Sacaton Riparian Grasslands:

Mapping Distribution and Ecological Condition using State-and-Transition Models in Upper Cienega Creek Watershed

Ron Tiller, Melissa Hughes, and Gita Bodner

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The Nature Conservancy in Arizona

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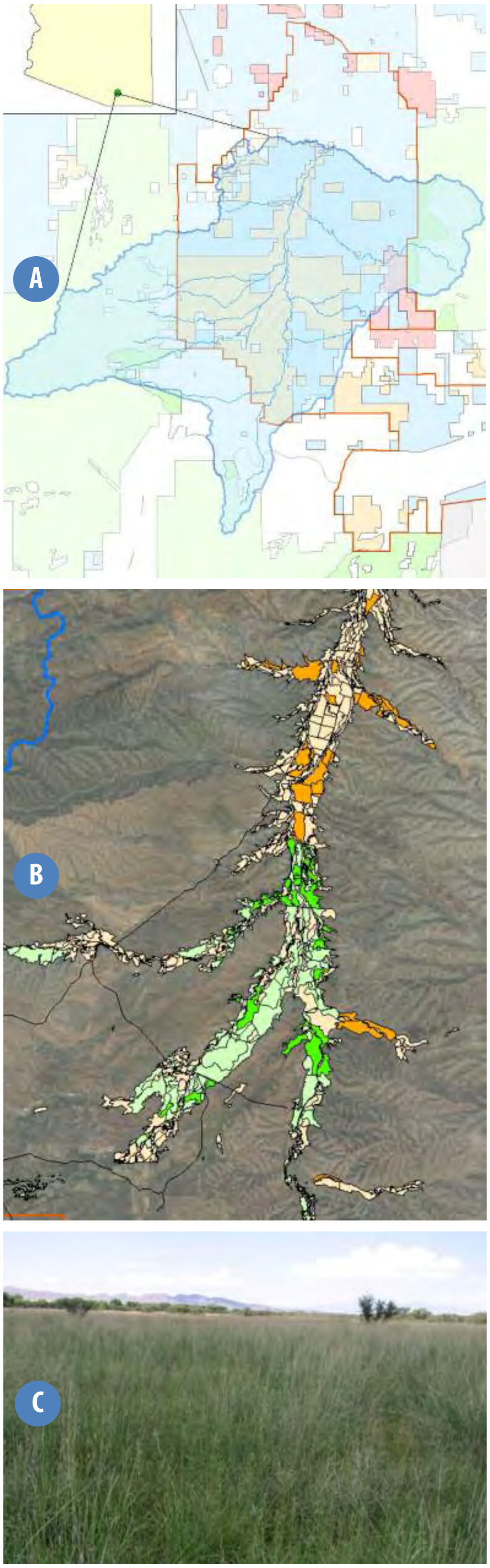

Three views of big sacaton in the upper Cienega Creek watershed — (A) the Cienega Creek watershed, (B) the evaluated valley bottom floodplain and riparian zones which host a mix of sacaton flats and related communities, and (C) a healthy, "classic" stand.

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Executive Summary

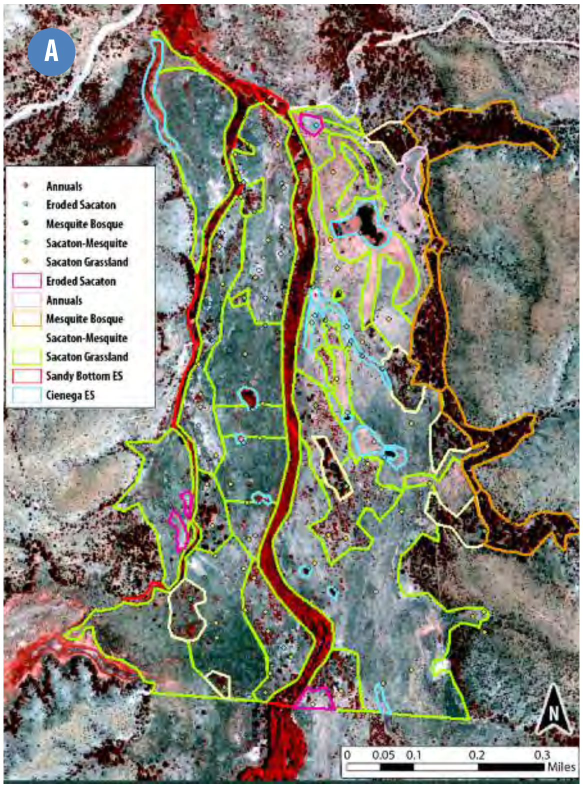
Grasslands dominated by big sacaton (*Sporobolus wrightii*) once occupied millions of acres of alluvial floodplain habitat in semi-arid southwestern North America, forming nearly pure stands of this robust, tussock-forming perennial grass. Sacaton riparian grasslands are recognized for their important ecological functions and landscape values — absorbing flood flows, controlling soil erosion, and intercepting and retaining sediments. As the most productive of semi-arid grassland communities, they provide abundant forage for livestock and habitat for wildlife.

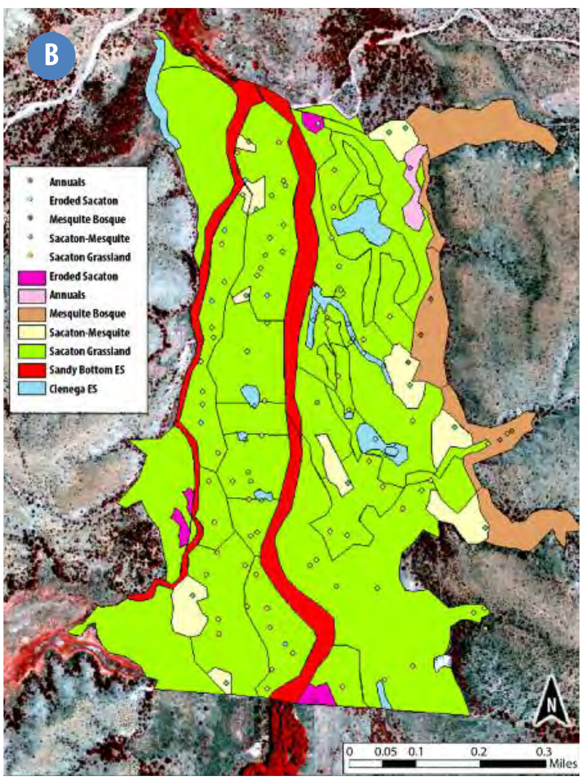
Across the region, these grasslands now occupy less than 5% of their original distribution. Causes of decline include agricultural conversion, historical downcutting of rivers and consequent reductions in overbank flow, dropping of water tables from groundwater pumping and stream diversion, sheet erosion, overgrazing, and shrub encroachment. Despite steep declines, sacaton grasslands can be found scattered across much of their former range, often occurring in smaller patches or less productive states than historic accounts suggest. Yet, there has been no comprehensive effort to identify where sacaton habitats remain in the region and what their management and restoration needs might be.

Sacaton flats form the heart of Sky Island grasslands; this valley is uniquely rich with them.

The upper Cienega Creek watershed is known to harbor extensive stands of big sacaton habitat. Although these stands are recognized as key resources for wildlife and livestock within the Bureau of Land Management's Las Cienegas National Conservation Area (LCNCA), they have suffered from a lack of attention in terms of research and management. Documenting big sacaton's distribution and assessing its condition in this valley are therefore important for contributing to a clearer picture of this community's status across the region and for providing the foundation from which to develop informed management objectives and actions that maintain, restore, and promote the resilience of this rangeland community.

Objectives for this study were to map the distribution and ecological condition of sacaton stands in the upper watershed of Cienega Creek, clarify ecological dynamics of riparian communities to inform management, and test methods for use in other valley bottoms in the region. Potential sacaton rangeland or mesquite forestland communities





Aerial images show the ecological conditions (states) found on a sample reach of Cienega Creek — (A) infrared bands accentuate rapidly growing vegetation — including mesquite in and along floodplain margins, and cottonwood-willow in the center, and (B) polygons delineate the states found at various observation points (small circles).

encompass about 6,620 acres — about 5% of the upper watershed. Our study area focused largely on valley-bottom lands previously mapped as Loamy Bottom ecological site by the Natural Resources Conservation Service. (Although we confined our field reconnaissance to lands under BLM and ASLD jurisdictions, we expect this report includes most of the valley's sacaton flats given that the lands not surveyed — private lands and US Forest Service lands —mostly occur outside of the alluvial valley bottoms.) The Loamy Bottom ecological site supports two communities — sacaton grassland in rangeland and mesquite bosque in woodland forms — which transition from one to another along a successional pathway ranging from historic climax plant communities to varying states of degradation.

We used a two-step approach to mapping: interpretation of aerial photography followed by field reconnaissance. Preparations for fieldwork involved drawing provisional polygons on aerial photographs using three layers of GIS information: ecological sites mapped by NRCS specifically for Las Cienegas (BLM 2003), county soil maps, and NAIP aerial photographs (USDA 2007). Field verification focused on areas with the greatest concentrations of sacaton rangeland, about 3,875 acres of Cienega Creek, Empire Creek, and Gardner Canyon. These field surveys enabled us to assign polygons into ecological conditions, where we observed a suite of Loamy Bottom rangeland states and one forestland state.

Mapping ecological conditions tells us a lot about the health of this area's sacaton flats

Sacaton grassland encompasses about 2,050 acres (68%) of the field-verified area with about 1,550 acres (52% of the area) existing as open grassland or grassland mildly encroached by woody plants. Roughly three-quarters of this intact or relatively intact rangeland state occurs at the mid- to upper reaches of the watershed (i.e., the field-verified area, 4,300-4,700 ft elevation). Sacaton grassland inhabits broad floodplain reaches of Cienega, Gardner, and Empire Creeks, and lower reaches and alluvial fans of several tributary drainages. Stands mapped as sacaton grassland were less homogeneous than anticipated — while we observed monospecific stands of big sacaton in many areas, we also observed sizeable areas with alkali sacaton (*Sporobolus airoides*), a close relative and acknowledged companion species under historic climax condition.

The "Sacaton Grassland" state rarely occupies the entire length or width of broad alluvial floodplains; instead these areas support a mosaic of rangeland and woodland forms. The "Sacaton-Mesquite" state is evident in sub-states or phases: in one phase, sacaton appears to co-exist with mesquite while in another appears to be in decline. Sacaton-Mesquite is often found in association with Sacaton Grassland above 4,300 ft elevation while Sacaton-Mesquite transitions to the "Mesquite Bosque" state below this elevation. Mesquite Bosque also dominates occasional floodplain margins, alluvial fans of tributary drainages, and at higher elevations, the

mouths of smaller side drainages of Cienega Creek. The vast majority of these Mesquite Bosque stands include big sacaton plants as an understory component, suggesting that these woodlands may have been Sacaton Grassland at some point (<150 years) in the past. "Eroded Sacaton" grasslands are evident, yet tend to occur as patches within Sacaton Grassland in areas of active erosion or areas that have largely healed from past downcutting or sheet erosion. The "Annuals" state occupies former agricultural fields.

Although State-and-Transition models (STMs) for Loamy Bottom ecological sites are generally helpful in assigning an ecological state to range or forest lands, we found that not all of the areas we identified fell neatly into an existing state. In fact, some states could be split into sub-states or phases reflecting their site potential, likelihood of transitioning to another ecological state, and management strategies for maintaining or improving productivity. Furthermore, the existing framework was not adequately capturing how states transition from one to the other within an ecological site (Sacaton Grassland to Mesquite Bosque) and between ecological sites (Sandy Bottom to Loamy Bottom). Our observations suggest that NRCS models for the Loamy Bottom ecological site provide a welcome framework, yet may benefit from structural modifications that recognize additional states and/or phases, alternate transitional pathways, and linkages between riparian ecological sites.

Knowing where these conditions occur helps managers make good decisions for improving the health of both sacaton flats and mesquite bosque

In order to meet land management objectives, sacaton stands in a particular ecological state may require management actions tailored to address the causal mechanisms associated with a shift in states. We identify specific management strategies for each sacaton grassland state based on our expertise, field observations, and background literature. For the purpose of exploring best practices, we split some of these states into phases and provided treatment strategies on this basis rather than limiting our treatment options to states within the existing STMs which could lead to conflicting or counterproductive management strategies.

Sizeable acreage of sacaton grassland are present in the upper Cienega Creek watershed — from classic open sacaton grasslands to those experiencing the early- to mid-stages of mesquite encroachment — supporting the contention that this site is one of the finest example of sacaton grassland in southeastern Arizona. To our knowledge, this work represents the first effort to map and classify sacaton riparian grasslands into ecological states using STMs. With a little more than half of the surveyed areas in this most open condition, our observations speak to the timeliness of this assessment, which we expect will lead to the development of informed management objectives and guidelines for sacaton grassland communities at sites like this.

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National Fish and Wildlife Foundation

U.S. Department of the Interior, Bureau of Land Management

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A Note to Our Readers

This area includes about 7,600 acres around Cienega Creek and its tributaries that we classified as alluvial — Loamy Bottom, Sandy Bottom, Sandy Wash, and Loamy Swale ecological sites. In this report, descriptions of each ecological site include state-and-transition models in which "states" depict commonly encountered plant and soil conditions, and "transitions" depict ecological dynamics by which states change or are maintained, e.g. fire or soil erosion. While in our research we relied heavily on NRCS terminology, there can be at least three different ways of referring to ecological sites or plant communities. The chart below should prove helpful.

Alluvial Ecological Site Descriptor (ESD)	ESD reference number (12-16" precipitation zone)	Common riparian plant community names
Loamy Bottom rangeland	R041XC312AZ	sacaton flat sacaton bottom sacaton grassland
Loamy Bottom forestland	F041XC310AZ	mesquite bosque
Sandy Bottom	F041XC317AZ	cottonwood-willow gallery forest
Sandy Wash	R041XC316AZ	rabbitbrush scrub xero-riparian strand
Cienega	[ESD not yet described]	cienega marsh
Loamy Swale (not usually considered riparian)	R041XC311AZ	grassy swale

We use initial caps when referring to "states" as described in the ESDs; those same terms without initial caps are being used as more general descriptions of vegetation (e.g., sacaton grassland). Throughout this document we use "Sacaton-Mesquite" in place of "Mesquite-Sacaton" nomenclature used by NRCS in the Loamy Bottom Rangeland STM. This reflects our interpretation of the predominant present-day transitional pathway from Sacaton Grassland toward Mesquite Bosque rather than the reverse; it is also more closely aligned with Brown et al. (1982) and others.

List of Abbreviations

ESD = ecological site descriptor
HCPC = historic climax plant community
STM = state-and-transition model

AGFD = Arizona Game & Fish Department
ASLD = Arizona State Land Department
BLM = Bureau of Land Management
LCNCA = Las Cienegas National Conservation Area
NAIP = National Agriculture Imagery Program
NRCS = Natural Resources Conservation Service
USDA = US Department of Agriculture

Introduction and Rationale

Classic (historic plant climax community) Sacaton Grasslands in the upper Cienega Creek watershed.

Sacaton Riparian Grasslands

When early explorers marveled at the Southwest's stands of grass "higher than the horses' bellies," they spoke of a unique grassland community type we now call *sacaton flats* or *sacaton bottoms*. Common on the region's gentle valleys and floodplain terraces, swaths of giant bunchgrass formed a transition between streams and their surrounding grassland slopes. These valley-bottom grasslands were recognized early on for their important ecological functions and values. These ecological functions included absorbing flood flows that spilled out of streambeds, controlling soil erosion, intercepting and retaining sediments (Griffiths 1901, Thornber 1910, Griffiths et al. 1915, Bryan 1928, Hubbell and Gardner 1950, Humphrey 1958, Cooke and Reeves 1976). In the way of values, they provided habitat for wildlife and abundant forage for livestock (Bock and Bock 1978, Cox et al. 1983, Bock and Bock 1986, Cox and Morton 1986, Cox 1988, Cox et al. 1989).

The sacaton flat habitat type is distinct from, yet shares features with, neighboring riparian habitats and upland grassland associations. At issue is the grass known as big sacaton *(Sporobolus wrightii* Munro ex Scribn.) and to a lesser extent alkali sacaton (*S. airoides;* see page 13 for discussion of its role in riparian grassland stands). Riparian plant associations such as mesquite bosque and cottonwood-willow gallery forest may have sacaton in their understory or along their edges. Similarly, sacaton plants may occur as scattered individuals or small patches within upland grass associations on hillsides and swales. But in the right soils and floodplain settings, sacaton grasses create a unique formation with a distinct history and management needs.

Historical Geography

Riparian grassland dominated by big sacaton once occupied millions of acres of floodplain habitat in semi-arid southwestern North America, forming nearly pure stands of robust perennial grass along perennial and intermittent streams (Humphrey 1958, Brown 1982, Bahre 1991). Prior to about 1880, such stands of big sacaton covered the floodplains of many southeastern Arizona rivers, including the riparian corridors and tributaries associated with the San Pedro and Santa Cruz Rivers (Cox et al. 1983, Cox 1988).

Declining Distributions

Across the region, sources estimate that these grasslands now occupy less than 5% of their original distribution (Humphrey 1960). Commonly cited causes of their decline include natural phenomena and anthropogenic influences: historical downcutting of rivers, dropping of water tables, and reduction in lateral spread of floodwaters; continued arroyo formation and soil erosion; groundwater pumping and diversions of stream water; overgrazing; agricultural conversion; and shrub encroachment (Humphrey 1958, 1960, Cox et al. 1983).

This decline has been well-documented in southeastern Arizona. During the late 1800s and early 1900s, fluctuations in climate and changes in land use practices caused dramatic changes in the composition of vegetation along many rivers (Cox et al. 1983). As early as 1915, it was reported that there were "faint traces" remaining of the dense growths of big sacaton that formerly covered the floodplains of southern Arizona (Griffiths et al. 1915). Extreme flooding, channelization, plowing of the flood plains, fuel wood logging and livestock grazing substantially decreased the distribution of big sacaton (Cox et al. 1983, Bahre 1991). In 1928, Bryan noted that big sacaton covering the Santa Cruz Valley near Tucson disappeared when arroyo cutting, began in the 1880s, caused the channel to drop more than 15 feet (>4.5 m) below the floodplain surface. With channel entrenchment, reductions in overbank flooding, and the advent of industrialized farming, vast expanses of *Sporobolus* grassland became ideally suited for agricultural production and many thousands of acres were converted to crops by the mid-1900s. More recently, Lacey et al. (1975) noted that deep-rooted mesquite were replacing sacaton in areas along the San Pedro River where channel-cutting had lowered the water table.

Current Geography and Condition

Despite steep declines, patches of bottomland sacaton grasslands can still be found scattered across much of their former range, often occurring in smaller patches or less productive condition than historic accounts suggest. The larger and more intact of these are most recognizable. Several big sacaton grasslands persist in the San Pedro and Santa Cruz watersheds of southeastern Arizona, particularly within the upper elevational limits of their distribution. For example, fine stands of big sacaton grasslands can still be found in the upper Cienega Creek basin, upper Babocomari River, upper San Pedro River in Mexico, and upper Santa Cruz River basin near Lochiel.

In many places where sacaton flats still remain, historic impacts and contemporary threats continue to affect their productivity and resilience (Stromberg 1993, Cox 1984). Condition of sacaton flats in the region is quite variable, ranging from stands with aging plants surviving on eroded, former floodplain terraces or under the canopy of mesquite woodlands, to extremely productive stands that exceed 6 ft in height with virtually no bare soil visible between plants and no woody plants among them.

Despite the value of these habitats, there has been no comprehensive effort to identify where they still exist in the region and what the restoration needs of remaining stands might be. Limited attempts have been made to map the contemporary distribution of sacaton and associated communities in the region. These efforts vary in the degree to which they single out sacaton flats as a distinct entity, and the spatial extent they cover. Some of the regional and statewide vegetation and riparian mapping efforts have included something akin to sacaton flats as one of their mapped communities (Harris et al. 2000) or partially mapped its distribution (Kubly et al. 1997, Halvorson et al. 2002). Our most spatially extensive knowledge of sacaton grassland distribution comes from work by the Natural Resources Conservation Service (NRCS 2005a) and The Nature Conservancy (Gori and Enquist 2003). NRCS's effort translated county soil survey data into maps of ecological sites across the Madrean Basin and Range Province (MLRA 41) of southeastern Arizona. These maps include the Loamy Bottom ecological site most typically associated with sacaton bottoms as described above (for explanation of ecological sites, see Methods section, page 4). Gori and Enquist's (2003) work attempted to map grassland extent and condition across the region using a combination of expert knowledge and field reconnaissance; sacaton riparian grasslands were the only specific grassland community singled out for recognition. Stands identified by this effort tended to be relatively intact examples, though the study did not explicitly evaluate their current condition.

