An Assessment of the Spatial Extent and Condition of Grasslands in Central and Southern Arizona, Southwestern New Mexico and Northern Mexico

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Animas Valley from the Sierra San Luis, Sonora, MX Photo: P. Warren

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EXECUTIVE SUMMARY

Grasslands of central and southern Arizona, southwestern New Mexico and northern Mexico, an area known as the Apache Highlands Ecoregion, have undergone dramatic vegetation changes over the last 130 years, including encroachment by shrubs, loss of perennial grass cover, and spread of non-native species. Changes in grassland composition and structure have not occurred uniformly across the region and their extent and distribution are poorly understood at a regional scale. Moreover, these changes are dynamic and ongoing. The purpose of this study was to rapidly assess and characterize the extent of the vegetation changes to grasslands and to identify the best remaining native grasslands and restorable grasslands for conservation planning and ecological management purposes.

We used an expert-based approach interviewing 24 range management specialists from the Forest Service (USFS), Natural Resources Conservation Service, Bureau of Land Management (BLM), University of Arizona, Arizona State Land Department, The Nature Conservancy and New Mexico Natural Heritage Program. Expert input was verified and corrected where necessary through extensive field reconnaissance and quantitative vegetation sampling at random sampling points. Two methods were used to evaluate the accuracy of expert input, yielding a lower- and upper-limit accuracy estimate of 76% and 88%, respectively. The accuracy of the final grassland map presumably exceeds these figures due to adjustments made during field work.

Six primary grassland condition types were identified through the course of this study: native grassland with low shrub cover (Type A); shrub-encroached native grassland with restoration potential using prescribed fire (Type B); sacaton riparian grassland (Type C); non-native grassland with low shrub cover (Type D); shrub-encroached non-native grassland (Type E); and former grassland that has undergone a type conversion to shrubland (Type F). Experts identified 13,115,000 acres in the U.S. and Mexico as current or former grassland; we assume that this represents the historic distribution/extent of grasslands. Most current and former grasslands, 10,724,000 acres, occur in the U.S. portion of the study area.

Vegetation change in grasslands has been extensive and dramatic. Native grasslands with low shrub cover now cover only 2 million acres or 15.4% of current and former grassland. Roughly three-quarters of this high-quality native grassland, or 1.4 million acres, occurs in the U.S. (13.7% of current and former U.S. grassland). Shrub encroachment has occurred on over 9.2 million acres or 70.7% of current and former grasslands. Approximately 3.8 million acres of this is restorable back to native grassland using grazing rest and prescribed burns (29.2% of current and former grassland). However, shrub cover has exceeded a threshold producing a type conversion from grassland to shrubland on over 4.1 million acres or 36% of the historic extent of grasslands in the ecoregion.

In the U.S., shrub encroachment has been more extensive and severe, affecting over 8.7 million acres (84.1% of current and former U.S. grasslands). Shrub-invaded native grasslands with restoration potential make up approximately 3.5 million acres of this total (32.4% of current and former U.S. grasslands), while type conversion to shrubland has occurred on approximately 3.8 million acres (37.1% of current and former U.S. grassland). Thus, the opportunity for restoration

of shrub-invaded native grassland using prescribed fire is substantial in the U.S. and time-sensitive, considering the amount of grassland that has already been converted to shrubland.

The spread of non-native perennial grasses within grasslands has also been significant. Boer lovegrass and Lehmann lovegrass to a greater extent are now common or dominant on more than 1.4 million acres. Restricted to southeastern Arizona where the two species were originally introduced, non-native grasslands comprise 14.2% of current and former U.S. grasslands and 22.6% of current U.S. grasslands.

In the U.S. 30.8% of current and former grasslands are on State lands, 30.3% on private land, 17.5% on BLM land and 11.5% on USFS land. Most native grasslands with low shrub cover are privately owned (44.3%) while 23.3% are managed by the State Land Dept., 9.4% by USFS and 7.7% by BLM. Most non-native grasslands are on private land (43.7%), followed by 31.1% on State lands, 10.8% on USFS land and only 1.4% on BLM land. Shrub-invaded native grasslands with restoration potential occur mostly on State (33.8%) and private lands (24.5%) followed by USFS (21.6%) and BLM (15.4%) land. More significant is the acreage of restorable native grassland in public ownership—approximately 2.5 million acres, including 1.3 million acres of BLM and USFS land and 1.2 million acres of State lands.

Most native grasslands have no legal protective status which would prevent conversion or clearing of their natural land cover. In the U.S. portion of the ecoregion, only 1.2% of native grasslands with low shrub cover are permanently protected from land cover conversion and have a mandated management plan to maintain them in a primarily natural state. In contrast, over 58.9% of these grasslands have no protective status. Similarly, only 5% of restorable native grasslands are highly protected compared to 55.1% of these that have no protective status. Thus, in a region that is experiencing one of the highest rates of population growth in the U.S., native grasslands are extremely vulnerable to urban, suburban, and exurban development.

Extent, in acres, and percent abundance of grassland types in U.S. and Mexico.

Grassland Type	US Acres	MX Acres	US-MX Acres	% All Grasslands*
Native (A, A&D)	1,472,056	547,046	2,019,098	15.4
Native with Restoration Potential (A&B, B)	3,478,246	350,702	3,828,948	29.2
Non-Native (D, E)	1,469,319	0	1,469,319	11.2
Riparian (C)	45,735	7,239	52,974	0.4
Former Grassland (F)	3,837,691	215,635	4,053,326	30.9
Unknown (UNK)	381,386	1,270,018	1,651,404	12.6

* Value represents the proportion of the total grassland acreage (13,114,857) for each US-MX grassland type.

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INTRODUCTION

The grasslands of central and southern Arizona, southern New Mexico and northern Mexico have undergone dramatic vegetation changes over the last 130 years including encroachment by shrubs, loss of perennial grasses, and spread of non-native species (Humphrey 1963, 1987; Buffington and Herbel 1964; Hastings and Turner 1965; Bahre 1991). The causes for these vegetation changes have been the subject of some debate with explanations ranging from changes in regional climate to human impacts including poorly managed livestock grazing and suppression of wildfires (Humphrey 1958; Hastings and Turner 1965; Cable 1967; Wright 1980; Bahre 1985, 1995; Swetnam 1990; Archer et al. 1995; Brown et al. 1997; McPherson and Weltzin 2000). These changes in grassland composition and structure have not occurred uniformly across the borderland region and their extent and distribution is poorly understood at a regional scale (Bahre 1991; Bahre and Shelton 1993). The purpose of this study was to broadly characterize the extent of these vegetation changes to grasslands and to identify the best-remaining native grasslands for conservation planning purposes.

The changes to borderland grasslands are not solely the consequence of past climatic events or human impacts but are ongoing today (Archer 1989). In the upper San Pedro River basin, there was a 16% loss of grasslands to mesquite woodland from 1970-1990 resulting in increased fragmentation of the remaining grassland there (Kepner et al. 2000). In a long-term study at Portal, Arizona, shrub density increased three-fold from 1977 to 1995 presumably as a result of increased winter precipitation which favored shrub establishment (Brown et al. 1997). However, despite a region-wide increase in winter precipitation, no detectable shrub increases occurred in large areas of grassland habitat, some within 20 km of the Portal site. Many factors, including climate, soil, fire, herbivory, grazing history, and existing vegetation have influenced the extent of shrub increases and loss of perennial grass cover (Glendening 1952; Buffington and Herbel 1965; Madany and West 1983; Dick-Peddie 1993; Archer 1994; Goldberg and Turner 1986; Turner 1990; Bush and Van Auken 1995; McAuliffe 1995).

Although the above studies, as well as a number of others, have documented vegetation change in grasslands locally, there have been few attempts to characterize the extent of change at broader spatial scales. A notable exception, Cox and Ruyle (1986) documented the extent of spread of Lehman's lovegrass (*Eragrostis lehmanniana*) in southern Arizona since 1932 when it was introduced from South Africa. The species has continued to spread since 1986 and it now appears as if the edaphic and climatic factors limiting its distribution were too narrowly defined by Cox and Ruyle (1986). However, there are still extensive areas in the state where the species is absent or rare.

