Sacaton Riparian Grasslands of the Sky Islands: Mapping Distribution and Ecological Condition Using State-and-Transition Models in Upper Cienega Creek Watershed

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***Abstract:** Riparian grasslands dominated by* Sporobolus wrightii *(big sacaton) were once widely distributed in the intermountain basins of the Madrean Archipelago. These alluvial grasslands are still recognized as key resources for watershed function, livestock, and wildlife. The upper Cienega Creek watershed in SE Arizona is thought to harbor some of the region's most extensive sacaton stands. Documenting their extent and ecological state is important for informing management in this valley and for contributing to a clearer picture of this community's status across the region. Our objectives were to map the distribution of sacaton; qualitatively assess stands of sacaton into ecological states; and test mapping and assessment methods for use in other valley bottoms in the region. We used a two-step approach: interpretation of aerial photography and soil maps followed by field reconnaissance. Field work consisted of qualitative, rapid assessments of ecological state using the Natural Resource Conservation Service's State-and-Transition (S&T) models for the Loamy Bottom Ecological Site. The most open and productive state of Sacaton Grassland occupies 54 percent of alluvial habitats evaluated, with remaining acreage in various states of degradation, recovery, or transition to Mesquite Bosque woodland. Our observations in the Cienega Creek watershed suggest potential modifications to the S&T models that may more accurately reflect site potential, likelihood of transitioning to other states, and management strategies tailored to maintaining or improving sacaton grassland conditions across the region.*

Introduction and Rationale

Riparian grasslands dominated by big sacaton (*Sporobolus wrightii*) once formed nearly pure stands of robust perennial grass along the Southwest's perennial and intermittent streams (Bahre 1991; Brown 1982; Humphrey 1958). The sacaton riparian habitat is distinct from, yet shares features with, neighboring riparian habitats and upland grassland associations. Individual plants and small clumps of this grass can be found in many settings. In the right soils and alluvial settings, however, big sacaton, and to a lesser extent alkali sacaton (*S. airoides*), creates a unique habitat formation sometimes called a sacaton "flat" or "bottom" with distinct history and management needs. Developing maps of sacaton grassland extent and ecological condition can provide a foundation from which to develop informed management objectives and actions that maintain, restore, and promote the resilience of this important community.

Historical Geography

Declining Distributions

Sources estimate sacaton grasslands now occupy less than 5 percent of their original distribution across the region (Humphrey 1960). Commonly cited causes of decline include natural phenomena and anthropogenic influences from as early as the late 1800s (Cooke and Reeves 1976; Cox and others 1983; Humphrey 1958, 1960). With channel entrenchment, reductions in overbank flooding, and the advent of industrialized farming, vast expanses of *Sporobolus* grassland became ideally suited for agriculture and many thousands of acres were converted to crops by the mid-1900s.

In: Gottfried, Gerald J.; Ffolliott, Peter F.; Gebow, Brooke S.; Eskew, Lane G.; Collins, Loa C., comps. 2013. Merging science and management in a rapidly changing world: Biodiversity and management of the Madrean Archipelago III; 2012 May 1-5; Tucson, AZ. Proceedings. RMRS-P-67. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Current Geography and Condition

Despite steep declines, stands of bottomland sacaton grassland are still found scattered across their former range with the larger, more intact examples most recognizable. Fine stands of big sacaton grasslands can still be found in upper reaches of gently sloping valleys like the upper Cienega Creek basin, upper Babocomari River, upper San Pedro River in Mexico, and upper Santa Cruz River basin near Lochiel. Condition of sacaton flats in the region varies widely from mature stands surviving on eroded former floodplain terraces or under the canopy of mesquite woodlands, to exceptionally productive stands with little bare soil or woody cover between plants that exceed 6 ft. in height.

These stands are recognized as key resources for watershed function, livestock, and wildlife and there is a growing interest in their conservation and management in Arizona. In the past 30 years, large-scale riparian conservation areas have been established within several watersheds that harbor extensive sacaton flats. Some of the finest remaining examples exist on the Las Cienegas National Conservation Area (LCNCA) managed by the Bureau of Land Management (BLM). The BLM is responsible for this and other conservation areas and has been particularly active in seeking direction regarding the status of these grasslands and guidance for management.

Limited efforts have been made to map the contemporary distribution of sacaton and associated communities in the Sky Island region. These vary in their spatial extent and the degree to which they treat sacaton flats as a distinct entity (table 1). We know of no efforts, however, that systematically evaluate ecological condition of sacaton grasslands in a focal watershed, let alone the region. Our case study examined alluvial habitats on the upper Cienega Creek watershed (fig. 1) to (1) map the distribution of bottomland sacaton stands in the study area; (2) qualitatively assign sacaton stands into ecological states to understand dynamics and inform management; and (3) test methods for mapping and evaluating sacaton communities elsewhere.

Methods

This mapping effort followed a framework laid out by the Natural Resources Conservation Service (NRCS), first mapping distribution of plant communities associated with particular soil and climate settings (Ecological Sites) (Briske and others 2006) and then mapping "states" or ecological condition within those (Bestelmeyer and others 2010). To map sacaton bottomlands, we used a two-step approach: interpretation of aerial photography and field reconnaissance. In preparation for fieldwork, we digitized provisional polygons based on aerial photos using three pieces of GIS information in ArcMap 10: (1) BLM's layer of ecological sites mapped by NRCS specifically for Las Cienegas (BLM 2003); (2) county soil maps and ecological sites NRCS associated with these soils (soildatamart.nrcs.usda.gov); (3) and, aerial photogaphs from the USDA's 2007 National Agricultural Imagery Program (NAIP; datagateway.nrcs.usda.gov). The first two layers guided our focus on alluvial soils capable of supporting bottomland sacaton stands (fig. 1). The third layer provided 1-m (3-ft.) resolution, 4-band digital aerial photographs. With the near infrared band expressed to provide greater differentiation of features, we drew polygons based on color, texture, and vegetation differences apparent across the alluvial ecological sites. Some polygons extended beyond soil map units to capture the full extent of target plant communities.

Field verification focused on areas with greatest concentration of sacaton grasslands (fig. 2). Using handheld GPS units (Trimble Juno SB) equipped with GIS (ArcPad 8), ground-level information was recorded at one or more locations within a polygon depending on the homogeneity or variability apparent between field maps and on-the-ground observations. Polygons were adjusted as necessary where sacaton stretched beyond or compressed within the boundaries of digitized projections. Unique features within a polygon were also catalogued. These included erosional features and other plant associations (e.g., tobosa or blue grama grasslands, cottonwood-willow forest, and rabbitbrush (*Ericameria* scrublands).

To evaluate current condition of sacaton stands in the field, we used rapid-assessment qualitative descriptions of habitat type, marked GPS

Table 1—Other vegetation mapping efforts with a variety of purposes and spatial extents that included upper Cienega Creek watershed.