Few site-specific efforts have singled out sacaton flats for mapping. These include field reconnaissance on the Audubon Research Ranch (Kennedy personal communication 2009), and helicopter overflights that Pima County staff used to map the extent of four large patches of interest to them (Fonseca 2000). We know of no efforts, however, that systematically evaluate ecological condition of sacaton grasslands in our Cienega watershed focal area, let alone the region.

There is a growing interest in the conservation and management of big sacaton grasslands in Arizona. In the past thirty years, several large-scale riparian conservation areas have been established within the watersheds of the upper San Pedro and Santa Cruz Rivers, including the San Pedro National Riparian Conservation Area and Las Cienegas National Conservation Area (LCNCA). Within these conservation areas are broad tracts of big sacaton grasslands and associated vegetation communities. Substantial acreage of active and abandoned agricultural fields was included in these projects. Natural recovery of these abandoned fields has been slow to non-existent, presenting opportunities for active restoration of big sacaton into former grassland habitats. Other areas that retain their original sacaton stands are showing signs of habitat degradation that may require specific management attention to maintain and recover ecological services.

The LCNCA is particularly renowned for its sacaton flats. The site's Resource Management Plan (RMP) provides specific objectives for managing near-stream riparian forests; however, it offers few existing objectives for other riparian communities, including sacaton grasslands (BLM 2003). As a consequence, active management of these grassland resources, beyond livestock grazing, has been limited. Nevertheless, the adaptive management approach of the RMP allows for adjustments in how these areas are treated. In addition, both the RMP and the associated Biological Opinion (USFWS 2003) call for using an ecosystem approach to managing the rare habitats that support priority species such as Botteri's Sparrow (*Aimophila botterii*), a federal Watch List species and a sacaton grassland specialist (Webb and Bock 1990, Merola-Zwartjes 2005). The Bureau of Land Management seeks direction regarding the status of these grasslands and guidance for their management.

Given that only a fraction of big sacaton habitat exists today, and that some of the finer remaining examples of it exist on the LCNCA, it is important to document its distribution and assess its condition. Furthermore, these stands are recognized as key resources for watershed function, livestock, and wildlife on the LCNCA. Developing maps of grassland extent and ecological state will provide the foundation from which to develop informed management objectives and actions that maintain, recover and restore, and promote the resilience of this important rangeland community.

Study Area and Methods

Objectives

Map the distribution of bottomland stands of big sacaton (*Sporobolus wrightii*) and alkali sacaton (*S. airoides*) in the upper watershed of Cienega Creek.

Qualitatively assign stands of sacaton into "states" to describe current conditions.

Make recommendations for management of particular sacaton grassland states.

Test mapping and evaluation methods applicable elsewhere.

Valley bottom vegetation in this area ranges from dense, open sacaton grass stands (foreground) to mesquite bosque (background).

Study Area

Our study area included the upper Cienega Creek watershed, about 146,000 acres, above "The Narrows" where Apache Canyon watershed contributes from the Whetstone Mountains to the east (Figure 1). The bulk of the valley in this upper watershed is owned by the ASLD and BLM and managed as part of the Las Cienegas National Conservation Area (BLM 2003). Our primary focus was the Loamy Bottom ecological site of the 12-16 inch precipitation zone (Robinett 2005a, b) as mapped by the NRCS and BLM for the Empire-Cienega ranch portion of the LCNCA (BLM 2003; Figure 2).

We confined our field reconnaissance to lands under the jurisdictions of the ASLD and BLM; private lands and US Forest Service lands were not surveyed (Figure 1). Nevertheless, we expect our reconnaissance to include most of the valley's sacaton flats given that the lands excluded from consideration in this study mostly occur outside of the alluvial valley bottoms.

Methods

We used a two-step approach to mapping: interpretation of aerial photography followed by field reconnaissance. Preparations for fieldwork involved drawing provisional polygons on aerial photographs. To do this, we used three pieces of GIS information: (1) BLM's layer of ecological sites mapped by NRCS specifically for Las Cienegas (BLM 2003); (2) County soil maps and the ecological sites that NRCS generally associates with these soils (**soildatamart.nrcs.usda.gov**); and (3) USDA's 2007 NAIP aerial photographs (**datagateway.nrcs.usda.gov/GDGOrder.aspx**).

We used the first two layers to guide our focus on alluvial (riparian-deposited) soils capable of supporting bottomland sacaton stands. An ecological site can be range land or forest land and is defined as having specific physical characteristics that distinguish it from other kinds of land in its ability to produce a distinctive kind and amount of vegetation (USDA 1997). Ecological site descriptors provide information describing the interactions among soils, vegetation, and land management. In this region, the Loamy Bottom Rangeland is the ecological site most typically associated with sacaton grasslands as described above (Robinett 2005a), but stands can occur in sites that have been mapped as other ecological sites. Loamy Bottom Forestland ecological site is the one most typically associated with mesquite bosque communities in this region (Robinett 2005b).

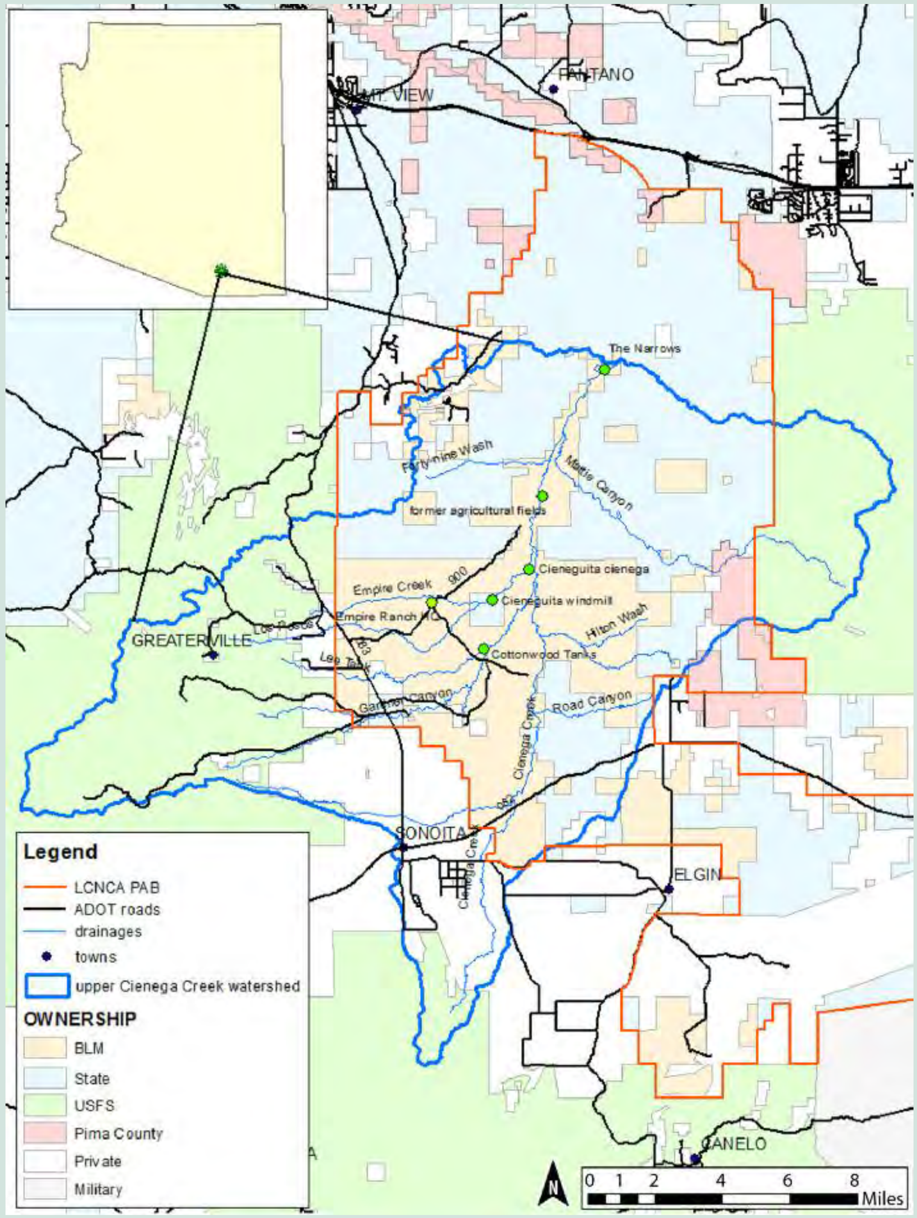


Figure 1. *Where the upper Cienega Creek watershed fits within the LCNCA's Planning Area Boundary (LCNCA PAB) and other jurisdictions.* <Click on figure for larger image.>

BLM's ecological site map for Las Cienegas included about 7,600 acres — four map units around Cienega Creek and its tributaries that we classified as alluvial — Loamy Bottom, Sandy Bottom, Sandy Wash, and Loamy Swale ecological sites. Because this map layer lumps Loamy Upland with Loamy Swale ecological sites, we used soil survey information (NRCS 2008) to separate the two — Pima, Riverroad and Comoro soils that occur on low gradient slopes — thereby creating a derived spatial layer designed to include only the alluvial components of the original BLM map unit. Interpretation of aerial imagery used 1-m (3 ft) resolution, 4-band digital aerial photographs collected by NAIP (June 2007) using ArcMap 10. With the infrared band expressed to provide greater differentiation of vegetation features, we digitized preliminary polygons based on color, texture, and compositional differences that were apparent across the alluvial ecological sites. Digitized polygons consisted of

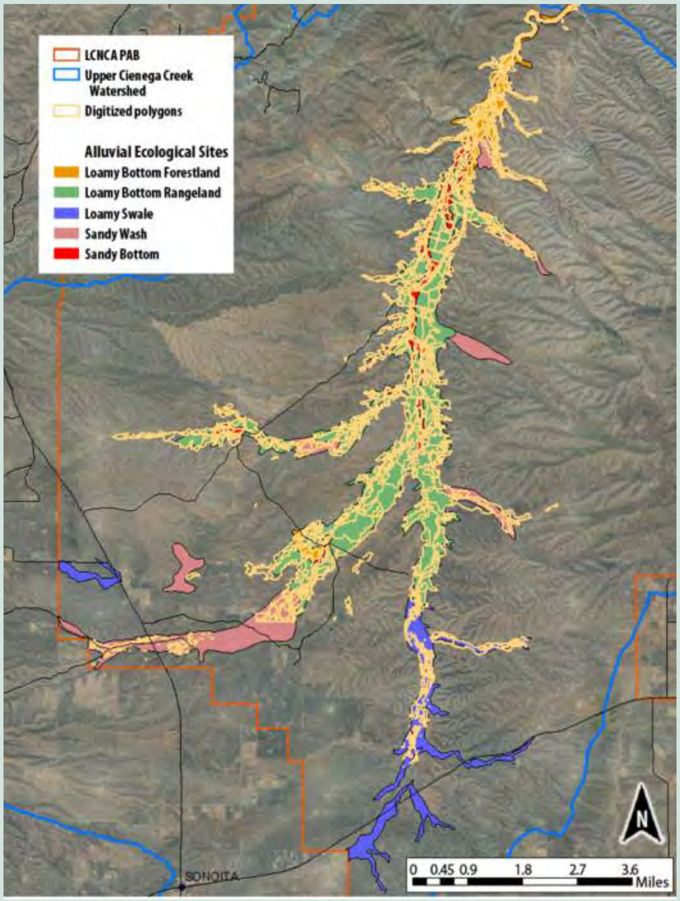
Table 1. *Natural Resource Conservation Service State and Transition models translated into tabular format to facilitate assigning states in the field. Original refers to NRCS model states; modified refers to finer divisions developed here (Appendix D).*

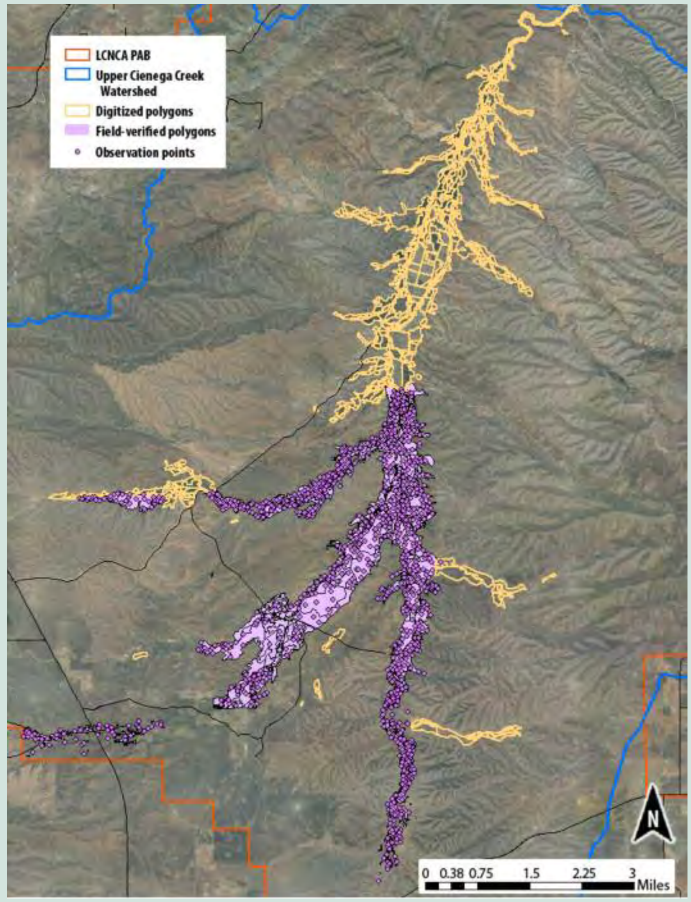
State Original > *Modified*	Sacaton	Mesquite	Other shrubs, succulents	Exotics *(Johnsongrass, bermuda)*	Annuals	Gully erosion	Flooding	Water table (ft)	*Causal Mechanisms for departure from HCPC*
	Canopy cover (%) and form								
LOAMY BOTTOM RANGELAND									
Sacaton Grassland									
A (HCPC)	25-80				0-20			<20	
B > *B1, B2, B3*	25-65	1-15						<20	
Sacaton-Mesquite*									
C > *C1, C2*	5-40	5-20	yes					<20	*lack of fire*
Exotics									
D		0-15		yes				<20	
Eroded Sacaton									
E > *E1, E2*	20-50					severe	reduced	>20	*gully erosion*
Annuals									
F	trace		0-10		yes		reduced	>20	*plowing, cultivation, burning, low soil moisture*
Eroded Mesquite									
G		20-80	0-10			severe	no flooding	25-50	
LOAMY BOTTOM FORESTLAND									
Mesquite Bosque-Native annuals									
H (HCPC)	trace	25-65, tall-form	0-5			yes	no flooding	25-50	
Mesquite Bosque-Exotic annuals									
I	trace	20-80, tall-form			yes; dominate	yes	no flooding	25-50	
Mesquite Thornscrub									
J	trace	5-20, shrubby	5-15		yes; fluctuate	yes	no flooding	25-50	*clearing, cultivation*
Mesquite Scrubland									
K	trace	5-20, shrubby	5-15		yes; fluctuate	yes	no flooding	25-50	*lowered water table*

more or less consistent groundcover and woody plant cover, and were allowed to extend outside of the soil map units described above if necessary to circumscribe visually consistent polygons and capture the full extent of target plant communities.

Polygons were field-verified using handheld GPS units (Trimble Juno SB) equipped with GIS (ArcPad 8). Ground-level surveys confirmed the distribution of big sacaton and alkali sacaton, and qualitatively assigned the state and condition of sacaton stands where they occurred. Where either or both species occurred, we treated them as equals in the eyes of the STM. Classification of polygons and point locations into specific plant communities and states was based on the NRCS ecological site descriptors for Loamy Bottom Rangeland and Forestland (MLRA 41, 12-16 inch precipitation zone, available at **esis.sc.egov.usda.gov**). These site descriptors include STMs that depict alternate vegetative states (also referred to as ecological conditions) as well as ecological thresholds and drivers of change (models reproduced here in Appendix A). To facilitate data collection and note-taking in the field, we referred to the STMs in their traditional forms as well as in a tabular form that we developed, which effectively merged the two models developed for rangelands and forestlands respectively (Table 1). To simplify data-recording during the field verification process, we assigned each state an arbitrary letter (e.g., A-K).

We traversed individual polygons to record observations, GPS coordinates, and photographs. Information was recorded at one or more locations within a polygon depending on how much within-





from left: Figure 2. *Digitized area (beige lines) superimposed over alluvial ecological sites mapped by NRCS for the BLM.* Figure 3. *Areas of prospective sacaton grassland and mesquite bosque communities in upper Cienega Creek watershed digitized from 2007 NAIP imagery. Tan and lavender areas represent the entire digitized area. Lavender areas represent areas field-verified as of September 2011.* *<Click on figures for larger images.>*

polygon variability was apparent on digital imagery-based field maps and existed on the ground. Using rapid assessment-type qualitative descriptions of present-day grassland or woodland condition, we assigned states to polygons based on visual estimates of the following: sacaton grass cover, woody plant cover (mesquite and other species), evidence of erosion, and mechanisms affecting change (e.g., fire/drought, gully erosion, agricultural conversion). At each assignment point, we snapped one or more voucher photographs. We redefined polygon boundaries as necessary where sacaton extended beyond digitized polygons and when sacaton only occupied a portion of a digitized polygon. When we encountered unique features within a polygon, we GPS'd, described, and most often photographed them. These included erosional features (areas of sheet erosion and gully erosion) and plant associations not typical of Loamy Bottoms (e.g., tobosa grasslands, blue grama grasslands, cottonwood-willow gallery forest, and rabbitbrush scrublands).

Our field verifications mapped the distribution and ecological condition of polygons across the primary sacaton-bearing drainages of Cienega Creek upstream of its confluence with Springwater Canyon Wash, Gardner Canyon, and Empire Creek from its confluence with Cienega Creek to the road-crossing below ranch headquarters (Figures 1, 3). Our surveys were not limited to areas previously mapped as Loamy Bottom ecological site or identified on aerial photographs. Where sacaton occurred beyond the boundary of this ecological site or a digitized polygon; we mapped and qualitatively assigned its condition.

Post-processing of field data included uploading point, line, and polygon files from ArcPad into ArcMap, redrawing polygon boundaries where necessary, cataloging and cross-referencing photographs to point data, and editing field notes.

Additional field work will be required to map and classify sacaton states along Cienega Creek north of Springwater Canyon to the abandoned agricultural fields (the terminus of sacaton-dominated states) and remaining tributary drainages with sacaton (Wood, Mattie, Springwater, and Road Canyons and Forty-nine Wash; Figure 1). The work we put into digitizing floodplain/alluvial polygons dominated by woodlands in addition to grasslands lays the foundation for future efforts to map and classify mesquite bosque (also a community of interest to the BLM and stakeholders in the region). This community dominates the alluvial sites north of the abandoned agricultural fields along Cienega Creek and the Empire Ranch headquarters area of Empire Creek.

Results

Interpretation of Aerial Photographs

A review of 2007 NAIP digital aerial imagery yielded about 6,616 acres of alluvial ecological sites with potential sacaton or mesquite bosque communities (Figure 3). The more straightforward areas to digitize were core alluvial habitats where sacaton or mesquite woodland communities traversed floodplains. The more difficult boundaries to delineate were those at the upper limits of sacaton distribution along the main stem of Cienega Creek and its tributaries. In these areas, sacaton grasslands generally transitioned to *Bouteloua gracilis* (blue grama) or *Pleuaphis mutica* (tobosa grass) grasslands in areas with finer surface soils, or to xeroriparian habitats in areas with coarser soils of alluvial fans and washes. It is in these areas where we made the greatest adjustments to the final boundaries of the sacaton and mesquite bosque habitats once they were field-verified.