Given the non-uniform distribution of vegetation changes to grasslands regionally, a broad-scale characterization of the spatial extent of these changes is needed for conservation planning and ecological management purposes. This would allow us to (i) assess the magnitude of the changes (thereby justifying the importance of grasslands as targets for conservation attention) and (ii) identify the remaining high-quality native grasslands and restorable native grasslands for protection and restoration.

Grasslands in the southwestern U.S. occur primarily on private and State Trust lands which currently have no long-term conservation protection. Because of their favorable climate and aesthetic qualities, grasslands are a prime target for subdivision and suburban/rural development. This development threatens the viability of certain grassland species like pronghorn, reduces the opportunities for habitat corridors linking adjacent mountain ranges, and prevents the restoration of important ecological processes like fire that are critical in maintaining plant species diversity and preventing shrub encroachment in grasslands (Ockenfels 1994; Heckert 1994; McPherson 1995; Valone and Kelt 1999). Based on demographic projections and population movement patterns within the U.S., if significant grassland sites are not protected in the next 10 years, they will likely be lost to development.

Assessing the condition of grasslands for conservation planning or ecological management purposes requires an approach that is appropriate to the scale of the planning unit. Working in tall- and mid-grass prairies in Kansas, Lauver and Whistler (1993) used several raw spectral bands and band transformations (NDVI and tasseled cap) in a combination of unsupervised and supervised classification of Landsat Thematic Mapper (TM) imagery to identify high vs. low quality grasslands for conservation purposes. Similarly, Muldavin et al. (2001) investigated the use of Landsat TM imagery to identify high-quality grasslands in the Chihuahuan Desert. Using a series of plots located in the Jornada Basin of central New Mexico, multiple regression indices were developed between perennial grass, litter, bare soil and shrub cover components and TM spectral band reflectance values; the different cover indices were combined in an overall grassland biodiversity index. The Jornada model was applied to a test-site in Mexico with moderate success. The regression coefficients between TM index covers and field-measured cover values ranged from 0.41 to 0.003; exposed soils tended to be overestimated by the TM indices, shrub cover was bimodally under- and over-estimated, whereas litter cover was poorly estimated possibly due to the influence of soils at the test-site. In general, the TM biodiversity index did identify extreme conditions of both high and low grass cover at the test-site but was far less satisfactory with respect to intermediate conditions. This includes distinguishing grassland sites with low shrub cover (< 10%) from sites with higher cover values (10-35%).

Although the use of satellite imagery shows some promise in describing broad-scale patterns in grassland condition, image preparation, field data to develop the regression models between spectral reflectance values and vegetation characteristics, and field testing to calibrate the model can be costly and require several years to complete (Muldavin et al. 2001). In addition, there are technical problems in distinguishing a number of common shrubs species that leaf-out and increase in canopy cover after the onset of the summer rains from warm season grasses and herbs which show maximum growth and maximum green biomass at this time (Warren and Hutchinson 1984; R. Marsett, pers. comm.). In addition, geologic substrates and soils frequently mask the spectral signature of vegetation in arid landscapes requiring selection of the appropriate vegetation index and re-calibration of satellite-derived indices with substrate changes (Huete and Jackson 1987; Huerte 1988; Elvidge and Lyon 1985; Ringrose et al. 1994; Qi et al. 1994; Muldavin et al. 2001).

We used an alternative, expert approach to develop a broad-scale, rapid assessment of grasslands in the Apache Highlands Ecoregion, a 30-million acre planning area described below. The approach involved the use of range management experts with in-depth knowledge of the local landscape to map the spatial extent of a series of grassland classes that we identified, field verification of the expert-derived maps to assess their accuracy, and re-mapping where necessary to correct inaccuracies. The objective of the assessment was to develop a spatial layer that identified the location and extent of the ecoregion's:

(1) best remaining native grasslands;

(2) non-native grasslands where introduced perennial grasses--primarily Lehmann lovegrass and Boer lovegrass (*Eragrostis curvula*)--are a common or dominant component of the grassland community;

(3) shrub-invaded native grasslands with restoration potential using grazing rest and prescribed fire (to reduce shrubs); and

(4) former grasslands that have crossed an ecological threshold with respect to shrub encroachment resulting in a type conversion to desert shrubland; in this case, restoration using grazing rest and prescribed fire is no longer possible (permanent conversion) or may be possible only after extended periods of grazing rest, i.e., 40+ years, and recovery of perennial grasses (Gardner 1950; Glendening 1952; Smith and Schmutz 1975; Hennessey et al. 1983; Roundy and Jordan 1988; Valone et al. 2002).

Identification of these shrublands is important for conservation planning purposes because they may still be part of an unfragmented landscape with biodiversity value (Muldavin et al. 2001).

<u>Study Area</u>

The Apache Highlands Ecoregion straddles the United States-Mexico border of southeastern Arizona, southwestern N. Mexico, northern Sonora and northwestern Chihuahua. It extends northwest through the Verde River and Big Chino valleys of central Arizona to the Mogollon Rim in the north and south through the isolated mountain ranges of northern Mexico to the main cordillera of the Sierra Madre Occidental (Figure 1). This 30-million acre ecoregion was defined by The Nature Conservancy based on Bailey (1995, 1998) and is roughly composed of the western portion of Bailey's Chihuahuan Desert Ecoregion and the northern portion of the Madrean Ecoregion. The southern boundary of the Apache Highlands Ecoregion roughly corresponds to the northern distributional limit of Sinaloan tropical deciduous thorn scrub (Brown and Lowe 1980).

The Apache Highlands Ecoregion encompasses the sky island mountain ranges of the borderlands and the Southwest's largest expanse of plains and semi-desert grassland. These isolated mountain ranges support high-elevation plant communities including Madrean oak encinal, Madrean pine-oak woodland, and mixed-conifer forest and are connected, or were historically, by broad valley-bottom grasslands (Nichols 1937, Whittaker and Niering 1965; Felger and Johnson 1995).

Description of Grassland Classes

We developed a series of grassland classes or types using information from range management experts and the literature to define threshold values for shrub cover (see references in McPherson 1997). The classes include:

Native grassland with low shrub cover, TYPE A: grassland with < 10% shrub cover whose herbaceous component is entirely or predominantly native perennial grasses and herbs; non-native perennial grasses are uncommon or absent. In the latter case, we did not specify a cover value for distinguishing uncommon from common but left this determination to the individual expert.

Shrub-invaded native grassland with restoration potential, TYPE B: grassland composed of native perennial grasses and herbs (non-natives absent or uncommon) with 10-35% total shrub cover and mesquite or juniper cover < 15%. A key characteristic of this type is its restoration potential--that is, shrub cover can be reduced using prescribed burns and the site restored back to TYPE A grassland either immediately or after some period of grazing rest (< 15 years) when sufficient fine fuels have accumulated for fire spread (Brunson et al. 2001).

Sacaton riparian grassland, TYPE C: grassland dominated by giant sacaton (*Sporobolus wrightii*) that occurs on floodplain terraces along drainages (Brown et al. 1979).

Non-native grassland with low shrub cover, TYPE D: grassland with < 10% shrub cover where non-native perennial grasses are common or dominant.

Shrub-invaded non-native grassland, TYPE E: grassland with 10-35% total shrub cover and mesquite or juniper cover < 15% and non-native perennial grasses are common or dominant; again, a defining characteristic for this type is its potential for shrub reduction using prescribed burns and "restoration" to TYPE D grassland.

Shrubland-former grassland, TYPE F: former grassland with > 15% canopy cover of mesquite and juniper combined and/or > 35% total shrub cover; perennial grass canopy cover usually < 1 %, always < 3 %; type conversion to shrubland that is either permanent or will require 40+ years of livestock exclusion for partial recovery of perennial grasses (Hennessey et al. 1983; Valone et al. 2002).

METHODS

Development of Expert Maps

We interviewed 24 range management specialists from several federal and state agencies, institutions and non-governmental organizations. These include the U.S. Forest Service, U.S.D.A. Natural Resources Conservation Service, Bureau of Land Management, University of Arizona, University of Arizona Cooperative Extension Service, Arizona State Lands Department, The Nature Conservancy, and New Mexico Natural Heritage Program (see

Acknowledgements). All experts had considerable knowledge of local range conditions. Following an explanation of the classification system, experts delineated polygons representing current and former grassland on maps that we provided, assigning a grassland type to each polygon. The maps were 1:100,000, 1:150,000, or 1:250,000 digital raster graph (DRG) maps overlain with the GAP vegetation associations for Arizona or New Mexico (Arizona Gap Project 1998; Thompson et al. 1996). Experts were encouraged to use the GAP vegetation overlay as a guideline but to base their mapping and type assignments on personal experience. If an area was extremely heterogeneous, the polygon was assigned a combined type, for example Type A&B grassland or Type A&D grassland (see Figure 1), however, this was done only when a preponderant grassland type could not be identified. During the interview we also asked experts to identify potential grasslands, current and former, that were in need of further reconnaissance; these were designated as unknown grassland.