Agency	What and where they surveyed	What they found in Cienega watershed
The Nature Conservancy (Gori and Enquist 2003)	Regional grassland condition survey combining expert knowledge and field reconnaissance.	723 acres of sacaton riparian grassland without condition evaluations.
Bureau of Land Management and NRCS (BLM 2003)	Empire and Empirita allotments and Las Cienegas NCA. Includes Cienega Creek and tributaties in an ecological site map for Las Cienegas.	7,600 acres we could classify as alluvial for ecological sites: Loamy Bottom, Sandy Bottom Swale, and Loamy Swale.
AZ Game and Fish Dept. (Kubly and others 1997)	AZ statewide riparian vegetation along the then-known extent of mapped perennial streams.	71 acres of sacaton, 384 acres of mesquite woodland.
USGS, AZ GAP vegetation mapping (Halvorson 2002)	AZ statewide riparian and upland vegetation communities; Cienega Creek, Empire Gulch, Gardner Canyon, and substantial upland areas outside of sacaton-dominated associations. This survey extended beyond strictly riparian stands.	4,680 acres of sacaton-scrub grassland
Pima County (Harris 2000)	Riparian communities within Pima County; included portions of Cienega watershed.	9,290 acres of semi-desert grassland (sacaton and upland together BLP series 143.1; Brown and others 1979), 427 acres of mesquite bosque (series 224.52), and 149 acres of abandoned agricultural fields (presumably mixed former sacaton and cienega habitats).
Pima County, aerial reconnaissance (Fonseca 2000)	Pima County, including upper watershed of Cienega Creek beyond its borders into Santa Cruz County, and sites in Altar Valley, sacaton focus.	732 acres of sacaton grassland communities discriminated from upland grasslands, 2,909 acres of mesquite-sacaton association, and 971 acres of cottonwood-willow forest-sacaton association.

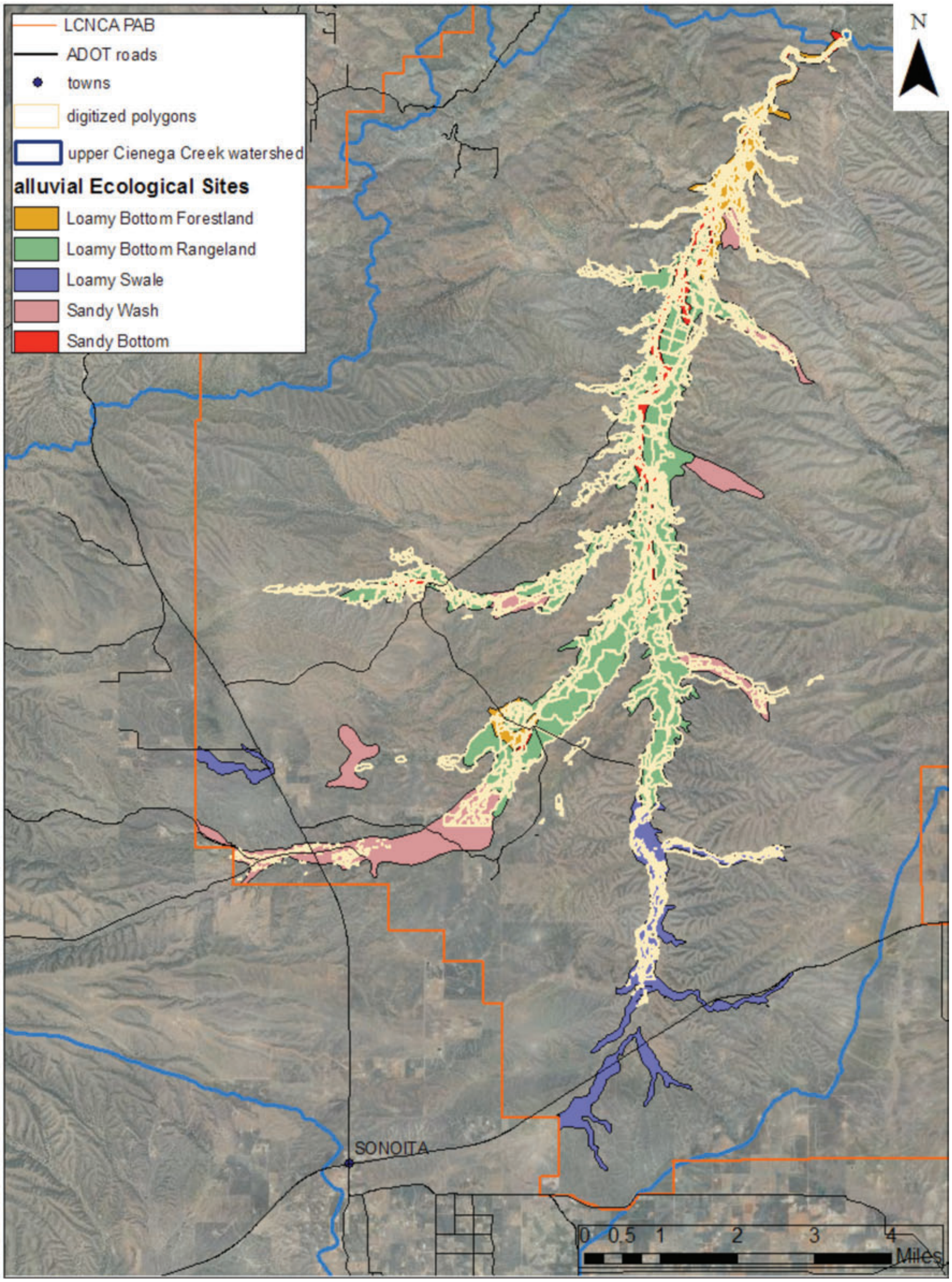

Figure 1—Areas of prospective sacaton grassland and mesquite bosque habitat in upper Cienega Creek watershed (beige lines), digitized from 2007 NAIP aerial imagery. These provisional stands are shown superimposed on alluvial Ecological Sites (colored polygons) previously mapped by NRCS and BLM.