The canopy in this Sacaton Grassland (B2 in the modified STM) shows early woody plant encroachment.

Field Verification

Field verification of digitized polygons focused on areas with the greatest concentration of sacaton grassland in the upper watershed: the main stem of Cienega Creek upstream of its confluence with Springwater Canyon, Empire Creek, and Gardner Canyon. All told, we groundtruthed 705 digitized polygons, totaling 3,874 acres. Within these areas, we collected 1,221 point-features and an untallied number of line and polygon features captured when redefining habitat boundaries and patches (Figure 3). We collected 1,714 photographs documenting state and condition at representative observation points.

Riparian communities (i.e., sacaton grassland, mesquite bosque, cienega, and cottonwood-willow gallery forest) of several alluvial ecological sites occupied 2,998 ac (77%) of the field-verified area. Alluvial fan or swale grassland communities (e.g., tobosa, vine mesquite (*Panicum obtusum*)) and upland grama-dominated grasslands (*Bouteloua* spp.) dominated the remainder of the field-verified area; these areas were excluded from further consideration.

State Maps: Observations of Sacaton Across a Continuum of Ecological Conditions

Field surveys of digitized polygons enabled us to classify both point locations and polygons into the states described in Tables 1, 2a, 2b, and Appendix A. We observed all Loamy Bottom Rangeland states except Eroded Mesquite (G). Owing to the fact that our study was focused on grassland states, the Loamy Bottom

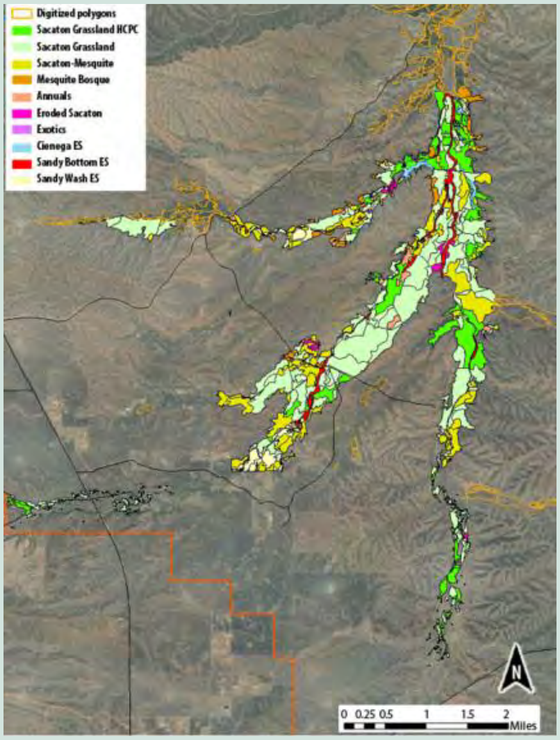


Figure 4. *A closeup of ecological states observed across field-verified areas.* <Click on figure for larger image.>

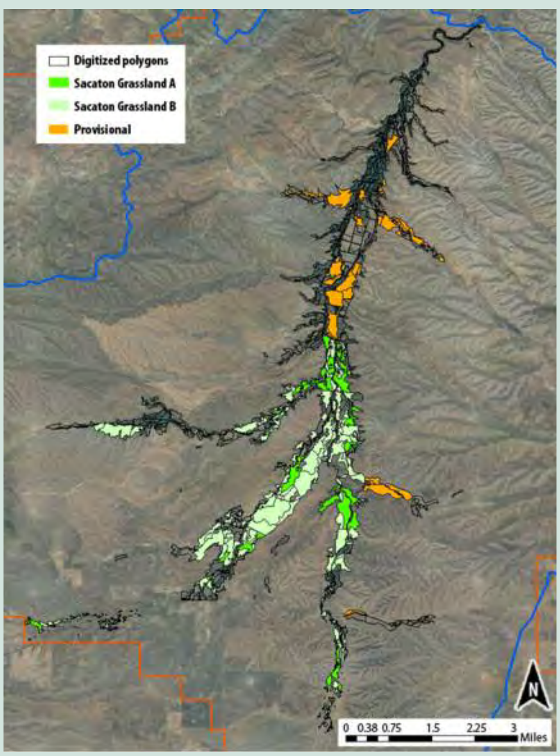


Figure 5. *Map of open Sacaton Grassland states (A and B) in the upper watershed of Cienega Creek. Green polygons represent classifications based on field verification (see also Figure 3) and orange areas represent provisional open Sacaton Grassland classifications based on interpretations of aerial photography and more limited field visits.* <Click on figure for larger image.>

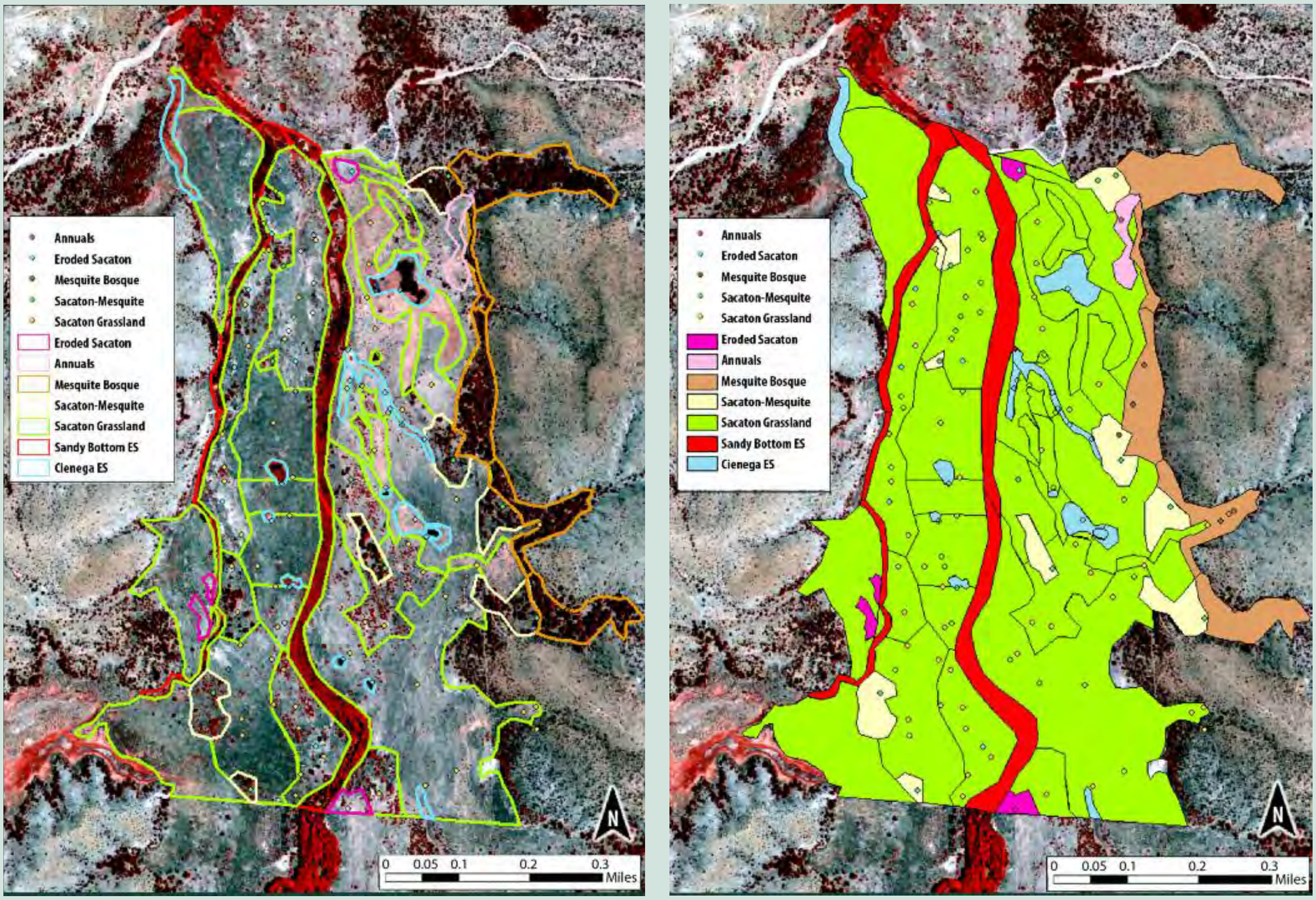
Forestland states we observed were grouped together as Mesquite Bosque (H). Sample photographs of the ecological conditions we observed are included as Appendix B.

Open Sacaton Grassland (A and B) encompasses about 2,047 acres or around 68% of the field-verified area. This acreage includes pure Sacaton Grasslands (A = 499 ac or 16.6%) with those experiencing the early- to mid-stages of mesquite encroachment (B1, B2 = 1049 ac or 35%, and B3 = 498 ac or 16.6%). Within the remaining unverified digitized area between the confluence of Springwater Canyon and The Narrows, Cienega Creek and its tributaries maintain another 600 acres of likely open-condition Sacaton Grassland (Figure 5). Classes A and B are combined here to maintain continuity with the STM for Loamy Bottom Rangeland. The bulk of these relatively intact states occur at 4,300-4,700 ft elevation.

These sacaton grasslands are distributed along the length of Cienega Creek from the region near the agricultural fields immediately south of the Cienega Creek-Mattie Canyon confluence, to the upper reaches of the watershed to just north of Highway 82. It covers expansive portions of Gardner Canyon from west of Highway 82 to its confluence with Cienega Creek (Figures 1, 7). It inhabits a broad floodplain reach of Empire Gulch immediately above the historic Empire Ranch headquarters and east of the 900 Road to its confluence with Cienega Creek (Figure 1, 8). Sacaton Grassland states also occur on the lower reaches and alluvial fans of several tributary drainages, the best examples being Mattie, Forty-nine, and Hilton Washes (Figures 1, 8). Regardless of the drainage or stream reach, sacaton grassland rarely occupies the entire length or width of a broad alluvial setting (Figures 6, 7). A mosaic of other rangeland states also occurs within sacaton grasslands including Sacaton-Mesquite (C), forestland classes such as Mesquite Bosque (H) and the Cienega ecological site (Figure 7).

Sacaton grasslands themselves are not as homogeneous as anticipated. In many areas, we observed monospecific stands of big sacaton (*Sporobolus wrightii*); however, we observed sizeable areas of sacaton grassland with alkali sacaton (*Sporobolus airoides*), a close relative of big sacaton and acknowledged companion species under historic climax condition (Robinett 2005a). Where the two species coexist, either one can be dominant with the other plant present in patches or as isolated individuals. Alkali sacaton-dominated areas are largely found on the lower reaches of Empire Creek, and cienega-bearing reaches of Cienega Creek between the tributaries of Springwater Canyon and Gardner Canyon (Figures 1, 5).

In this study area, Eroded Sacaton grasslands (E) are evident on the landscape, yet tend to occur as patches or inclusions within Sacaton Grasslands (A and B) rather than wholesale areas; as isolated patches they occupy about 40 acres or 1.3% of sacaton grassland states. Large eroded areas immediately north of the



Figures 6 and 7. *Ecological condition classifications for Loamy Bottom Rangeland and Forestland along an example area of Cienega Creek. On the left figure, infrared bands accentuate rapidly growing vegetation — mesquite in and along floodplain margins, cottonwood-willow in the center, and cienega in the southwest corner. On the right figure, small circles mark observation points from which states were assigned and polygons delineate the boundaries of states.* <Click on figure for larger image.>

agricultural fields and Cottonwood Tank are likely former cienegas that experienced substantial sheet and gully erosion, promoting a badland-like environment with vestiges of big or alkali sacaton in and around their margins. The presence of gleyed surface soils (mineral wetland soil that is or was always wet, resulting in soil colors of gray, greenish gray, or bluish gray) seems to support this observation (Donahue et al. 1983).

Patches of eroded sacaton occur in areas of active erosion or areas that have healed from past downcutting or sheet erosion. Active erosion occurs in the form of headcutting or sheet erosion, which we documented where we encountered it (30 ac or 1%). We observed substantial active sheet and gully erosion in the Empire Creek floodplain up- and down-gradient of the Cieneguita Windmill. In Gardner Canyon, we observed substantial active sheet erosion downgradient of the 900 Road all the way to its confluence with Cienega Creek. In the case of Empire Creek, the surrounding areas have been encroached by mesquite, while in Gardner Canyon surrounding areas have been encroached by mesquite and wait-a-minute bush (*Mimosa biuncifera*).

Along the main stem of Cienega Creek, we observed areas of healed or mostly healed, eroded sacaton (10 ac or 0.3%). We observed gullies with peeled-back walls well-vegetated with sacaton. Occasionally, the bottoms of these healing gullies were occupied by wetland plants such as rushes (*Juncus* sp.), sedges (*Cyperus*), yerba mansa or lizardtail (*Anemopsis californica*), and/or saltgrass (*Distichlis stricta*), illustrating a transitional link between sacaton grasslands and cienegas. In other places, we spied areas largely healed from sheet erosion where all but a shallow cutbank was recolonized with sacaton and mesquite (e.g., an excellent example of this occurs on the west side of Cienega Creek immediately above its confluence with Mud Spring Canyon/Hilton Wash). These areas we classified as Sacaton-Mesquite (C) with inclusions of Eroded Sacaton.

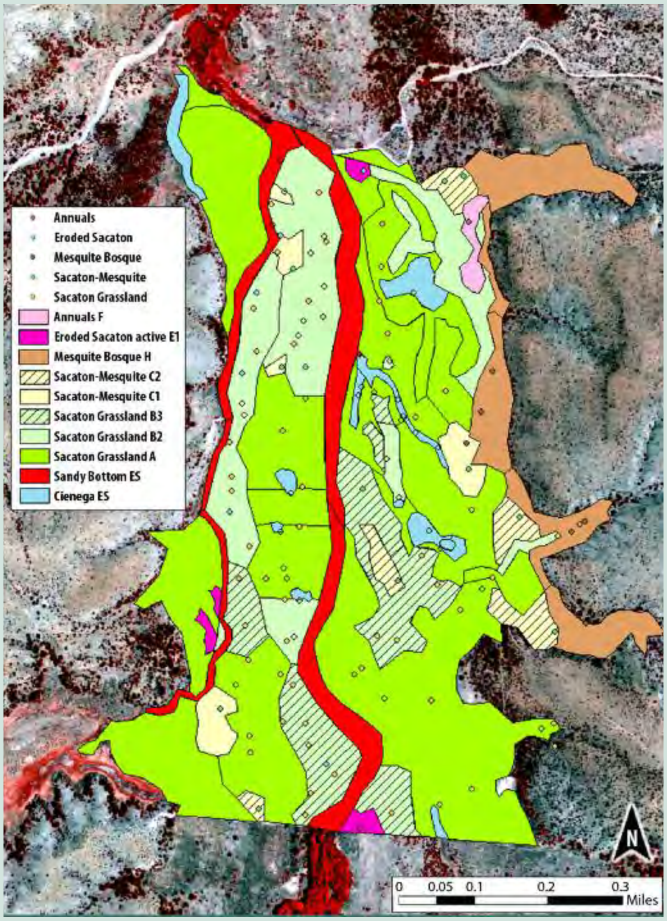


Figure 8. *Ecological condition classifications for Loamy Bottom Rangeland and Forestland along an example area of Cienega Creek. Small circles are observation points from which states and state phases were assigned (solid color polygons) per a modified State and Transition model for Loamy Bottom Rangeland.* <Click on figure for larger image.>

The next most abundant state after Sacaton Grassland is Sacaton-Mesquite (C; 614 ac or 20.5%), often found in association with Sacaton Grassland south of the agricultural fields and transitional to Mesquite Bosque north of this point. Evidence of woodcutting or clearing (not quantified as part of this study) indicates that larger expanses of Sacaton-Mesquite and Mesquite Bosque once occurred in the lower- to mid-portions of the watershed.

Sacaton-Mesquite is evident in two phases: (1) low-medium cover of scrubby mesquite (approx. 6-12 ft tall) with vigorously growing sacaton with moderate cover (84 ac or 2.8%), and (2) low-medium cover of tree-form (>12 ft tall) mesquite with low-medium cover of less vigorously growing sacaton (530 ac or 17.7%). In the former, sacaton appeared to co-exist with mesquite while in the latter condition the grass appeared to be in decline.

Small patches of the perennial Exotic (D) state occur within existing Sacaton Grassland (A and B). Johnsongrass (*Sorghum halepense*) is most often the exotic perennial grass, rarely occupying more than an acre. We recorded patches of this grass in lower Empire Canyon upgradient of the Cieneguita cienega. Most often it occurs at the margins of cienegas within larger Sacaton Grassland (A and B) complexes.

The Annuals (F) state occupies nearly 50 acres (1.7%), generally occurring as patches or as mosaic within sacaton grasslands. Many of these areas show evidence of sacaton mortality and in some cases fire-charred tussocks are evident. Another 150 acres of former agricultural fields, north of the area we field-verified, also occur in the Annuals state. Since their abandonment in the mid-1980s, this former Sacaton Grassland/Cienega complex has slowly recolonized with patches and scattered individuals of sacaton, while mesquite has actively colonized parts of the southern half of these fields. Cienega has reclaimed about 1/3 of an acre nearest an extant cienega to the south (Salywon personal communication 2011).

Mesquite Bosque (H) dominates the northern portion of Cienega Creek where Mattie Canyon joins the Cienega Creek floodplain downstream to The Narrows (north of the area we verified). It also dominates the western margin of the agricultural fields, occasional margins, alluvial fans of tributary drainages, and mouths of smaller side drainages of the Cienega Creek floodplain. The vast majority of these mesquite bosque stands include big sacaton plants as an understory component. Within the field-verified area, we observed 108 acres (3.6%) of mesquite bosque largely at the mouth of alluvial fans and upland swales where they meet lower gradient floodplains.

Looking Closer: An Example Area on Cienega Creek

This project produced an extensive GIS database that can inform management decisions across the basin (Figure 1). This database includes attribute tables with field observation notes and hyperlinks to ground-level photographs. In this section, we illustrate the contents of this database in an example area with acreages and polygon boundaries and their designated STM classifications. This example area covers about 272 acres of the Cienega Creek floodplain immediately upstream of its confluence with Springwater Canyon. At this juncture, Empire Creek parallels Cienega Creek to its confluence (Figures 1, 5). This area maintains

Comparisons of composition and ecological conditions

Table 2. Sacaton grasslands at LCNCA.

Table 3. Example area on Cienega Creek.

