Sustaining the Grassland Sea: Regional Perspectives on Identifying, Protecting and Restoring the Sky Island Region's Most Intact Grassland Valley Landscapes

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Abstract—*Grasslands of the Sky Islands region once covered over 13 million acres in southeastern Arizona and adjacent portions of New Mexico, Sonora, and Chihuahua. Attempts to evaluate current ecological conditions suggest that approximately two thirds of these remain as intact or restorable grassland habitat. These grasslands provide watershed services such as flood control and aquifer recharge across the region, and continue to support dozens of species of concern. Prioritizing conservation interventions for these remaining grassland blocks has been challenging. Reliable data on condition and conservation value of grasslands in the region have not been systematically summarized. State and national boundaries further complicate efforts to identify where the best remaining habitats and populations of grassland obligate species still exist. We present results of an effort to merge grassland condition assessments, compile information on target species locations, and identify "priority grassland valley landscapes" across the region. We evaluate these priority landscapes in terms of the number of target species, critical threats, and enabling conditions for long-term conservation success such as activity by local cooperative groups dedicated to sustaining their landscapes. Lastly, we discuss the opportunities and challenges of designing and implementing effective restoration activities in these large multi-jurisdictional landscapes.*

Introduction

The grasslands of central and southern Arizona, southern New Mexico, and northern Mexico, referred to here as Sky Island grasslands, form the "grassland seas" that surround small forested mountain ranges, transitioning into desert scrublands as elevations drop, or into foothill woodlands or chaparral as elevations rise. At the continental scale, Sky Island grasslands form a unique setting where the large blocks of Great Plains and Chihuahuan Desert grasslands east of the Rockies and Sierra Madre Mountains spill over a low spot in the Continental Divide. This ecotone geography and the ecological gradients associated with "Sky Island mountains and grassland seas" add tremendous floral and faunal diversity to the region as a whole (McClaran and Van Devender 1997). Grassland valley landscapes here are often recognized as distinct and important places by their respective human communities, who self-organize to varying degrees in order to benefit from and protect the ecological and economic values of these places.

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.

Sky Island grasslands have undergone dramatic vegetation changes over the last 130 years including encroachment by shrubs and trees, loss of perennial grass cover and spread of non-native species (Humphrey 1987; Bahre 1991). The causes for these vegetation changes have been the subject of debate and range from changes in regional climate to human impacts including poorly managed livestock grazing and suppression of wildfires (Humphrey 1958; Buffington and Herbel 1965; Hastings and Turner 1965; Cable 1967; Wright 1980; Bahre 1985, 1995; Swetnam 1990; Brown and others 1997; McPherson and Weltzin 2000).

Changes in grassland composition and structure have not occurred uniformly across the borderland region, nor are they solely the consequence of past climatic events or human impacts but are ongoing today (Archer 1989; Bahre 1991; Brown and others 1997; Ceballos and others 2010). These changes, combined with increased fragmentation due to exurban development and agricultural conversion, have caused significant declines in grassland species, especially wide-ranging ones.

Although the above studies, as well as others, have documented change to grasslands locally, there have been only a few attempts to characterize the extent of change or assess current grassland condition of borderland grasslands at broader scales (Cox and Ruyle 1986; Enquist and Gori 2008; Yanoff and others 2008).

In 2009, The National Fish and Wildlife Foundation (NFWF) launched its Sky Island Grassland Initiative, a 10-year plan to protect and restore grasslands and embedded wetland and riparian habitats in the Sky Island region (fig. 1). The Initiative emphasizes grassland restoration, protecting threatened land and water, and restoring

