens*) Shrubland Alliance
          Atriplex canescens/Sporobolus airoides PA
          Atriplex canescens/Sporobolus wrightii PA
          Atriplex canescens/Sparse PA
          Atriplex canescens/Muhlenbergia porteri PA
          Atriplex canescens/Scleropogon brevifolius PA

        VI. Shadscale (*Atriplex confertifolia*) Shrubland Alliance
          Atriplex confertifolia/Sparse PA

    IV. Broad-leaved and Microphyllous-leaved evergreen extremely xeromorphic subdesert shrubland
      V. Chihuahuan Evergreen Desert Scrub
        VI. Creosotebush (*Larrea tridentata*) Shrubland Alliance
          Larrea tridentata/Bouteloua eriopoda PA
          Larrea tridentata/Erioneuron pulchellum PA
          Larrea tridentata/Muhlenbergia porteri PA
          Larrea tridentata/Sparse PA
          Larrea tridentata/Hilaria jamesii PA
          Larrea tridentata/Sporobolus airoides PA
          Larrea tridentata-Gutierrezia sarothrae PA
          Larrea tridentata/Scleropogon brevifolius PA

Table 2. Provisional Vegetation Classification -- Sevilleta National Wildlife Refuge (Cont.).

I. Herbaceous vegetation
 II. Perennial graminoid (grasslands)
  III. Temperate or subpolar grassland (without a significant tree or shrub layer)
   IV. Tall bunch temperate grassland
    V. Lowland/Swale Tall Desert Grassland
     VI. Giant Sacaton (*Sporobolus wrightii*) Herbaceous Alliance
       Sporobolus wrightii-Panicum obtusum PA
       Sporobolus wrightii/Monotypic PA

   IV. Medium-tall bunch temperate grassland
    V. Rocky Mountain Subalpine-Montane Grassland
     VI. Mountain Muhly (Muhlenbergia montana) Herbaceous Alliance
       Muhlenbergia montana/Yucca baccata PA

    V. Plains-Mesa-Foothill Mid-grass Grassland
     VI. New Mexico Needlegrass (*Stipa neomexicana*) Herbaceous Alliance
       Stipa neomexicana-Bouteloua eriopoda PA

     VI. Sand Dropseed (*Sporobolus cryptandrus*) Herbaceous Alliance
       Sporobolus cryptandrus/Aristida purpurea PA

    V. Lowland/Swale Medium-tall Desert Grassland
     VI. Alkali Sacaton (*Sporobolus airoides*) Herbaceous Alliance
       Sporobolus airoides Monotype

   IV. Short sod temperate or subpolar grasslands (including sod or mixed sod and bunch graminoids)
    V. Plains-Mesa-Foothill Short-grass Grassland
     VI. Purple Threeawn (*Aristida purpurea*) Herbaceous Alliance
       Aristida purpurea/Thymophila acerosa PA
       Aristida purpurea-Aristida adscensiones PA
       Aristida purpurea/Gutierrezia sarothrae PA

     VI. Blue Grama (*Bouteloua gracilis*) Herbaceous Alliance
       Bouteloua gracilis-Lycurus phleoides PA
       Bouteloua gracilis-Muhlenbergia torreyi PA
       Bouteloua gracilis/Opuntia clavata PA
       Bouteloua gracilis/Opuntia phaeacantha PA
       Bouteloua gracilis-Tridens muticus PA
       Bouteloua gracilis/Yucca glauca PA
       Bouteloua gracilis/Monotypic PA
       Bouteloua gracilis-Scleropogon brevifolius PA
       Bouteloua gracilis/Yucca baccata PA

     VI. Hairy Grama (*Bouteloua hirsuta*) Herbaceous Alliance
       Bouteloua hirsuta-Aristida purpurea PA
       Bouteloua hirsuta-Bouteloua gracilis PA
       Bouteloua hirsuta/Dalea formosa PA

Table 2. Provisional Vegetation Classification -- Sevilleta National Wildlife Refuge (Cont.).

V. Great Basin Short-grass Grassland
VI. Galleta (*Hilaria jamesii*) Herbaceous Alliance
Hilaria jamesii-Bouteloua eriopoda PA
Hilaria jamesii-Oryzopsis hymenoides PA
Hilaria jamesii-Scleropogon brevifolius PA
Hilaria jamesii-Sporobolus contractus PA
Hilaria jamesii-Bouteloua gracilis PA

IV. Short bunch temperate or subpolar grassland
V. Lowland/Swale Short-grass Desert Grassland
VI. Scleropogon brevifolius Alliance
Scleropogon brevifolius-Sporobolus contractus PA
Scleropogon brevifolius/Monotypic PA
Scleropogon brevifolius/Sparse PA

VI. Gyp Dropseed (*Sporobolus nealleyi*) Shrub Herbaceous Alliance
Sporobolus nealleyi/Selinocarpus lanceolatus PA

III. Temperate or subpolar grassland with a shrub layer (generally 10-25%)
IV. Medium-tall sod temperate or subpolar grasslands (including sod or mixed sod and bunch graminoids) with sparse, broad-leaved evergreen or semi-evergreen shrubs
V. Plains-Mesa-Foothill Shrub/Medium-tall Grassland
VI. Sideoats Grama (Bouteloua curtipendula) Shrub Herbaceous Alliance
Bouteloua curtipendula/Nolina microcarpa PA

IV. Short sod temperate or subpolar grasslands (including sod or mixed sod and bunch graminoids) with sparse, broad-leaved evergreen or semi-evergreen shrubs
V. Plains-Mesa-Foothill Shrub/Short-grass Grassland
VI. Blue Grama (*Bouteloua gracilis*) Shrub Herbaceous Alliance
Bouteloua gracilis/Krascheninnikovia lanata PA

IV. Short temperate or subpolar grasslands with sparse xeromorphic (evergreen or deciduous) shrubs
V. Foothill-Piedmont Desert Shrub-Grassland
VI. Black Grama (*Bouteloua eriopoda*) Shrub Herbaceous Alliance
Bouteloua eriopoda-Bouteloua curtipendula PA
Bouteloua eriopoda-Bouteloua gracilis PA
Bouteloua eriopoda/Thymophylla acerosa PA
Bouteloua eriopoda-Sporobolus flexuosus PA
Bouteloua eriopoda-Tiquilia canescens PA
Bouteloua eriopoda/Yucca glauca PA
Bouteloua eriopoda/Artemisia bigelovii PA
Bouteloua eriopoda/Ephedra torreyana PA
Bouteloua eriopoda/Parthenium incanum PA
Bouteloua eriopoda-Aristida purpurea PA

Between the woodlands and desert shrublands lie the extensive grasslands of the mid-elevations of the Sevilleta. Among the desert grasslands, the most important is the Black Grama (*Bouteloua eriopoda*) Alliance representing the Chihuahuan Desert Grassland group, and the Galleta (*Hilaria jamesii*) and Indian Ricegrass (*Oryzopsis hymenoides*) Alliances from the Great Basin group. On more mesic sites, Plains grasslands become more prominent and represented by the Blue Grama (*Bouteloua gracilis*) and Hairy Grama (*B. hirsuta*) Alliances. Plains-Mesa Sandscrub represented by the Sandsage (*Artemisia filifolia*) Alliance is found occasionally on sandier sites in the grasslands. Chaparral and montane shrublands represented Shrub Live-oak (*Quercus turbinella*) and Mountain Mahogany (*Cercocarpus montanus*) Alliances, respectively, grade up from the grasslands along the lower mountain slopes up in amongst the juniper and pinyon woodlands.

The alliances separate out well from one another floristically with only limited amounts of overlap. A canonical discriminant analysis (CDA) of the major grassland versus shrubland alliances indicated they could be significantly separated from one another based on the key species dominants (Figures 4 and 5). Creosotebush (LATR2) was isolated on CDA axis 2 from the grassland alliances. The Galleta (HIJA) Alliance was separated out on the negative side of CDA axis 1. Similarly, Saltbush (ATCA2) was fairly well discriminated on CDA 4, and Black Grama (BOER4) and Blue Grama (BOGR20) on axis 3.

In a separate analysis, the higher elevation woodlands are also well-separated from the mid-elevation grasslands (Figure 6). Furthermore, the Oneseed Juniper (JUMO) Alliance representing lower elevation woodland savannas was well isolated on CDA axis 2 from the Pinyon (PIED) Alliance of the higher mountain tops of CDA axis 1.