Polygons drawn on the hard-copy expert maps were digitized in Arcview 3.2 using an on-screen digitizing approach; the GAP vegetation layer and elevation contour lines from the DRG's were used as guides to more accurately define polygon boundaries. Individual ArcView GIS files ("shape" files) were made for each expert. Both authors and two trained volunteers digitized the hard-copy expert maps.

Field Verification

We developed field maps of grassland-type polygons from individual expert shape files at scales ranging from 1:100,000 to 1:150,000; areas where experts overlapped and disagreed on the grassland type designation were highlighted. These maps included all paved and unpaved roads to facilitate orientation in the field as well as 25-30 random points that were used in the selection of field sampling sites.

Between May 2002 and August 2002 we conducted 17 trips to assess the accuracy of the expert-derived maps. Prior to departure, we inspected the field maps and 1:200,000 BLM land cover/land ownership maps to establish a proposed route that would take us through the major polygons in an area and provide access to the greatest number of random field sampling points. Since it was logistically impossible to visit all polygons, native grasslands with low shrub cover (Type A), larger polygons of the other grassland types, and areas of disagreement between experts were targeted for visitation and sampling. In instances where we could not hike to the approximate location of a random sampling point, we stopped along the road at a place that was closest to that point on federal or State land. No assessments were made on private land without the prior consent of the landowner. Unfortunately, access to all points was not possible due to locked gates. When these were encountered while trying to reach a random point, we back-tracked along the road for a randomly determined distance of 0.5, 1, 1.5, or 2 miles and sampled at this location. When sampling in the vicinity of a road, we walked 100-200 m perpendicular to the road before sampling to eliminate the effect of any disturbance from the road on vegetation. This included the occurrence of Lehmann or Boer lovegrass, which frequently grew along roads. However, unless these non-native grasses are widely distributed in an area (which can easily be determined by sight), we found that a distance of 100-200 m from the road was sufficient for them to completely disappear as a component of the herbaceous vegetation.

The assessment was initiated with a rapid reconnaissance of the sampling site for a period of at least 15 observer-minutes. We then estimated canopy cover (in percent) of all shrubs, of mesquite and juniper, and of perennial grasses to the nearest 5%. A species list of shrubs and perennial grasses was also made with the dominant grass and shrub identified. For the first 7 trips, canopy cover was estimated using 3-6 pace transects, each 150-200 meters in length, for a total of 400-600 sampling points per site (Avery 1975; Cook and Stubbendiek 1986). On later trips, ocular estimates of canopy cover were made, interspersed periodically with pace transects to maintain consistent cover estimates.

The abundance of exotic perennial grasses was ranked at each sampling site on an ordinal scale as dominant, common, scattered, rare, or absent (Shaver et al. 2000). To make this scale more quantitative and enhance consistency between observers and sampling trips, we used a modified frequency sampling method, recording the presence or absence of Lehmann or Boer lovegrass in 4, 3-m x 3-m quadrats placed at 15 m intervals along transect lines. Transects were approximately 180 m in length with a total of 3-4 transects and 144-200 quadrats per site. Lehman and Boer lovegrass were considered rare at a site if frequency in quadrats was <10%, scattered if the frequency was 10-20%, and common or dominant if the frequency was >20%. Common was distinguished from dominant based on whether the combined canopy cover of non-native lovegrasses was or was not greater than any other single species at the site. Quantitative (frequency) sampling of non-native grass abundance was used in making assignments of non-native rank abundance during the first 7 trips; after this, ocular estimates of rank abundance were made.

At each site we also ranked the potential for using prescribed fire to reduce shrubs and restore "open" grassland conditions, using the following ranking scheme:

Rank 1 Fine fuels are continuous at the site and sufficient at the present time to permit fire spread and mortality or top-killing of shrubs (approximately 800-1000 kg/ha);

Rank 2 Fine fuels discontinuous and amount insufficient to allow fire spread; grazing rest for a period < 5 years is required for the build-up of fine fuels.

Rank 3 Fine fuels discontinuous and amount insufficient to allow fire spread; grazing rest for a period > 5 years required for the build-up of fine fuels.

Rank 4 Type conversion, fuels unlikely to build up to a level to permit fire spread because of excessive soil erosion and competition with shrubs.

The rank determinations were made by DFG based on experience conducting prescribed burns and with the recovery of semi-desert grassland sites following the removal of livestock.

At each site we also noted any evidence of soil erosion such as the presence of rills, pedestals, terracettes, water flow, litter movement, and gullies. Using the Rangeland Health Evaluation methodology, the severity of erosion was given an overall ranking of extreme, moderate to extreme, moderate, slight to moderate or slight based on the condition of the site relative to reference areas (Shaver et al. 2000). Finally, 2-4 photographs were taken at each site and comments on any human-caused threats or impacts were made.

When driving through polygons to reach the random field sampling points, we recorded notes on the field maps indicating the grassland type we were passing through. If a discrepancy between the expert map and our assessment of the condition class arose, either at the assessment site or when driving between sites, we attempted to clarify the discrepancy with additional mapping. Often this was done by driving to a location that would provide an overlook of the area, at other times we did some additional driving on roads within the area in question to get a better sense of the extent of the contested area. A portion of the field verification was conducted during the spring-summer dry season following several years of below-average precipitation. Although this undoubtedly affected perennial grass cover and a site's potential for burning immediately vs. after some period of grazing rest, the grassland types were distinguished primarily on the basis of shrub canopy cover which was not strongly affected by the drought.

In addition to our field sampling points, we used shrub and perennial grass cover data derived from long-term monitoring plots (n= 93) to further assess the accuracy of the expert maps. The plots were located on the Muleshoe Ranch Cooperative Management Area and Aravaipa Canyon Preserve, in the Galiuro Mountains, Arizona, on the Gray Ranch in southwestern New Mexico, and on the San Rafael Short Grass Prairie Preserve in southeastern Arizona. The plots were not visited during the field assessment portion of the study but were last measured in 1998-2000 for the Galiuros plots, in 1992-1993 for the Gray Ranch plots and in 2000 for the San Rafael plots.

Map Modifications Based on Field Data

The original expert maps were corrected based on data from field sampling points, notes made while traversing polygons, and field mapping. Expert polygon files were intersected with a hexagon-shaped grid surface (resolution of 50 ha) to facilitate the modification of polygon classifications and boundaries. After all corrections were made, the modified hexagon shape files were dissolved to generate continuous polygons of like grassland type for each expert; these individual expert maps were then merged together to create a full grassland coverage for the U.S. portion of the study area. This layer was edited to remove sliver polygons inadvertently created in the dissolve and merge processes. The spatial layer developed by the Instituto del Medio Ambiente y el Desarollo Sustentable del Estado de Sonora (IMADES) for Mexican grasslands (see below) was then merged with the U.S. layer and edited as necessary to create a seamless cross-border data set.

Delineation of Grasslands in Mexico

Two training sessions were conducted in the U.S. and Mexico to instruct IMADES and two range management specialists from Mexico in the grassland classification system and field assessment methods. Delineation of the extent of different grassland types in Mexico was accomplished through a combination of expert mapping and analysis of seasonal Landsat TM images using a mixed strategy of supervised and unsupervised classification; the resulting determinations were verified with field sampling. Because the amount of field verification was less than that conducted in the U.S. and because there was a lack of current expert knowledge in certain areas, a significant amount of potential grassland was not assigned a grassland type; these were designated and mapped as unknown grasslands.