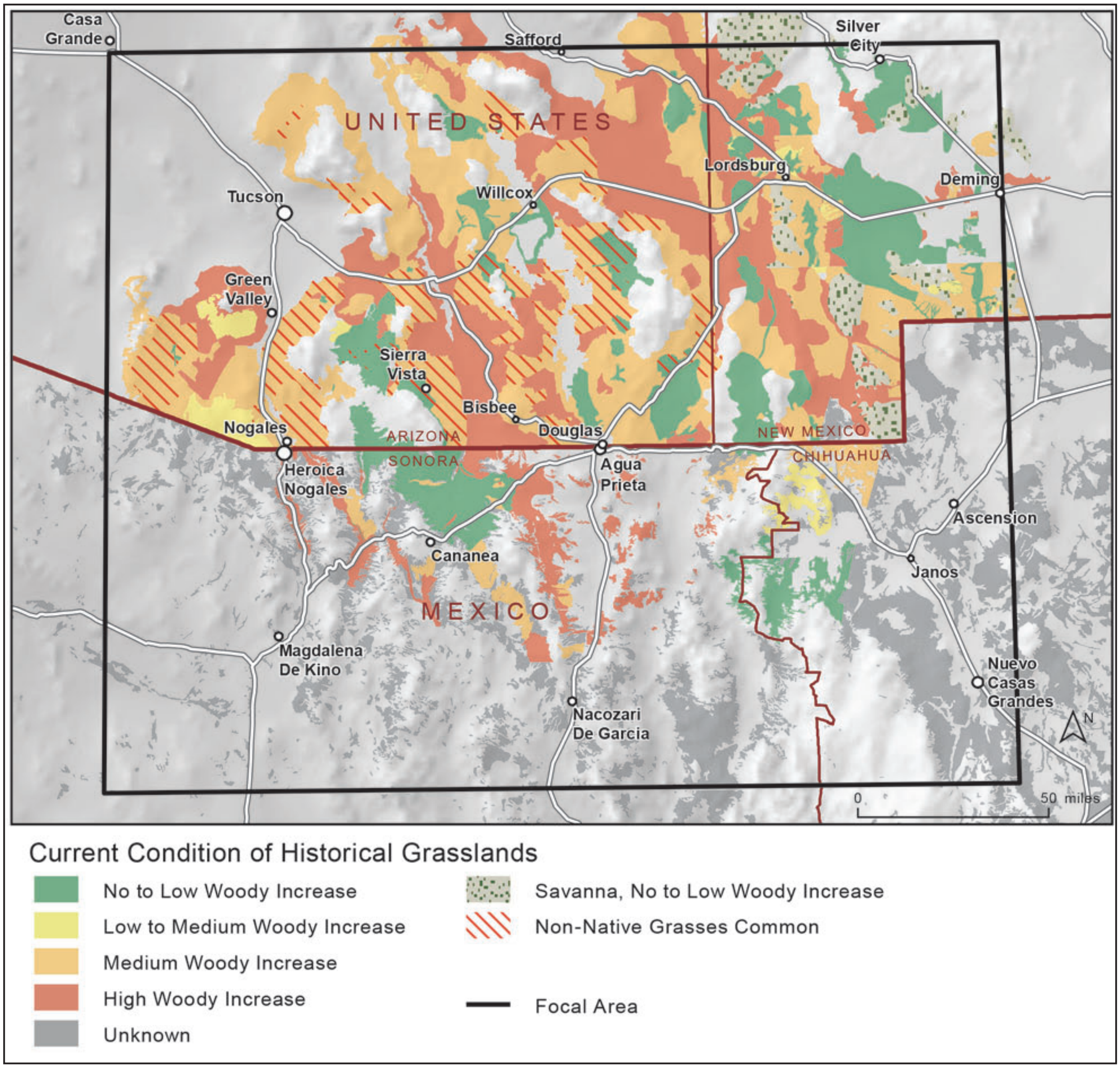

Figure 1—Current condition of Grasslands in the Sky Island focal area.

populations of target wildlife species (NFWF 2009). The Foundation anticipates investing millions of dollars to achieve these goals and expects to leverage additional millions in federal, state and private funds. The question is: where will this investment yield the greatest returns in terms of restoring grassland health and recovering wildlife species across the region?