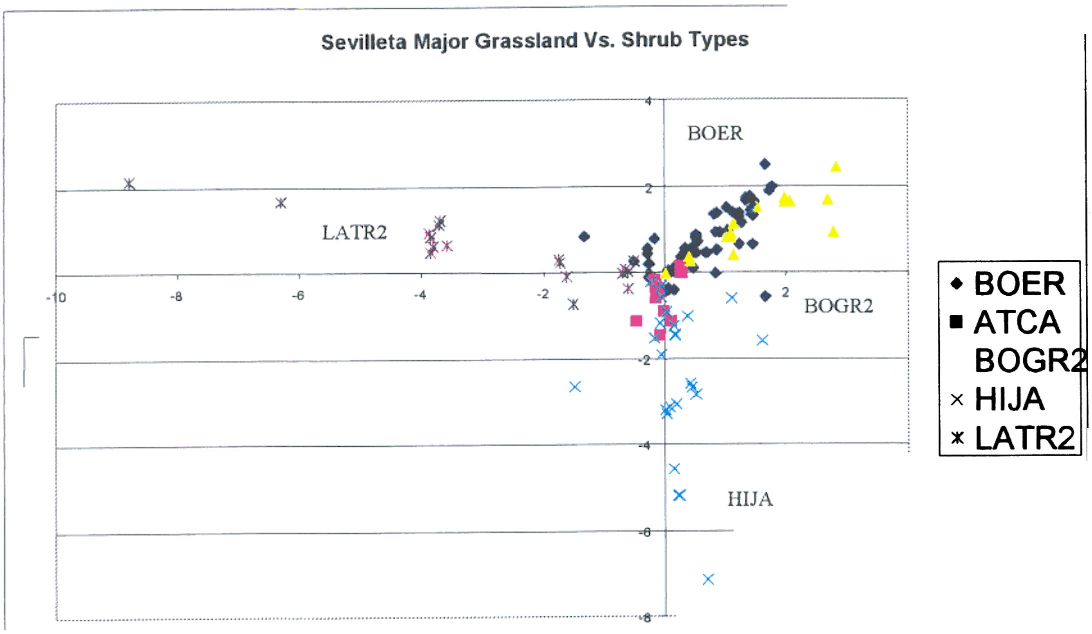


Figure 4. Canonical Discriminant Analysis (CDA) of grassland versus shrub alliances. Functions 1 and 2

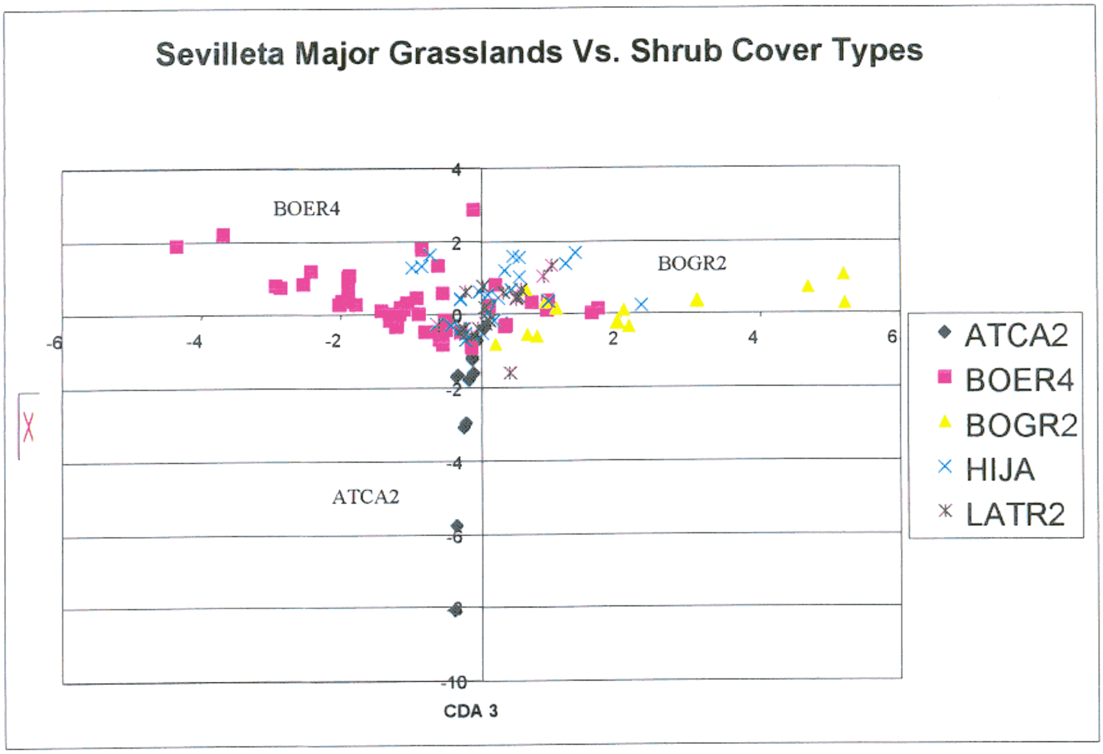


Figure 5. Canonical Discriminant Analysis (CDA) of grassland versus shrub alliances. Functions 3 and 4

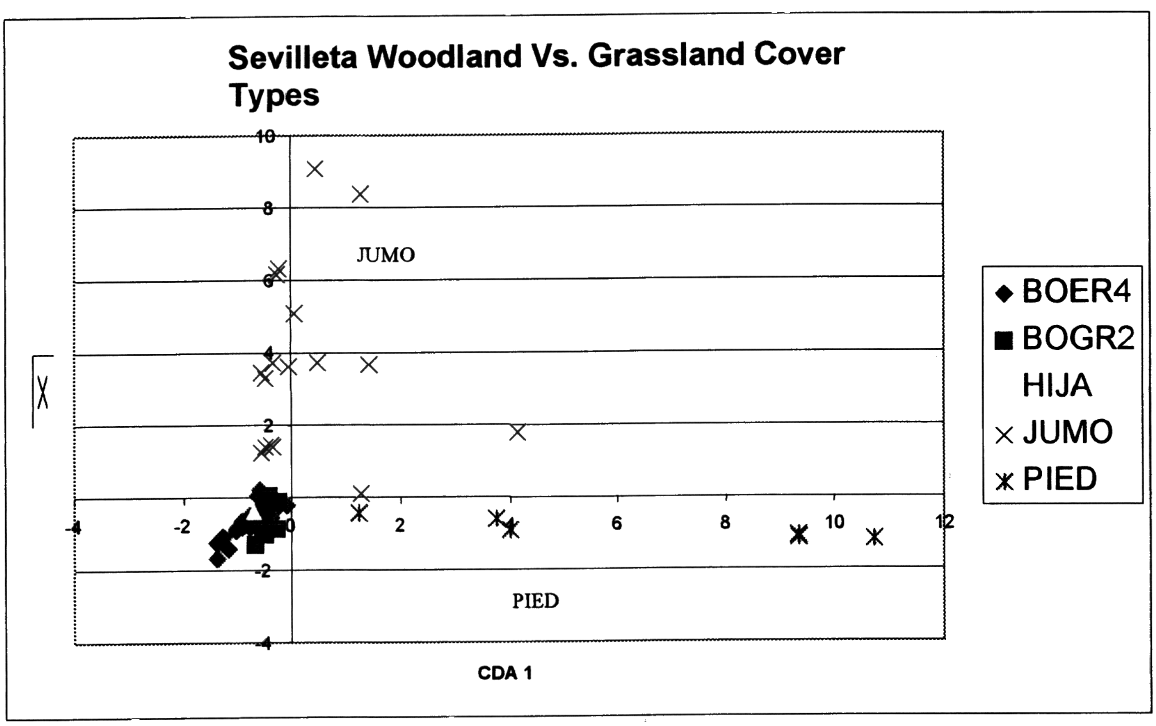


Figure 6. Canonical Discriminant Analysis (CDA) of woodland versus grassland alliances. Functions 1 and 2.

Sevilleta National Wildlife Refuge Vegetation Map

Version 1.0 of the Sevilleta Vegetation Map is presented in Figure 7 at approximately 1:250,000 scale. Figure 7 is primarily for illustration purposes; a full size version at working scale of 1:70,000 has also been produced separately that is approximately three by four feet. The map is available in a digital format and can be reproduced at any scale, but 1:70,000 has historically been the most commonly used scale in the project area for day to day uses.

The final vegetation map is composed of 13 major map units that represent the grouping of the original 32 TM spectral image classes of the unsupervised classification (Table 3). The definition of each major map unit is based on four to ten field plots, and there is sometimes a wide variation within a unit with respect to Alliances (reflected in the labels of the image classes of Table 3). As a result of this wide variation, the map units sometimes reflect somewhat broad classes from a vegetation perspective, but the overall pattern of biome differences and transitions is readily apparent upon inspection. Montane woodland and savanna units (11 & 12) dominate the mountainous areas of the Los Pinos and Ladrones. At lower elevations along foothills and piedmont plains (bajadas) grassland units prevail. The higher elevation grasslands are Plains Grasslands (7) that intermix further downslope with Chihuahuan Desert Grasslands dominated by black grama (5 & 6). Map unit 4 represents a transition from Chihuahuan Desert to Great Basin Grasslands dominated by Indian ricegrass and galleta. Great Basin influences increase going north-westward across the Rio Grande as indicated by the distribution of Great Basin Grasslands (3) strongly dominated by Indian ricegrass and galleta (particularly at lower elevations). The desert grassland units are inter-fingered with desert shrublands dominated by saltbush & broom dalea (10) and creosote (9). In lowland basins and swales are dominated by sacaton and burrograss (*Scleropogon brevifolius*) grasslands (8) along with sparsely vegetated alluvial flats and badlands (2). Finally, along the washes and in the Rio Grande corridor are Riparian Woodlands (13) composed of cottonwood (*Populus deltoides var. wislizeni*) and salt cedar (*Tamarix ramosissima*).