Statistical Analysis

From the completed grassland map, we tabulated basic statistics on grassland extent by type, including total area, minimum and maximum polygon sizes, and mean and median polygon sizes for each grassland type. The proportion of each grassland type found in the ecoregion was also calculated. In addition, using spatial layers of GAP protection status (Weinstein 2002) and land ownership (ALRIS 1998), we tabulated the area and relative proportion of each grassland type by GAP rank, by general land manager, and by specific land manager. For purposes of analysis and discussion, we considered Type A&B grassland, along with Type B, as shrub-encroached native grassland with restoration potential. Similarly, Type A&D grassland was included with Type A as native grassland with low shrub cover. This was reasonable in the latter case since only a single Type A&D polygon was identified and at this site Lehmann lovegrass was patchily distributed; non-native grass patches were surrounded by extensive areas of entirely native perennial grass cover.

RESULTS AND DISCUSSION

Accuracy Assessment

We assessed the accuracy of the original, uncorrected expert maps for the U.S. portion of the ecoregion using two methods. The first method uses the field sampling and monitoring plot data and estimates accuracy as the percent of these points or plots that “agree” with the expert’s determination for that area. Using this method, 212 out of 279 sites or 76% were correctly classified by the experts. This method provides a conservative estimate of the accuracy of the expert mapping approach for the following reason. We avoided field sampling in large homogenous areas of shrubland (type F) where we would get a high correspondence between our field-based categorization and an expert’s determination, e.g., former grasslands in the San Simon Valley, Arizona, or north of Lordsburg, New Mexico. Instead, we focused our field assessment on open grasslands (Type A and Type D) and shrub-encroached native grasslands with restoration potential (Type B). These areas appeared to be more heterogeneous in terms of shrub cover and perennial grass composition than former grasslands were and hence, the likelihood of a discrepancy between expert categorization and field data was greater. Had we focused on former grasslands instead we would have greatly increased the number of “correct” points.

The second method tallies the number of hexagonal grid cells that were *incorrectly* mapped by experts and that were corrected based on field reconnaissance and sampling (Figure 1). Percent accuracy is expressed as the number of grid cells that the experts *correctly* designated divided by the total number of grassland grid cells in the U.S. portion of the ecoregion. Doing this, the percent accuracy was 88%. This method is likely an overestimate since there were areas within the ecoregion that we did not visit and where the experts were assumed to be correct without field verification. Thus, the two methods provide a lower- and upper-limit estimate for the accuracy of the original, uncorrected expert map of 76% and 88%, respectively. It is important to note that the accuracy of the final grassland map (Figure 1) should be greater than the above figures because it was revised and corrected based on field data.

The accuracy estimates for the original grassland map compare favorably to those for land cover maps derived from analysis of Landsat sattelite imagery. Using an unsupervised classification of Landsat MSS imagery and ancillary data to separate mixed classes, Kepner et al. (2000) described 10 land cover classes, including grassland and mesquite shrubland, in the upper San Pedro River basin; overall map accuracy was 74.8%. A hierarchical unsupervised and supervised classification of Landsat TM imagery was used to identify native grasslands with high plant species diversity in eastern Kansas for conservation planning purposes; classification accuracy was 57% and 63.4% for previously unknown and known sites, respectively (Lauver and Whistler 1993). Halvorson et al. (2001) reported an overall map accuracy of 58.8% for the Arizona GAP land cover map which distinguished 53 land cover classes, including 5 grassland types, using Landsat TM imagery and a variety of spectral classification procedures. In another study, using Landsat TM imagery and a hybrid unsupervised/supervised classification technique, Miller et al. (in review) identified 16 vegetation-fuel load classes in the Huachuca Mountains, Arizona, including 2 grassland classes that differed in elevation and shrub cover. Overall map accuracy was 84% for the general vegetation classification and 54% for the vegetation-fuels classification. Finally, Ringrose et al. (1999), using Landsat TM imagery, distinguished 11 rangeland cover types in the wet season and 9 dry-season types based on differences in shrub and grass cover and degree of erosion in the southeast Kalahari, Botswana. Overall map accuracy was 78% for the wet season and 73% for the dry season.

Historic Distribution of Grasslands

Experts in the U.S. and Mexico identified 13,115,000 acres as extant or former grassland, which corresponds to 43.7 % of the ecoregion; we assume that this represents the historic distribution/extent of grassland in the ecoregion. Considering only the U.S. portion, our figure of 10,724,000 acres of current and former grassland corresponds well with the 9,474,000 acres of grassland identified by Brown and Lowe (1980). However, our figure is higher than the 6,713,000 acres identified by the Arizona-New Mexico GAP vegetation maps (Thompson et al. 1996; Arizona Gap Project 1998).

Native and Shrub-Invaded Grasslands

The summary statistics for the area of grassland in the various grassland types underscore the extent of the vegetation changes (Table 1). Only 1,975,000 acres or 15.1% of current and former grasslands still remain relatively shrub free and composed of native perennial grasses (Type A). These figures increase slightly if Type A&D grasslands are included, placing an upper limit on high-quality native grasslands within the ecoregion of 2,019,000 acres or 15.4% of their historic distribution. In comparison, shrub encroachment, in some places extensive, has occurred on over 9,273,000 acres or 70.7 % of current and former grasslands (including Types B, A&B, B&F, E and F). Approximately 3,829,000 acres or 29.2% of current and former grasslands can be restored back to native grassland using grazing rest and prescribed fire (Types B, A&B). However, shrub cover has exceeded a threshold of 35-40% on over 4.1 million acres, producing a type conversion from grassland to shrubland (Type F) on 36% of the historic extent of grasslands in the ecoregion.

This latter figure may be slightly overestimated since Valone et al. (2002) found that rest from grazing for 40- but not 20-years at a shrubland site resulted in an increase in perennial grass canopy cover from 2.5% outside an exclosure to 9.5% inside the exclosure. This represents only a partial recovery from a restoration standpoint because total fine fuels were still insufficient to carry a fire intense enough to reduce shrubs at the site. However, the results suggest that full recovery over longer time periods *may* be possible at certain sites depending on factors such as soil type, degree of soil erosion, and the identity of shrub species that occur there. In contrast, no increase in perennial grass cover was observed at another site following an increase in shrubs above the threshold value even after 50 years of grazing rest suggesting a permanent conversion from grassland to shrubland there (Hennessey et al. 1983).

Sacaton riparian grasslands (Type C) are rare in the ecoregion covering only 53,000 acres and comprising 0.4% of current and former grasslands (Table 1). The largest patch of sacaton riparian grassland (8,374 acres) occurs in the Animas Valley, New Mexico.

Non-Native Grasslands

The spread of non-native perennial grasses within grasslands has also been substantial. Boer lovegrass and, to a greater extent, Lehmann lovegrass are now common or dominant on 1,470,000 acres such that non-native grassland (Types D, E) comprises 11.2% of current and historic grasslands in the ecoregion (Table 1). The distribution of these grasslands is not uniform but restricted to southeastern Arizona where the two lovegrass species were initially introduced to prevent soil erosion and provide forage for livestock in the 1930's (Figure 1, Cox and Ruyle 1986). Although the current distribution of non-native grasslands is presumably a function of the species' physiological tolerances and soil type preferences, it seems likely that Lehmann lovegrass will continue its spread, increasing in abundance to the north, east and especially to the south in Mexico.

U.S.-Mexico Differences

Unfortunately, over 1,651,000 acres of potential grassland or 12.6% of the area identified as current or former grassland could not be classified into a grassland type by experts due to a lack of current information or experience in the area (Table 1). This figure is heavily influenced by the uncertainty of grassland status in Mexico where 1,270,000 acres or 53.1% of current and former Mexico grasslands are designated as unknown grasslands (Table 3). The figure for the U.S. portion of the ecoregion is 381,000 acres or 1.6% of the current and former U.S. grasslands (Table 2).

The relative frequency of the other grassland types also differ markedly in the U.S. and Mexico (Tables 2 and 3). Excluding unknown grasslands from the analysis, high-quality native grasslands (Types A, A&D) are proportionately 3.6 times more common in Mexico than the U.S. (56.9% in Mexico vs. 14.2% in the U.S.) and sacaton riparian grasslands (Type C) are 1.5 times more common in Mexico (0.6% vs 0.4%). In the U.S., high-quality native grasslands cover 1,472,000 acres and sacaton riparian grasslands cover 46,000 acres. In contrast, the relative frequency of shrub-invaded but restorable native grasslands (Types B, A&B) is similar in the U.S. and Mexico (33.6% in U.S. vs. 31.3% in Mexico). However, shrublands that were formerly grasslands (Type F) are relatively more common in the U.S. than Mexico comprising 37.1% of current and former grasslands in the U.S. compared to 19.2% in Mexico. In the U.S., restorable native grasslands cover 3,478,000 acres and former grasslands cover 3,838,000 acres. Lehman lovegrass occurs sporadically in Mexico but is a common or dominant component of grasslands only in the U.S.; non-native grasslands (Types D, E) cover over 1,469,000 acres and comprise 14.2% of current and former grasslands in the U.S. and 22.6% of current U.S. grasslands.