This report attempts to answer this question at a regional scale by integrating two recent spatial assessments of the historical extent and current condition of Sky Island grasslands and savannas as well as compiling information on the occurrence of grassland-dependent wildlife and species of concern. Using this information and an expert-based approach, we identify 12 priority landscapes where the potential for restoring grasslands and recovering target species have the greatest probability of success. We identify and evaluate these priority landscapes based on their size, condition, landscape context, number of target species and natural communities, and human enabling conditions for long-term conservation success. The latter factor includes the existence of partnerships, such as local cooperative groups dedicated to sustaining their landscape; land protection efforts; and ongoing ecological restoration and management.

Methods

Mapping Grassland Condition

Two recent assessments of historical grassland extent and current condition form the basis of this Sky Island Grassland Assessment and cover most of the historical and remaining grasslands and savannas in the Sky Island region: the Apache Highland Grassland Assessment (AHGA; Gori and Enquist 2003) and the New Mexico Rangeland Ecological Assessment (REA; Yanoff and others 2008). The AHGA defined a series of grassland condition classes using expert opinion and the peer-reviewed literature to define threshold values for shrub cover. Mapping of these condition classes was done by 24 range management specialists from federal and state agencies, academic institutions and non-governmental organizations for the U.S. and a combination of experts and LANDSAT satellite imagery analysis for Mexico. Mapping was at approximately 1:100,000 to 1:250,000 scale. AHGA condition classes were defined by percent woody plant cover, compared to historical condition, and whether the grass species were native, non-native, upland or riparian (table 1). The AHGA considered fire to be a major natural disturbance that controlled woody plants and maintained grass dominance historically. The AHGA included a comprehensive accuracy assessment using 234 field sampling points in the U.S. portion of the Apache Highlands ecoregion. The overall accuracy rate of the final map was greater than 77%.

The New Mexico Rangeland Ecological Assessment (REA) was limited to southern New Mexico and includes the northeastern portion of the Sky Islands project area. Mapping was completed by 70 experts at approximately 1:23,000-1:100,000 scale. Condition classes in the REA are vegetation states in the state-and-transition models that accompany Natural Resources Conservation Service's ecological site descriptions (NRCS 2009b). REA condition classes are similar to those of the AHGA in that most altered classes reflect increases in woody plant cover over historical condition. However, REA classes are finer-scale, being associated with ecological sites, and stress *relative* rather than *quantitative* woody cover, the distribution of grasses between or under woody plants, grass composition dominated by long-lived perennial grasses versus sparse ruderal perennial or annual species, and non-vegetative indicators such as soil erosion (table 1). The REA did not map non-native grasses, as the spread of Lehmann and Boer lovegrass into southwest New Mexico was limited before 2007 (Gori and Enquist 2003; Schussman and others 2006). The REA did not include an accuracy assessment.

For this analysis, the two assessments were combined into one spatial dataset by grouping the finer-scale REA condition classes up to AHGA classes (table 1). The combined spatial data set does not identify grasslands in Mexico outside of the Apache Highlands ecoregion. To represent these grasslands, we used the Instituto Nacional de Estadística y Geografía (INEGI) land cover map that contains no information on the current condition of grasslands or on the spatial extent of former grasslands. Using the combined data set, we summarized the historical extent and current condition of grasslands and savannas across the project area (fig. 1).

Mapping Sensitive Species and Natural Communities

To assist in the identification and evaluation of Sky Island grasslands, we summarized existing information from a variety of sources on the distribution of sensitive grassland species and riparian-aquatic species that occur in wetland habitats embedded within grasslands (table 2). These species were identified as targets in NFWF's Sky Island Business Plan (NFWF 2009). In addition, we summarized occurrence information for several natural communities that have declined significantly (>90% from historical extent) over the last 100[+] years due primarily to human impacts: ciénega wetlands, sacaton riparian grasslands, and Chihuahuan black grama grasslands (Hendrickson and Minckley 1984; Humphrey 1960; Yanoff and others 2008). Occurrence records obtained from the Natural Heritage Programs in Arizona, New Mexico, and Sonora were screened to identify grassland and riparian-aquatic species. Natural Heritage data were not available for Chihuahua.