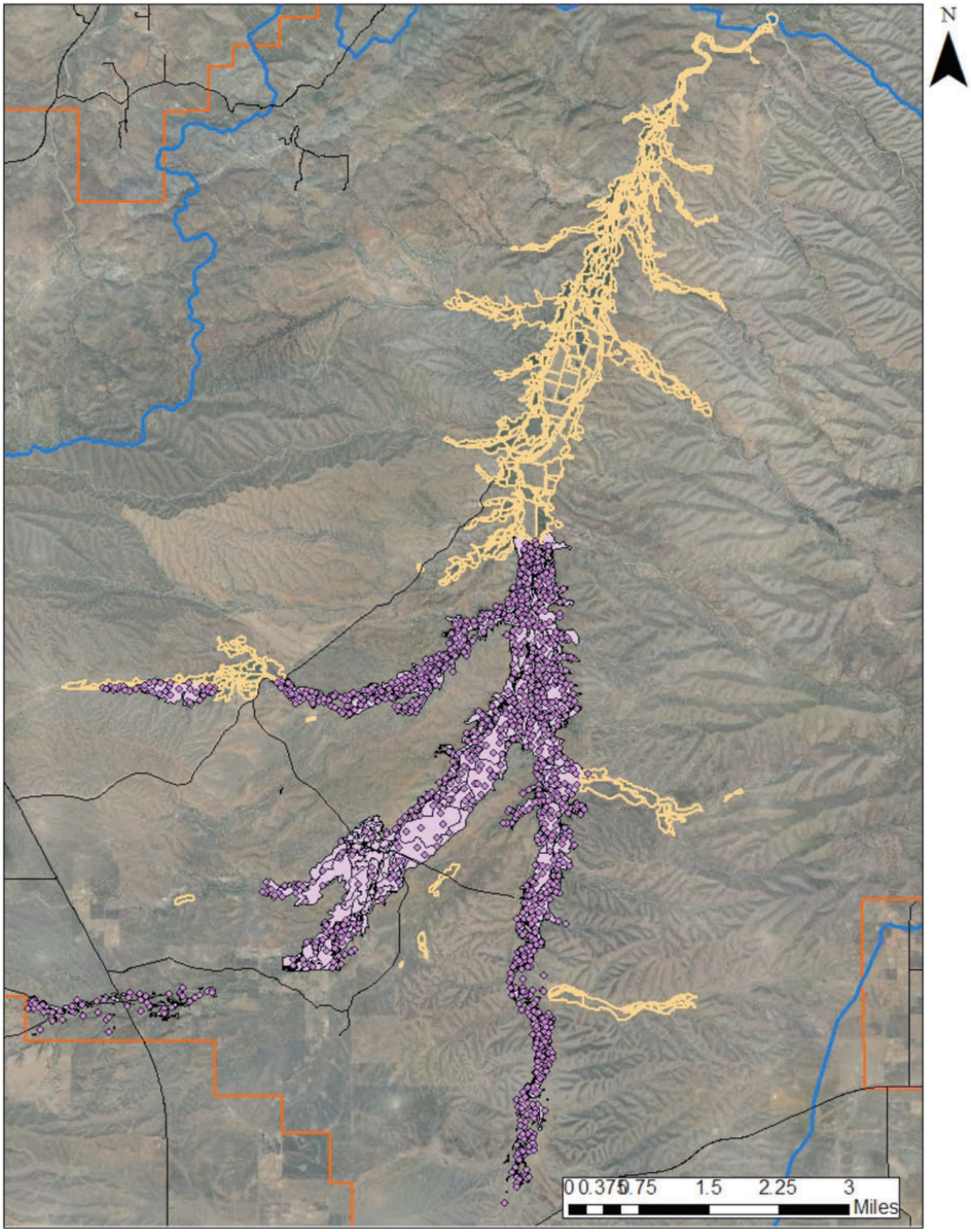

Figure 2—Field verification of extent and condition: Lavender polygons represent areas field-verified and classified according to ecological condition as of September 2011. Purple dots illustrate point locations where field notes were recorded and voucher photographs of features and ecological condition were taken. This field work covered 3,732 acres of alluvial habitats in 560 polygons.

points, snapped voucher photographs, and assigned state categories based on visual estimates of the following: sacaton grass cover (both *Sporobolus* species were treated as equals), woody plant cover (mesquite and other species), evidence of erosion, and mechanisms affecting change (e.g., fire/drought, gully erosion, agricultural conversion) (table 2). Ecological condition categories corresponded to states initially described in the NRCS Loamy Bottom Rangeland State-and-Transition (S&T) models (rangeland: R041XC312AZ and (forestland: F041XC310AZ). However, to more accurately reflect what we found on the ground, we concluded it would be necessary to refine this model by splitting certain states into phases or sub-states to reflect different site potential, likely transitional pathways, and need for more specific prospective management strategies (fig. 3).

Results

Reviewing aerial imagery and soil data yielded 6,563 acres of alluvial ecological sites with potential sacaton or mesquite bosque communities. We field verified 3,874 acre of this digitized area (figs. 2 and 4). Of the area found to be sacaton rangeland, 72 percent had previously been mapped as Loamy Bottom rangeland, 3 percent Loamy Bottom forestland, 5 percent as Loamy Swale, and 8 percent as Sandy Wash (R041XC316AZ). The remaining areas consisted of upland soils (7 percent) and Sandy Bottom (5 percent; cottonwood-willow forest; F041XC317AZ).

The more straightforward areas to delineate were core alluvial habitats where sacaton or mesquite communities traversed floodplains from side to side. The more difficult boundaries to outline were those at the upper limits of sacaton distribution along the main stem of Cienega Creek and its tributaries. In these areas, sacaton grassland generally transitioned to *Bouteloua gracilis* (blue grama) or P*leuraphis mutica* (tobosa grass) grasslands in areas with finer surface soils, or to xeroriparian habitats in areas with coarser soils (alluvial fans and washes). At these outer reaches we made the greatest adjustments to the final boundaries of sacaton and mesquite bosque habitats once they were field verified.

Field surveys enabled us to classify point locations and full polygons into states as shown in figure 5. Sample photographs are included in figure 6. USDA, NRCS =S&T models were helpful for assigning states to rangelands/forestlands, but not all of our observed areas fell within

Table 2—Combined Loamy Bottom Ecological Sites (rangeland and forestland), 12-16 inch precipitation zone, in tabular format for quick field reference. Letters represent original models' states; numbers represent revised model's sub-state distinctions. An asterisk (*) denotes naming convention differs from Mesquite-Sacaton state described in Loamy Bottom rangeland S&T model.

	Rangeland							Forestland			
State	Sacaton Grassland (HCPC)	Sacaton Grassland	*Sacaton-Mesquite	Exotics	Eroded Sacaton	Annuals	Eroded Mesquite	Mesquite Bosque-native annuals (HCPC)	Mesquite Bosque - exotic annuals	Mesquite Thornscrub	Mesquite Scrubland
Original state	A	B	C	D	E	F	G	H	I	J	K
Refined sub-state		B1,B2,B3	C1,C2		E1,E2		[not observed]				
	Canopy cover (%)							Canopy cover (%)			
Sacaton	25-80	25-65	5-40		20-50	trace					
Mesquite		1-15	5-20	0-15			20-80	25-65; large	20-80; large	5-20; shrubby	5-20; shrubby
Other shrubs, succulents			yes			0-10	0-10	0-5		5-15	5-15
Exotics (johnsongrass, bermuda)				yes							
Annuals	0-20					yes			yes; dominate	yes; fluctuate	yes; fluctuate
Gully erosion					severe		severe	yes	yes	yes	yes
Flooding					reduced	reduced	no flooding	no flooding	no flooding	no flooding	no flooding
Water table (ft)	<20	<20	<20	<20	>20	>20	25-50	25-50	25-50	25-50	>60
Causal Mechanisms			lack of fire	plowing, cultivation, burning low SM	gully erosion	plowing, cultivation, burning low SM				clearing, cultivation	lowered water table