Overall, the absolute extent of grasslands, current and former, is greater in the U.S. than in Mexico (10,724,000 acres in the U.S. vs. 2,391,000 acres in Mexico) as is their relative abundance compared to other vegetation types (59.9% in the U.S. vs. 25.3% in Mexico; Tables 2 and 3).

<u>Grasslands by Land Manager</u>

In the U.S., most grasslands and former grasslands are on State lands (30.8% of the U.S. total) and private land (30.3%); 17.5% are on BLM land and 11.5% are on USFS land. Together these 4 land managers manage 90.1% of current and former U.S. grasslands. The relative abundance of different grassland types does not precisely follow the expected distribution based on the amount of land managed by the 4 entities. This presumably reflects differences in management history as well as physical factors such as elevation which affects the rate of mesquite encroachment, spread of Lehmann lovegrass and land management patterns (e.g., USFS land is generally higher in elevation than BLM or State land). For example, most high-quality native grasslands (Types A, A&D) are privately owned (44.3%) while 23.3% are managed by the State Land departments, 9.4% by USFS and 7.7% by BLM (Table 4). This suggests a disproportionate abundance of high-quality native grasslands in private ownership.

In general terms, shrub encroachment appears to occur at random with respect to land manager, with the relative frequency of shrub-invaded grasslands and shrublands combined (Types B, A&B, B&F, E, and F) closely matched to the percentage of current and former grasslands managed by the 4 entities. Most shrub-invaded grasslands and former grasslands occur on State lands (33.5%); 27.6% occur on private land, 18.9% on BLM and 12.3% on USFS land. However, former grasslands that have been converted to shrubland (Type F) are relatively more abundant on BLM land and less abundant on USFS land than expected (Table 4). That is, 28.6% of these shrublands occur on BLM land and only 3.8% occur on USFS land compared to an expected occurrence of 17.5% and 11.5%, respectively, based on the amount of current and former grasslands managed by the 2 agencies. The percent occurrence of former grasslands on private land is 25% and 33.7% on State lands. Similarly, shrub-encroached native grasslands with restoration potential (Types B, A&B) are relatively more abundant on USFS land than expected. That is, 21.6% of this grassland type occurs on USFS land, which significantly exceeds the 11.5% of current and former grasslands managed by them. Besides this, there are only slight differences in the observed vs. expected distribution of shrub-invaded native grasslands with restoration potential on private, BLM and State lands; 24.5% of this grassland type occurs on private land, 15.4% on BLM land and 33.8% on State lands. More significant is the area of restorable native grassland in public ownership—approximately 2.5 million acres or 72.1% of this grassland type in the U.S. This includes roughly 1.3 million acres managed by the

BLM and USFS, and 1.2 million acres managed by State land departments. Thus, the opportunities for grassland restoration on public lands are significant.

The occurrence of non-native grasslands (types D & E) appears non-random with respect to land ownership (Table 4). Approximately 43.7% of non-native grasslands occur on private lands although only 30.3% of current and former U.S. grasslands are in private ownership. In contrast, only 1.4% of non-native grasslands are on BLM land despite the fact that this agency manages 17.5% of current and former grasslands in the U.S. portion of the ecoregion. The percent occurrence of non-native grasslands on State lands and USFS land is 31.1% and 10.8%, respectively, which parallels the proportion of land in these categories of ownership.

Sacaton riparian grasslands show the most skewed pattern of occurrence with respect to land manager (Table 4). With only 45,700 acres in the U.S. portion of the ecoregion, 67.2% of these sacaton grasslands occur on private land, while only 2.6% occur on BLM land and 0.3% on USFS land; 21.9% of the sacaton riparian grasslands in the U.S. occur on State lands.

Conservation Status of Grasslands

Most grasslands have no legal status which would prevent conversion or clearing of their natural land cover to anthropogenic habitats. Table 5 summarizes current and former grasslands by GAP protection status rank (Weinstein 2002; http://www.gap.uidaho.edu). The ranking scheme is as follows: GAP Ranks 1, 2 are assigned to areas that have permanent protection from natural land cover conversion and that have a mandated management plan in operation to maintain a primarily natural state. GAP Rank 3 areas are also protected from natural land cover conversion but are subject to extractive uses including grazing (extensive) and mining (intensive). Areas assigned to GAP Rank 4 have no public or private mandates or legally recognized easements or deed restrictions in place preventing vegetation clearing or conversion. Only 1.2% of native grasslands with low shrub cover (Types A, A&D) in the U.S. portion of the ecoregion are protected from natural cover conversion and have a mandated management plan to maintain them in a primarily natural state, that is GAP Rank 1 or 2. In contrast, over 58.9% of these grasslands are unprotected, i.e., GAP Rank 4.

Similarly, only 5% of shrub-invaded native grasslands with restoration potential (Types B, A&B) are protected from natural cover conversion and have a mandated management plan to maintain them in a primarily natural state, GAP status 1 and 2, whereas 55.1% of this grassland type is unprotected (GAP Rank 4). The figures are both more and less encouraging for sacaton riparian grasslands with 10.3% of this rare grassland type being highly protected (GAP Rank 1 or 2) but with 67.3% having no permanent protective status. Thus, in a region that is sustaining the highest rate of population growth in the U.S., the grasslands are extremely vulnerable to urban, suburban, and exurban development.

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Table 1. General statistics for grasslands (U.S. and Mexico) in the Apache Highlands Ecoregion.

Grassland Type	# Grass-land Patches	Total Acres	Minimum Acres	Maximum Acres	Median Acres	Mean Acres	Total Hectares	Minimum Hectares	Maximum Hectares	Median Hectares	Mean Hectares	% All Grass-lands	% Entire Eco-region
Native; <10% shrub cover (Type A)	53	1,975,188	75	400,516	11,292	37,268	790,075	30	160,206	4,517	14,907	15.1	6.6
Native; 10-35% shrub cover (Type B)	140	3,354,958	22	492,151	2,019	23,964	1,341,983	9	196,860	808	9,586	25.6	11.2
Sacaton riparian grassland (Type C)	27	52,974	11	8,374	968	1,962	21,189	5	3,350	387	785	0.4	0.2
Exotic; <10% shrub cover (Type D)	10	118,509	629	25,771	11,043	11,851	47,404	252	10,308	4,417	4,740	0.9	0.4
Exotic; 10-35% shrub cover (Type E)	21	1,350,810	471	259,262	38,062	64,324	540,324	188	103,705	15,225	25,730	10.3	4.5
Former grassland shrub cover >35% (Type F)	47	4,053,326	51	2,230,332	13,904	86,241	1,621,330	21	892,133	5,562	34,496	30.9	13.5
A & B Mosaic	13	473,990	506	111,042	21,473	36,461	189,596	202	44,417	8,589	14,584	3.6	1.6
A & D Mosaic	1	43,910	43,910	43,910	43,910	43,910	17,564	17,564	17,564	17,564	17,564	0.3	0.1
B & F Mosaic	25	39,788	25	12,230	517	1,592	15,915	10	4,892	207	637	0.3	0.1
Unknown type	684	1,651,404	0	89,283	374	2,414	660,562	0	35,713	149	966	12.6	5.5

TOTAL US-MX GRASSLAND ACRES: 13,114,857

% ENTIRE ECOREGION: 43.7

Table 2. General statistics for grasslands within the U.S. portion of the Apache Highlands Ecoregion.