Table 1—Sky Island Grassland Assessment condition classes and the original AHGA and REA classes.

Original assessment class	Source	Sky Island assessment class
Native grassland and savanna with low woody cover [a]	AHGA	No or low woody increase, native grassland and savanna
Native grassland with or without ruderal grasses	REA	“
Native savanna with or without ruderal grasses	REA	“
Bottomland sacaton (*Sporobolus wrightii*, *S. airoides*) grassland	AHGA REA	“
Woody-invaded native grassland and savanna with medium woody cover [b]	AHGA	Medium woody increase, native grassland and savanna
Woody-invaded native grassland with or without ruderal grasses	REA	“
Woody-encroached native savanna with or REA without ruderal grasses	“	
Non-native grassland and savanna with low woody cover, where non-native perennial grasses, Lehmann and Boer lovegrass, are common or dominant [a]	AGHA	No or low woody increase, non-native grassland and savanna
Non-native grassland and savanna with medium woody cover, where non-native perennial grasses, Lehmann and Boer lovegrass, are common or dominant [b]	AHGA	Medium woody increase, non-native grassland and savanna
Former grassland and savanna with high woody cover [c]	AHGA	High woody increase, former grassland and savanna
Woody-dominated former grassland	REA	“
Woody-dominated former savanna	REA	“
Highly eroded former grassland	REA	“
Highly eroded former savanna	REA	“

[a]Woody cover < 10%
[b]Woody cover 10-35%, with cover of mesquite or juniper, *Prosopis* and *Juniperus*, <15%
[c]Woody cover >15% cover mesquite and juniper combined and/or >35% total woody cover; perennial grass cover always <3%; type conversion from grassland or savanna to shrubland.

Table 2--Spatial data collected and data sources for analysis of NFWF target and high-priority grassland and riparian-aquatic species occurrences in priority grassland landscapes.

Biological feature	Data source
Ciénega	Ciénega database and spatial layer developed by TNC-AZ based on literature, agency reports, expert knowledge and field reconnaissance
Sacaton riparian grasslands	Mapped by experts, AHGA (Gori & Enquist 2003; Enquist and Gori 2008) and REA (Yanoff and others 2008)
Black grama grasslands	Mapped by experts: historical extent and current condition on Sandy and Shallow Sandy ecological sites; REA (Yanoff and others 2008)
Black-tailed prairie dog (*Cynomys ludovicianus*) colonies	Database and spatial layer developed by TNC-AZ based on literature, agency reports & expert knowledge.
Pronghorn (*Antilocapra americana*)	Spatial layer developed by TNC-AZ & NM based on Brown and Ockenfels (2007), AZGFD (2010) and expert knowledge
Jaguar (*Panthera onca*)	Spatial layer developed by TNC-NM and AZ based on agency reports and expert knowledge
Bison (*Bison bison*)	Spatial layer developed by TNC-NM and AZ based on agency reports and expert knowledge
Mexican gartersnake (*Thamnophis eques megalops*)	Location information cited in Rosen and others (2001)
Sensitive grassland and riparian/aquatic species	Spatial information on species occurrences from Natural Heritage Programs in AZ and NM and Centro de Datos para la Conservación de Sonora; sensitive grassland and riparian-aquatic species and subspecies have global ranks of G1-G3 and T1-T3

Tapping Expert Knowledge to Delineate and Evaluate Highlight Priority Landscapes

In the process of compiling the information above, we recognized that these sources did not fully capture the collective knowledge that we knew to exist for the region. In September 2010, we assembled several experts to both expand our understanding of grasslands across the region and to explicitly delineate focal areas. Participants included: Angel Montoya, Peregrine Fund and Partners for Fish and Wildlife; Dan Robinett, NRCS retired; Miles Traphagen, Turn of The Century Monitoring Inc.; and from The Nature Conservancy: Gita Bodner, Dave Gori, Peter Warren, and Steven Yanoff, assisted by Anne Bradley and Lara Miller.