OBSERVED ECOLOGICAL SITES

Table 2a.	Acres	% of Area
Loamy Bottom ecological site		
RANGELAND STATES		
Sacaton Grassland (HCPC; A)	2,046	68.3
Sacaton Grassland (B)		
Sacaton-Mesquite (C)	614	20.4
Eroded Sacaton (E)	40	1.3
Annuals (F)	50	1.7
Exotics (D)	1	0.0
FORESTLAND STATE		
Mesquite Bosque (H)	108	3.6
Cienega ecological site		
Cienega*	29	1.0
Sandy Bottom ecological site		
Cottonwood-Willow Gallery Forest	110	3.7
Total	2,998	100.0

Table 3a.	Acres	% of Area
Loamy Bottom ecological site		
RANGELAND STATES		
Sacaton Grassland (HCPC; A)	202	74.3
Sacaton Grassland (B)		
Sacaton-Mesquite (C)	13	4.8
Eroded Sacaton (E)	2	0.7
Annuals (F)	2	0.7
Exotics (D)	0	0.0
FORESTLAND STATE		
Mesquite Bosque (H)	22	8.1
Cienega ecological site		
Cienega*	8	2.9
Sandy Bottom ecological site		
Cottonwood-Willow Gallery Forest	23	8.5
Total	272	100.0

THE MODIFIED STATE AND TRANSITION MODEL

Table 2b.	Acres	% of Area
Loamy Bottom ecological site		
RANGELAND STATES		
Sacaton Grassland (HCPC; A)	499	18.1
Sacaton Grassland (HCPC; B1)	9	0.3
Sacaton Grassland (B2)	1041	37.8
Sacaton Grassland (B3)	498	18.1
Sacaton-Mesquite (C1)	84	3.1
Sacaton-Mesquite (C2)	530	19.3
Eroded Sacaton (E1)	30	1.1
Eroded Sacaton (E2)	10	0.4
Annuals (F)	50	1.8
Exotics (D)	1	0.0
FORESTLAND STATE		
Mesquite Bosque (H)	108	3.6
Cienega ecological site		
Cienega*	29	1.0
Sandy Bottom ecological site		
Cottonwood-Willow Gallery Forest	110	3.7
Total	2998	100.0

Table 3b.	Acres	% of Area
Loamy Bottom ecological site		
RANGELAND STATES		
Sacaton Grassland (HCPC; A)	137	50.6
Sacaton Grassland (HCPC; B1)	0	0
Sacaton Grassland (B2)	39	14.2
Sacaton Grassland (B3)	26	9.7
Sacaton-Mesquite (C1)	5	1.8
Sacaton-Mesquite (C2)	8	2.9
Eroded Sacaton (E1)	2	0.7
Eroded Sacaton (E2)	0	0.0
Annuals (F)	2	0.7
Exotics (D)	0	0.0
FORESTLAND STATE		
Mesquite Bosque (H)	22	8.1
Cienega ecological site		
Cienega*	8	2.9
Sandy Bottom ecological site		
Cottonwood-Willow Gallery Forest	23	8.5
Total	272	100.0

* Although recognized as distinct, an ecological site description and its ancillary states have not yet been completed for cienegas (Robinett 2011, personal communication). *(letter) = class assigned to ecological conditions observed within the Rangeland and Forestland types of the Loamy Bottom ecological site; (number) = class assigned to ecological conditions observed with a modified State and Transition model for the Loamy Bottom ecological site.*

several of the states described in the STM for Loamy Bottom Rangeland and Forestland and serves as a good example for the overall study area. Inclusions of Cienega ecological site (not described in STMs) and cottonwood-willow gallery forest of the Sandy Bottom ecological site are also represented in this area.

Sacaton Grassland maintained as either pure grassland (HCPC, A) or Sacaton Grassland with low mesquite cover (B), dominates this area (74% of the total; Table 3a; Figure 6). Cienegas are interspersed within the grassland boundaries occupying 3% of the area. Pockets of Sacaton-Mesquite (C), areas moderately encroached by mesquite, are present in relatively small amounts (13%). Mesquite Bosque (H) occurs along much of the eastern boundary of the floodplain and mouth of tributary drainages (8%). Cottonwood-willow gallery forest, not classified as part of this project, occupies a strip through the center and western margin of the example area (9%).

When expressed through the lens of a modified STM (Appendix C), a slightly different picture of the ecological condition of the Loamy Bottom Rangeland emerges. Sacaton Grassland (HCPC,A) still dominates 50% of the sample area (Table 3b, Figure 8); however, Sacaton Grasslands (B2 and B3), lightly to moderately encroached by mesquite, occupy 24% of the sample area or about 1/3 of sacaton grassland classified via the existing STM for Loamy Bottom Rangeland. The Sacaton-Mesquite ecological condition encroached by scrubby mesquite (C1), occupies about 2% of the sample area; another 3% is occupied by tree-form mesquite (C2) transitioning toward Mesquite Bosque (H). Eroded Sacaton (E1) is present at actively eroding sites (<1%).

Using a modified STM, these Sacaton Grasslands (B2 and B3), Sacaton-Mesquite (C1), and Eroded Sacaton (E1) would be targeted for active management to transition them back towards the historic climax plant community, i.e., Sacaton Grassland (A). Sacaton-Mesquite (C2) might either be managed to transition back towards the historic climax plant community or be allowed to continue its transition towards Mesquite Bosque.

Discussion

Sizeable acreage of open sacaton grassland state (nearly 2,647 ac; 2,047 ac field-verified and about 600 ac unverified-digitized) is present in the upper Cienega Creek watershed, supporting the contention that some of the finer examples of sacaton grassland in southeast Arizona occur in this drainage. The field-verified portions of this acreage include pure sacaton grasslands with those experiencing the early- to mid-stages of mesquite encroachment. With around 52% of the verified alluvial areas assigned as Sacaton Grassland A, B1, and B2 (i.e., open to mildy encroached by woody plants), our observations speak to the timeliness of the BLM's request for information on the baseline condition of sacaton communities and

The canopy in this Sacaton Grassland (B1 in the modified STM) is still dominated by sacaton (25-60%), but also includes a 1-15% mesquite cover.

its desire to develop management objectives and guidelines.

Sacaton grassland communities are restricted to low gradient, alluvial environments yet not entirely confined to what had been mapped as Loamy Bottom Rangeland. We observed appreciable sacaton grassland communities in areas previously mapped as Loamy Swale and Sandy Wash ecological sites. We recognize two possibilities as to why this may be the case:

1) The precision of the ecological site mapping in the mid-1990s may have been coarse enough that these sacaton grassland communities plot in Loamy Swale or Sandy Wash ecological sites as well as the occasional upland ecological site.

2) Some areas mapped as Loamy Swale and Sandy Wash are actually transitional between these ecological sites and Loamy Bottom. In a broad area, roughly 2.7 creek miles from Cienega Creek near Antelope Well and confluence with the Road Canyon, there a mosaic of small and large patches of sacaton grassland growing amongst blue grama, tobosa grass, and vine mesquite. The same is true for a large expanse of the upper Gardner Canyon drainage along about 3.2 miles of the creek (east and west of Highway 83). Large and small patches of big sacaton grassland occur within a diverse mixture of Sandy Wash woody vegetation including ash (*Fraxinus velutina*), Arizona walnut (*Juglans arizonica*), netleaf hackberry (*Celtis reticulata*), desert willow (*Chilopsis linearis*), catclaw acacia (*Acacia greggii*), and perennial grasses such as sideoats grama (*Bouteloua curtipendula*) and green sprangletop (*Leptochloa dubia*).

Alkali sacaton commonly occurs in the sacaton grasslands of the Loamy Bottoms of Cienega Creek, Empire and Gardner Creeks. In several places, it is the dominant perennial grass of the floodplain with big sacaton being non-existent to highly scattered, patchy, or restricted to the margins of the floodplain. The STM for Loamy Bottom Rangeland specifically addresses big sacaton with alkali sacaton playing only a supporting role (Robinett 2005a). It is possible that some of the area designated as Loamy Bottom is actually Saline Bottom (Womack 2005, Robinett 2011) or a combination of Loamy Bottom and Saline Bottom. Cox (1984, 1985) reports that big sacaton occurs on moderately alkaline and slightly calcareous soils, and is usually replaced by alkali sacaton in areas with very alkaline or saline soils. We observed white alkali and black alkali surface soils and humus-laden black pools in portions of the Cienega Creek floodplain near its confluence with Empire Creek and lower Empire Creek above the Cieneguita wetlands (Figures 1, 5). Womack (2005) states that the Saline Bottom ecological site "must" be verified based on soils and climate, and that the current plant community cannot be used to identify the ecological site, so our observations must be taken with some caution.

Sacaton, big and alkali, are shade-intolerant C_4 grasses requiring a high light environment and finely textured soils with access to relatively shallow groundwater levels ($\leq$ 15 ft) to achieve and maintain maximum cover and productivity (Stromberg et al. 1996, Scott et al. 2006, Stromberg et al. 2009). The dynamics of change within sacaton grasslands, and the factors driving these changes, are somewhat speculative. Under one scenario, sacaton may: (1) establish in young Fremont cottonwood stands after flood flows; (2) persist in the understory as the cottonwoods age; (3) increase in cover as relatively short-lived cottonwoods die, as understory light availability increases, and as the floodplain aggrades; and (4) ultimately dominate the floodplain. Mesquite may establish simultaneously with sacaton in the cottonwood understory, and co-dominate with sacaton over time. Periodic fire or frost may serve to reduce the abundance of mesquite and other woody plants, transforming a riparian woodland/savannah to riparian grassland (Stromberg 1993).

The vast majority of mesquite bosque stands of the upper Cienega Creek watershed include big sacaton plants as an understory component, indicating that these woodland communities are probably a product of recent environmental change (i.e., past 130 years) and not one of originating on these sites (Bryan 1928). Sacaton growing in the understory of these woodlands is most likely remnant of a former grassland condition and may persist in part where high water tables persist (Lacey et al. 1975). Mesquite bosque may contain big sacaton, but at 5-10% of its productive capacity (Robinett 2005b).

Mesquite bosque with a trace or no sacaton understory is observed primarily at the mouth of upland swales that drain to sacaton grassland communities via side drainages. Many of these bosques above 4,350 ft elevation (confluence of Springwater Canyon and Cienega Creek) may be recent in occurrence since they are not evident in the earliest aerial photography captured in the mid-1930s; mesquite is present in the Loamy Bottom at this elevation, yet as part of sacaton-mesquite rangeland.

Comparisons with Previous Mapping Efforts

In addition to being the only attempt we know of to systematically evaluate ecological health of sacaton flats in a watershed of this size, this effort represents the most comprehensive effort to map the distribution of sacaton flats and associated communities within the Cienega basin. Other vegetation mapping efforts have included this watershed, albeit with a variety of purposes and spatial extents. Some did not treat sacaton flats as a distinct mapping element (e.g., Harris 2000), at least in the sense that we view this plant community here; others did recognize a comparable vegetative community (e.g. Gori and Enquist 2003, Kubly et al. 1997). It may therefore be of interest to compare rough numbers of acres recognized by these various mapping efforts in the same watershed area.

The Arizona Game and Fish Department (Kubly et al. 1997) mapped riparian vegetation along what was at time thought to be the extent of perennial streams in the state. Kubly et al.'s mapping included a portion of Cienega Creek from The Narrows to Oak Tree Canyon, where they documented only 71 acres of sacaton grassland and 384 of mesquite woodland. Recent efforts by the BLM and TNC to map perennial waters (**azconservation.org/projects/water/wet_dry_mapping**) found about 4 miles of year-round flow in the reach covered by Kubly et al., plus about three additional miles of perennial flow along Cienega Creek and the tributaries of Mattie Canyon and Empire Gulch. Had the AGFD mapping included these additional areas of perennial flow, its acreages would have been greater for sacaton grassland and mesquite woodland; however, it would still have omitted large expanses of sacaton grassland and mesquite woodland inhabiting intermittent and ephemeral reaches of these and other tributary drainages.

The USGS delineated 4,680 acres of sacaton-scrub grassland in the upper watershed as part of its AZ GAP vegetation mapping effort (Halvorson et al. 2002). Their mapping generally overlies the sacaton grassland areas of Cienega Creek, Empire Gulch, and Gardner Canyon, yet includes substantial upland areas where vegetation does not form the kinds of sacaton-dominated floodplain associations evaluated here. This effort also excludes appreciable sacaton grassland between Hilton Wash and the Cienega Creek headwaters as well as several tributary drainages with sacaton.

Gori and Enquist's (2003) work attempted to map grassland extent and condition across the region using a combination of expert knowledge and field reconnaissance. In an effort to reflect the importance of these grasslands in a watershed context, sacaton riparian grasslands were the only specific grassland community singled out for recognition. Sacaton stands identified by this effort tended to be relatively intact examples, though the study did not explicitly evaluate their current condition. This study identified 723 acres of sacaton grassland in the upper reaches of the Cienega watershed.

Harris (2000) delineated riparian communities within Pima County. In the Pima County portion of the Cienega watershed, this study delineated 9,290 acres of semi-desert grassland (BLP series 143.1; Brown et al. 1979), which lumped sacaton grasslands with upland grasslands, 427 acres of mesquite bosque (series 224.52), and 149 acres of abandoned agricultural fields (presumably a mix of former sacaton grassland and cienega habitats).

An aerial reconnaissance by Pima County (Fonseca 2000) discriminated sacaton-bearing communities from upland grasslands and mapped sacaton grasslands of the upper watershed of Cienega Creek beyond its borders into Santa Cruz County. This mapping noted 732 acres of sacaton grassland communities, 2,909 acres of sacaton-mesquite association, and 971 acres of cottonwood-willow gallery forest–sacaton association.

As referenced in Methods and Results sections of this report, NRCS and BLM staff mapped 3,744 acres of Loamy Bottom Rangeland (i.e., predominantly sacaton flats) and 581 acres of Loamy Bottom Forestland (i.e., mesquite bosque) as part of their mapping of ecological sites across the LCNCA (BLM 2003).

Of the 2,998 acres of riparian communities, we found that 75% occurred on what had been mapped as Loamy Bottom, 5% as Loamy Swale, 8% as Sandy Wash, and 5% as Sandy Bottom. Another 7% of what we found to be riparian had been mapped as upland grassland, pointing to the general accuracy of the NRCS and BLM mapping effort (2003). As evidenced in Figures 2 and 3, we observed and assigned sacaton grasslands on areas that had been mapped as Loamy Bottom, Loamy Swale and Sandy Wash ecological sites.

Application of STMs for Loamy Bottoms

STMs for Loamy Bottom ecological sites are generally helpful for assessing ecological condition of rangelands and forestlands; however, per our observation, not all areas fall into the existing states. Although we assigned polygons to states based on the models, we noted that certain states could be split into substates or phases reflecting their site potential, likelihood of transitioning to another state, and prospective management strategies (Appendix C).

For example, stands with medium to high sacaton cover (25-65%) and low to medium mesquite (1-15%) cover per the STM might be split three ways:

1) Sacaton Grassland with low mesquite cover (1-15%) on coarse surface sediments (e.g., areas where coarse sediments deposit downgradient of a drainage or arroyo). Sacaton cover on these substrates appears to be limited by the water-holding capacity of the surface soils. These sites with reduced sacaton cover provide microsites for mesquite to colonize, yet not enough of canopy-threatening mesquite cover to reduce the cover of or displace sacaton; removing mesquite from these areas may not appreciably increase sacaton cover. *We've designated these as Sacaton Grassland (B1) in Appendix C.*
2) Sacaton Grassland with low mesquite cover (1-5%) on fine surface sediments. These stands may be in the early stages of encroachment by mesquite. Natural or prescribed fire appears to be the strategy for managing mesquite in these areas. *We've assigned these as Sacaton Grassland (B2) in Appendix C.*
3) Sacaton Grassland with medium mesquite cover (5-15%) on fine surface sediments. These stands may be in a more advanced stage of encroachment by mesquite. Sacaton cover and productivity is not appreciably reduced, yet appears headed towards sacaton-mesquite; management of these areas may call for cut-and-spray and prescribed or natural fire. We've designated these as *Sacaton Grassland (B3) in Appendix C.*

Sacaton Grassland and Mesquite Bosque states transition from one to the other along transitional trajectories (Appendix C). To reflect conditions on the ground, one or more clear linkages might be made between Loamy Bottom Rangeland and Forestland ecological sites, allowing them to flow fluidly between one another. Other connections to the STM for Loamy Bottom Rangeland also could be made, documenting linkages between mature, senescing cottonwood-willow gallery forest of the Sandy Bottom ecological site and developing sacaton grasslands, and between the Cienega ecological site and sacaton grasslands (Appendix C).

Depth-to-groundwater descriptors are useful and important in the STM yet are difficult to evaluate on the ground. In the absence of water level monitoring data (**gisweb.azwater.gov/waterresourcedata/GWSI.aspx**), the paucity of wells drilled and perforated in the shallow aquifer, and high-resolution topographic information, it may be difficult to estimate water levels in some situations. Fortunately, several water wells and piezometers are situated in alluvium and/or perforated in the shallow aquifer across LCNCA, which will allow for the comparison of depth to groundwater and ecological condition at some point locations. However, water level information is not sufficient to produce groundwater contours encompassing the alluvial ecological sites. As a result, we were unable to use subsurface water level data to facilitate the assignment of ecological condition as a whole.

Management Implications for each State

The following section presents possible strategies for the management of each state or state phase of Loamy Bottom Rangeland, and is based on the expertise and field observations of the authors and background literature in support of what we found. Strategies applied to the management of this and other riparian ecological sites may differ from those of adjacent upland ecological sites. For example, the fine soils of the Loamy Bottom ecological site, with their high silt and clay content and greater water-holding capacity, are more vulnerable to erosion and soil compaction, making some ground-disturbing mechanical treatments — highly effective when applied in upland settings — unsuitable for the Loamy Bottom Rangeland.

Classic (historic plant climax community) sacaton grasslands in the upper Cienega Creek watershed.

Sacaton Grassland

Sacaton Grassland A 25-80% sacaton cover; no woody cover; 0-20% annuals, <20 ft depth to water table.

Sacaton Grassland B1 Coarse substrate, 25-60% sacaton cover, 1-15% woody cover, <20 ft depth to water table.

Sacaton Grassland B2 Early woody plant encroachment — 25-60% sacaton, 1-5% woody cover, scrubby; <20 ft depth to water table.

Management Goals: 1) Maintain high cover of sacaton, and, 2) maintain or reduce woody plant cover.

Fire

Fire may play a role in reducing establishment of mesquite in sacaton grasslands. In a summary of fire in the southern desert grasslands and shrublands, Wright and Bailey (1982) concluded that if rangelands are in good condition, fire can be used as an effective management tool to reduce some shrubs and small trees during wet weather cycles. Fire probably has the greatest value for managing tobosa, big sacaton, alkali sacaton, and mixed grama ranges (Wright and Bailey 1982, Britton and Wright 1983).

Burning that is too frequent, too extensive, or that occurs during an inappropriate season, can pose a threat to sacaton grasslands. Humphrey (1960) suggested that 3 to 4 years is an optimum burn interval; more frequent burns may reduce the vigor or biomass of sacaton, allowing the encroachment of other plant species and resulting in the conversion to another ecological state.

There is some divergence of opinion on effects of season-of-burn on sacaton grasslands. Land managers have traditionally recommended burning big sacaton grassland in either fall or winter (Britton and Henry 1983, Cox 1988) outside the timeframe when natural, lightning-caused fires are most likely to occur in early summer (Cox 1988). According to Cox and Morton (1986) and Cox (1988), fall, winter, and spring burns can have long-term detrimental effects on big sacaton plant production with effects lasting for at least three summer growing seasons. The loss of summer-formed leaves inhibits the formation of winter leaves, and root crowns of big sacaton may be damaged by frost.

While winter burning may reduce plant litter, making green foliage more available to livestock, it reduces the long-term viability of big sacaton plants (Cox et al. 1990). Big sacaton is best adapted to summer fires, but post-fire recovery is influenced by fire severity (Cox 1988, Bock and Bock 1990). Ungrazed big sacaton on the Audubon Research Ranch recovered to pre-fire coverage after 2 to 3 years (Bock and Bock 1990).

Some researchers and resource specialists report greater reductions in biomass and less rapid recovery from summer burns, while others report the same for winter or spring burns. Cox (1988), who conducted much of his sacaton research on the Empire Ranch, suggests that fall and winter defoliation by fire or grazing ought to be discontinued, but Humphrey (1960) does not concur. Womack (2005) recommends burning alkali sacaton in late-February to early March, but only in years with good winter-spring rainfall. Robinett (2011) suggests that this approach, employed by the Babocomari Ranch on the nearby Sonoita Plain, has maintained big sacaton grasslands in good condition. At the Babocomari Ranch, sacaton bottoms are burned in the spring (March) in years with 3-4 inches of rainfall between November 1 and March 1, with at least three-year intervals between burns. Burned areas are grazed from May 1 to mid-June, yet rested during the summer rainy season. Rather than advocating controlled burns, Bock and Bock (1978, 1986) believe that fires should be allowed to burn naturally in sacaton stands.

As burning applies to mesquite, some studies in Arizona suggest that velvet mesquite is killed by summer fires (Humphrey 1949, Blydenstein 1957). Not only may summer fires more effectively reduce brush, but also they may allow managers to burn without having an extended preburn grazing deferral (Ansley and Taylor 2004). The high biomass of sacaton bottoms may make fires more effective at reducing woody plant cover. Where fire top-kills mesquite with a tree-like growth form, it can turn into multi-stemmed bush that may be more competitive with grasses. Controlling mesquite in this form may require a long-term management commitment whereby every 7-10 years prescribed fire is reapplied or allowed to burn naturally.