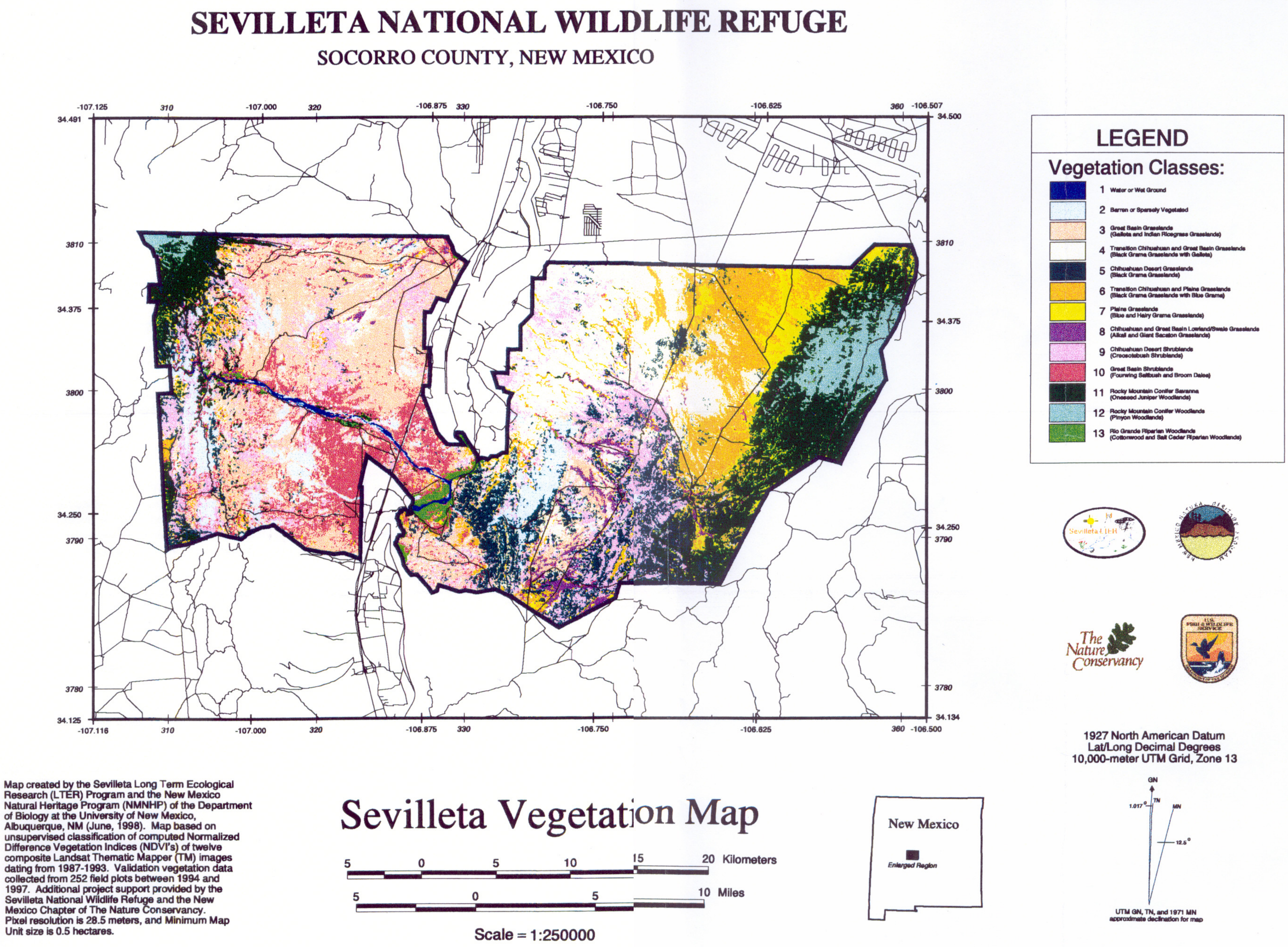


Figure 7. Vegetation map of Sevilleta National Wildlife Refuge, Version 1.0

Table 3. Annotated legend for the Sevilleta National Wildlife Refuge Vegetation Map.

There are 13 major map units indicated by number, name, and size in hectares and acres. A brief biological and physical description is given along with the Thematic Mapper (TM) spectral classes included in each map unit. The TM classes are indicated by their class number and are labeled according to the major component cover types (Alliances) they represent (see Table 1). Inclusions representing less than 10% of the class are also indicated. Elevations are derived from the map and represent a modal range (95% of the entire range).

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1. Water or Wet Ground [514 ha; 1,270 acres]

Water and wet ground of river, streams channels or tanks, with inclusions of barren or very sparsely vegetated ground. This unit is mostly associated with drainage bottoms of the Rio Salado, Rio Puerco and Rio Grande (1,400 – 1,500 m; 4,600-4,900 ft.). It may include some sparsely vegetated dunelands north of the Rio Salado confluence and some alluvial flats.

TM· Water and barren, probably wet disturbed ground

2. Barren or Sparsely Vegetated [5,258; 12,985 acres]

Open alluvial flats of basin bottoms (1,430 - 1,550 m; 4,700-5,090 ft) that are either barren or sparsely vegetated with alkali sacaton (*Sporobolus airoides)* and burrograss (*Scleropogon brevifolius*), or are barren hills (badlands).

TM-3. Sparse Grassland (Alkali Sacaton); barren disturbed ground
TM-2. Sparse Grassland (Black Grama or Galleta); barren disturbed ground

3. Great Basin Grasslands (Galleta and Indian Ricegrass Grasslands) [18,134 ha; 44,790 acres]

Sparse grasslands most often associated with lowland sandy soils predominantly on the west side of the Sevilleta (1,450-1,750 m; 4,750-5,750 ft). The Grasslands are usually dominated by species with Great Basin affinities such as galleta (*Hilaria JamesiiI),* Indian ricegrass (*Oryzopsis hymenoides*) and sand dropseed (*Sporobolus cryptandrus*). Where the unit extends up hillslopes, black grama (*Bouteloua eriopoda*) grasslands may occur. Shrubs or dwarf shrubs are often abundant in these grassland stands, and there are inclusions of fourwing saltbush (*Atriplex canescens*), broom dalea (*Psorothamnus scoparius*) and shadscale (*Atriplex confertifolia*) shrublands.

TM-4. Galleta or Black Grama Grasslands; Inclusion: Shadscale Shrubland
TM-8. Galleta or Sand Dropseed Grasslands
TM-12. Galleta or Burrograss Grasslands; Inclusion: Fourwing Saltbush Shrubland
TM-11. Indian Ricegrass or Black Grama Grasslands, or Broom Dalea Shrubland

4. Transition Chihuahuan and Great Basin Grasslands (Black Grama Grasslands with Galleta) [13,326 ha; 32,915 acres]

Grasslands associated with sandy to coarse loamy soils of the east side of the Sevilleta along the lower piedmont that extends out westward from the base of the Los Pinos Mountains, and in the foothills of Ladrones Mountains (1,450-1,700m; 4,750-5,575 ft). They are typically dominated by black grama (*Bouteloua eriopoda*), a species with the center of its distribution in the southwest U.S. and northern Mexico. Galleta (*Hilaria jamesii*), a Great Basin Grassland indicator is an important associate, sometimes dominating stands along with mesa dropseed (*Sporobolus flexuosus*). Blue grama (*B. gracilis*) is also an important component of many stands, particularly along the upper elevation margins. On deeper sands, Plains-Mesa Microphyllous Sand Scrub dominated by sand sagebrush (*Artemisia filifolia)* may occur as a minor inclusion.

TM-9, 10 & 17. Black Grama Grassland; Inclusion: Galleta Grassland

5. Chihuahuan Desert Grasslands (Black Grama Grasslands) [8,641 ha; 21,343 acres]

Grasslands dominated by black grama (*Bouteloua eriopoda*) and associated with alluvial piedmonts (bajadas) and foothills from low to mid-elevations (1,500-1,800m; 4,925-5,900 ft). Soils are typically loamy (sometimes sandy) and underlain by thick caliche layers (calcium carbonate accumulations). Purple threeawn (*Aristida purpurea*) grasslands can occur as a minor inclusion on more disturbed sites. Other common associates are blue grama (*B. gracilis*), featherplume (*Dalea formosa*), Torrey's jointfir (*Ephedra torreyana*), soapweed yucca (*Yucca glauca*) and woody crinklemat (*Tequila canescens*).

TM-5. Black Grama Grassland
TM-14. Black Grama Grassland; Inclusion: Purple Threeawn

6. Transition Chihuahuan and Plains Grassland (Black Gram Grasslands with Blue Grama) [8,937 ha; 22,074 acres]

Grasslands dominated by both black grama (*Bouteloua eriopoda*) and blue grama (*B. gracilis*), indicator species for Chihuahuan Desert Grasslands and Great Plains Grasslands, respectively. They occur primarily on alluvial piedmonts (bajadas) of the west side of the Sevilleta, but also to a limited degree in the foothills on both sides (1,500-1,800m; 4,925-5,900 ft). Soils are commonly sandy on the surface, but loamy with depth and underlain by caliche layers (calcium carbonate accumulations). Creosotebush (*Larrea tridentata*) shrublands can occur as a minor inclusion. Other common associates include the shrubs Torrey's jointfir (*Ephedra torreyana*), soapweed yucca (*Yucca glauca*) and broom snakeweed (*Gutierrezia sarothrae*); the grasses sand dropseed (*Sporobolus crytandrus*), burrograss (*Scleropogon brevifolius*) and purple threeawn (*Aristida purpurea*); and forbs such as mock vervain (*Glandularia wrightii*), desert marigold (*Baileya multiradicata*) and zinnia (*Zinnia grandiflora*).