Participants were asked to map areas they viewed as particularly promising for sustaining the region's grasslands over the long term, drawing on their own knowledge and a variety of supporting information provided at the workshop. We seeded the discussion with suggested criteria for identifying, delimiting, and evaluating "priority grassland landscapes" and with polygons used in the NFWF Business Plan (NFWF 2009), but participants were free to map and describe attributes of these delineated areas as they saw fit. Suggested criteria included size of grassland blocks, ecological condition of those blocks, presence of embedded streams and wetlands and target wildlife species, fragmentation versus connectivity of grassland habitat and of native vegetation more broadly, presence of intractable threats, and existence of conservation efforts such as local community partnerships. Spatial data sets provided to participants included information on vegetation classifications, AHGA and REA grassland condition assessments, soil classifications, species occurrence locations and habitat models, land protection status, and results of various groups' efforts to identify priority conservation areas for other purposes .
Once polygons were drawn and met with group agreement, participants were asked to fill out a matrix of conservation value and feasibility for each. Criteria evaluated included many of the same ones used to inform the drawing of the polygons, but this exercise required participants to rate criteria for each site as low, medium, or high and, where necessary, explain those ratings. This was done as a group effort, with discussion of rankings along the way. Filling out the matrix together also spawned discussions about the characteristics of each grassland landscape, and about additional sources of information about distributions of target species and communities.

Results and Discussion

Hereafter, we will refer to "grasslands and savannas" collectively as "grasslands" to streamline the presentation and discussion of results.

Historic Distribution and Current Condition of Sky Island Grasslands

Experts in the United States and Mexico identified 13,902,000 acres as current or former grassland, which corresponds to almost half of the area we analyzed (table 3; fig. 1). We assume that this represents a conservative figure for the historic distribution and extent of grasslands in this area. Furthermore, grasslands were highly connected historically, allowing wide-ranging species, like bison, pronghorn, and grassland birds, as well as species with more limited dispersal capabilities, like black-tailed prairie dogs, to move freely within and between these habitats.

Only 2.6 million acres or 18.9% of these grasslands are currently dominated by native grasses and relatively open and shrub free. By comparison, shrub encroachment has occurred on over 8,159,000 acres or 58.7% of current and former grasslands. Approximately 4.9 million acres or 35.1% of current and former grasslands have experienced more shrub encroachment but still fall into classes where this change is considered reversible, for example, with prescribed fire or other brush control methods. However, shrub cover and associated soil erosion has exceeded a threshold on over 3.2 million acres, producing a type conversion from grassland to shrubland on almost one quarter of the historic grasslands and savannas in this region. Such areas are considered difficult if not impossible to return to open grassland states

Table 3—General statistics for grasslands (U.S. and Mexico) in the Sky Island region.

Grassland type	# Patches	Total acres	% All grasslands
No or low woody increase, native grassland	102	2,144,488	15.4
No or low woody increase, native savanna	48	478,953	3.5
Medium woody increase, native grassland and savanna	138	3,212,191	23.1
No or low woody increase, non-native grassland and savanna	11	162,417	1.2
Medium woody increase, non-native grassland and savanna	19	1,342,952	9.7
High woody increase, former grassland and savanna	185	3,275,463	23.6
Mix of low and medium woody increase, native grassland and savanna	26	328,574	2.4
Undetermined grassland and savanna	5,764	2,956,650	21.3
Total U.S.-MX Grassland/Savanna		**13,901,688**	

on any substantial scale, though small patches might conceivably be recovered with heavy investment of resources.