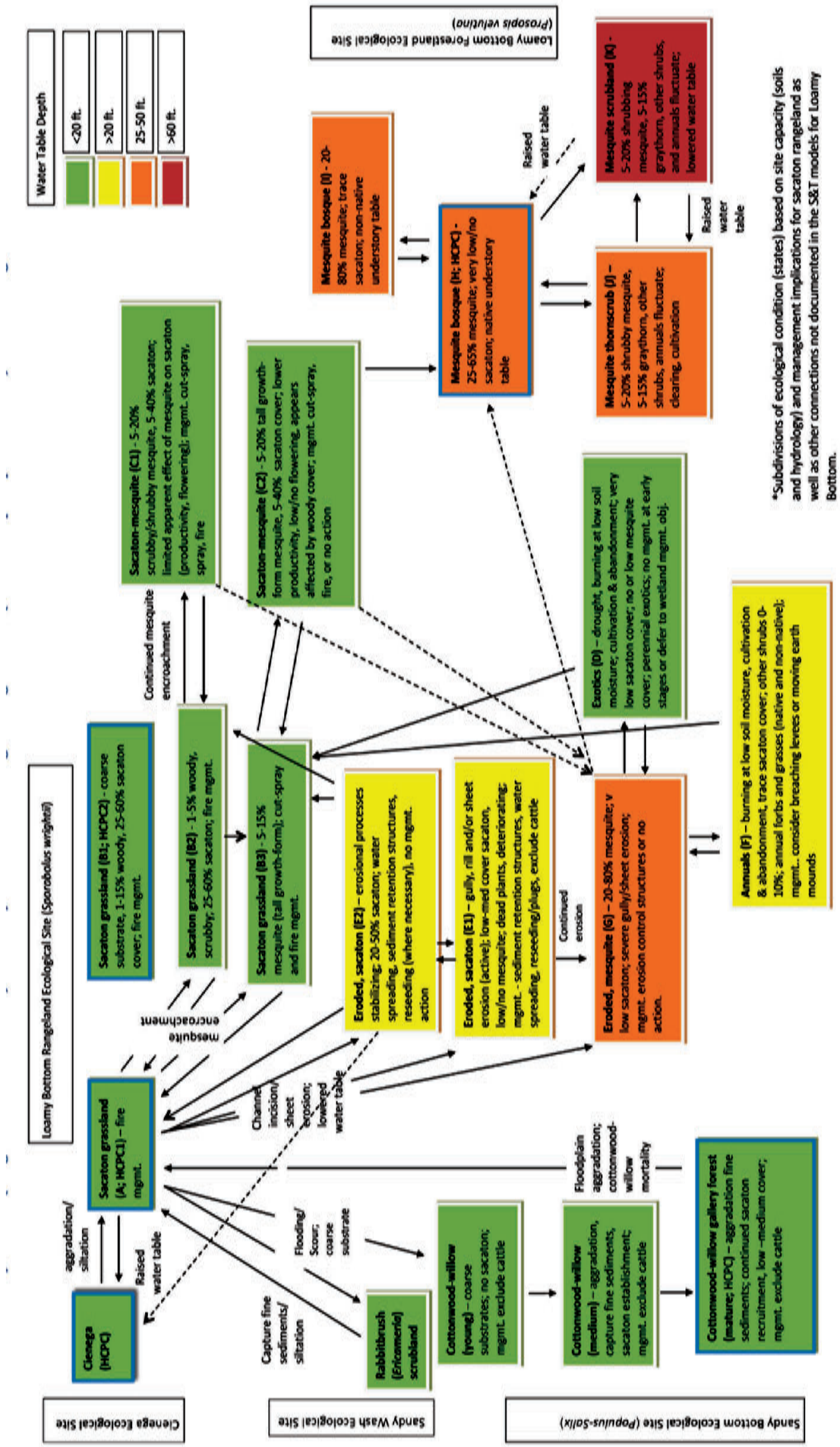

Figure 3—Modified State-and-Transition model for MLRA 41-3 Loamy Bottom Rangeland and Forestland, Cienega, Sandy Wash, and Sandy Bottom Ecological Sites (12-16 inch precipitation zone) based on observations at Las Cienegas National Conservation Area. Our subdivisions of NRCS's states are based on site capacity (soils and hydrology), divergent ecological dynamics, and on management implications for sacaton rangeland. This model also documents several connections among alluvial ecological sites, with transition pathways that are not well illustrated in the NRCS S&T models for Loamy Bottom. Note, for example, the transitional pathways that can transform a sacaton grassland into a mesquite bosque, both of which are highly prized by land managers and wildlife alike.