Observations by Robinett (2011) suggest that the effectiveness of fire on mesquite in sacaton bottoms may be influenced by the location of the bud zone in relation to the soil surface. If trees are on a surface where considerable sedimentation has occurred since mesquite establishment, fire tends to top-kill rather than outright kill mesquite and may create a thorn thicket of resprouting mesquite (see above). If the bud zone of mesquite is at or near the soil surface, and there is enough fine fuel from sacaton (5,000-6,000 lbs/ac air-dry), then an early summer fire can kill mesquite (Robinett 2011). Mesquite research in Texas and Arizona has shown that at least 4,000 lbs/ac of fine fuels is required to have any appreciable fire mortality on mesquite (Wright and Bailey 1982).

Grazing

Big sacaton grasslands have been extensively used by livestock in southern Arizona. Sacaton grasslands sometimes were grazed year-round although their mature leaves and stems become coarse and tough in summer and have relatively low forage value (Humphrey 1970). More frequently, cattle and horses grazed sacaton in winter and spring, because it produced small quantities of fresh and palatable forage at a time when other native perennial grasses were dormant (Thornber 1910, Cox 1984).

For maximum big sacaton forage production, Cox et al. (1989) recommend grazing big sacaton in the spring, not grazing in dry summers and dry years, and discontinuing fall grazing when herbage is high in silicates. Robinett (2011) suggests the best time to graze big sacaton is in the spring and early summer (May-June, prior to the monsoon) when adjacent uplands are dry and lacking green feed and livestock will eat it. Winter or spring grazing causes the least change in plant production by big sacaton (Humphrey 1958, Cox et al. 1989). Hickey and Springfield (1966) also report

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Sacaton Grassland *continued*

that alkali sacaton is more tolerant to winter or spring grazing than to grazing in other seasons.

Grazing management may affect how sacaton plants respond to other disturbances, with implications for the health of the grass stand. Fall defoliation exposes crowns of big sacaton to below freezing temperatures; crown exposure may reduce forage production for up to 4 years (Cox 1988) or kill plants (Cox et al. 1989). Observations by Cox also suggest that fall grazing ought not be followed with a cool season burn (fall-spring), due to the adverse combined effects of these factors. Experience of managers at the Babocomari Ranch suggests grazing and burning can co-exist if managed carefully. The combination of stressors or disturbances often amplifies the effect of each factor. With respect to grasslands, the combination of fire and grazing produces very different effects from the effect of either activity alone (Vogl 1974). Grazing and trampling after a severe burn have been noted to cause soil erosion and permanent loss of plant cover in sacaton grasslands, and may be one cause of the historical decline of sacaton grasslands in Arizona (Bock and Bock 1978).

Sacaton Grassland — Sacaton-Mesquite

Sacaton Grassland (B3) Encroached grassland transitioning to Sacaton-Mesquite — 25-60% sacaton cover, 5-15% tall mesquite growth, <20 ft depth to water table.

Sacaton-Mesquite (C1) Scrubby/shrubby encroached grassland — 5-40% sacaton cover, 5-20% scrubby/shrubby mesquite cover; <20 ft depth to water table.

Management Goals: 1) Reduce woody plant cover, and, 2) maintain or increase sacaton cover.

Mechanical control of woody plants (soil-disturbing methods not appropriate)

The highly effective mechanical control technique (grubbing via backhoe) used on mesquite in the uplands grasslands of Las Cienegas NCA is not relevant or practical for managing mesquite in alluvial floodplain environments. Loamy Bottom soils are highly erosive (Robinett personal communication 2010) therefore soil disturbance brought about by trails created by machinery and/or excavation of mesquite root crowns could cause irreversible damage to sacaton grassland communities. Root crowns on floodplain terraces may be buried with up to 6 ft of fine silt and sand (Minckley and Clark 1984). Deeply buried mesquite would require substantial excavating and disturbance to remove individual plants in addition to substantial time and expense. The BLM's own experience thinning dense, tree-form mesquite in the Lee Tank area bears this out.

Herbicide control of woody plants

Studies show that woody plant control with herbicides can significantly increase grass productivity (Scifres and Mutz 1978, Beasom et al. 1982, Herbel et al. 1983) with forb productivity being short-lived to unaffected by herbicides. Herbaceous plant response is greatest when mesquite cover is reduced below 3%, precipitation is favorable, and livestock grazing is deferred (Herbel et al. 1983).

Aerial: Broadcast aerial applications of past decades have seldom achieved more than 20% root kill of mesquite; however, dozens of large-scale research plots have consistently produced mesquite root-kill greater than 60% and often greater than 75% when a mixture of Reclaim (clopyralid) and Remedy (triclopyr) is applied. Both herbicides are moderately residual in soil, plants and water sources, requiring precautions that prevent spray drift.

Even the most effective herbicide combinations will not be successful if they are applied under improper conditions. The most important consideration is to apply the spray mixture uniformly to healthy, mature foliage that is at the proper physiological stage and under proper environmental conditions. Dahl and Sosebee (1991) identified several environmental factors that contribute to the success of aerial herbicide application on mesquite. The most important environmental parameter is soil temperature. Soil temperature must exceed 75° F at 12-18 inches below the soil surface. Additionally, the mesquite canopy should not contain light green foliage. Relative humidity should be above 50% and ambient temperature should not exceed 90-95° F.

Mesquite is relatively easy to control if two criteria are met: (1) soil temperature at 12-18 inches depth must be at least 75° F, preferably higher, and (2) the plant must be physiologically capable of responding to foliar-

from top: Encroached Sacaton Grassland (B3) transitioning to Sacaton-Mesquite — 5-15% of the canopy at this stage is tall mesquite. In the Sacaton-Mesquite state (C1), sacaton has been encroached by 5-20% scrubby/shrubby mesquite cover.

applied herbicides (i.e., carbohydrates must be translocating to tissues in the basal bud zone). Dahl and Sosebee (1991) identified soil temperature as the most important environmental parameter affecting mesquite's ability to respond to foliar application. Study sites in west Texas, the Texas panhandle, and eastern New Mexico confirmed that no mesquite were root-killed if soil temperature was <70° F at the time of herbicide application. Root-kill was as high as 98% as soil temperature increased up to at least 86° F and plant physiological conditions were appropriate.

Of equal importance, carbon translocation to the basal bud zone of mesquite trees essentially occurs during two periods in the annual cycle of the trees: (1) yellow flower to pod formation, 42-63 days post bud-break, and (2) post-pod elongation, 72-85 days post-budbreak (Sosebee and Dahl 1991).

Mesquite is very difficult to control if sprayed during the first 42 days post-budbreak, regardless of the soil temperature. It is relatively easy to control 42-63 days post-budbreak, if soil temperature is 75° F or higher (the higher, the better), and nearly impossible to control during pod elongation 63-72 days post-budbreak, regardless of soil temperature. Mesquite is most easily controlled post-pod elongation, 72-85 days post-budbreak, if the soil temperature is 75° F or higher (Sosebee 2004).

Spot-foliar or stem sprays: Spraying individual mesquite plants (< 6 ft tall) with foliar or stem sprays is very effective when conducted under proper conditions. Best results have been obtained using a spray mixture of 0.5% Reclaim + 0.5% Remedy with a surfactant (0.25% of spray mixture). This mixture usually provides 80% or better root-kill (2 years after application). Brush Busters (**texnat.tamu.edu/about/ brush-busters/mesquite/ stem-spray-method**) recommends for stem spray a mixture of 15% Remedy + 85% diesel fuel for small mesquite with smooth bark (less than 1.5 in diam). Larger stems with rough bark require 25% Remedy mixture with diesel. Spray this mixture lightly but evenly on the lower 12 inches of each stem. Spray all sides of the stem until wet, but runoff is unnecessary. This method is most effective in hot weather, but works well all year.

Timing is much less critical for spot-foliar application of herbicides than it is with aerial application. Spot-foliar treatment trees are usually sprayed "to wet". Hence, each tree or shrub receives a larger amount of herbicide solution, relative to aerial applications when the tree's system is apparently "flooded". Mesquite can be effectively controlled by individual plant spot-treatment anytime between mid-May and September 1. For similar reasons, soil temperature is not a critical consideration (Sosebee 2004).

The most important consideration in spraying regrowth is the physiological age of the resprouts. "Long-shoot" resprouts are those with long internodes; they are fast-growing and remain vegetative. Most, if not all, of the photosynthate that is produced by the leaves goes to support structural growth of the resprouts and none goes to the basal bud zone. In contrast, "short shoots" are those in which the internodes are not, or have not, elongated, but have begun to produce flowers (i.e., reproductive shoots). If the resprouts have advanced to this stage, which has nothing to do with the chronological age of the resprouts, then the resprouts are relatively easy to control with individual plant treatments because the carbon translocation pattern is to the basal bud zone and not into structural material for the stems (Sosebee 2004).

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Sacaton Grassland — Sacaton-Mesquite *continued*

Basal Application: Conventional basal application of diesel oil or low volume application of diesel oil and herbicide mixture to shrubs or trees such as mesquite is quite effective. Timing of application is not a factor. Basal treatments can be applied any time of year. If conventional application of diesel oil (which includes pouring or spraying diesel oil on the soil around the base of the plant) is used, the soil should be dry. Diesel oil does not infiltrate well into wet soil and it is imperative that the diesel oil envelop the basal bud zone if this method is used. If low volume basal application of diesel oil and herbicide is used (which involves spraying only the lower 12-14 inches of the stem base), there are no restrictions on the time at which applications can be made.

Robinett (2011) reports that cut stumps of mesquite treated with Tordon 22K mixed 50% in water provides 95-100% control and mortality if the cambium is treated with the herbicide/water solution immediately after cutting.

Fire

Herbicide treatments are useful in integrated brush management programs in combination with fire. This approach would best apply to the B3 (5-15%) and C1 (shrubby/non-tree form of mesquite; 5-20%) state phases described in Appendix C. To maintain an open grassland condition over time, the treatments described above should be followed with prescribed fire or be allowed to burn via wildfire under appropriate conditions (see fire section above).

Grazing

See recommendations for grazing in previous section.

Sacaton-Mesquite — Mesquite Bosque

C2 Transitioning toward Mesquite Bosque — 5-40% sacaton cover, 5-20% tall growth mesquite, <20 ft depth to water table.

Management Goals: 1) Reduce woody plant cover and maintain or increase sacaton cover, or 2) Allow these areas to transition to mesquite bosque (i.e., leave alone).

On its own without management intercedence, this landscape will most likely transition to Mesquite Bosque (H).

This particular class of sacaton grassland community with tree-form mesquite is most often transitioning towards mesquite bosque. In these areas, a site-by-site evaluation may have to be made on whether or not to control mesquite. In many cases, these areas abut extant bosque woodland, yet in others they occupy “islands” within Sacaton Grasslands (A and B2). Areas abutting extant mesquite bosque may be left to complete a transition to woodland whereas the island areas may be considered for girdling or cutting and spraying (see Basal Application of Herbicides section above). Girdling and chemically treating mesquite may prove the most suitable option since it would preclude leaving large diameter wood and slash onsite to burn at high temperatures, potentially killing grass and sterilizing soil.

Distinguishing characteristics of Eroded Sacaton (E1) landscapes are reduced sacaton cover, active gullies, rills and/or sheet erosion, deteriorating and/or dead plants, and up to 15% mesquite cover.

Eroded Sacaton

E1 Active gully, rill, and/or sheet erosion —20-50% sacaton cover, deteriorating and/or dead plants, 0-15% mesquite cover, >20 ft to water table.

E2 Stabilized erosional processes — 20-50% sacaton, 0-15% mesquite, >20 feet to water table.

Management Goals: E1 (actively eroding): 1) Stabilize or reverse soil loss, and 2) Maintain or increase ground cover of sacaton and other native grasses. **E2** (healing/healed): Maintain or increase ground cover of sacaton and other native grasses.

The Eroded Sacaton state is evident in the upper Cienega Creek watershed in two subdivisions or phases: actively eroding and healing/healed. This section applies to actively eroding sacaton grasslands (E1) as the other form has healed or is healing of its own accord (E2). Actively eroding sacaton grassland pertains to areas of headcuts and gullies or sheet erosion. Largely, active headcuts and gullies consist of either individual or cluster of erosional features within sacaton grassland communities. Sheet erosion areas are more widespread, ranging from patches (~1 ac) to several acres in sizes. Sheet erosion is widespread and interspersed with sacaton grassland and sacaton-mesquite in the floodplain of Gardner Canyon downgradient of the 900 Road. Another area of extensive erosion is present above and below the Cieneguita windmill along Empire Creek, although this area also suffers from a combination of gully and sheet erosion.

Management actions may include attempts to treat select headcuts that threaten to dewater high-quality Sacaton Grasslands (A, B1, and B2). Treatments may include a combination of methods (e.g., Zuni bowls, one-rock dams, and medialunas; Zeedyk and Clothier 2009). Sheet erosion areas may require construction of media lunas or installation of erosion control socks to slow overland flow and capture sediment. Additional measures may include reseeding and/or revegetation with sacaton and other native grasses grown from seed or plugs. In concert with these measures or alone, these or select areas might be fenced or rested from grazing for an indeterminate period. A series of exclosures (with and without treatments) and grazing areas would

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Two examples of actively healing or healed Eroded Sacaton (E2) landscapes in the upper Cienega Creek watershed.

Eroded Sacaton *continued*

aid in determining the effectiveness of these treatments at stabilizing and recovering these eroded grasslands.

Management actions in the main stem of Cienega Creek and Empire Creek would benefit sacaton grasslands and their associated cienegas. Maintaining the in-stream headcut structure in Cienega Creek upstream of its confluence with Springwater Canyon Wash would ensure that this reach maintains a shallow watertable and overbank flows that recharge the neighboring sacaton grassland. Along Cienega Creek (between the Springwater-Empire Creek confluence and Gardner Canyon confluence), slowly raising the channel via sediment retention structures, particularly along reaches that support extant and former cienega habitats, would promote resilience of the sacaton grasslands and likely improve hydrologic conditions in associated cienega wetlands.

Annuals

F Native and non-native annual forbs and grasses, trace amounts of sacaton, other shrubs 0-10%, >20 ft water table.

Management Goals: 1) No action; in the abandoned agricultural fields allow Annuals state to transition to a new state; 2) Assess recovery potential of Annuals to transition to other desired state in Loamy Bottom Rangeland or Forestland within the agricultural fields; and/or, 3) Actively manage abandoned fields to facilitate transition of Annuals state to other desired state in Loamy Bottom Rangeland or Forestland; 4) Stabilize or reverse soil loss, maintain or increase native grass cover in Annuals areas that have experienced grass mortality due to fire.

The Annuals (F) landscape — dominated by native and non-native forbs and grasses with trace amounts of sacaton and shrubs — was, prior to agricultural cultivation, a mix of sacaton grassland and cienega.

At this site, the Annuals state is largely restricted to the abandoned agricultural fields, which pre-cultivation were occupied by cienega and sacaton grassland. These fields are partially recolonized by sacaton, but more so by mesquite.

The "Grand Canal" that runs along their eastern boundary, precludes overland flow from tributary drainages, deposits of fresh sediment, and sacaton and other propagules from entering the fields. Engineering solutions addressing this issue have been evaluated in the past 20 years, but have been tabled due to budgetary constraints.

In the absence of engineering fixes that would hasten recovery of the agricultural fields from the south, smaller scale earth-moving might serve to promote recovery of sacaton and expansion of extant cienega from the south. Presently, surface water from the cienega is precluded from moving across the southern portion of the fields by 3-5 ft levees that could be breached.

Monitoring the rate and direction of sacaton and woody plant encroachment onto the fields is a viable, low-budget option for tracking the progress of the fields with or without modifications to the levee or canal system. This information would aid in deciphering why some areas are recolonizing with sacaton and woody plant while others are not.

In areas where the Annuals state occurs in non-cultivated areas, a more active management approach may be necessary. Areas of sacaton that may have died as a result of fire may benefit from a management strategy that seeks to increase native grass cover. These areas may require construction of media lunas or installation of erosion control socks to slow overland flow and capture sediment. Additional measures may include reseeding and/or revegetation with sacaton and other native grasses grown from seed or plugs. In concert with these measures, or alone, these or select areas might be fenced or rested from grazing for an indeterminate period.

Exotics

D Exotic perennial grasses (e.g. Johnsongrass, yellow bluestem, and bermudagrass) w/without mesquite, <20 ft depth to water table.

Management Goals: 1) Monitor rate of spread of exotic perennial species, and 2) actively manage only where exotic species pose a threat to overall sacaton grassland condition at this site.

In this Exotics (D) landscape, Johnsongrass (Sorghum halepense) *dominates a patch of former sacaton grassland in the upper third of this photo.*

Across the alluvial ecological sites, we observed small pockets of exotic perennial grasses (e.g., Johnsongrass, bermudagrass (*Cynodon dactylon*), and yellow bluestem (*Bothriochloa ischaemum*). The bulk of the Johnsongrass and bermudagrass were associated with Cienega ecological site interspersed within Loamy Bottoms or along stream channels and gravel bars of Sandy Bottom ecological sites. We also occasionally observed Johnsongrass on disturbed soils around cattle tanks. In only one instance did we encounter an area — less than one-acre — where Johnsongrass had replaced big sacaton in a grassland setting (Empire Creek immediately downstream of Rattlesnake Tank). We observed a small patch of yellow bluestem in a sacaton grassland in the vicinity of Antelope Tank, north of Highway 82.

At present, these grasses do not appear to threaten overall sacaton grassland condition since these grasses appear to be more or less confined to wetland and near stream sites. Cienega wetland management objectives should address the issue of exotic species. Periodic monitoring and mapping of Johnsongrass in the sacaton grasslands may be warranted at sites identified in this survey to confirm its rate of spread.

Mesquite Bosque

H Trace amounts of sacaton, 25-65% large mesquite, 0-5% other shrubs and succulents, 25-50 ft to water table.

Management Goal: *1) No action (i.e., allow younger, shorter stature mesquite bosque to transition to a mature woodland; maintain existing woodland structure of mature mesquite bosque).*

Classic Mesquite Bosque (HCPC, H) in the upper Cienega Creek watershed.

Mesquite bosques support a great number and variety of invertebrates, which in turn provide an important resource base for birds, bats and other animals. Mesquite bosques are believed to support the second highest densities of birds in the Southwest behind cottonwood-willow forests (Ohmart et al. 1988). Bosques serve as prime habitat for many animals, mammals in particular, because of the abundance and nutritional quality of available food (mesquite beans) and high structural diversity.

Greater than 90% of the pre-settlement bosques no longer exist (Szaro 1989). Coupled with the aforementioned wildlife values and directives of the RMP for Las Cienegas to protect and maintain mesquite bosques, it makes sense to leave these woodlands alone regardless of how they came to form. Present-day environmental conditions clearly favor mesquite woodland over sacaton grassland in some areas above and most areas below 4,300 ft elevation.

Ongoing and Future Work

The University of Arizona Office of Arid Lands Studies (OALS) is quantifying woody plant and bare ground cover within Loamy Bottom ecological sites via remote sensing software. This work, under contract to The Nature Conservancy in Arizona, is part of a larger effort to quantify woody plant cover within the semi-desert and plains grasslands of the upper Cienega Creek watershed and adjoining Sonoita Plain. Results of woody plant cover and bare ground may be integrated into our existing framework for assigning sacaton grassland states. From these woody plant data, one could quantify, rather than estimate as we did, the amount of woody plant or bare ground cover within predefined polygons to reaffirm or change an assigned classification. Bare ground cover may be used as a surrogate for determining plant cover (which we also estimated) and/or establishing a baseline condition from which to observe changes in bare ground over time (i.e., quantify active erosion or recovery of eroded sacaton grasslands).

Data from the OALS effort will also supplement our maps of prospective mesquite woodlands digitized as part of the sacaton mapping effort. Prior to field-verifying the ecological condition of mesquite forestland, investigators will have woody plant cover already derived for respective polygons.