The spread of non-native perennial grasses within grasslands has also been substantial (table 3). Boer lovegrass and, to a greater extent, Lehmann lovegrass are common or dominant on at least 1.5 million acres such that non-native grasslands with little to moderate woody increase comprise 11% of this area's current and former grasslands. When the AHGA was completed in 2003, non-native grasslands were largely restricted to Arizona. However, Lehmann lovegrass appears to be spreading into southwestern New Mexico as it is now present in long-term monitoring plots where it had not previously been recorded (P. Sundt 2009). Implications of this spread are mixed, with some wildlife species more impacted than others (Bock and others 1986; Albrecht and others 2008). Native grasses remain present in many invaded areas, albeit at lower density. Fire regimes and hydrology can be affected but are not as radically transformed as in the case with many plant invasions (Emmerich and Cox 1992).

Identification, Delineation, and Evaluation of Priority Landscapes

Participants largely agreed on locations of "best" remaining grassland landscapes (fig. 2), Polygon boundaries were adjusted based on additional knowledge about locations of valued features (e.g. extending the Janos polygon north into the Playas Valley to reflect movements of a wild bison herd) or ongoing conservation efforts (e.g. expansion of Muleshoe-Aravaipa polygon to include an area known as the Bonita grassland where landowners are combating shrub invasion). Experts suggested addition of polygons (e.g. Buenaventura) to incorporate areas that met many of the suggested criteria but whose values have not been widely known among practitioners in this region. The group also recommended dropping two polygons (Santa Cruz and San Pedro-U.S.) that had been previously delineated but rated low in grassland-specific values (table 4). Both areas continue to harbor other habitats of high conservation value, particularly riparian systems, which may in turn benefit from grassland restoration activities. Nevertheless, for the purposes of grassland conservation per se, these areas were seen as being less likely than other landscapes to host large blocks of grassland habitat into the future. Parts of the initial Santa Cruz polygon that still have substantial grassland patches were added to the Altar Valley polygon, with which experts identified relatively high landscape connectivity (an impression substantiated by the multi-year movements of a wandering jaguar known as Macho B). In two cases, participants chose to further refine polygon boundaries by examining additional information after the workshop. Overlaying draft polygons on Google Earth proved especially useful for modifying boundaries to exclude highly modified areas such as center-pivot agriculture in Chihuahua.

The 12 final polygons incorporated almost all the substantial blocks of highest-quality grassland that the condition assessments had identified within the region (83% of overall acreage in native no-to-low woody increase classes) as well as substantial acreage of surrounding patches deemed restorable grassland (fig. 2). These polygons also succeed at encompassing many of the other target biological features associated with grasslands (fig. 3, table 5). For example, all but two riparian sacaton grassland patches identified in grassland assessments were included in final polygons. The two that were not identified are relatively isolated from other grassland blocks, one being on the southwestern edge of the region where terrain changes to highly dissected Sonoran scrub, and the other being on the northern end where terrain rises towards the Mogollon Plateau. The latter is near the Burro Cienega-Hachita polygon but is separated from it by a large open pit mine.

Delineations of these major grassland landscapes largely conformed to units defined by individual valleys. This evaluation bore out previous observations that the largest remaining blocks of open grassland tend to be in mid-elevation valley bottoms (e.g. San Rafael, Empire-Cienega-Sonoita). Grassy hills contribute substantial blocks in some areas (e.g. Tumacacori and Sierrita portions of the Altar polygon). In others (North Peloncillos, Southern Sulphur Springs, Aravaipa-Muleshoe-Willcox), grassland habitat primarily occurs on bajada or foothills terrain above lowlands that have undergone vegetation and/or land use conversions. We applied the valley names most commonly used by local communities to refer to these grassland landscapes. Participants discussed combining nearby polygons but decided that the smaller units more accurately reflect differences among nearby polygons in enabling conditions, e.g. in community culture or development threats among nearby polygons.