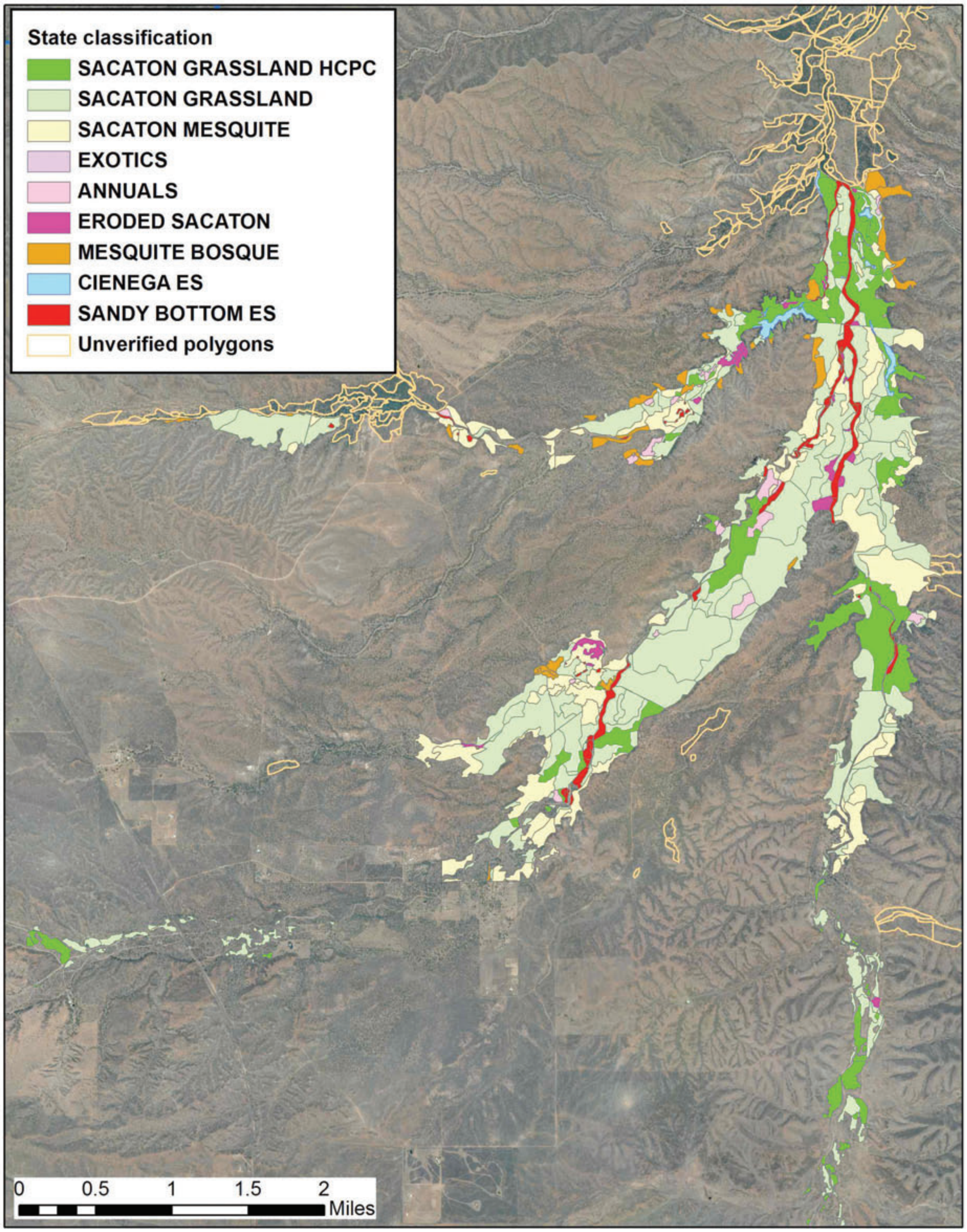

Figure 4—Ecological state map showing condition of sacaton stands (green through pink polygons) , plus extent of related riparian communities (orange, blue and red polygons with mesquite bosque, cienega, and cottonwood-willow forest respectively). Bright green represents highly productive, open sacaton stands in the condition closest to what is considered the "historic climax plant community " (HCPC).

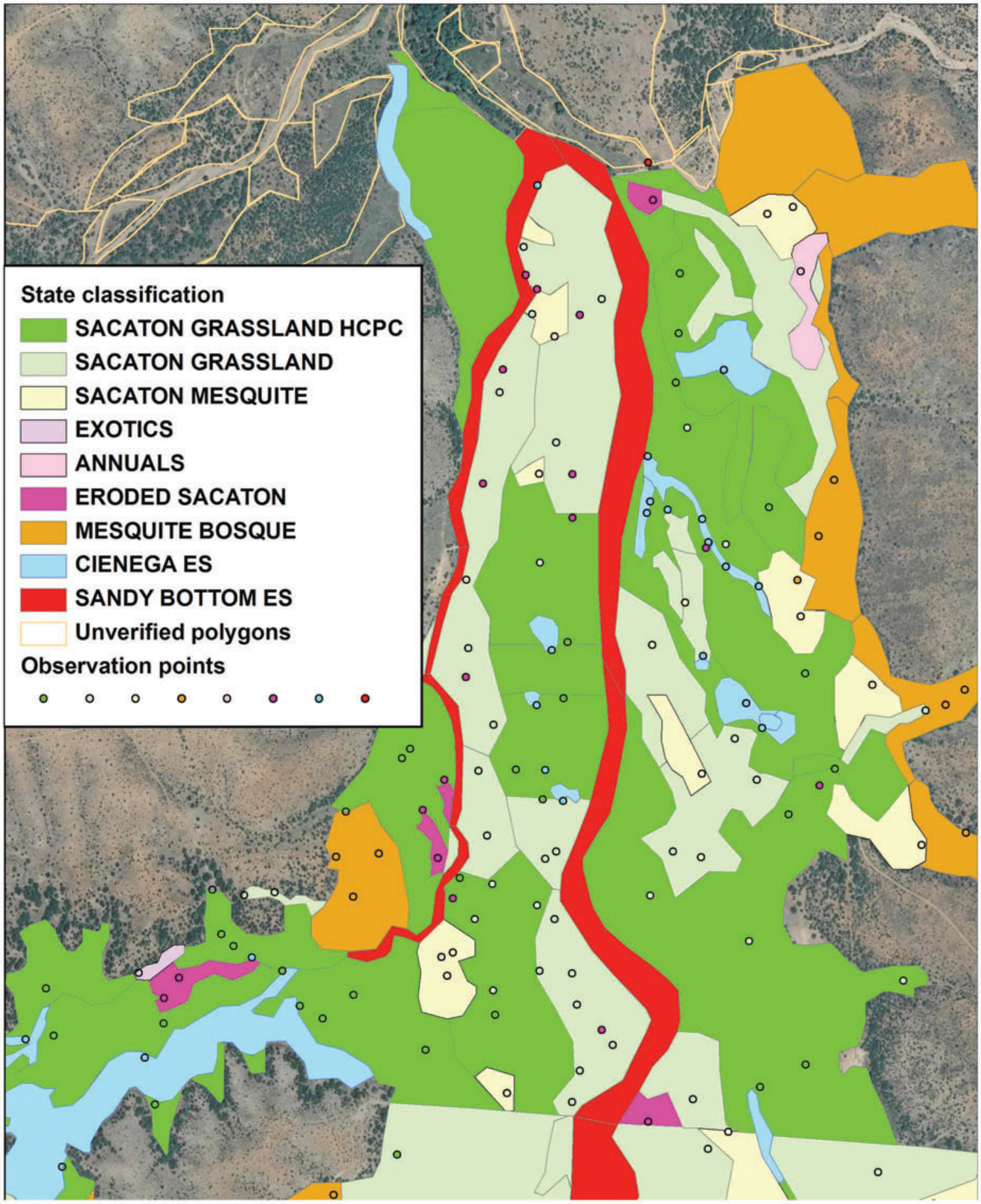

Figure 5A—Ecological state map, close up. Condition classifications (solid color polygons) for an example area that covers 272 floodplain acres and shows most of the ecological states described in the NRCS State-and-Transition models for Loamy Bottom sites. Inclusions of Cienega and Sandy Bottom (cottonwood-willow forest) Ecological Sites occur here. Small circles are observation points from which polygons' ecological states were assigned and voucher photographs were taken; some identify point features, e.g. eroding gullies, that occur within other polygons.