Grassland Type	# Grassland Patches	Total Acres	Minimum Acres	Maximum Acres	Median Acres	Mean Acres	Total Hectares	Minimum Hectares	Maximum Hectares	Median Hectares	Mean Hectares	% Total Grass-lands	% Entire Ecoregion
Native; <10% shrub cover (Type A)	52	1,428,146	75	174,630	10,288	27,464	571,259	30	69,852	4,115	10,986	13.3	4.8
Native; 10-35% shrub cover (Type B)	127	3,094,595	22	492,151	1,791	24,367	1,237,838	9	196,860	716	9,747	28.8	10.3
Sacaton riparian grassland (Type C)	16	45,735	11	8,374	2,683	2,858	18,294	5	3,350	1,073	1,143	0.4	0.2
Exotic; <10% shrub cover (Type D)	10	118,509	629	25,771	11,043	11,851	47,404	252	10,308	4,417	4,740	1.1	0.4
Exotic; 10-35% shrub cover (Type E)	21	1,350,810	471	259,262	38,062	64,324	540,324	188	103,705	15,225	25,730	12.6	4.5
Former grassland shrub cover >35% (Type F)	36	3,837,691	51	2,230,332	14,176	106,603	1,535,076	21	892,133	5,670	42,641	35.8	12.8
A & B Mosaic	12	383,651	506	111,042	16,830	31,971	153,460	202	44,417	6,732	12,788	3.6	1.3
A & D Mosaic	1	43,910	43,910	43,910	43,910	43,910	17,564	17,564	17,564	17,564	17,564	0.4	0.1
B & F Mosaic	25	39,788	25	12,230	517	1,592	15,915	10	4,892	207	637	0.4	0.1
Unknown type	147	381,386	1	89,283	23	2,594	152,554	0	35,713	9	1,038	3.6	1.3
TOTAL U.S. ACRES:		10,724,222											
% ENTIRE ECOREGION:		35.7											

Table 3. General statistics for grasslands within the Mexico portion of the Apache Highlands Ecoregion.

Grassland Type	# Grassland Patches	Total Acres	Minimum Acres	Maximum Acres	Median Acres	Mean Acres	Total Hectares	Minimum Hectares	Maximum Hectares	Median Hectares	Mean Hectares	% Total Grass-lands	% Entire Ecoregion
Native; <10% shrub cover (Type A)	4	547,046	4	333,559	106,742	136,761	218,818	1	133,424	42,697	54,705	22.9	1.8
Native; 10-35% shrub cover (Type B)	13	260,363	256	100,823	9,185	20,028	104,145	102	40,329	3,674	8,011	10.9	0.9
Sacaton riparian grassland (Type C)	12	7,239	2	2,216	535	603	2,895	1	886	214	241	0.3	0
Former grassland shrub cover >35% (Type F)	12	215,635	136	81,638	9,574	17,970	86,254	55	32,655	3,830	7,188	9	0.7
A & B Mosaic	1	90,339	90,339	90,339	90,339	90,339	36,136	36,136	36,136	36,136	36,136	3.8	0.3
Unknown type	537	1,270,018	0	70,263	447	2,365	508,007	0	28,105	179	946	53.1	4.2

TOTAL MX ACRES: 2,390,639

% ENTIRE ECOREGION: 8.0

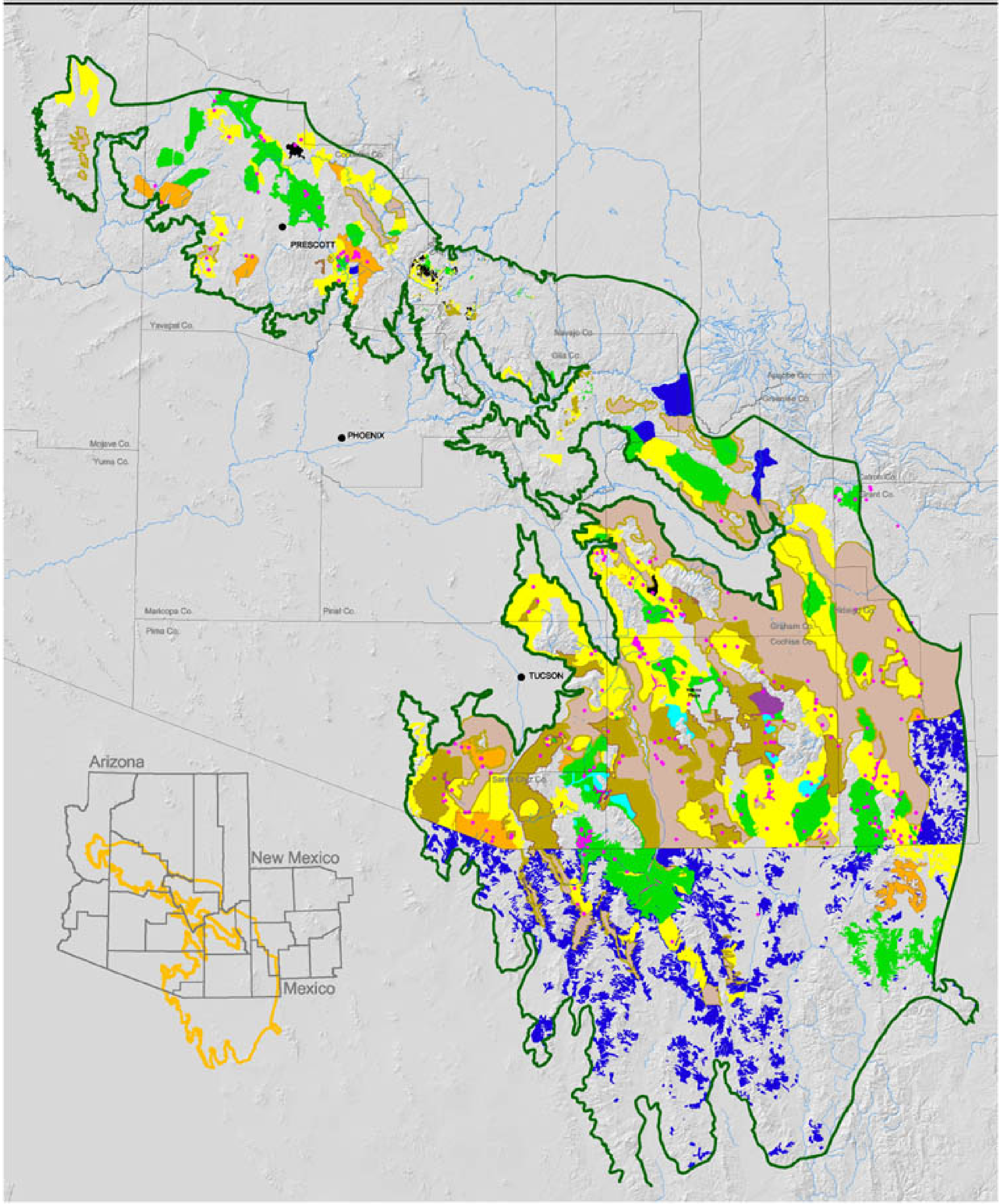
Table 4. Native, non-native grasslands and shrublands by land manager in the U.S. portion of the Ecoregion.

Land Manager	Native, <10% Shrub Cover (A, A&D)	Non-Native (D, E)	Riparian Grassland (C)	Shrubland-Former Grassland (F)	Unknown Grassland	Native w/ Restoration Potential (B, A&B)
State Land	342,333 (23.3%)	456,718 (31.1%)	10,032 (21.9%)	1,289,518 (33.7%)	14,946 (3.9%)	1,171,278 (33.8%)
Private	549,055 (37.3%)	641,092 (43.6%)	26,680 (58.3%)	935,198 (24.5%)	92,074 (24.1%)	752,831 (21.7%)
USFS	137,823 (9.4%)	157,975 (10.8%)	149 (0.3%)	145,814 (3.8%)	17,164 (4.5%)	747,803 (21.6%)
BLM	112,591 (7.7%)	19,903 (1.4%)	1,199 (2.6%)	1,094,944 (28.6%)	104,002 (27.3%)	534,597 (15.4%)
Native Americans	212,427 (14.4%)	--	--	311,133 (8.1%)	141,989 (37.2%)	123,281 (3.6%)
Private NGO	102,780 (7.0%)	501 (0.0%)	4,056 (8.9%)	21,944 (0.6%)	11,206 (2.9%)	97,032 (2.8%)
USFWS	0 (0%)	95,844 (6.5%)	3,120 (6.8%)	6,076 (0.2%)	--	16,170 (0.5%)
Arizona State Parks	2,967 (0.2%)	2,657 (0.2%)	498 (1.1%)	672 (0.0%)	--	10,440 (0.3%)
USDOD	8,881 (0.6%)	48,849 (3.3%)	--	1,237 (0.0%)	--	622 (0.0%)
City of Tucson	0 (0%)	671 (0.0%)	--	--	--	5,769 (0.2%)
AGFD	614 (0%)	19 (0.0%)	--	429 (0.0%)	--	2,562 (0.1%)
U of A	0 (0%)	41,657 (2.8%)	--	1,570 (0.0%)	--	2,214 (0.1%)
Pima County	0 (0%)	434 (0.0%)	--	6,483 (0.2%)	--	2,038 (0.1%)
USNPS	1,485 (0.1%)	2,600 (0.2%)	--	7,034 (0.2%)	--	16 (0.0%)
N/A	0 (0%)	0 (0.0%)	--	--	--	154 (0.0%)
TOTAL	1,470,956	1,468,921	45,735	3,822,054	381,382	3,466,808

Note: Acreages in this table may differ slightly from those in Table 2 because the land management data used here from Weinstein (2002) were based on a different ecoregional boundary.