Lessons Learned

As the field survey and data refinement phases of this project matured, modifications to improve the efficiency of future mapping efforts became apparent. Creating dropdown menus for field recordings using a suite of site descriptors would increase the consistency and expediency of note-taking and subsequent data-proofing. Employing a tablet PC with ArcMap, GPS capabilities and digital aerial photography, instead of Juno units, would facilitate validation of site conditions and reduce post-processing time by integrating field data directly into a GIS database. Lastly, future mapping efforts with limited time for field visits might consider reducing time spent classifying transitional areas — where we expended a greater percentage of our time relative to the amount of sacaton grassland we assigned, — and using aerial imagery to emphasize work in larger contiguous stands.

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Figures

Figure 1. *Where the upper Cienega Creek watershed fits within the LCNCA's Planning Area Boundary (LCNCA PAB) and other jurisdictions.*

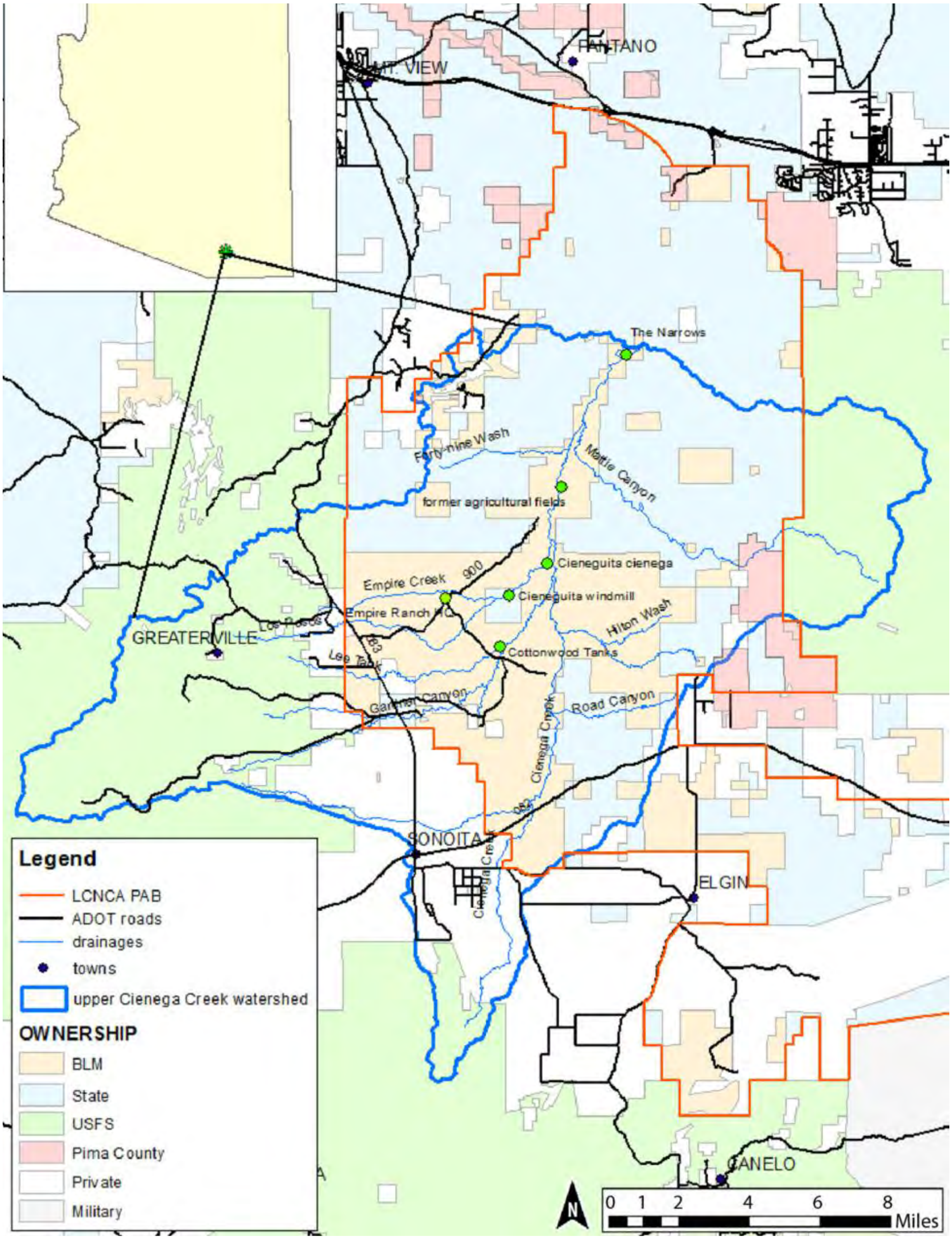


Figure 2. *Digitized area (beige lines) superimposed over alluvial ecological sites mapped by NRCS for the BLM.*

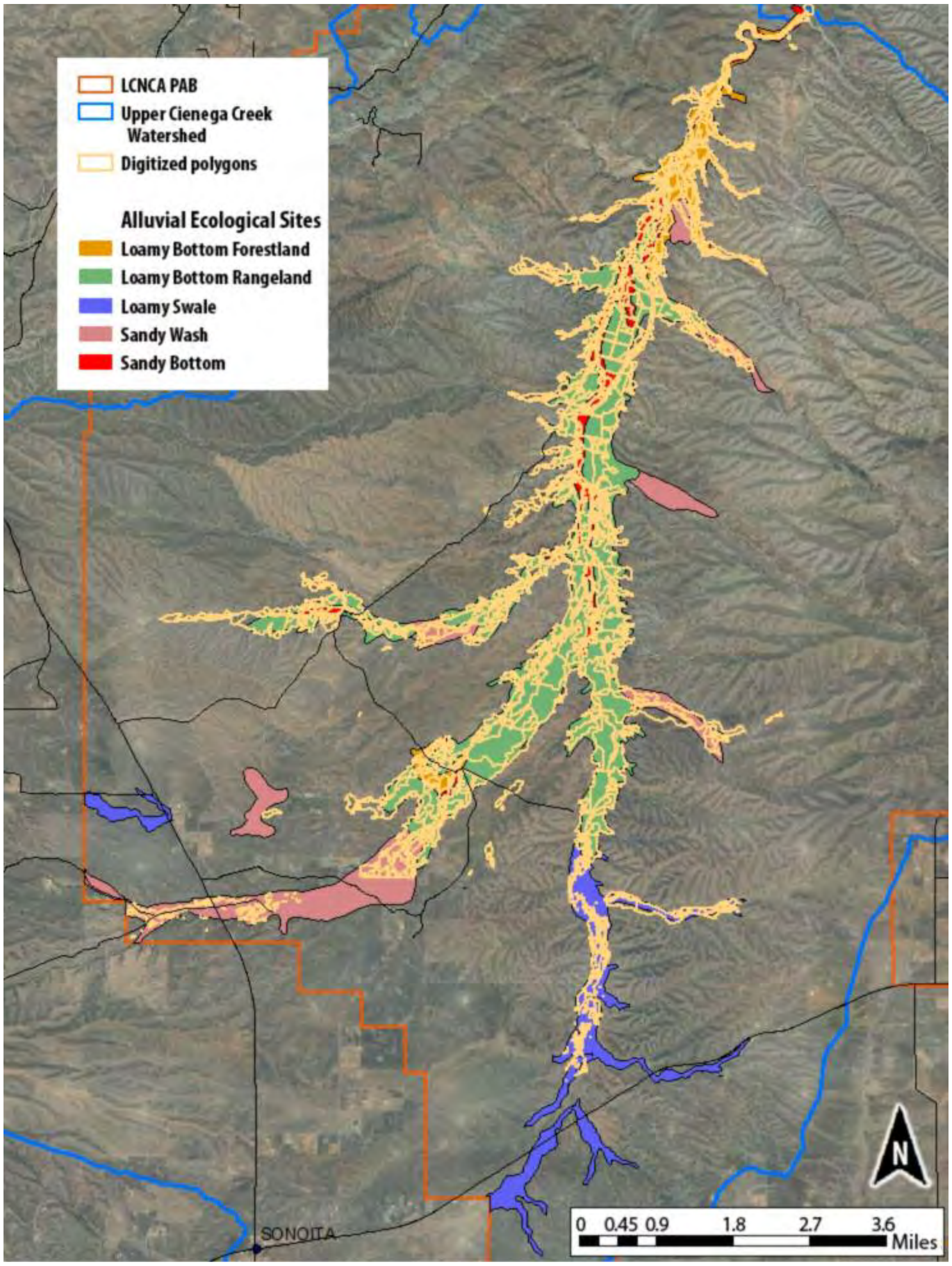


Figure 3. *Areas of prospective sacaton grassland and mesquite bosque communities in upper Cienega Creek watershed digitized from 2007 NAIP imagery. Tan and lavender areas represent the entire digitized area. Lavender areas represent areas field-verified as of September 2011.*

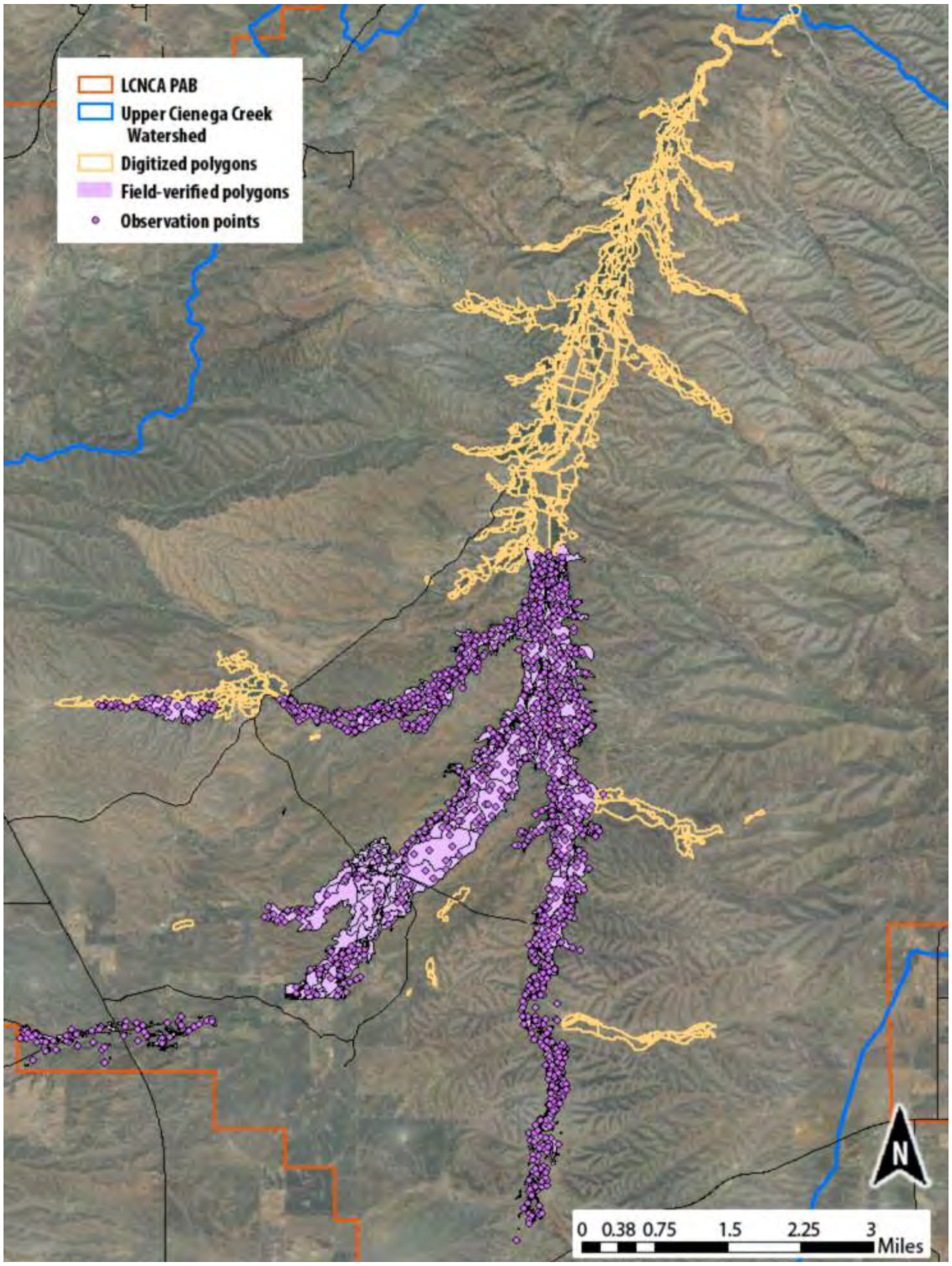


Figure 4. *Ecological states observed across field-verified areas.*

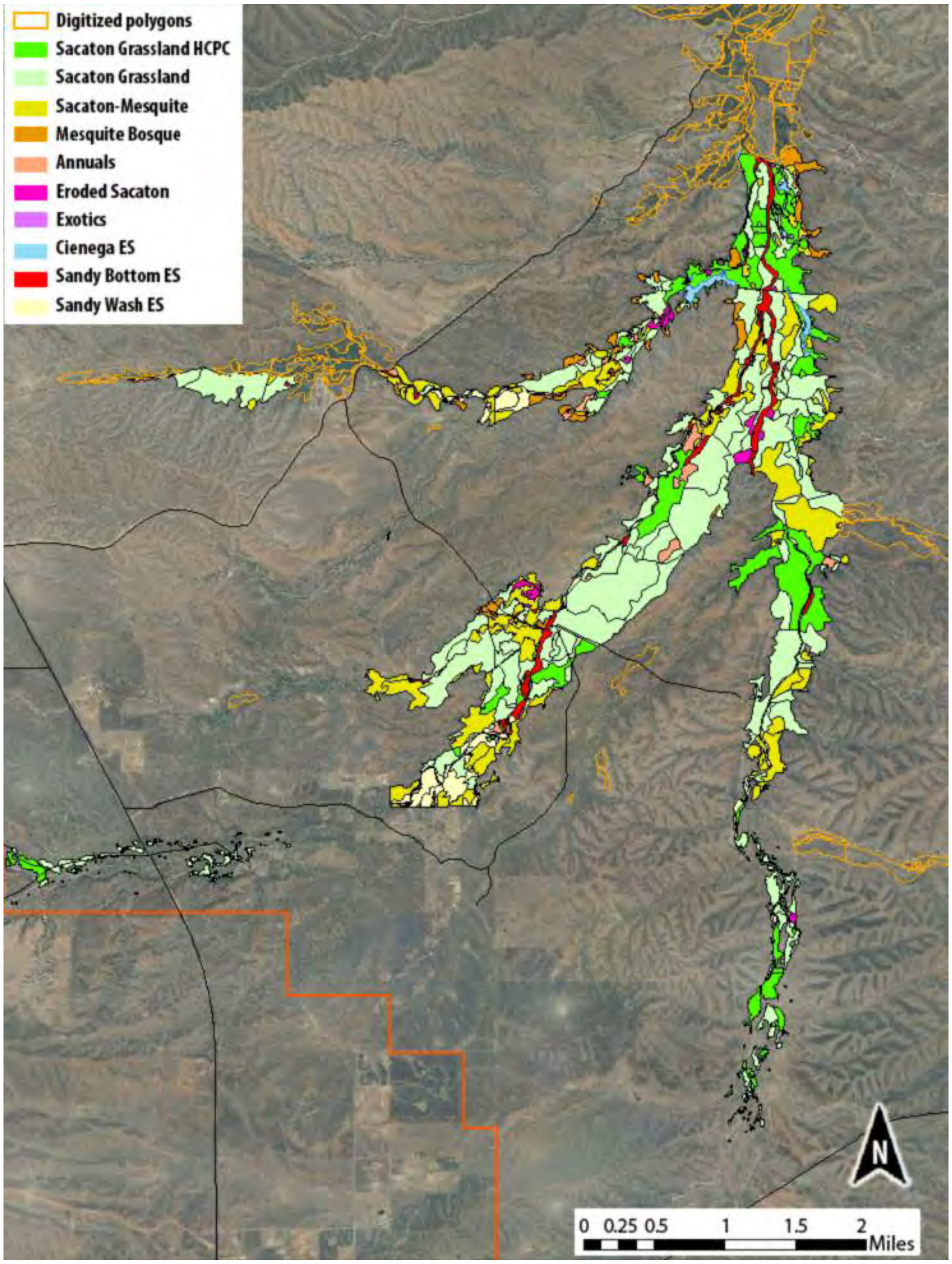
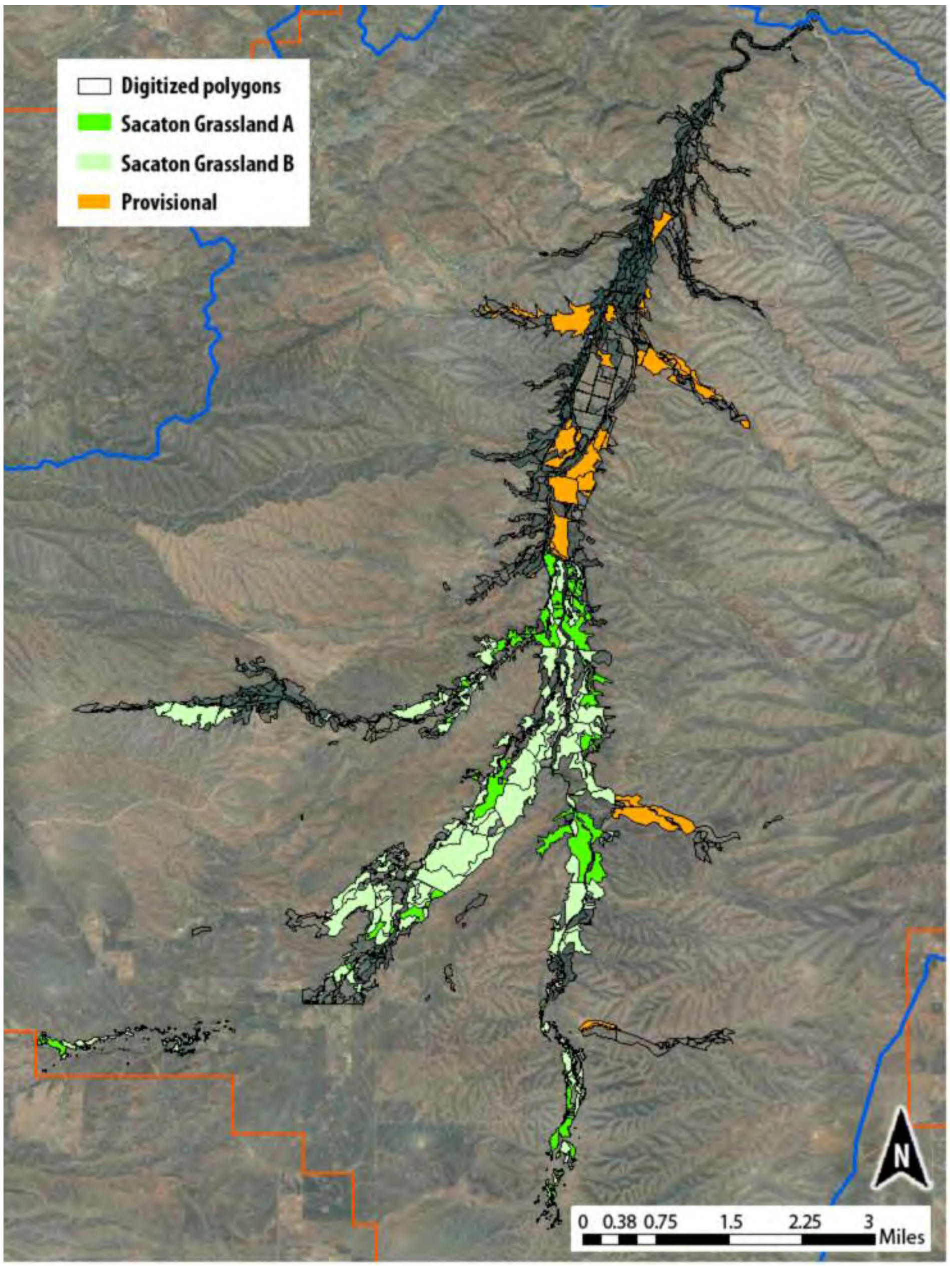
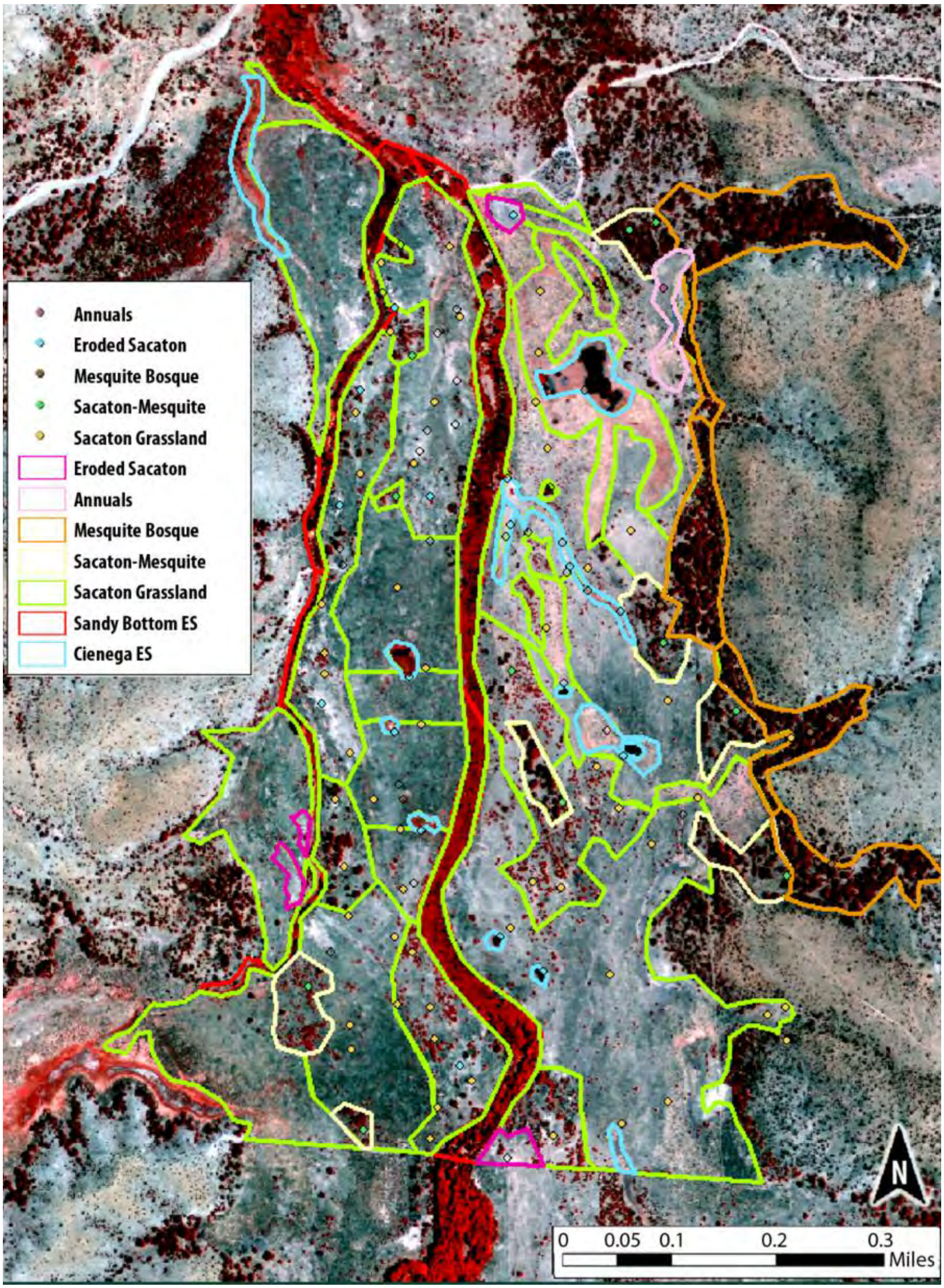