TM-15. Black Grama Grassland; Inclusion Creosotebush Shrubland
TM-18. Black Grama or Blue Grama Grasslands
TM-19. Black Grama or Blue Grama Grasslands

7. Plains Grasslands (Blue Grama and Hairy Grama Grasslands) [3,645 ha; 9,003 acres]

Grasslands dominated by blue grama (*Bouteloua gracilis*) with hairy grama as a common co-dominant (*B. hirsuta*), both common short-grass species of the Great Plains. They occur along upper piedmont slopes (bajadas), foothills and in mountain valleys (1,500-1,950m; 4,825-6,400 ft). Soils are often moderately well-developed with loamy to clayey textures and underlain by caliche layers (calcium carbonate accumulations). Giant Sacaton Grasslands occur as an inclusion in some valleys. Common associates include the shrubs winterfat (*Krascheninnikovia lanata*), fourwing saltbush (*Atriplex canescens*); the grasses black grama (*B. eriopoda*), sideoats grama (*B. curtipendula*) and dropseeds (*Sporobolus contractus & S. cryptandrus*); and forbs such as lacy tansyaster (*Machaeranthera pinnatifida*) and Douglas' groundsel (*Senecio flacicidus* var. *douglasii*).

TM-25. Blue Grama or Giant Sacaton Grasslands
TM-24. Blue Grama; Inclusions: Black Grama Grassland, Galleta Grassland or Sand Sage Shrubland

8. Chihuahuan or Great Basin Lowland/Swale Grasslands (Alkali or Giant Sacaton Grasslands)

[1,708 ha; 4,219 acres]

Grasslands dominated by either the hummock-forming alkali sacaton (*Sporobolus airoides*) of Great Basin affinity, or the taller giant sacaton (*S. wrightii*) of Chihuahuan Desert affinity. Alkali sacaton grasslands often occur as large, monotypic stands of moderate cover on heavy clay soils in swales or alluvial flats of lowland valleys and basins (1,450-1,700m; 4,750-5,575 ft). Burrograss (*Scleropogon brevifolius*) can occur as a co-dominant along with scattered fourwing saltbush (*Atriplex canescens*). In contrast, giant sacaton forms tall and dense stands along lower-elevation drainageways of ephemeral streams (arroyos). Shrubs are uncommon or absent. Stands of Fourwing Saltbush Shrublands with understories dominated by alkali sacaton can occur as significant inclusions intermixed among the grasslands.

TM-29. Giant Sacaton Grassland
TM-20. Alkali Sacaton Grassland or Fourwing Saltbush Shrubland

9. Chihuahuan Desert Shrublands (Creosotebush) [10,742 ha; 26,532 acres]

Shrublands dominated by the evergreen creosote bush (*Larrea tridentata*), a widespread and characteristic evergreen shrub of the Chihuahuan Desert. Ground cover is sparse to well-represented by grasses such as black grama (*Bouteloua eriopoda*) or fluff grass (*Erioneuron pulchellum*). The shrublands occur on lower piedmonts (bajadas), foothills and alluvial flats (1,450-1,750m; 4,750-5,750 ft). Soils are relatively shallow and underlain by dense caliche layers (calcium carbonate accumulations that are sometimes exposed at the surface). They are commonly interspersed with Black Grama, Galleta (*Hilaria jamesii*) or Indian Ricegrass (*Oryzopsis hymenoides*) Grasslands. There are minor inclusions of Shadscale Shrubland and barrens areas, and, at upper elevations, Oneseed Juniper Woodlands. Other common associates include pricklyleaf dogweed (*Thymophylla acerosa*), Fendler's bladderpod (*Lesquerella fendleri*), and broom snakeweed (*Gutierrezia sarothrae*).

TM-13. Creosotebush Shrubland and Black Grama Grassland
TM-6. Creosote Shrubland, and Galleta or Indian Ricegrass Grasslands
Inclusion: Shadscale Shrubland or Barren Ground
TM-21. Creosotebush Shrubland (in part see No. 11).

10. Great Basin Shrublands (Fourwing Saltbush or Broom Dalea) [7,130 ha; 17,611 acres]

Shrublands dominated by fourwing saltbush (*Atriplex canescens*), a widespread species with the center of their distribution in the Great Basin. They occur primarily on the west side on sandy deposits, alluvial flats of lowland valleys and, occasionally, on recent alluvial fan deposits (1,430-1,700m; 4,700-5,575 ft). Broom dalea (*Psorothamnus scoparius*), a Chihuahuan element may also be abundant and mixed in with the saltbush. Where the sands are particularly deep, coppice dunes can form around stems of the broom dalea. Understories are either barren or dominated by grasses. On alluvial flats alkali sacaton (*S. airoides*) is the common dominant. Sandier sites are characterized by scattered grasses and forbs such as dropseeds (*Sporobolus flexulosus, S. cryptandrus, S. contractus* and *S. gigantea*), desert marigold (*Baileya multiradicata*), and spectaclepod (*Dimorphocarpa wislizeni*). There are occasional inclusions of disturbed sites dominated by threeawn grasses (*Aristida* spp.).

TM-7. Broom Dalea Shrubland
TM-16. Fourwing Saltbush or Honey Mesquite or Broom Dalea Shrubland
TM-22. Fourwing Saltbush Shrubland; Inclusion: Threeawn Grassland

11. Rocky Mountain Conifer Savanna (Oneseed Juniper Woodlands) [10,235 ha; 25,280 acres]

Very open woodlands of lower elevation foothills, escarpments, and piedmonts (bajadas) and alluvial fans (1,550-2,100m; 5,100-6,900 ft). Stands are characterized by scattered, low-statured oneseed juniper (*Juniperus monosperma*) trees with the grassy inter-tree spaces dominated by grama grasses (*Bouteloua gracilis, B. hirsuta, B. eriopoda,* and *B. curtipendula*). Pinyon pines (*Pinus edulis*) are sub-dominant or absent. Stands are often intermixed at the lower elevations with patches of Blue or Black Grama Grasslands, and Shrub Live Oak Shrublands at higher elevations. Shrub live oak stands are particularly prominent on escarpment slopes of the Los Pinos Mountains. Diversity can be moderately high, and common associates are the shrubs banana yucca (*Yucca bacata*), broom snakeweed (*Gutierrezia sarothrae*), tree cholla (*Opuntia imbricata*), and tulip pricklypear (*O. phaeacantha*); the grasses New Mexico needlegrass (*Stipa neomexicana*), galleta (*Hilaria jamesii*) and purple threeawn (*Aristida purpurea*); and a wide variety of forbs such as plains blackfoot (*Melapodium leucanthum*) and zinnia (*Zinnia grandiflora*).

TM-23. Oneseed Juniper Woodland Savanna; Inclusion: Blue Grama Grassland
TM-26. Oneseed Juniper Woodland, or Shrub Live Oak Shrubland, or Black Grama or Blue Grama Grasslands
TM-28. Oneseed Juniper Woodland, or Shrub Live Oak Shrubland
TM-21. Oneseed Juniper Woodland (in part, see No.9)

12. Rocky Mountain Conifer Woodlands (Pinyon Woodlands) [3,173 ha; 7,837]

Open to moderately closed woodlands dominated by low-statured pinyon pine (*Pinus edulis*) with oneseed juniper (*Juniperus monosperma*) as sub-dominant associate. These woodlands are associated with moderate to steep slopes of the highest elevations of the Los Pinos and Ladrones Mountains (1,850-2,300; 6,050-7,550 ft). Understories are a mixture of shrubs and scattered grasses and forbs. Shrub live oak (*Quercus turbinella*), mountain mahogany (*Cercocarpus montanus*), banana yucca (*Yucca bacata*) and sacuahista (*Nolinia microcarpa*) are often well represented to abundant. Sideoats grama (*Bouteloua curtipendula*), blue grama (*B. gracilis*), and wolfstail (*Lycurus phleoides*) are the most common grasses. Forb diversity can be moderate to high; ragleaf bahia (*Bahia dissecta*), false pennyroyal (*Hedeoma nana*) and Fendler's sandmat (*Chamaesyce fendleri*) are common. Inclusions of mountain mahogany stands occur on rugged escarpment slopes and commonly on sites that have been burned. Near the summit of the Ladrones there are small inclusions of Ponderosa Pine (*Pinis ponderosa* var. *scopulorum*) Woodland.