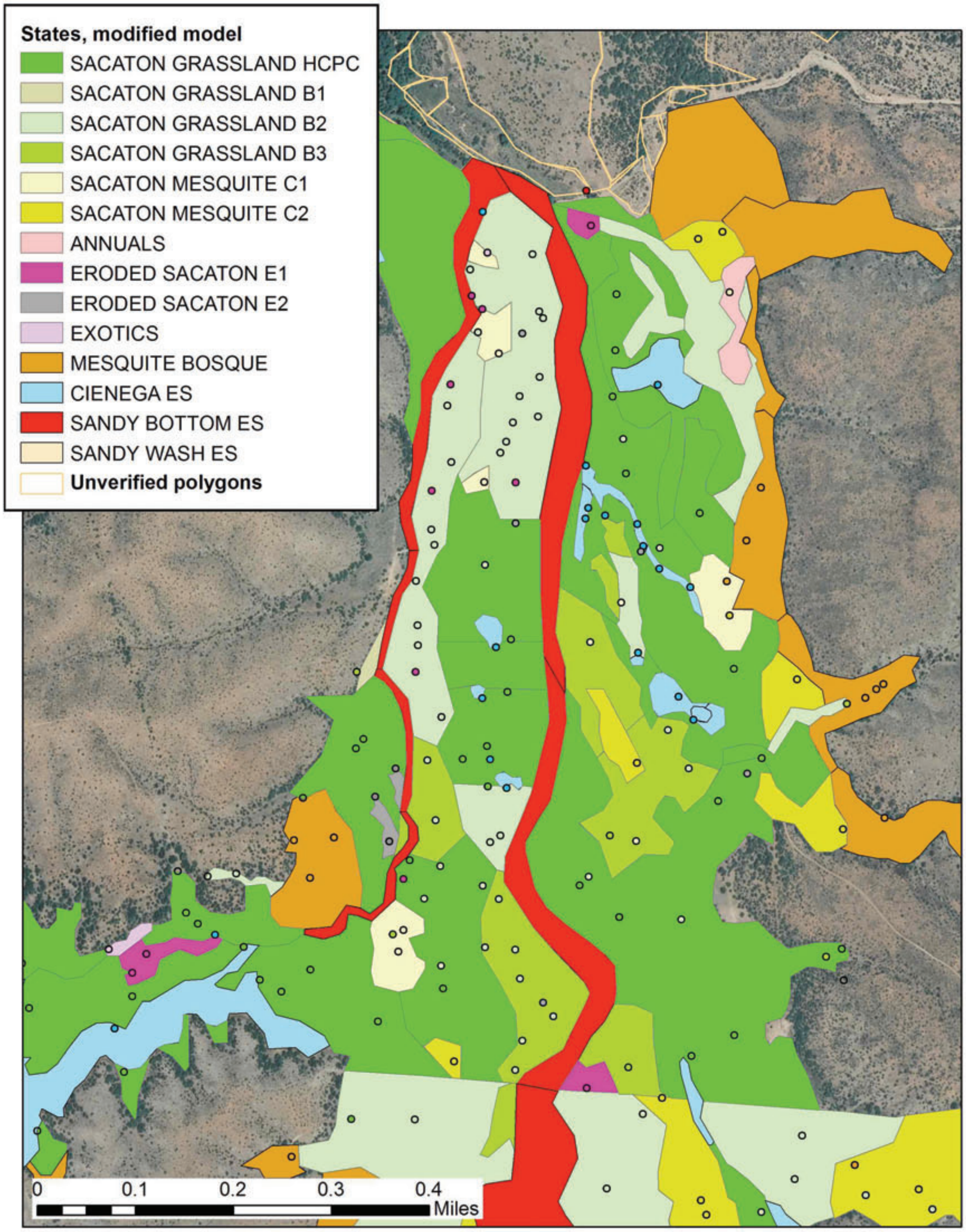

Figure 5B—Ecological state map using the modified model described in Figure 3. This classification shows finer distinctions in condition than are found among NRCS model states. Some model modifications call out distinctions that may be especially useful to managers, e.g. between actively eroding state E1 that may require restoration interventions versus stabilized erosion E2 that is healing on its own. Others reflect different dynamics observed in the field, e.g. sacaton-mesquite C1 with shrub form mesquite encroachment versus tree form mesquite in C2 on a more obvious trajectory towards mesquite bosque.

Figure 6—Example photographs of ecological conditions of Loamy Bottom ecological sites (rangeland and forestland) encountered in the upper Cienega watershed. Text conforms to Ecological Site descriptions; class letter assignments are those of authors.

Sacaton Grassland (Historic Climax Plant Community; state A): 25-80% sacaton ground over, 0-20% annuals, <20 feet depth to water table.

Sacaton Grassland (state B): 25-60% sacaton ground cover, 1-15% mesquite, <20 ft depth to water table.

Sacaton-Mesquite (state C): 5-40% sacaton ground cover, 5-20% mesquite, other shrubs and succulents, <20 ft depth to water table. This state known as Mesquite-Sacaton in Loamy Bottom S&T model.

Exotics (state 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 (state E): 20-50% sacaton ground cover, no mesquite, exotic grasses present, gully erosion, >20 ft depth to water table.

Annuals-Sacaton Grassland (state F): Trace sacaton cover, no mesquite, 0-10%other shrubs and succulents, annuals present, >20 ft depth to water table.

Mesquite Bosque, native annuals (Historic Climax Plant Community; state H): no sacaton, 25-65% large mesquite, 0-5% other shrubs and succulents, 25-50 ft to water table.

existing conditions. Blending and refining models for rangeland and forestland sites and adding our observations of sub-states and linkages between them produced an alternate model (fig. 3) we believe more accurately represents what we mapped across Las Cienegas NCA. We offer management suggestions for Loamy Bottom Rangelands by state based on the revised S&T model, expertise of the authors, and supporting literature.

Sacaton Grasslands (states A, B1, B2, and B3) occupy about 2,156 acres here. While distributed along the length of the creek, these stands rarely occupy the entire length or width of a broad alluvial setting. Sacaton stands are not as homogeneous as anticipated; a mosaic of other conditions occurs around states A, B1 and B2, including Sacaton-Mesquite and Mesquite Bosque (see states below). Cienega and Sandy Bottom Ecological Sites also are found within and around this mosaic. The S&T model and additional research results suggest that Sacaton Grassland states A, B1, and-B2 primarily require low-intensity management designed to maintain high grass cover and low shrub cover. Fire arguably has the greatest value for managing big sacaton and alkali sacaton ranges (Britton and Wright 1983; Wright and Bailey 1982) provided that frequency, extent, and seasonality of fire occurrence are considered for their overall health. Grazing management may affect how sacaton plants respond to other disturbances, with implications for the health of the grass stand. For maximum forage production, Cox and others (1989) recommend grazing big sacaton in the spring, not grazing in dry summers and dry years, and discontinuing fall grazing. The combination of fire and grazing produces very different effects compared to that of either activity alone (Vogl 1974).

Sacaton patches with moderate cover and appreciable woody plant encroachment are evident in three states. Sacaton Grassland (state B3) occurs with low-medium cover of tall mesquite (>12 ft. tall) and vigorously growing sacaton with moderate cover. Sacaton-Mesquite conditions C1 and C2 are also evident (see below for C2). State C1 occurs with low-medium cover of shrubby mesquite (<12 ft. tall) with low-medium cover of less vigorous sacaton. In condition B3, sacaton appeared to co-exist with mesquite while in condition C1 the grass appeared to be in decline. Both states would benefit from management aimed at reducing woody cover with minimal soil disturbance. While mechanical grubbing is not recommended (Robinett personal communication, 2011), studies show that woody plant control with herbicides can significantly increase grass and forb production. Targeted applications to individual woody plants are best and might be useful in integrated brush management programs followed with fire.

Sacaton-Mesquite (state C2; known as Mesquite-Sacaton in Loamy Bottom S&T model) stands with tree-form mesquite (>12 ft. tall) appear to be in transition towards Mesquite Bosque (State H). This transitional pathway represents an important contribution of this study since it is not articulated in existing Ecological Site Descriptions (ESD) and their respective models for Loamy Bottoms. Our observations suggest that a site-by-site evaluation would need to be made on whether to control mesquite in these areas or allow them to transition to bosque, a desirable and rare plant community in its own right.