Table 5. U.S. acreages of the Apache Highland Ecoregion's grasslands by Gap Rank (as determined by Weinstein 2002). A rank of "1" constitutes the highest level of legally mandated permanent land protection; a rank of "2" constitutes lands with permanent protection but which may receive uses or management practices that degrade the quality of existing natural communities; lands with a rank of "3" have some degree of protection but are subject to extractive uses which may involve land cover clearing; a rank of "4" constitutes lands without legally mandated protection; a rank of "5" constitutes lands with unknown status (see Weinstein 2002 for further details).

Grassland Type	GAP RANK 1	GAP RANK 2	GAP RANK 3	GAP RANK 4	GAP RANK 5
Native; <10% shrub cover (Type A)	6,800 (0.5%)	10,355 (0.7%)	374,415 (26.2%)	823,038 (57.7%)	212,439 (14.9%)
Native; 10-35% shrub cover (Type B)	42,510 (1.4%)	117,511 (3.8%)	1,046,154 (33.9%)	1,753,755 (56.9%)	123,892 (4.0%)
Sacaton riparian grassland (Type C)	4,204 (9.2%)	498 (1.1%)	10,275 (22.5%)	30,758 (67.3%)	--
Exotic; <10% shrub cover (Type D)	--	911 (0.8%)	37,473 (31.6%)	80,125 (67.6%)	--
Exotic; 10-35% shrub cover (Type E)	103,396 (7.7%)	10,976 (0.8%)	229,130 (17.0%)	1,006,909 (74.6%)	--
Former grassland shrub cover >35% (Type F)	16,622 (0.4%)	99,600 (2.6%)	1,180,204 (30.9%)	2,214,496 (57.9%)	311,133 (8.1%)
A & B Mosaic	2,209 (0.6%)	10,174 (2.7%)	213,799 (55.8%)	156,637 (40.9%)	165 (0.04%)
A & D Mosaic	--	--	1,190 (2.7%)	42,720 (97.3%)	--
B & F Mosaic	--	7,718 (19.4%)	20,291 (51.0%)	11,779 (29.6%)	--



Apache Highlands Ecoregional Boundary
U.S. Counties
Field Assessment Sample Points
Perennial Rivers and Streams

Grassland Type
- A = Native grass dominated; < 10% shrub cover
- B = Native grass dominated; 10-35% shrub cover
- C = Sacaton riparian grassland
- D = Exotic grass dominated; < 10% shrub cover
- E = Exotic grass dominated; 10-35 % shrub cover
- F = Shrub cover > 35%; historical grassland
- A & B mosaic
- B & F mosaic
- A & D mosaic
- Unknown grassland type

Assessment of the Current and Former Grasslands of the Apache Highlands Ecoregion

January 2003

N

Scale: 1 : 5,000,000

The Nature Conservancy

70 0 70 140 Kilometers

50 0 50 100 Miles

Appendix: Extent (in acres) of Grasslands by Type and Specific Land Manager in the U.S. Portion of the Apache Highlands Ecoregion.

Land Management Unit	**Native; <10% shrub cover (Type A)**	**Native; 10-35% shrub cover (Type B)**	**Sacaton riparian grassland (Type C)**	**Exotic; <10% shrub cover (Type D)**	**Exotic; 10-35% shrub cover (Type E)**	**Former grassland shrub cover >35% (Type F)**	**A & B Mosaic**	**A & D Mosaic**	**B & F Mosaic**	**Unknown type**
111 Ranch RNA-ACEC, BLM						42				
Agua Fria National Monument, BLM	2,052	21,017					151			4,678
Alamo Hueco Mountains RNA-WSA, BLM										6,904
Antelope Pass RNA BLM	905					7,724				
Apache Box ACEC-WSA, BLM						1,401				
Apache-Sitgreaves National Forest		17,790				10,069				17,164
Appleton-Whittell Research Ranch, Nationa Audubon Society	5,919		1,084		222	456				
Aravaipa Canyon Preserve, The Nature Conservancy		3,773				686				
Aravaipa Canyon Wilderness, BLM	222	7,768				232				
Arivaca Lake, AZ Game and Fish Dept.		142				6	73			
Baboquivari Peak Wilderness, BLM		201								
Baker Canyon WSA, BLM		2,549				432				
Bear Springs Badlands ACEC, BLM						339				
Bellota/A7 Ranch, City of Tucson, AZ	-	6,538	-	-	671	-	-	-	-	-
Big Hatchet Mountains ACEC-WSA, BLM										10,181
BLM (General)	69,230	420,608	476	818	12,473	981,480	18,013	610		82,239
Blue Creek WSA, BLM						13,819				
Bog Hole AZ Game and Fish Dept/USFS Wildlife Area	309			19						
Bowie Mountain Scenic ACEC, BLM					2			485		
Buehman Canyon Preserve, The Nature Conservancy		832								
Buenos Aires National Wildlife Refuge, USFWS		12,284	3,079		95,844	4,915				
Burro Creek Riparian and Cultural ACEC, BLM	915						64			
Canelo Hills Cienega Preserve, The Nature Conservancy	48									
Castle Creek Wilderness, USFS		1,225								
Catalina State Park, AZ State Parks		5,232								
Cedar Bench Wilderness, USFS		270								
Central Peloncillo Mountains ACEC, BLM		2,372				1				

Abbreviations are: ACEC = Area of Critical Environmental Concern; RNA = Research Natural Area; WSA = Wilderness Study Area.

Appendix: Extent (in acres) of Grasslands by Type and Specific Land Manager in the U.S. Portion of the Apache Highlands Ecoregion.

Land Management Unit	**Native; <10% shrub cover (Type A)**	**Native; 10-35% shrub cover (Type B)**	**Sacaton riparian grassland (Type C)**	**Exotic; <10% shrub cover (Type D)**	**Exotic; 10-35% shrub cover (Type E)**	**Former grassland shrub cover >35% (Type F)**	**A & B Mosaic**	**A & D Mosaic**	**B & F Mosaic**	**Unknown type**
Central Peloncillo Mountains ACEC/Gray Peak WSA, BLM		749								
Chiricahua Cave Creek Preserve, The Nature Conservancy		17								
Chiricahua Wilderness, USFS		5,325		892	1,317	2,432				
Chiricahua National Monument, USNPS	344					101				
Cienega Creek Natural Preserve, Pima Co., AZ						2,771				
Cienega Creek Natural Preserve/Empirita Ranch, Pima Co., AZ					54	816				
Cluff Ranch Wildlife Area, AZ Game and Fish Dept.						423				
Coconino National Forest	3,770	56,882				21,190				
Colossal Cave Mountain Park, Pima Co. Parklands Foundation						2,636				
Colossal Cave Mountain Park, Pima Co. AZ/BOR						177				
Coronado National Memorial, USNPS	1,130				415					
Coronado National Forest	53,837	265,618	149	10,186	133,344	66,334	108,217	84		
Cowboy Spring ACEC, BLM	4,469					2,344				
Desert Grasslands - Sombrero Butte ACEC BLM		386								
Dos Cabezas Mountains Wilderness, BLM		1,038				695				
Douglas Military Reservation, USDOD		622								
Escondido Falls Preserve, The Nature Conservancy		44								
Fishhooks Wilderness, BLM	150	8,250				1,645				
Fort Bowie National Historic Site, USNPS								11		
Fort Huachuca, USDOD	7,499			22,008	26,840	1,237				
Fossil Springs Wilderness, USFS		-								
Galiuro Wilderness, USFS		9,304								
Gila Box Riparian National Conservation Area BLM		595				4,911				
Gila Lower Box ACEC, BLM						9,303				

Abbreviations are: ACEC = Area of Critical Environmental Concern; RNA = Research Natural Area; WSA = Wilderness Study Area.