Pinyon or Oneseed Juniper Woodlands; Inclusions of Mountain Mahogany Shrubland and Sideoats Grama Grassland
Pinyon Woodland

13. Rio Grande Riparian Woodlands (Rio Grande Cottonwood and Salt Cedar Riparian Woodland) [886 ha; 2,188 acres]

These are riparian woodlands or forested wetlands that occur along river bars and terraces of the Rio Grande, Rio Puerco and Rio Salado drainages (1,430-1,550m; 4,700-5,100 ft). They range from open canopied woodlands of the native Rio Grande Cottonwood (*Populus deltoides* var. *wislizeni*) with grassy understories of alkali sacaton (*Sporobolus airoides*), inland saltgrass (*Distichlis spicata*) or vine mesquite grass (*Panicum obtusum*), to dense, shrub-like stands of the introduced salt cedar (*Tamarix ramosissima*) with little or no understory.

TM-30. Salt Cedar Woodland or Fourwing Saltbush Shrubland
TM-32. Salt Cedar or Rio Grande Cottonwood Woodland

Figure 8. An example of a sparsely vegetated hillslope or "badlands" site found in Map Unit 2 near Arroyo Milagro.

Figure 9. A contrasting site at Arroyo Milagro dominated by giant sacaton, major component of Map Unit 8, Desert Lowland/Swale Grasslands.

Figure10. Creosotebush shrublands like these in the foothills of the Ladrones near Red Tank are major component of Map Unit 9.

Figure Pinyon pine dominated stands such as these on Cerro Montosa are typical of Map unit 7. nit

Discussion

This version of the Sevilleta Vegetation Map represents the most detailed map yet produced for the project area. Previous maps have been at much coarser scales, providing minimal information for natural resources management and research design. With version 1.0 we have made a significant step towards meeting the needs of the variety of users of the refuge, particularly for refuge-wide planning processes. However, maps developed from TM imagery have inherent spatial and spectral limitations that limit their resolution. This map is most appropriately used at a 1:50,000 and higher scale, and should not be applied to site level planning and design.

The evaluation of smaller areas (tens of square kilometers rather than 100's) requires maps made from higher resolution imagery and with different image analysis techniques. But, with the improvements of technology that have already occurred since the inception this project, such higher resolution maps are possible within the same financial framework (better is getting cheaper). As a next step, we would recommend the development of digital maps at 1:12,000 to 1:24,000 scale based on a combination of satellite imagery and high resolution ortho-rectified aerial photography. It has been shown that using this combination of imagery along with both spectral and textural analysis can yield highly accurate, high resolution maps that can be used effectively for site-level planning and research design (Muldavin, Harper and Neville, 1996).

At this time, the accuracy of the map over a wide area remains to be tested. We would recommend a formal accuracy assessment by gathering an independent ground validation data set based on objective sampling criteria. Validation based on high-resolution photography or videography is also possible. The validation data sets can also serve to support small revisions of this map and provide the foundation for the later development of the next generation of higher resolution maps.

With respect to the provisional vegetation classification, several new plant associations were tentatively identified for the Sevilleta that have not been recorded elsewhere in New Mexico and need further documentation. This, along with additional intensive botanical surveys (both inside and outside the refuge) are needed to support the concept of the Sevilleta not only as being unique from an ecological perspective, but also as a critical site for the maintenance of biodiversity in the Southwest.

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Appendix A. Sevelleta Vegetation Classification and Map Plant Species List (Continued).

Common Name	Scientific Name	Authority	Family	Species Code	Origin
cane bluestem	Bothriochloa barbinodis	(Lag.) Herter	Poaceae	BOTBAR	
carelessweed	Amaranthus palmeri	S. Wats.	Amaranthaceae	AMAPAL	
Christmas cactus	Opuntia leptocaulis	DC.	Cactaceae	OPULEP	N
club cholla	Opuntia clavata	Engelm.	Cactaceae	OPUCLA	N
cocklebur	Xanthium strumarium var. canadense	(Mill.) Torr. & Gray	Asteraceae	XANSTRC	N
Colorado four o'clock	Mirabilis multiflora	(Torr.) Gray	Nyctaginaceae	MIRMUL	N
common hoptree	Ptelea trifoliata ssp. angustifolia	(Benth.) Bailey	Rutaceae	PTETRIA	N
common kochia	Kochia scoparia	L. Schrad	Chenopodiaceae	KOCSCO	
common purslane	Portulaca oleracea	L.	Portulacaceae	POROLE	
common sunflower	Helianthus annuus	L.	Asteraceae	HELANN	N
common wolfstail	Lycurus phleoides	Kunth	Poaceae	LYCPHL	N
conyza	Laennecia coulteri	(Gray) Nesom	Asteraceae	LAECOU	
Coulter's wrinklefruit	Tetraclea coulteri	Gray	Verbenaceae	TETCOU	
creosotebush	Larrea tridentata	(Sesse & Moc. ex DC.) Coville	Zygophyllaceae	LARTRI	N
Croton spp.	Croton spp.	L.	Euphorbiaceae	CROTON	
curlycup gumweed	Grindelia squarrosa	(Pursh) Dunal	Asteraceae	GRISQU	N
curlyleaf muhly	Muhlenbergia setifolia	Vasey	Poaceae	MUHSET	N
Davis Mountain mock vervain	Glandularia wrightii	(Gray) Umber	Verbenaceae	GLAWRI	N
desert holly	Acourtia nana	(Gray) Reveal & King	Asteraceae	ACONAN	
desert marigold	Baileya multiradiata	Harvey & Gray ex Gray	Asteraceae	BAIMUL	N
desert seepweed	Suaeda suffrutescens	S.Wats.	Chenopodiaceae	SUASUF	
doubleclaw	Proboscidea parviflora	(Woot.) Woot. & Standl.	Pedaliaceae	PROPAR	N
dwarf mentzelia	Mentzelia pumila	Nutt. ex Torr. & Gray	Loasaceae	MENPUM	
dwarf prairieclover	Dalea nana	Torr. ex Gray	Fabaceae	DALNAN	
ear muhly	Muhlenbergia arenacea	(Buckl.) A.S. Hitchc.	Poaceae	MUHARE	N
ear muhly	Muhlenbergia arenacea	(Buckl.) Hitchc.	Poaceae	MUHARE1	N
falsepennyroyal	Hedeoma nana	(Torr) Briq.	Lamiaceae	HEDNAN	
feather fingergrass	Chloris virgata	Sw.	Poaceae	CHLVIR	N
featherplume	Dalea formosa	Torr.	Fabaceae	DALFOR	
Fendler threeawn	Aristida purpurea var. longiseta	(Steud.) Vasey	Poaceae	ARIPURL	N
Fendler's bladderpod	Lesquerella fendleri	(Gray) S. Wats.	Brassicaceae	LESFEN	
Fendler's falsecloak fern	Argyrochosma fendleri	(Kunze) Windham	Adiantaceae	ARGFEN	
Fendler's globemallow	Sphaeralcea fendleri	Gray	Malvaceae	SPHFEN	N
Fendler's penstemon	Penstemon fendleri	Torr. & Gray	Scrophulariaceae	PENFEN	
Fendler's sandmat	Chamaesyce fendleri	(Torr. & Gray) Small	Euphorbiaceae	CHAFEN	

Appendix A. Sevilleta Vegetation Classification and Map Plant Species List (Continued).

Common Name	Scientific Name	Authority	Family	Species Code	Origin
fetid goosefoot	Chenopodium graveolens	Willd.	Chenopodiaceae	CHEGRA	N
field bindweed	Convolvulus arvensis	L.	Convolvulaceae	CONARV	I
fineleaf hymenopappus	Hymenopappus filifolius	Hook.	Asteraceae	HYMFIL	N
firewheel	Gaillardia pulchella	Foug.	Asteraceae	GAIPUL	N
flax spp.	Linum spp.	L.	Linaceae	LINUM	
flaxflowered gilia	Ipomopsis longiflora	(Torr.) V. Grant	Polemoniaceae	IPOLON	N
fluffgrass	Erioneuron pulchellum	(Kunth) Tateoka	Poaceae	ERIPUL	N
foothill sagewort	Artemisia ludoviciana ssp. ludoviciana	Nutt.	Asteraceae	ARTLUDL	N
fourwing saltbush	Atriplex canescens	(Pursh) Nutt.	Chenopodiaceae	ATRCAN	N
Fremont's goosefoot	Chenopodium fremontii	S. Wats.	Chenopodiaceae	CHEFRE	N
galleta grass	Hilaria jamesii	(Torr.) Benth.	Poaceae	HILJAM	N
Geyer's onion	Allium geyeri	S. Wats.	Liliaceae	ALLGEY	N
giant dropseed	Sporobolus giganteus	Nash	Poaceae	SPOGIG	N
giant sacaton	Sporobolus wrightii	Munro	Poaceae	SPOWRI	N
Gilia	Gilia spp.	none	Polemoniaceae	GILIA	N
gilia beardtongue	Penstemon ambiguus	Torr.	Scrophulariaceae	PENAMB	
goosefoot moonpod	Ammocodon chenopodioides	(Gray)Standl.	Nyctaginaceae	AMMCHE	
gray fiveeyes	Chamaesaracha coniodes	(Moric. ex Dunal) Britt.	Solanaceae	CHACON	
green sprangletop	Leptochloa dubia	(Kunth) Nees	Poaceae	LEPDUB	N
gyp dropseed	Sporobolus nealleyi	Vasey	Poaceae	SPONEA	N
gypsum moonpod	Selinocarpus lanceolatus	Woot.	Nyctaginaceae	SELLAN	
gypsum scorpionweed	Phacelia integrifolia	Torr.	Hydrophyllaceae	PHAINT	
hairy coldenia	Tiquilia hispidissima	(Torr. & Gray) A. Richards	Boraginaceae	TIQHIS	
hairy grama	Bouteloua hirsuta	Lag.	Poaceae	BOUHIR	N
hairy woollygrass	Erioneuron pilosum	(Buckl.) Nash	Poaceae	ERIPIL	
hairyseed bahia	Bahia absinthifolia	Benth.	Asteraceae	BAHABS	
Hall's panicgrass	Panicum hallii	Vasey	Poaceae	PANHAL	N
Hartweg's sundrops	Calylophus hartwegii	(Benth.) Raven	Onagraceae	CALHAR	N
Havard's threeawn	Aristida havardii	Vasey	Poaceae	ARIHAV	N
heath wrightwort	Carlowrightia linearifolia	(Torr.) Gray	Acanthaceae	CARLIN	
hiddenflower	Cryptantha crassisepala	(Torr. & Gray) Greene	Boraginaceae	CRYCRA	
hoary tansyaster	Machaeranthera canescens ssp. glabra	Gray	Asteraceae	MACCANG	
honey mesquite	Prosopis glandulosa	Torr.	Fabaceae	PROGLA	N
Hopi tea greenthread	Thelesperma megapotamicum	(Spreng.) Kuntze	Asteraceae	THEMEG	N
Indian ricegrass	Oryzopsis hymenoides	(Roemer & Schultes) Ricker ex Piper	Poaceae	ORYHYM	N