Eroded Sacaton Grassland is evident in two phases at this site: actively eroding (E1) and healing/healed (E2). In this watershed, State E1 appears as patches throughout the alluvial landscape, in areas of headcuts and gullies or sheet erosion. Management actions might focus on arresting and/or repairing erosion, for example, treating headcuts that threaten to dewater high quality sacaton grasslands. Treatments may include a combination of methods (e.g., Zuni bowls, one-rock dams, and media lunas; Zeedyk and Clothier 2009). Sheet erosion areas vary from about one to several acre patches in size interspersed within grasslands (A-B2) and sacaton-mesquite (B3-C2) in the floodplains of Gardner Canyon and Empire Creek. Installation of controls to slow overland flow and capture sediment may be recommended management actions. Additional measures may include reseeding and/or re-vegetation with sacaton, or possibly with other native grass species. Select areas might be rested from grazing to enable re-establishment of plant cover on bare soils.

Eroded sacaton (state E2) occurs as healed or healing gullies or sheet erosion. We observed areas of former cutbanks with peeled back walls well-vegetated with sacaton or occasional wetland plants. In other places, we saw areas healing from sheet erosion where all but the original sparsely vegetated shallow cutbank was visible. Since state E2 is healing or healed of its own devices, we suggest no management actions.

Exotic perennials (state D) occur as small patches within states A and B. Johnsongrass (*Sorghum halepense*) is the most often observed exotic perennial grass, rarely occupying more than an acre at this site. Johnsongrass and bermudagrass (*Cynodon dactylon*) are most often associated here with cienega wetlands or along stream channels and gravel bars of Sandy Bottom ecological sites. At present, these grasses do not appear to threaten overall sacaton grassland condition since they appear to be more or less confined to wetland and near stream sites.

Annuals (state F) is largely restricted to abandoned agricultural fields. These fields are partially recolonized by sacaton, but more so by mesquite. Small-scale earth-moving might serve to promote recovery of sacaton and expansion of extant cienega. Presently, surface water from a cienega is precluded from reoccupying the southern portion of the fields by short levees (3-5 ft.) that could be breached. Monitoring the rate and direction of sacaton and woody plant encroachment onto these fields is a viable, low budget option for tracking the recovery of the fields with or without modifications to the levee or canal system.

Mesquite Bosque comprises state H. Most Mesquite Bosque found along Cienega Creek includes big sacaton plants as an understory component. Mesquite bosques support several trophic levels and great varieties of invertebrates, birds, bats and other animals because of the abundance and nutritional quality of food and high structural diversity. Considering wildlife values and Resource Management Plan directives for Las Cienegas NCA to protect and maintain mesquite bosque, the best management strategy may be to leave these woodlands alone regardless of how they came to be formed. Present day environmental conditions clearly favor mesquite bosque over sacaton grassland in some areas above, and most areas below, 4,300 ft. elevation.

Discussion

We produced an extensive GIS database for referencing our map of on-site sacaton grassland conditions and their distribution. Sacaton grassland is present on over 2,100 acres, supporting the contention that some of the finer examples in southeast Arizona occur in this drainage. This acreage includes pure sacaton flats with those experiencing the early-to mid-stages of mesquite encroachment. With little over half of the verified alluvial areas found to be in the most productive states (A-B2) of Sacaton Grassland, our observations speak to the timeliness of the BLMs request for information on the baseline condition of sacaton communities and its desire to guide management.

Sacaton communities are restricted to low gradient, alluvial environments yet, not entirely confined to what had been mapped as Loamy Bottom ecological site. We observed appreciable sacaton stands (states A-C1) in areas mapped as Loamy Swale and Sandy Bottom Wash Ecological Sites. Possibilities as to why this may be include: precision of ecological site mapping in the mid-1990s was coarse enough that some sacaton grassland communities plot in Loamy Swale or Sandy Wash ecological sites; and, broad areas mapped as Loamy Swale and Sandy Wash are actually transitional between these ecological sites and Loamy Bottom.

Alkali sacaton (*S. airoides*) commonly occurs in states A-B3 of upper Cienega Creek watershed; it is even the dominant perennial grass in some areas. Cox (1984, 1985) reports that *S. wrightii* occurs on moderately alkaline and slightly calcareous soils, and is usually replaced by *S. airoides* in areas with very alkaline or saline soils. Since the S&T model for Loamy Bottom specifically addresses *S. wrightii* with *S. airoides* playing only a supporting role (Robinett 2005a), it is possible that some of the area previously mapped as Loamy Bottom is actually Saline Bottom (Womack 2005) or a combination of the two. Our field verifications did not include digging soil pits to validate Ecological Site classification at point locations, but we recognize this is a valuable effort when feasible.

The dynamics of change within sacaton grasslands, and the factors driving these changes, deserve additional validation and research. Field observations and review of the literature for this project suggested transitional pathways between sacaton grasslands and other riparian vegetation communities. These are addressed more fully elsewhere (Tiller and others 2012). Sacaton Grassland and Mesquite Bosque states transition between each other along successional trajectories. One or more linkages might be made between rangeland and forestland ecological sites, allowing them to flow fluidly between one another.

The vast majority of mesquite bosque stands of the upper Cienega Creek watershed include big sacaton plants as an understory component, suggesting that these woodland communities may be a product of recent environmental change (i.e., past 130 years; Bryan 1928). Sacaton growing in the understory of these woodlands is most likely a remnant of a former grassland condition and may persist in part where water tables remain high (Lacey and others 1975). Mesquite Bosque with 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 also may be recent in occurrence since above 4,300 ft. elevation they are not visible in the earliest aerial photography captured in the mid-1930s.

As the field survey and data refinement phases of this project matured, modifications to improve efficiency in the future became apparent. Creating dropdown menus for field recordings using a suite of site descriptors would increase the consistency and reduce post-processing time by integrating field data directly into a GIS database. Future efforts with limited time for field visits might be best served by reducing field time spent classifying transitional areas and use aerial imagery to emphasize work in larger areas of specific interest.

Our case study represents a substantial contribution to the field because it provides (1) a more accurate map of what sacaton rangeland occurs and its ecological condition at this site; (2) a more inclusive model for understanding dynamics and management needs of sacaton, and related communities, across the region; and (3) refined methods for evaluating the distribution and condition of sacaton communities elsewhere. At present, the development of ESDs and S&T models is moving into a field validation phase (Dan Robinett, personal communication, 2011b). This case study has the potential to aid in the refinement of these models for use in other sacaton bottomland sites across the Sky Island region.

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References

Bahre, C.J. 1991. A legacy of change: Historic human impact on vegetation in the Arizona borderlands. The University of Arizona Press, Tucson. 231 p.

Bestelmeyer, Brandon T., Mosley, K., Shaver, P.L., Sanchez, H., Briske, D.D., Fernandez-Gimenez, M. 2010. Practical Guidance for Developing State-and-Transition Models. Rangelands. 32(6):23-30.

Briske, D. D., S. D. Fuhlendorf and F. E. Smeins. 2006. A unified framework for assessment and application of ecological thresholds. Rangeland Ecology and Management 59:225-236.

Britton, C.M. and H.A. Wright. 1983. Brush management with fire. Pages 61-68 in McDaniel, K.C., ed. Proceedings: brush management symposium; 1983 February 16; Albuquerque, NM. Society for Range Management, Denver, CO.

Brown, D.E., C.H. Lowe, and C.P. Pase. 1979. A digitized classification system for the Biotic communities of North America, with community (series) and associated examples for the Southwest. Journal of the Arizona-Nevada Academy of Science 14: 1-16.