Figure 5. *Map of open Sacaton Grassland states (A and B) in the upper watershed of Cienega Creek. Bright green polygons represent classifications based on field verification (bright green areas; see also Figure 2) and orange areas represent anticipated sacaton grassland classifications based on interpretations of aerial photography.*



Figures 6. *Ecological condition classifications for Loamy Bottom Rangeland and Forestland along an example area of Cienega Creek. Small circles are observation points from which states were assigned; polygons delineate the boundaries of states. Infrared bands accentuate rapidly growing vegetation — mesquite in and along floodplain margins, cottonwood-willow in the center, and cienega in the southwest corner.*



Figures 7. *Ecological condition classifications for Loamy Bottom Rangeland and Forestland along an example area of Cienega Creek. Polygons delineate the boundaries of states.*

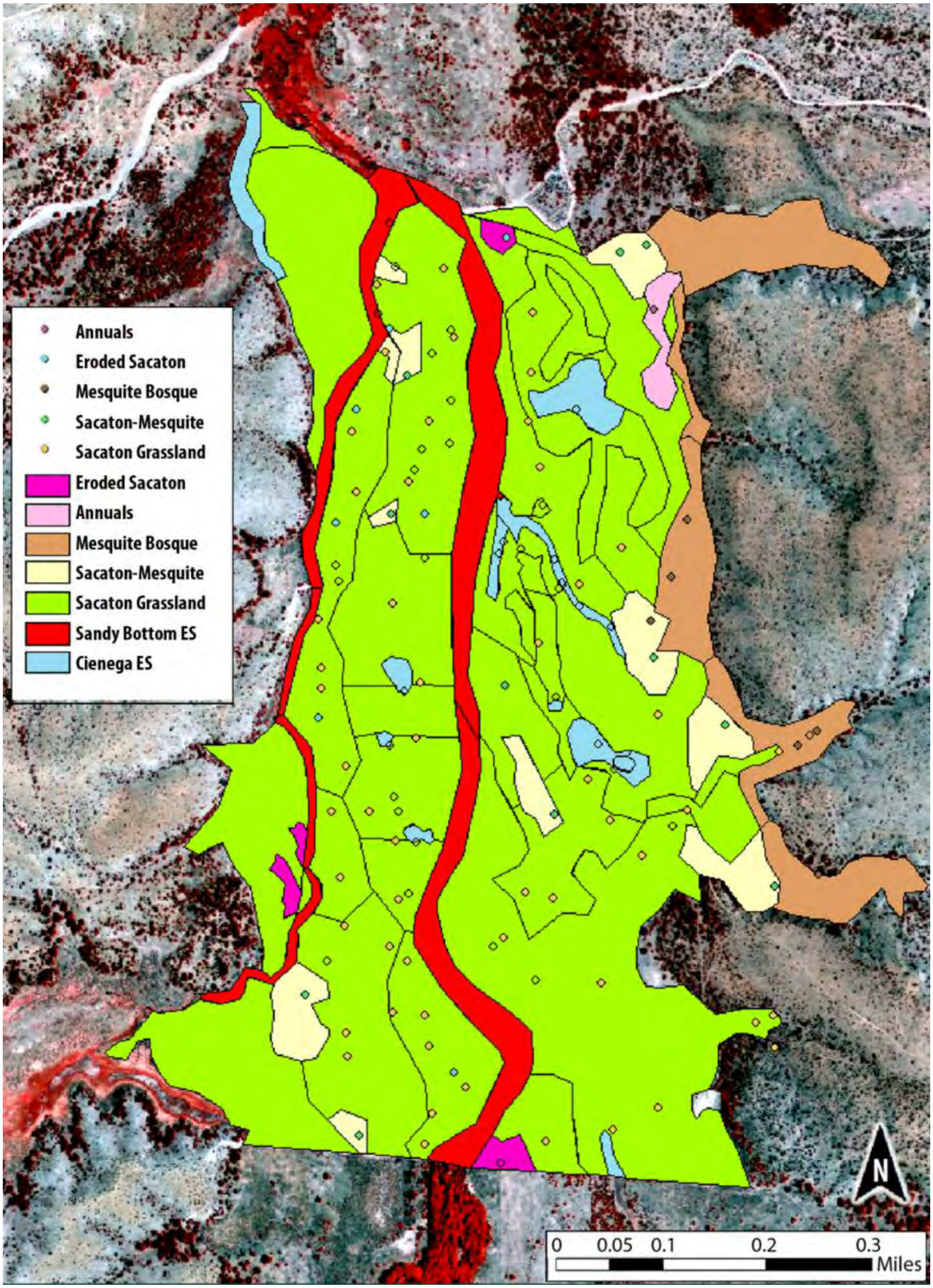
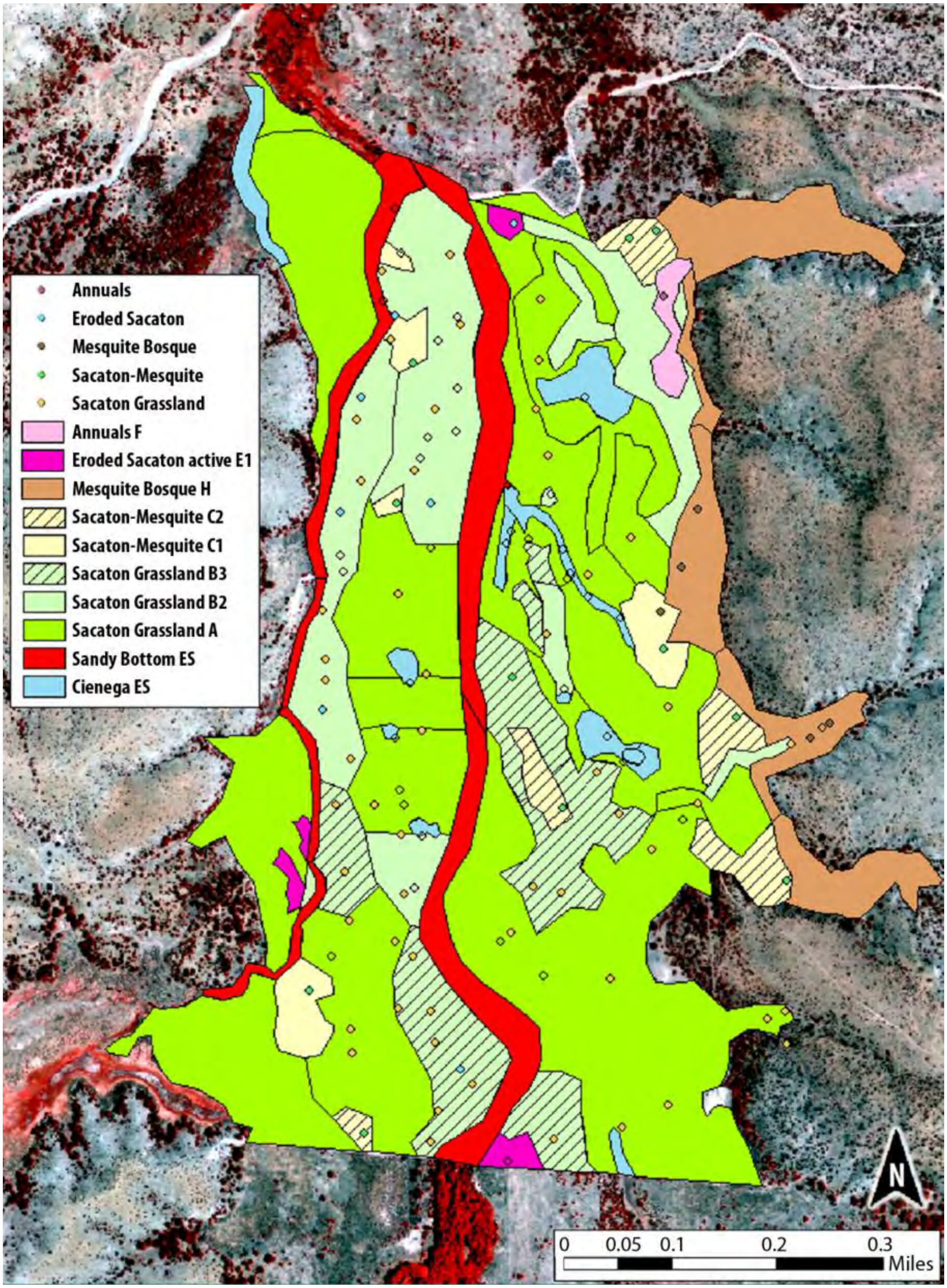


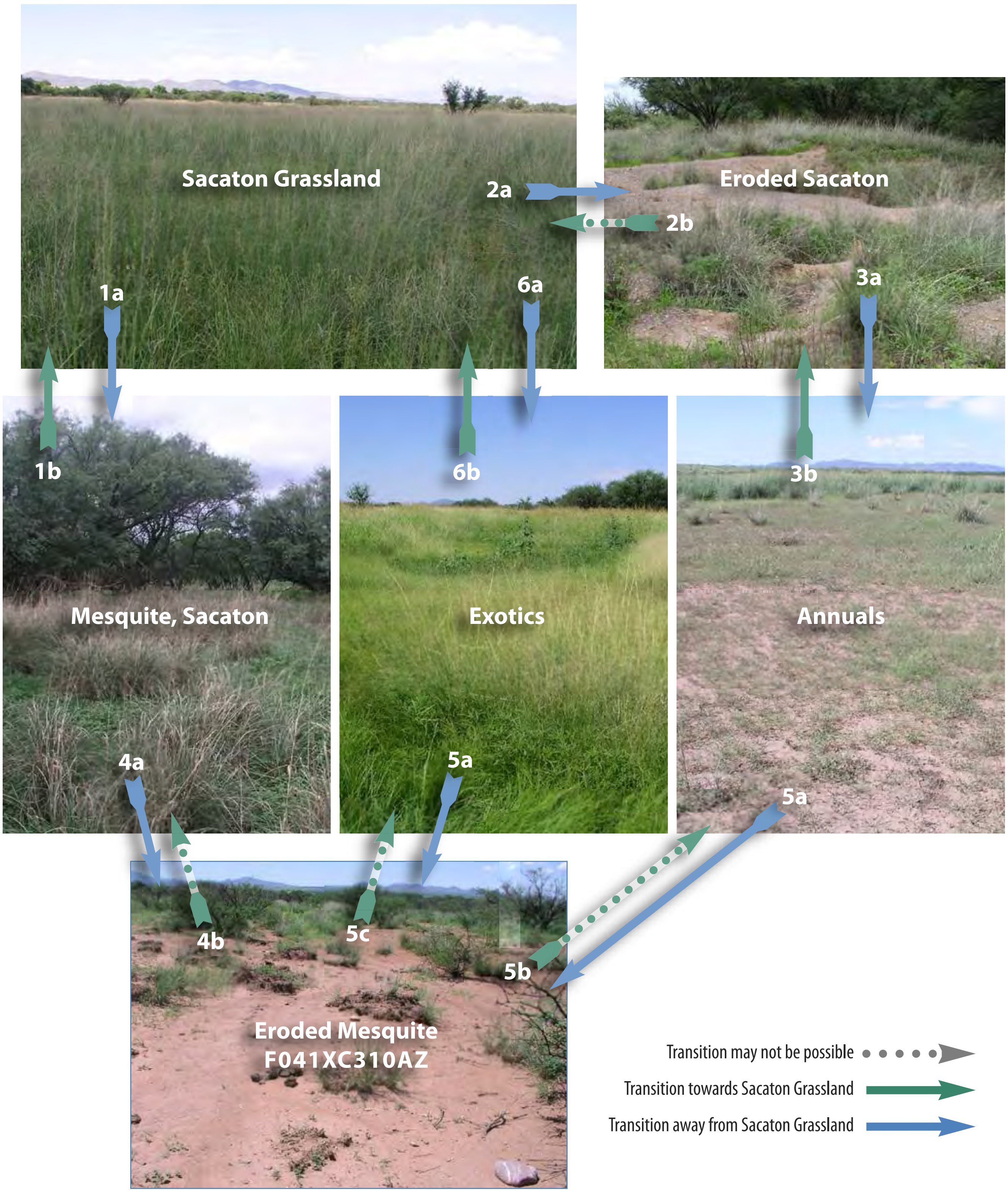
Figure 8. *Ecological condition classifications for Loamy Bottom Rangeland and Forestland along an example area of Cienega Creek. Small circles are observation points from which states and state phases were assigned (solid color polygons) per a modified State and Transition model for Loamy Bottom Rangeland.*

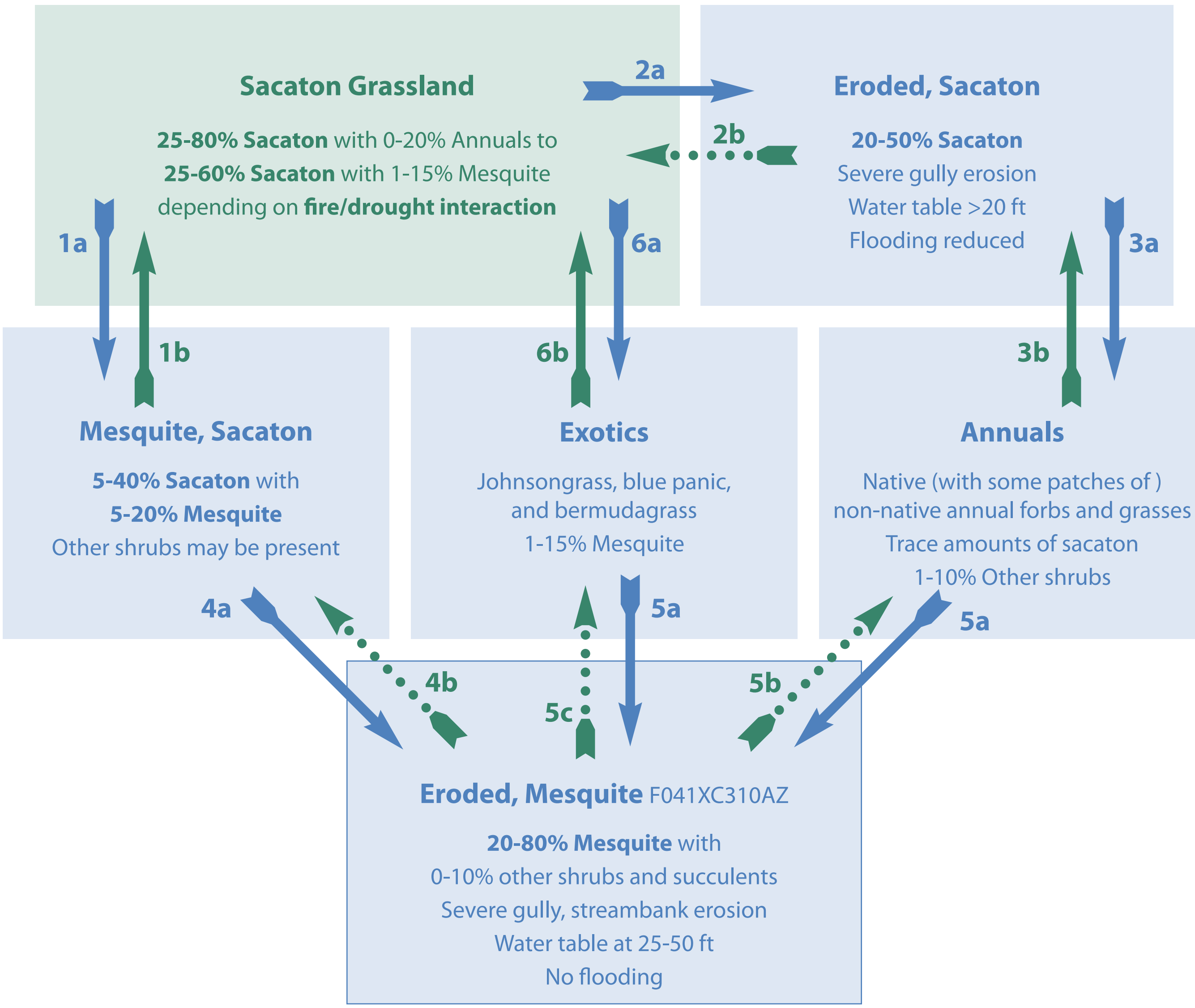


Appendices

Appendix A. *State and Transition models for Loamy Bottom Rangeland and Forestland (MLRA41, 12-16 inch precipitation zone) from Robinett (2005a, 2005b)*

Sacaton Grassland (Rangeland)





1a Mesquite seed source present or introduced. Lack of fire for long periods of time. Mesquite increases to 20% canopy.