Appendix A. Sevelleta Vegetation Classification and Map Plant Species List (Continued).

Common Name	Scientific Name	Authority	Family	Species Code	Origin
Indian rushpea	Hoffmannseggia glauca	(Ortega) Eifert	Fabaceae	HOFGLA	N
inland saltgrass	Distichlis spicata	(L.) Greene	Poaceae	DISSPI	N
ivyleaf groundcherry	Physalis hederaefolia	Gray	Solanaceae	PHYHED	
James' buckwheat	Eriogonum jamesii	Benth.	Polygonaceae	ERIJAM	N
James' catseye	Cryptantha cinerea	Cronq.	Boraginaceae	CRYCIN	
James' prairieclover	Dalea jamesii	(Torr.) Torr. & Gray	Fabaceae	DALJAM	
juniper mistletoe	Phoradendron juniperinum	Engelm.	Viscaceae	PHOJUN	
kingcup cactus	Echinocereus triglochidiatus	Engelm.	Cactaceae	ECHTRI	
kisses	Gaura suffulta ssp. nealeyi	(Coult.) Raven & Gregory	Onagraceae	GAUSUFN	
lacy germander	Teucrium laciniatum	Torr.	Lamiaceae	TEULAC	N
largeflower wild onion	Allium macropetalum	Rydb.	Liliaceae	ALLMAC	
littleleaf sumac	Rhus microphylla	Engelm. ex Gray	Anacardiaceae	RHUMIC	N
lyreleaf greeneyes	Berlandiera lyrata	Benth.	Asteraceae	BERLYR	
mariola	Parthenium incanum	Kunth	Asteraceae	PARINC	
matted sandmat	Chamaesyce serpens	(Kunth) Small	Euphorbiaceae	CHASER	N
mesa dropseed	Sporobolus flexuosus	(Thurb.) Rydb.	Poaceae	SPOFLE	N
mesa greggia	Nerisyrenia camporum	(Gray) Greene	Brassicaceae	NERCAM	N
Missouri gourd	Cucurbita foetidissima	Kunth	Cucurbitaceae	CUCFOE	N
mormon tea	Ephedra viridis	Coville	Ephedraceae	EPHVIR	
mountain muhly	Muhlenbergia montana	(Nutt.) Hitchc.	Poaceae	MUHMON	N
mountain pepperweed	Lepidium montanum	Nutt.	Brassicaceae	LEPMON	N
mountain tanseymustard	Descurainia incana ssp. incisa	(Engelm.) Kartez & Gandhi	Brassicaceae	DESINCI	N
narrowleaf cottonwood	Populus angustifolia	James	Salicaceae	POPANG	N
narrowleaf four o'clock	Mirabilis linearis	(Pursh) Heimerl	Nyctaginaceae	MIRLIN	
narrowleaf pectis	Pectis angustifolia	Torr.	Asteraceae	PECANG	N
needle grama	Bouteloua aristidoides	(H.B.K.) Griseb.	Poaceae	BOUARI	
New Mexico birdsfoot trefoil	Lotus plebeius	(Brand) Barneby	Fabaceae	LOTPLE	
New Mexico copperleaf	Acalypha neomexicana	Muell.-Arg.	Euphorbiaceae	ACANEO2	
New Mexico goosefoot	Chenopodium neomexicanum	Standl.	Chenopodiaceae	CHENEO	
New Mexico muhly	Muhlenbergia pauciflora	Buckl.	Poaceae	MUHPAU	N
New Mexico needlegrass	Stipa neomexicana	(Thurb.) Scribn.	Poaceae	STINEO	N
New Mexico thistle	Cirsium neomexicana	Gray	Asteraceae	CIRNEO	N
nineawn pappusgrass	Enneapogon desvauxii	Beauv.	Poaceae	ENNDES	
nodding onion	Allium cernuum	Roth	Liliaceae	ALLCER	N
ocotillo	Fouquieria splendens	Engelm.	Fouquieriaceae	FOUSPL	N

Appendix A. Sevelleta Vegetation Classification and Map Plant Species List (Continued).

Common Name	Scientific Name	Authority	Family	Species Code	Origin
oneseed juniper	Juniperus monosperma	(Engelm.) Sarg.	Cupressaceae	JUNMON	N
oneseed juniper	Juniperus monosperma - adv regen	(Engelm.) Sarg.	Cupressaceae	JUNMON2	N
oneseed juniper	Juniperus monosperma - mature	(Engelm.) Sarg.	Cupressaceae	JUNMON3	N
pale wolfberry	Lycium pallidum	Miers	Solanaceae	LYCPAL	N
perennial blazingstar	Mentzelia perennis	Woot.	Loasaceae	MENPER	
pinyon pine	Pinus edulis - mature	Engelm.	Pinaceae	PINEDU3	N
pinyon pine	Pinus edulis	Engelm.	Pinaceae	PINEDU	N
plains blackfoot	Melampodium leucanthum	Torr. & Gray	Asteraceae	MELLEU	N
plains flax	Linum puberulum	(Engelm.) Heller	Linaceae	LINPUB	
plains pricklypear	Opuntia polyacantha var. tricophora	(Engelm. & Bigel.) Coult.	Cactaceae	OPUPOLT	N
plains pricklypear	Opuntia polyacantha	Haw.	Cactaceae	OPUPOL	N
poverty threeawn	Aristida divaricata	Humb. & Bonpl. ex Willd.	Poaceae	ARIDIV	N
prairie junegrass	Koeleria macrantha	(Ledeb.) Schultes	Poaceae	KOEMAC	N
prickly Russian thistle	Salsola kali	L.	Chenopodiaceae	SALKAL	
pricklyleaf dogweed	Thymophylla acerosa	(DC.) Strother	Asteraceae	THYACE	N
purple pricklypear	Opuntia macrocentra	Engelm.	Cactaceae	OPUMAC	N
purple threeawn	Aristida purpurea var. purpurea	Nutt.	Poaceae	ARIPURP	N
purple threeawn	Aristida purpurea	Nutt.	Poaceae	ARIPUR	N
ragleaf bahia	Bahia dissecta	(Gray) Britt.	Asteraceae	BAHDIS	N
red barberry	Mahonia haematocarpa	(Woot.) Fedde	Berberidaceae	MAHHAE	
red bluet	Houstonia rubra	Cav.	Rubiaceae	HOURUB	
red dome blanketflower	Gaillardia pinnatifida	Torr.	Asteraceae	GAIPIN	
redjoint pricklypear	Opuntia macrocentra var. macrocentra	Engelm.	Cactaceae	OPUMACM	N
ring muhly	Muhlenbergia torreyi	(Kunth) Hitch. ex Bush	Poaceae	MUHTOR	N
Rio Grande cottonwood	Populus deltoides ssp. wislizenii	(S. Wats.) Eckenwalder	Salicaceae	POPDELW	N
rocky mountain beggarticks	Bidens heterosperma	Gray	Asteraceae	BIDHET	N
Rocky Mountain zinnia	Zinnia grandiflora	Nutt.	Asteraceae	ZINGRA	
rose heath	Chaetopappa ericoides	(Torr.) Nesom	Asteraceae	CHAERI	
rough bugleweed	Lycopus asper	Greene	Lamiaceae	LYCASP	N
rough menodora	Menodora scabra	Gray	Oleaceae	MENSCA	
roundleaf buckwheat	Eriogonum rotundifolium	Benth.	Polygonaceae	ERIROT	
roving sailor	Maurandella antirrhiniflora	(Humb. & Bonpl. ex Willd.) Rothm.	Scrophulariaceae	MAUANT	N
rubber rabbitbrush	Chrysothamnus nauseosus	(Pallas ex.Prush) Britt.	Asteraceae	CHRNAU	N
Russian olive	Elaeagnus angustifolia - seedling	L.	Elaeagnaceae	ELAANG0	I
sacahuista	Nolina microcarpa	S. Wats.	Agavaceae	NOLMIC	

Appendix A. Sevelleta Vegetation Classification and Map Plant Species List (Continued).