In filling out the evaluation matrix for these polygons, participants largely agreed on ratings (table 4). Where there was initial disagreement, further discussion was usually enough to bring the group to consensus on a final rating. One exception came in trying to rate an aspect of conservation feasibility that reflects the influence that active community and partner groups have by promoting and/or implementing conservation measures in a given landscape. Participants agreed on the importance of this factor, discussed activities of various partner

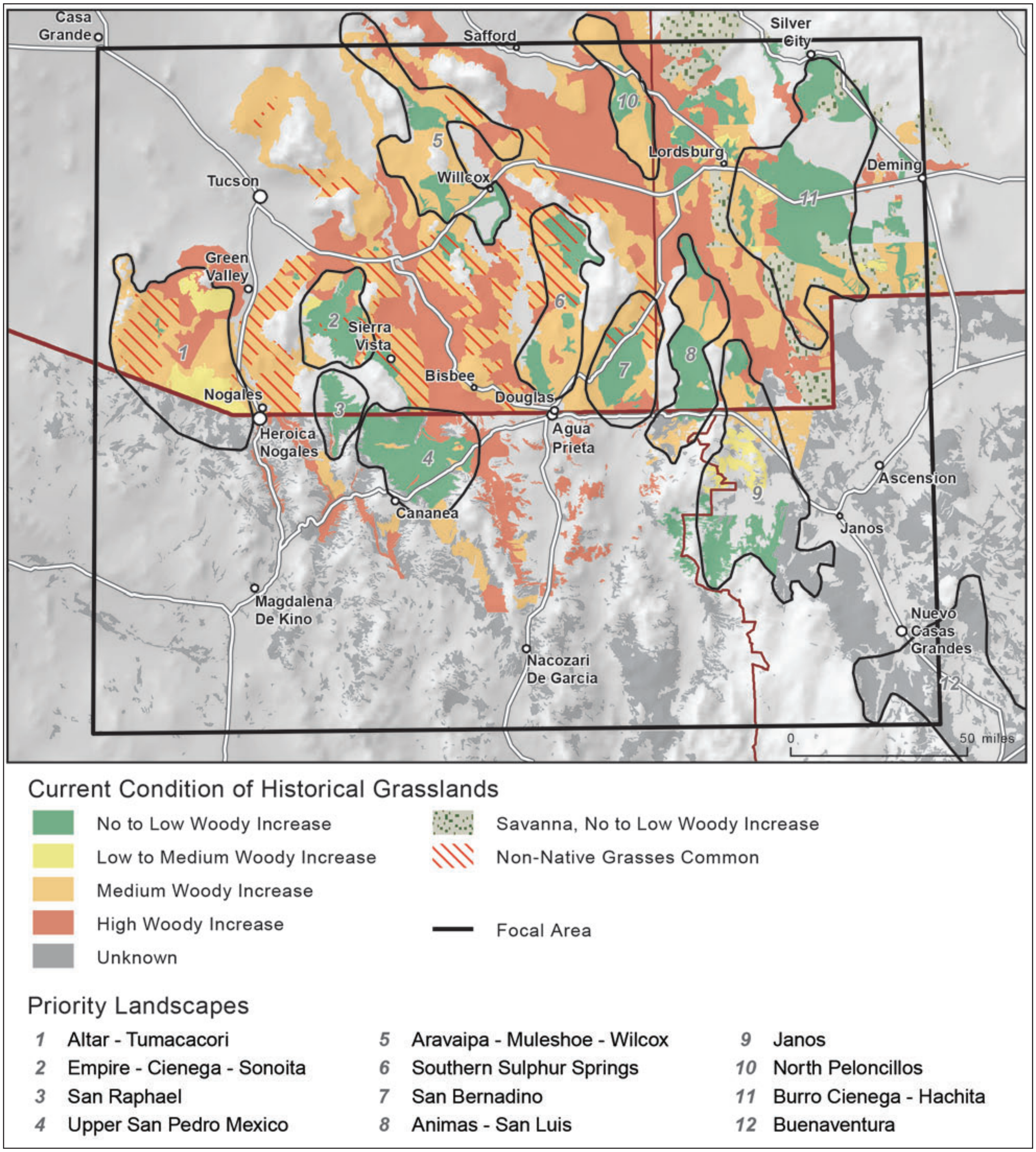

Figure 2—Priority grassland landscapes, showing ecological condition.

groups and modified some polygon boundaries to reflect partner work, but ultimately decided that this factor could not be readily distilled into a comparative rating. In all areas, participants recognized that (1) additional information or increased conservation efforts could change these ratings, (2) that all 12 polygons hold substantial promise for conservation of grasslands and associated species, and (3) that both opportunities and needs vary among the set.

Discussion among participants also drew out observations about a number of ecological gradients present across the region, added to information on target species, described both threats and conservation values of particular landscapes in greater detail, and added information about partners and their conservation activities (elaborated in Gori and others 2012).

Applications for Protection and Restoration

In each of these landscapes, successful grassland conservation will need to include three key components: (1) strong partnerships within the local community, which in turn support, (2) land protec-

Table 4—Conservation value and feasibility of success for Sky Island grassland landscapes.

Grassland conservation value												
Landscape name	Altar-Tumacacori	Empire-Cienega-Sonoita	San Rafael	Upper San Pedro Mexico	Aravaipa-Muleshoe-Wilcox	Southern Sulphur Springs	San Bernadino	Animas-San Luis	Janos	North Peloncillos	Burro Cienega-Hachita	Buenaventura