Appendix: Extent (in acres) of Grasslands by Type and Specific Land Manager in the U.S. Portion of the Apache Highlands Ecoregion.

Land Management Unit	**Native; <10% shrub cover (Type A)**	**Native; 10-35% shrub cover (Type B)**	**Sacaton riparian grassland (Type C)**	**Exotic; <10% shrub cover (Type D)**	**Exotic; 10-35% shrub cover (Type E)**	**Former grassland shrub cover >35% (Type F)**	**A & B Mosaic**	**A & D Mosaic**	**B & F Mosaic**	**Unknown type**
Gila Lower Box ACEC/Blue Creek WSA, BLM						716				
Gila Lower Box BLM ACEC/Gila Lower Box WSA, BLM						2,645				
Gila National Forest	9,075									
Goodding Research Natural Area, USFS							155			
Goodding Research Natural Area/Pajarita Wilderness, USFS							2,054			
Granite Gap ACEC, BLM		1,066				661				
Gray Peak WSA, BLM		12				1,141				
Guadalupe Canyon ACEC, BLM		1,217				342				
Guadalupe Canyon/Baker Canyon ACEC WSA, BLM		103				5				
Hellsgate Wilderness, USFS		748								
Hot Springs Watershed ACEC, BLM		13,273								
Kartchner Caverns State Park, AZ State Parks						638				
Las Cienegas National Conservation Area BLM	32,809	358	723	4,135		2,129	2,822			
Leslie Canyon National Wildlife Refuge, USFWS		2,505	41			212				
Lordsburg Playa BLM Resource Natural Area						4,505				
Mazatzal Wilderness, USFS	588	16,251							7,718	
Montezuma Well National Monument, USNPS						255				
Mount Wrightson Wilderness, USFS					1,720					
Mt Graham WSA-RNA, USFS		246				5,849				
Muleshoe Ranch CMA, The Nature Conservancy		5,168								
Native American Land-Unspecified						93	56			
North Santa Teresa Wilderness, BLM						5,684				
Northern Peloncillo Mountains ACEC/Peloncillo Mountains WSA, BLM		780								
Oracle State Park, AZ State Parks		2,205								

Abbreviations are: ACEC = Area of Critical Environmental Concern; RNA = Research Natural Area; WSA = Wilderness Study Area.

Appendix: Extent (in acres) of Grasslands by Type and Specific Land Manager in the U.S. Portion of the Apache Highlands Ecoregion.

Land Management Unit	Native; <10% shrub cover (Type A)	Native; 10-35% shrub cover (Type B)	Sacaton riparian grassland (Type C)	Exotic; <10% shrub cover (Type D)	Exotic; 10-35% shrub cover (Type E)	Former grassland shrub cover >35% (Type F)	A & B Mosaic	A & D Mosaic	B & F Mosaic	Unknown type
Page Springs Fish Hatchery, AZ Game anc Fish Dept.		206								
Pajarita Wilderness, USFS							5,475			
Patagonia Lake State Park, AZ State Parks					600					
Patagonia-Sonoita Creek Preserve, The Nature Conservancy		401			186					
Peloncillo Mountains WSA, BLM		1,744				1,466				
Peloncillo Mountains Wilderness, BLM		17,539				1,900				
Prescott National Forest	56,695	97,133			2,216	23,351	72,336		11,648	
Private land	604,186	781,607	29,653	60,459	581,014	955,772	57,808	41,194	4,169	103,281
Pusch Ridge Wilderness, USFS		12,331			2,838					
Redfield Canyon Wilderness, BLM		6,768								
Rincon Mountain Wilderness, USFS		10,139			5,463	5,547				
Saguaro National Park, USNPS					0	358				
Saguaro Wilderness, USNPS					2,155	6,321				
Salome Wilderness, USFS		1,036								
Salt River Canyon Wilderness, USFS		89								
San Bernardino National Wildlife Refuge, USNPS		1,381				950				
San Carlos Apache Reservation	212,427	96,710				304,543				54,189
San Pedro Riparian National Conservatior Area, BLM					2,476	49,382				
San Rafael Short Grass Prairie Preserve, AZ State Parks	2,967		498							
San Rafael Valley, The Nature Conservancy	450									
San Xavier Reservation						6,056				
Santa Rita Experimental Range and Wildlife Area, University of Arizona		2,214			41,657	1,570				
Santa Teresa Wilderness, USFS						4,364				
Sierra Ancha Experimental Forest, USFS		2,916								
Sierra Ancha Wilderness, USFS		13								
Sonoita Creek State Natural Area, AZ State Parks		3,003			2,057					

Abbreviations are: ACEC = Area of Critical Environmental Concern; RNA = Research Natural Area; WSA = Wilderness Study Area.

Appendix: Extent (in acres) of Grasslands by Type and Specific Land Manager in the U.S. Portion of the Apache Highlands Ecoregion.

Land Management Unit	Native; <10% shrub cover (Type A)	Native; 10-35% shrub cover (Type B)	Sacaton riparian grassland (Type C)	Exotic; <10% shrub cover (Type D)	Exotic; 10-35% shrub cover (Type E)	Former grassland shrub cover >35% (Type F)	A & B Mosaic	A & D Mosaic	B & F Mosaic	Unknown type
State Land, AZ/NM	340,807	1,072,448	10,032	19,993	436,725	1,289,518	98,830	1,526	7,610	14,946
Table Mountain RNA-ACEC, BLM		8								
Tohono O'Odham Reservation		26,485								
Tonto Natural Bridge State Park, AZ State Parks		0							28	
Tonto National Forest	13,773	44,068				6,336	12,122		8,615	
Tortolita Mountain Park, Pima Co. Parks		2,038								
Tumacacori (Calabazas Mission) Nationa Historic Site, USNPS					22					
Tumacacori (Guevavi Mission) National Historic Site, USNPS					8					
Turkey Creek Riparian ACEC, BLM		448								
Tuzigoot National Monument, USNPS		16								
Upper Burro Creek Wilderness, BLM							4,699			
Upper San Pedro, The Nature Conservancy	38				93	174				
Upper Verde (Granite Cr) Wildlife Area, AZ Game and Fish Dept.		230								
Upper Verde (Sullivan Lake) Wildlife Area, AZ Game and Fish Dept.		65								
Verde River Greenway, AZ State Parks						173				
Verde Wild and Scenic River, USFS		2,501				342				
Verde Wild and Scenic River/Wilderness, USFS		252								
West Clear Creek Wilderness, USFS		471								
White Mountain Apache Reservation						1				87,800
Whitewater Wildlife Area, AZ Game and Fish Dept.		1,290								
Wild Chile Botanical Area, USFS		2,836								
Willcox Playa Wildlife Area, AZ Game and Fish Dept.	305									
Willcox Playa National Natural Landmark ACEC, BLM	745									
Willcox Dry Lake Bombing Range, USDOD	1,382									

Abbreviations are: ACEC = Area of Critical Environmental Concern; RNA = Research Natural Area; WSA = Wilderness Study Area.

Appendix: Extent (in acres) of Grasslands by Type and Specific Land Manager in the U.S. Portion of the Apache Highlands Ecoregion.

Land Management Unit	**Native; <10% shrub cover (Type A)**	**Native; 10-35% shrub cover (Type B)**	**Sacaton riparian grassland (Type C)**	**Exotic; <10% shrub cover (Type D)**	**Exotic; 10-35% shrub cover (Type E)**	**Former grassland shrub cover >35% (Type F)**	**A & B Mosaic**	**A & D Mosaic**	**B & F Mosaic**	**Unknown type**
Yavapai Apache Reservation		31				440				
TOTAL	1,427,046	3,083,823	45,735	118,509	1,350,412	3,822,054	382,985	43,910	39,788	381,382

Note : Total acreages in the Appendix may differ slightly from those in Table 2 because the land management data used here, from Weinstein (2002), were based on a different ecoregional boundary.

Abbreviations are: ACEC = Area of Critical Environmental Concern; RNA = Research Natural Area; WSA = Wilderness Study Area.