Common Name	Scientific Name	Authority	Family	Species Code	Origin
sacred thornapple	Datura wrightii	Regel	Solanaceae	DATWRI	N
sand dropseed	Sporobolus cryptandrus	(Torr.) Gray	Poaceae	SPOCRY	N
sand fiddleleaf	Nama carnosum	(Woot.) C.L. Hitch.	Hydrophyllaceae	NAMCAR	
sand muhly	Muhlenbergia arenicola	Buckl.	Poaceae	MUHARE2	N
sand reverchonia	Reverchonia arenaria	Gray	Euphorbiaceae	REVARE	N
sand sagebrush	Artemisia filifolia	Torr.	Asteraceae	ARTFIL	N
sanddune wallflower	Erysimum capitatum	(Dougl. ex Hook.) Greene	Brassicaceae	ERYCAP	N
sandhill muhly	Muhlenbergia pungens	Thurb.	Poaceae	MUHPUN	N
sawtooth sage	Salvia subincisa	Benth.	Lamiaceae	SALSUB	N
sawtooth sandmat	Chamaesyce serrula	(Engelm.) Woot. & Standl.	Euphorbiaceae	CHASER3	
scaly globemallow	Sphaeralcea leptophylla	(Gray) Rydb.	Malvaceae	SPHLEP	
scarlet beeblossom	Gaura coccinea	Nutt. ex Pursh	Onagraceae	GAUCOC	N
scarlet globemallow	Sphaeralcea coccinea	(Nutt.) Rydb.	Malvaceae	SPHCOC	N
shaggy dwarf morningglory	Evolvulus nuttallianus	J.A. Schultes	Convolvulaceae	EVONUT	
Shaggy mountain mahogany	Cercocarpus montanus var. paucidentatus	(Wats.) F.L. Martin	Roasaceae	CERMONP	
showy flameflower	Talinum parviflorum	Nutt.	Portulacaceae	TALPAR	
shrub live oak	Quercus turbinella	Greene	Fagaceae	QUETUR	N
sicklepod holdback	Caesalpinia drepanocarpa	(Gray) Fisher	Fabaceae	CAEDRE	
sideoats grama	Bouteloua curtipendula	(Michx.) Torr.	Poaceae	BOUCUR	N
silkcotton purslane	Portulaca halimoides	L.	Portulacaceae	PORHAL	
Silver beardgrass	Bothriochloa saccharoides	(Sw,) Rydb.	Poaceae	BOTSAC	N
silverleaf nightshade	Solanum elaeagnifolium	Cav.	Solanaceae	SOLELA	N
sixweeks grama	Bouteloua barbata	Lag.	Poaceae	BOUBAR	N
sixweeks threeawn	Aristida adscensionis	L.	Poaceae	ARIADS	N
skunkbush sumac	Rhus trilobata	Nutt.	Anacardiaceae	RHUTRI	N
sleepy silene	Silene antirrhina	L.	Caryophyllaceae	SILANT	
slender goldenweed	Machaeranthera gracilis	(Nutt.) Shinners	Asteraceae	MACGRA	N
slim tridens	Tridens muticus	(Torr.) Nash	Poaceae	TRIMUT	N
slimflower muhly	Muhlenbergia tenuifolia	(Kunth) Trin.	Poaceae	MUHTEN	N
slimleaf plainsmustard	Schoenocrambe linearifolia	(Gray) Rollins	Brassicaceae	SCHLIN	N
slippery globemallow	Sphaeralcea digitata	(Greene) Rydb.	Malvaceae	SPHDIG	
smooth spreading four o'clock	Mirabilis oxybaphoides	(Gray) Gray	Nyctaginaceae	MIROXY	
snowball sand verbena	Abronia fragrans	Greene	Nyctaginaceae	ABRFRA	
soaptree yucca	Yucca glauca	Nutt.	Agavaceae	YUCGLA	N
Sonoran sandmat	Chamaesyce micromera	(Boiss.) Woot. & Standl.	Euphorbiaceae	CHAMIC	N

Appendix A. Sevelleta Vegetation Classification and Map Plant Species List (Continued).

Common Name	Scientific Name	Authority	Family	Species Code	Origin
sorrel buckwheat	Eriogonum polycladon	Benth.	Polygonaceae	ERIPOL	N
southwestern rabbitbrush	Chrysothamnus pulchellus	(Gray) Greene	Asteraceae	CHRPUL	
spectacle pod	Dimorphocarpa wislizeni	(Engelm.) Rollins	Brassicaceae	DIMWIS	N
spike dropseed	Sporobolus contractus	Hitchc.	Poaceae	SPOCON	N
spiny chloracantha	Chloracantha spinosa	(Benth.) Nesom	Asteraceae	CHLSPI	
spinystar	Escobaria vivipara	(Nutt.) Buxbaum	Cactaceae	ESCVIV	
spreading fleabane	Erigeron divergens	Torr. & Gray	Asteraceae	ERIDIV	N
squawthorn	Lycium torreyi	Gray	Solanaceae	LYCTOR	
star cloak fern	Notholaena standleyi	Maxon	Adiantaceae	NOTSTA	
stinging serpent	Cevallia sinuata	Lag.	Loasaceae	CEVSIN	
Texas croton	Croton texensis	(Klotzsch) Muell.-Arg.	Euphorbiaceae	CROTEX	N
threadleaf ragwort	Senecio flaccidus var. flaccidus	Less.	Asteraceae	SENFLAF	
toothed spurge	Euphorbia dentata	Michx.	Euphorbiaceae	EUPDEN	N
Torrey's jointfir	Ephedra torreyana	S. Wats.	Ephedraceae	EPHTOR	
trailing windmills	Allionia incarnata	L.	Nyctaginaceae	ALLINC	N
tree cholla	Opuntia imbricata	(Haw.) DC.	Cactaceae	OPUIMB	N
tulip pricklypear	Opuntia phaeacantha	Engelm.	Cactaceae	OPUPHA	N
twinleaf senna	Senna bauhinioides	(Gray) Irwin & Barneby	Fabaceae	SENBAU	
velvet mesquite	Prosopis pubescens	Benth.	Fabaceae	PROPUB	
velvetweed	Gaura parviflora	Dougl. ex Lehm.	Onagraceae	GAUPAR	N
vine mesquite	Panicum obtusum	Kunth	Poaceae	PANOBT	N
warty caltrop	Kallstroemia parviflora	Nort.	Zygophyllaceae	KALPAR	N
wavyleaf twinevine	Sarcostemma crispum	Benth.	Asclepiadaceae	SARCRI	
weakleaf bur ragweed	Ambrosia confertiflora	DC.	Asteraceae	AMBCON	
western wheatgrass	Pascopyrum smithii	(Rydb.) Love	Poaceae	PASSMI	N
white fishhook cactus	Sclerocactus intertextus	(Engelm.) N.P. Taylor	Cactaceae	SCLINT	
white milkwort	Polygala alba	Nutt.	Polygalaceae	POLALB	N
White Sands fanmustard	Nerisyrenia linearifolia	(Wats.) Green	Brassicaceae	NERLIN	
wholeleaf Indian paintbrush	Castilleja integra	Gray	Scrophulariaceae	CASINT	N
winterfat	Krascheninnikovia lanata	(Pursh) Guldenstaedt	Chenopodiaceae	KRALAN2	
witchgrass	Panicum capillare	L.	Poaceae	PANCAP	N
woody crinklemat	Tiquilia canescens	(DC.) A. Richards	Boraginaceae	TIQCAN	
woolly paperflower	Psilostrophe tagetina	(Nutt.) Greene	Asteraceae	PSITAG	N
woolly paperflower	Psilostrophe tagetina var. tagetina	(Nutt.) Greene	Asteraceae	PSITAGT	N
woolly plantain	Plantago patagonica	Jacq.	Plantaginaceae	PLAPAT	N

Appendix A. Sevelleta Vegetation Classification and Map Plant Species List (Continued).

Common Name	Scientific Name	Authority	Family	Species Code	Origin
woolly prairieclover	Dalea lanata	Spreng.	Fabaceae	DALLAN	
wooly tidestromia	Tidestromia lanuginosa	(Nutt.) Standl.	Amaranthaceae	TIDLAN	
wormwood	Artemisia dracunculus	L.	Asteraceae	ARTDRA	N
Wright's beebrush	Aloysia wrightii	Heller ex Abrams	Verbenaceae	ALOWRI	N
Wright's buckwheat	Eriogonum wrightii	Torr. ex Benth.	Polygonaceae	ERIWRI	
Wright's globemallow	Sphaeralcea wrightii	Gray	Malvaceae	SPHWRI	
Wright's silktassel	Garrya wrightii	Torr.	Garryaceae	GARWRI	N
Wright's thelypody	Thelypodium wrightii	Gray	Brassicaceae	THEWRI	
Wrights threeawn	Aristida purpurea var. wrightii	(Nash) Allred	Poaceae	ARIPURW	N
Wyoming Indian paintbrush	Castilleja linariifolia	Benth.	Scrophulariaceae	CASLIN	N

Appendix B. Vegetation of the Sevilleta National Wildlife Refuge

Key to Major Vegetation Classes and Alliances

Dichotomous key the all known Alliances (Cover Types) of the Sevilleta National Wildlife Refuge based on Table 2 of the text along with some additional types that are potentially present, but have not yet been documented for the refuge e.g., tarbush, beebrush, mariola and littleleaf sumac.