1b Herbicide or mechanical means to remove mesquite. Proper/no grazing.

2a Continuous heavy grazing. Base level changes cause gully and headward erosion. Flooding reduced. Water table lowered to >20 ft.

2b Proper/no grazing. Mechanical control of gullies at headcuts.

3a Continuous heavy grazing, managing for annuals. Burning/continuous heavy grazing to freshen sacaton. Hay mowing. Irrigated cultivation and abandonment. Base level changes in main stream causes downcutting and gully formation on the floodplain. Flooding reduced.

3b Proper/no grazing. Mechanical gully control measures. Sacaton seeding with weed control and water. Re-establish flooding.

4a Continuous heavy grazing combined with drought, burning with low soil moisture. Reduction of surface soil (A horizon), organic material and litter; compaction, sheet and rill erosion. Reduced infiltration, greatly increased runoff. Runoff and very limited recruitment of perennial grasses. Base level change in main stream causes downcutting in swales.

4b Mechanical/herbicide treatment of shrubs to <20% canopy. Seeding of sacaton, maintenance treatments for shrubs at 15 years. Mechanical control of gully erosion.Re-establish flooding.

5a Continuous heavy grazing. Interruption of overland flow, diversion of runoff. Severe soil compaction from traffic (livestock or equipment). Base level changes in main stream causes downcutting and gully formation on the floodplain.

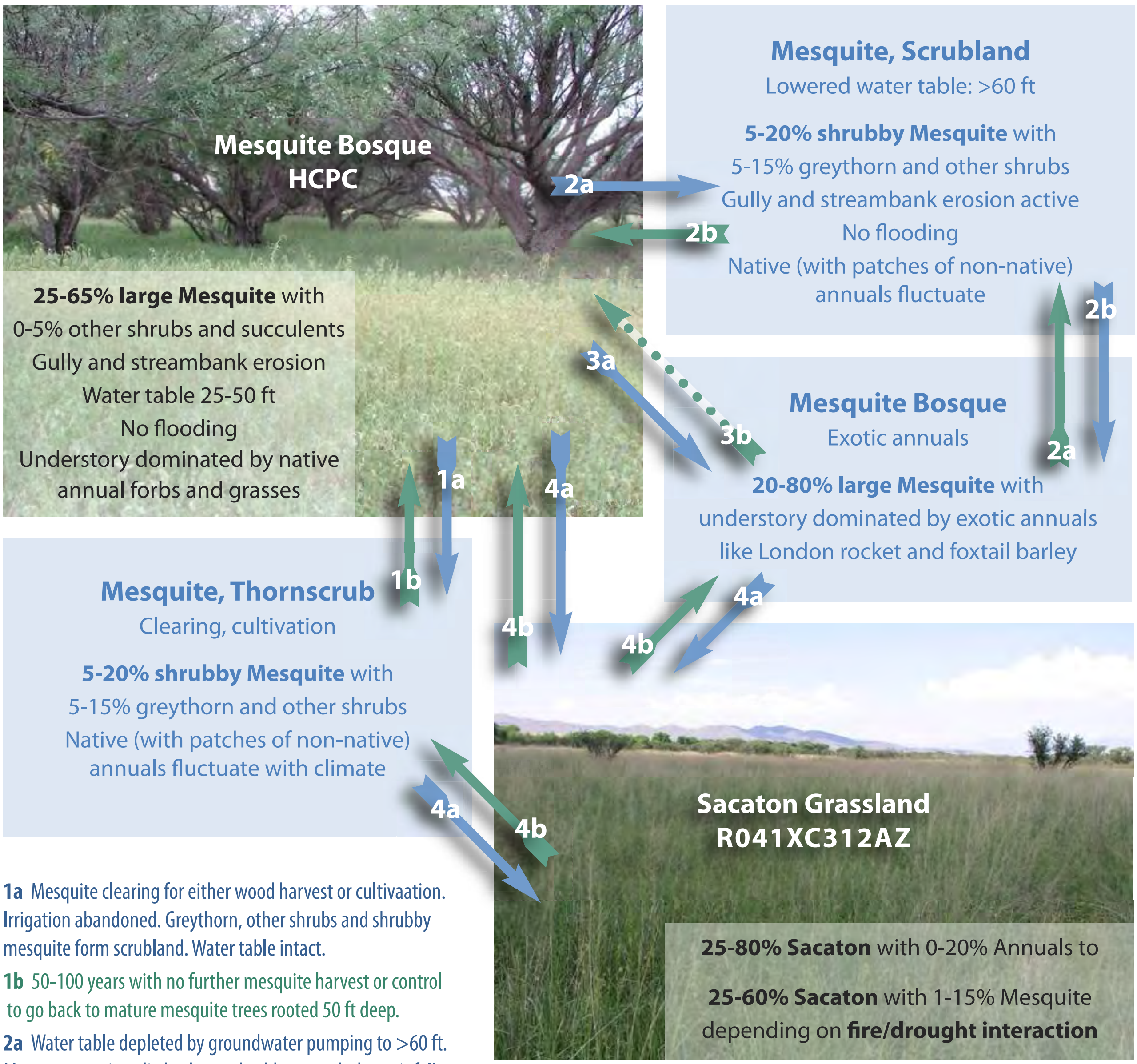
5b Mechanical control of gullies. Mesquite control or wood harvest with stump treatments (herbicide). Re-establish flooding.

5c Mechanical control of gullies. Mesquite control to <15% cover. Seeding of exotic grasses. Re-establish flooding.

6a Continuous heavy grazing combined with drought, burning with low soil moisture. Plowing of sacaton for cultivation with subsequent abandonment. Introduction or planting of seeds of exotic perennial grasses.

6b Herbicide control of exotic grasses. Seeding of sacaton with weed control and irrigation or flooding.

Mesquite Bosque (Forestland)



1a Mesquite clearing for either wood harvest or cultivaation. Irrigation abandoned. Greythorn, other shrubs and shrubby mesquite form scrubland. Water table intact.

1b 50-100 years with no further mesquite harvest or control to go back to mature mesquite trees rooted 50 ft deep.

2a Water table depleted by groundwater pumping to >60 ft. Mature mesquites die back to a shurbby growth that rainfall can support. No return if pumping is associated with urban areas or development.

2b Cessation of groundwater pumping may allow water tables to rise over time to within 50 ft of surface; time depends on depth of depletion and amount of pumping reduced. This will not occur in urban or developing areas.

3a Introduction of a seed source for non-native annuals like London rocket, foxtail barley, red brome and resource brome.

3b Unkown, possible herbicide control of exotic annuals.

4a Sedimentation of main stream system will cause water tables to rise, eventually drowning out mesquite. Water tables are within rooting depth (20 ft) of sacaton. Gullies and stream channels fill with sediment and flooding resumes. Site returns to sacaton potential with proper/no grazing.

4b Gully and stream erosion deepn channels and lower water table to more than 20 ft from the surface. Sacaton thins out, mesquite increases and slowly forms a mature bosque.

Appendix B. *Example photographs for states of Loamy Bottom ecological sites (Rangeland and Forestland) encountered in the upper Cienega watershed. Text conforms to ecological site descriptions except where noted; state assignments are those of authors.*

Sacaton Grassland Historic Climax Plant Community (A)

25-80% sacaton ground cover, 0-20% annuals, <20 feet depth to water table.

Sacaton Grassland (B)

25-60% sacaton ground cover, 1-15% mesquite, <20 ft depth to water table. This state is listed as Sacaton-Mesquite in the Rangeland STM.

Sacaton-Mesquite (C)

5-40% sacaton ground cover, 5-20% mesquite, other shrubs and succulents, <20 ft depth to water table.

Exotics (D)

Exotic perennial grasses (e.g., Johnsongrass, yellow bluestem, and bermudagrass) with/without mesquite, <20 ft depth to water table. Johnsongrass (*Sorghum halepense*) dominates a patch of former sacaton grassland in the upper third of photo.

Eroded Sacaton (E)

20-50% sacaton ground cover, no mesquite, exotic grasses present, gully erosion, >20 ft depth to water table.

Annuals-Sacaton Grassland (F)

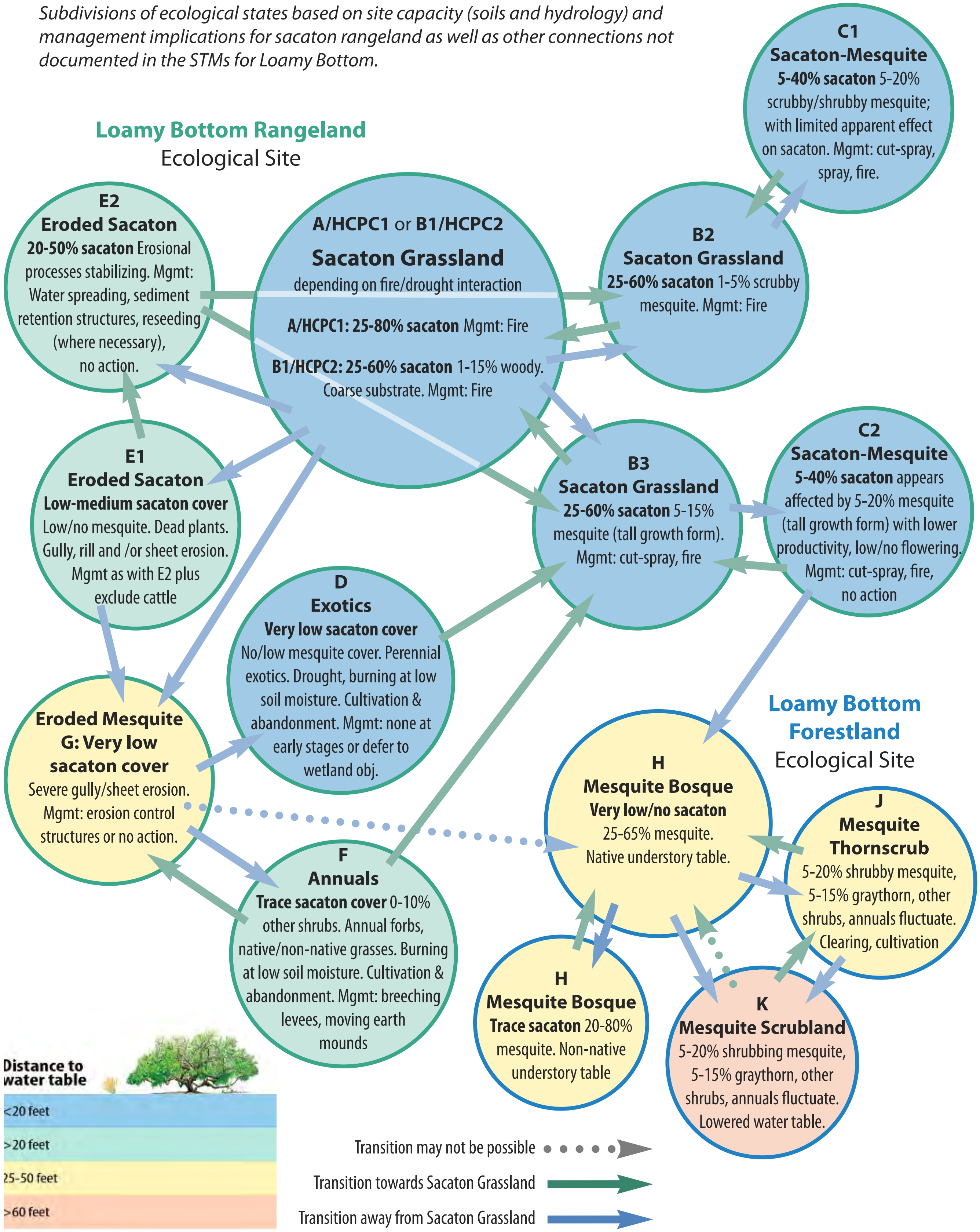
Trace sacaton cover, no mesquite, 0-10% other shrubs and succulents, annuals present, >20 ft depth to water table.

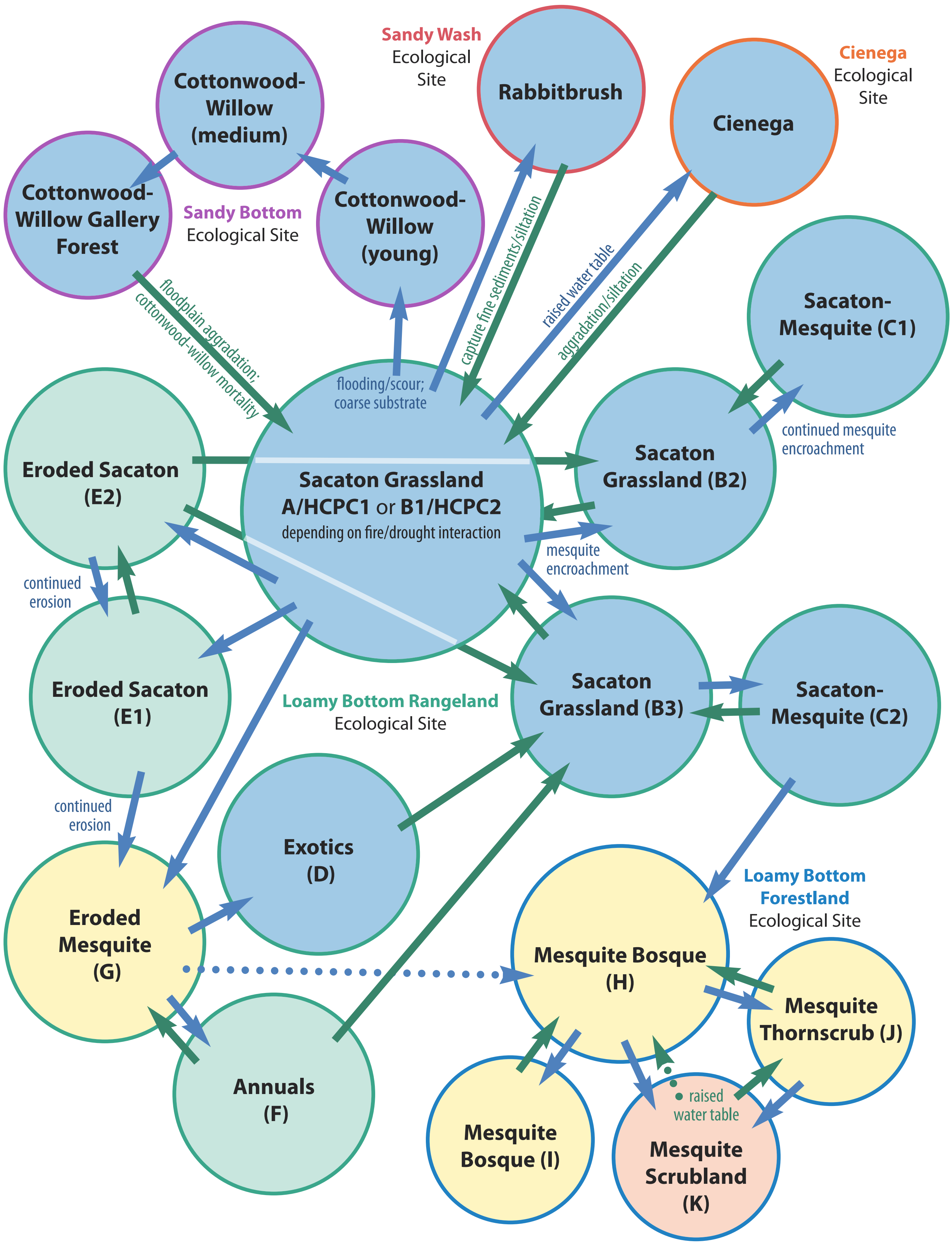
Mesquite Bosque, native annuals (HCPC, H)

No sacaton, 25-65% large mesquite, 0-5% other shrubs and succulents, 25-50 ft to water table.

Appendix C. *Modifications and Linkages to State and Transition Models MLRA 41-3 Loamy Bottom (Rangeland and Forestland) and Sandy Bottom ecological sites (12-16 inch precipitation zone) to better fit observations made at Las Cienegas National Conservation Area.*

Subdivisions of ecological states based on site capacity (soils and hydrology) and management implications for sacaton rangeland as well as other connections not documented in the STMs for Loamy Bottom.




Sandy Wash
Ecological
Site
Rabbitbrush
Cienega
Ecological
Site
Cienega
Cottonwood-
Willow
(medium)
Cottonwood-
Willow Gallery
Forest
Sandy Bottom
Ecological Site
Cottonwood-
Willow
(young)
capture fine sediments/siltation
raised water table
aggradation/siltation
floodplain aggradation;
cottonwood-willow mortality
Sacaton-
Mesquite (C1)
flooding/scour;
coarse substrate
Sacaton
Grassland (B2)
continued mesquite
encroachment
Eroded Sacaton
(E2)
Sacaton Grassland
A/HCPC1 or B1/HCPC2
depending on fire/drought interaction
mesquite
encroachment
continued
erosion
Eroded Sacaton
(E1)
Sacaton
Grassland (B3)
Sacaton-
Mesquite (C2)
Loamy Bottom Rangeland
Ecological Site
continued
erosion
Exotics
(D)
Loamy Bottom
Forestland
Ecological Site
Eroded
Mesquite
(G)
Mesquite Bosque
(H)
Mesquite
Thornscrub (J)
Annuals
(F)
raised
water table
Mesquite
Bosque (I)
Mesquite
Scrubland
(K)

Appendix D. *Example photographs of condition classes for modifications to the Sacaton Grassland State and Transition model.*

This updated model subdivides states into states and phases, adds states to the Loamy Bottom ecological site (Rangeland and Forestland), and makes connections to the Cienega and Sandy Loam ecological sites (12-16 in precipitation zone). Text associated with individual states conforms to language in existing State and Transition models, except where the authors have proposed new states or state phases and assigned letters to them.

Sacaton Grassland Historic Climax Plant Community (A)

25-80% sacaton cover; no woody cover; 0-20% annuals, <20 ft depth to water table.

Sacaton Grassland (B1)

Coarse substrate, 25-60% sacaton cover, 1-15% woody cover, <20 ft depth to water table.

Sacaton Grassland (B2) early woody plant encroachment

25-60% sacaton, 1-5% woody cover, scrubby; <20 ft depth to water table.

Sacaton Grassland (B3) encroached grassland transitioning to Sacaton-Mesquite

25-60% sacaton cover, 5-15% tall-form mesquite, <20 ft depth to water table.

Sacaton-Mesquite (C1) scrubby/shrubby-encroached grassland

5-40% sacaton cover, 5-20% scrubby/shrubby mesquite cover; <20 ft depth to water table.

Exotics (D)

*Exotic perennial grasses (e.g. Johnsongrass, yellow bluestem, and bermudagrass) w/without mesquite, <20 ft depth to water table. Johnsongrass (*Sorghum halepense*) dominates a patch of former sacaton grassland in the upper third of photo.*

Two examples of **Sacaton-Mesquite** (C2) transitioning toward **Mesquite Bosque** (H)
5-40% sacaton cover, 5-20% tall growth mesquite, <20 ft depth to water table.

Two examples of **Eroded Sacaton** (E1)

Active gully, rill, and/or sheet erosion: 20-50% sacaton cover, deteriorating and/or dead plants, 0-15% mesquite cover, >20 ft to water table.

Two examples of **Eroded Sacaton** (E2)

Stabilized erosional processes — 20-50% sacaton, 0-15% mesquite, >20 feet to water table.

Annuals (F)

Native and non-native annual forbs and grasses, trace amounts of sacaton, 0-10% other shrubs, >20 ft water table.

Cienega ecological site embedded within **Sacaton Grassland** (A and B)

Loamy to clayey soils with redox features, perennial water table 3-15 ft.

Mature **Cottonwood-Willow Gallery Forest** (*Populus-Salix)* in Sandy Bottom ecological site transitioning to **Sacaton Grassland** (A)

Intermittent-perennial streamflow regime, perennial water table 3-15 ft, occasionally deeper ephemeral where water table has dropped due to channel incision (<20 ft depth to water table).

Rabbitbrush Scrubland (*Ericameria nauseosus*)

Coarse substrates of Sandy Wash ecological site (12-16 in precipitation zone), ephemeral stream reaches, soils without a high water table, aggrading and capturing fine sediments that promote sacaton recruitment.