Brown, D.E. 1982. Biotic communities of the American Southwest-United States and Mexico. Desert Plants 4:1-342.

Bryan, K. 1928. Change in plant association by change in ground water level. Ecology 9(4):474-478.

Cooke, R. U. and R. W. Reeves. 1976. Arroyos and environmental change in the American southwest. Oxford: Clarendon Press.

Cox, J.R. 1984. Shoot production and biomass transfer of big sacaton (*Sporobolus wrightii*). Journal of Range Management 37(4):377-380.

Cox, J.R. 1985. Above-ground biomass and nitrogen quantities in a big sacaton (*Sporobolus wrightii*) grassland. Journal of Range Management 38:273-276.

Cox, J.R. 1988. Seasonal burning and mowing impacts on *Sporobolus wrightii* grasslands. Journal of Range Management 41(1):12-15.

Cox, J.R., R.L. Gillen, and G.B. Ruyle. 1989. Big sacaton riparian grassland management: seasonal grazing effects on plant and animal production. Applied Agricultural Research 4(2):127-134.

Cox, J.R., H.L. Morton, J.T. LaBaume, and K.G. Renard. 1983. Reviving Arizona's rangelands. Journal of Soil and Water Conservation 38:342-345.

Fonseca, J. 2000. Map Guide: Sacaton Grasslands Special Element. Sonoran Desert Conservation Plan.

Gori, D.F., and C.A.F. Enquist. 2003. An a ssessment of the spatial extent and condition of grasslands in central and southern Arizona, Southwestern New Mexico and Northern Mexico.

Halvorson, W. L., K. Thomas, L. Graham, M R. Kunzmann, P. Bennett, C. Van Riper, C. Drost. 2002. The Arizona Gap Analysis Project final report. USGS Sonoran Desert Field Station, University of Arizona. Research Performed Under: Cooperative Agreement No.14-45-0009- 1580, 14-45-0009-1054, No.14-45-0009-94-1069, KR9-1165-CIV, and Arizona Collections Agreement HAB 96-117.

Harris, L.K., J.A. Wennerlund, and R.B. Duncan. 2000. Riparian vegetation mapping and classification, Sonoran Desert Conservation Plan. Pima County Government, Tucson, AZ. Contract #07-30-H-127196-0100. 56 pp.

Humphrey, R. R. 1958. The desert grassland: a history of vegetational change and an analysis of causes. Botanical Review 24: 193-253.

Humphrey, R. R. 1960. Forage production on Arizona ranges: V. Pima, Pinal and Santa Cruz Counties. University of Arizona Agricultural Experiment Station Bulletin 302:1-x.

Kubly, D.M., R.A. Winstead, L.J. Allison, C.R. Wahl, S.R. Boe, and J.A. Wennerlund (editors). 1997. Statewide riparian inventory and mapping project (executive summary). Nongame Technical Report 111 & 112. Arizona Game and Fish Department, Phoenix, AZ.

Lacey, J. R., P. R. Ogden, and K. E. Foster. 1975. Southern Arizona Riparian Habitat: Spatial Distribution and Analysis. University of Arizona Office of Arid Lands Bulletin 8:1-148.

Robinett, D. 2005a. Ecological site description for Site ID: R041XA312AZ, *Sporobolus wrightii* (big sacaton), Loamy Bottom, 12-16 inch precipitation zone, Major Land Resource Area 041 - Southeastern Arizona Basin and Range. U.S. Department of Agriculture, Natural Resources Conservation Service. Online: http://esis.sc.egov.usda.gov/esis_report/fsReport.aspx?id= R041XC312AZ [Accessed 10-2011].

Robinett, D. 2005b. Ecological site description for Site ID: F041XC310AZ, *Prosopis velutina - Prosopis glandulosa* var. *torreyana* / / *Sporobolus wrightii* (velvet mesquite - western honey mesquite / / big sacaton), Loamy Bottom 12-16 inch precipitation zone, Major Land Resource Area 041 - Southeastern Arizona Basin and Range. U.S. Department of Agriculture, Natural Resources Conservation Service. Online: http://esis.sc.egov.usda.gov/esis_report/fsReport.aspx?id= R041XC310AZ [Accessed 10-2011].

Robinett, D. 2011a. [Personal communication]. Verbal communication with Ron Tiller. D. Robinett is retired, USDA National Resources Conservation Service, Tucson, AZ.

Robinett, D. 2011b. [Personal communication]. Letter to Ron Tiller, December 11, 2011. On file at: The Nature Conservancy, Tucson, AZ.

Stromberg, J.C. 1993. Element Stewardship Abstract: Sacaton Grasslands. Tucson, AZ: The Arizona Chapter of the Nature Conservancy.

Tiller, R.; Hughes, M.; Bodner, G. 2012. Sacaton riparian grasslands: Using state-and-transition models to map distribution and ecological condition in the upper Cienega Creek Watershed. Tucson, AZ: The Arizona Chapter of the Nature Conservancy.

U.S. Department of Agriculture, Natural Resources Conservation Service. 2008. Soil Survey Geographic (SSURGO) database for Santa Cruz and Parts of Cochise and Pima Counties, Arizona (AZ667). Fort Worth, Texas.

U.S. Department of Agriculture, Natural Resources Conservation Service. 2005. Ecological Site Inventory System (ESIS). Major Land Resource Area 41-3. Online: http://esis.sc.egov.usda.gov.

U.S. Department of Interior, Bureau of Land Management (BLM). 2003. Approved Las Cienegas resource management plan and record of decision. Arizona State Office and Tucson Field Office.

U.S. Department of the Interior, Fish and Wildlife Service (USFWS). 2002. Biological and conference opinion summary, effects of the proposed Las Cienegas National Conservation Area Resource Management Plan in Pima and Santa Cruz counties, Arizona; October 4, 2002. Phoenix, AZ: U.S. Department of the Interior, U.S. Fish and Wildlife Service.

U.S. Geological Survey (USGS) and U.S. National Park Service (NPS). 2000. Vegetation Mapping Program. Online: http://biology.usgs.gov/npsveg/. [Accessed Dec. 2007].

Vogl, R.J. 1974. Effects of fire on grassland. In: Kozlowski, T.T.; Ahlgren, C.E., (eds.). Fire and ecosystems. New York: Academic Press: 139-194.

Womack, D. 2005. Ecological site description for Site ID: F041XC315AZ, alkali sacaton - inland saltgrass (*Sporobolus airoides - Distichlis spicata*), Saline Bottom 12-16 inch precipitation zone, Major Land Resource Area 041 - Southeastern Arizona Basin and Range. U.S. Department of Agriculture, Natural Resources Conservation Service. Online: http://esis.sc.egov.usda.gov/esis_report/fsReport.aspx?id= R041XC315AZ [Accessed 10-2011].

Wright, H.A.; Bailey, A.W. 1982. Fire ecology: United States and southern Canada. New York: John Wiley & Sons. 501 p.

Zeedyk, B.; Clothier, V. 2009. Let the water do the work: Induced meandering, an evolving method for restoring incised channels. Washington, DC: Island Press. 240 p.