1 Upland terrestrial communities..2

1 Riparian communities in the floodplains of perennial or ephemeral streams or rivers, and in or adjacent to waterbodies and dominated by obligate wetland species .... **RIPARIAN/WETLANDS**

Total tree cover greater than 25%, or if less than 25%, then trees clearly dominant over, or co-dominant with, shrubs, sub-shrubs or herbs (includes woodland savanna) .... **FORESTS/WOODLANDS**

Tree cover less than 25% and clearly subordinate to shrubs, sub-shrubs, or herbs 3

3. Tall shrubs (>0.5 m) greater than 25% total cover, or if less than 25%, then shrubs clearly dominant, or co-dominant with sub-shrubs and grasses (herbs generally sparse and of less cover, or absent).**SHRUBLANDS**

3. Tall shrub cover less than 25% and clearly subordinate to sub-shrubs or herbaceous cover 4

4. Sub-shrubs (<0.5 m) greater than 25% total cover, or if less than 25%, then sub-shrubs clearly dominant, or co-dominant with other shrubs and herbaceous cover.................... **DWARF-SHRUBLANDS**

4. Sub shrub cover less than 25% and clearly subordinate to herbaceous cover 5

5. Grasses common to luxuriant (usually > 25% cover); shrubs and trees low in cover or absent, clearly subordinate .... **GRASSLANDS**

5. Other miscellaneous communities, usually on disturbed sites where natural vegetation is highly altered or absent.. **MISCELLANEOUS**

Key to the Forest/Woodland Alliances (Cover Types)

1. Conifers (pines and junipers) dominate the overstory canopy 2

1. Deciduous or evergreen oaks dominate the canopy as shrubs and sometimes as small trees (see **Shrublands**)

2. *Pinus ponderosa* (ponderosa pine) dominant, very open-canopied forest with a grassy understory.................... **Ponderosa Pine Alliance**

2. *Pinus* ponderosa (ponderosa pine) absent or accidental.. 3

3. Pinyon pine (*Pinus edulis*) dominant overstory tree; oneseed juniper (*Juniperus monosperma*) usually subdominant (occassionally co-dominant but not > 50% of canopy) .... **Pinyon Pine Alliance**

3. Oneseed juniper (*Juniperus* monosperma) dominant; pinyon pine sub-dominant or absent .... **Oneseed Juniper Alliance**

Key to the Shrubland and Dwarf-Shrubland Alliances (Cover Types)

Shrublands dominated by mesic shrubs – Gambel's oak, Shrub live oak, or mountain mahogany .... Temperate (Montane) Shrublands

Shrublands dominated by desert shrubs -- ....Desert (Extremely Xeromorphic) Shrublands

Temperate (Montane) Shrublands

1. Gambel's oak (*Quercus gambelii*) well represented as dominant tree or shrub **Gambel's Oak Alliance**
1. Gambel's oak poorly represented or absent.. 2

2. Shrub live oak (*Quercus turbinella*) common to well represented as dominant or co-dominant shrub .... **Shrub Live Oak Alliance**
2. Shrub live oak poorly represented or absent, Mountain mahogany (*Cercocarpus montanus*) common to well represented as dominant or co-dominant shrub .... **Mountain Mahogany Alliance**

Desert (Extremely Xeromorphic) Shrublands

Creosotebush (*Larrea tridentata*) common to well represented as dominant or co-dominant shrub .... **Creosotebush Alliance**
Creosotebush poorly represented to absent or not dominant or co-dominant shrub 2

2. Tarbush (*Flourensia cernua*) common to well represented as the dominant or co-dominant shrub .... **Tarbush Alliance**
2. Tarbush poorly represented to absent or not dominant or co-dominant shrub 3

3. ,ittleleaf sumac (*Rhus microphylla*) common to well represented as dominant or co-dominant shrub............. .... **Littleleaf Sumac Alliance**
3. Littleleaf sumac poorly represented to absent 4

4. Ocotillo (*Fouquieria splendens*) dominant shrub, with other shrubs usually scarce. **Ocotillo Alliance**
4. Ocotillo uncommon or absent.. ...5

5. Broom dalea (*Psorothamnus scoparius*) common to well represented as dominant or co-dominant shrub........ .... **Broom Dalea Alliance**
5. Broom dalea poorly represented to absent 6

6. Sand sagebrush (*Artemesia filifolia*) well represented as dominant shrub **Sand Sagebrush Alliance**
6.. Sand sagebrush poorly represented to absent or not dominant shrub....... 7

7. Honey mesquite (*Prosopis glandulosa*) common to well represented as dominant or co-dominant shrub.......... .... **Honey Mesquite Alliance**
7. Honey mesquite poorly represented to absent, or not dominant or co-dominant shrub 8

8. Fourwing saltbush (*Atriplex canescens*) common to well represented as dominant or co-dominant shrub .... **Fourwing Saltbush Alliance**
8. Fourwing saltbush poorly represented to absent, or not dominant or co-dominant shrub.................................9

9. Shadscale (*Atriplex confertifolia*) common to well represented as dominant or co-dominant shrub .... **Shadscale Alliance**
9. Shadscale (*Atriplex confertifolia*) poorly represented to absent, or not dominant or co-dominant shrub 10

10. Beebrush (*Aloysia wrightii*) common to well represented as dominant or co-dominant shrub .... **Beebrush Alliance**
10. Beebrush (*Aloysia wrightii*) poorly represented to absent, mariola (*Parthenium incanum*) common to well represented as dominant or co-dominant s hrub .... **Mariola Alliance**

Key to the Grassland Alliances (Cover Types)

1. Gyp dropseed (*Sporobolous nealleyi*) common to well represented as dominant or co-dominant grass, generally on gypsic soils .... **Gyp Dropseed Alliance**
1. Gyp dropseed poorly represented to absesnt 2

2. Galleta (*Hilaria jamesii*) well represented as dominant grass **Galleta Alliance**
2. Galleta poorly represented to absent or not dominant grass 3

3. Indian ricegrass (*Oryzopsis hymenoides*) well represented as dominant grass. **Indian Ricegrass Alliance**
3 Indian ricegrass poorly represented to absent or not dominant grass 5

4. New Mexico needlegrass (*Stipa neomexicana*) common to well represented as dominant or co-dominant grass .... **New Mexico Needlegrass Alliance**
4. New Mexico needlegrass poorly represented to absent or not dominant grass 5

5. Hairy grama (*Bouteloua hirsuta*) common to well represented as dominant or co-dominant grass .... **Hairy Grama Alliance**
5. Hairy grama poorly represented to absent or not dominant 6

6. Black grama (*Bouteloua eriopoda*) common to well represented as dominant or co-dominant grass; occasionally sub-dominant to sideoats grama .... **Black Grama Alliance**
6. Black grama poorly represented to absent or not dominant 7

7. Blue grama (*Bouteloua gracilis*) common to well represented dominant **Blue Grama Alliance**
7. Blue grama poorly represented to absent or not dominant 8

8. Sideoats grama (*Bouteloua curtipendula*) common to well represented as dominant or co-dominant grass .... **Sideoats Grama Alliance**
8. Sideoats grama poorly represented to absent or not dominant 9

9. Giant Sacaton (*Sporobolous wrightii*) well represented as dominant grass. **Giant Sacaton Alliance**
9. Giant Sacaton poorly represented or absent 10

10. Alkali sacaton (*Sporobolous airoides*) common to well represented as dominant or co-dominant grass .... **Alkali Sacaton Alliance**
10. Alkali sacaton poorly represented or absent 11

11. Burrograss (*Scleropogon brevifolius*) well represented as dominant grass **Burrograss Alliance**
11. Burrograss poorly represented to absent or not dominant 12

12. Mountain muhly (*Muhlenbergia montana)* well represented as dominant grass... **Mountain Muhly Alliance**
12. Mountain muhly poorly represented to absent or not dominant 13

13. sand, mesa, spike or giant dropseed (*Sporobolus cryptandrus, S. flexuosus, S contractus* or *S. giganteus*) common to well represented as dominant or co-dominant grasses; communities of sandy soils**Dropseed Alliance**

13. Purple threeawn (*Aristida purpurea)* or other threeawn species dominant **Purple Threeawn Alliance**

RIPARIAN/WETLANDS

10. Rio Grande cottonwood (*Populus fremontii*) the dominant tree forming open canopies on river bars .... **Plains or Rio Grande Cottonwood Alliance**

10. Salt cedar (*Tamarix ramossisima*) the dominant canopy species, often forming dense shrublands. Rio Grande cottonwood poorly-represented or absent, ... **Salt Cedar Alliance**