Polygon map #	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
Intact landscape												
Size of potential grassland block	High	High	Med	High	High	Med	Med-high	High	High	Low	High	High
Connectivity* across single valley	High	High	High	High	Med	Low	High	High	High	Med	High	High
Connectivity* with other grassland landscapes	Med-low	High	High	High	Med-low	Low	High	High	High	Med	Med	High
International connectivity, north-south	High	Med-low	High	High	Low	Low	Med	High	High	Low	High	Med-low
Existing habitat quality												
Grassland	Med	High	High	Med-high	High	Med	High	High	High	Med-high	Med-high	High
Riparian grassland	Med-high	High	High	High	Med-high	Med	Med	High	Med	Low	Med	?
Associated wetland habitats	High	High	High	High	High	Med-high	High	High	Low	Low	Med-high	Med
Summary rating	29	32	33	34	25	17	30	35	29	17	29	31
Conservation Feasibility												
Progress to date												
Land protection	High	High	High	Low	Med	Med-low	Med-high	High	Med-high	Med	Med-low	Low
Ecological land management	High	High	Med-high	Low	Med	Med-low	High	High	Low	Low	Med	Low
Intractable threats (low = 5)	Med	Med	Low	Med	Med	Med	Low	Low	Med	Low	Low	Med
Summary rating	13	13	14	5	9	7	14	15	8	9	10	5

High = 5, Med-high = 4, Med = 3, Med-low = 2, Low = 1

Ranking Criteria based on size, condition, conservation importance of species present, landscape context. See Gori et al. 2012 for descriptions of embedded wetlands considered in ratings, descriptions of threats, names and selected activities of known partners active in each landscape.
Shading indicates adjacent landscapes that experts considered merging but chose to instead identify as complexes.
*Connectivity ratings here are based on proximity of grassland blocks with one another via areas of similar grassland habitat; this is meant to reflect how grassland-obligate, terrestrial animals such as pronghorn would perceive connectivity. For species that readily travel across non-grassland natural habitats such as forests or scrublands, these connectivity ratings could be considerably higher.

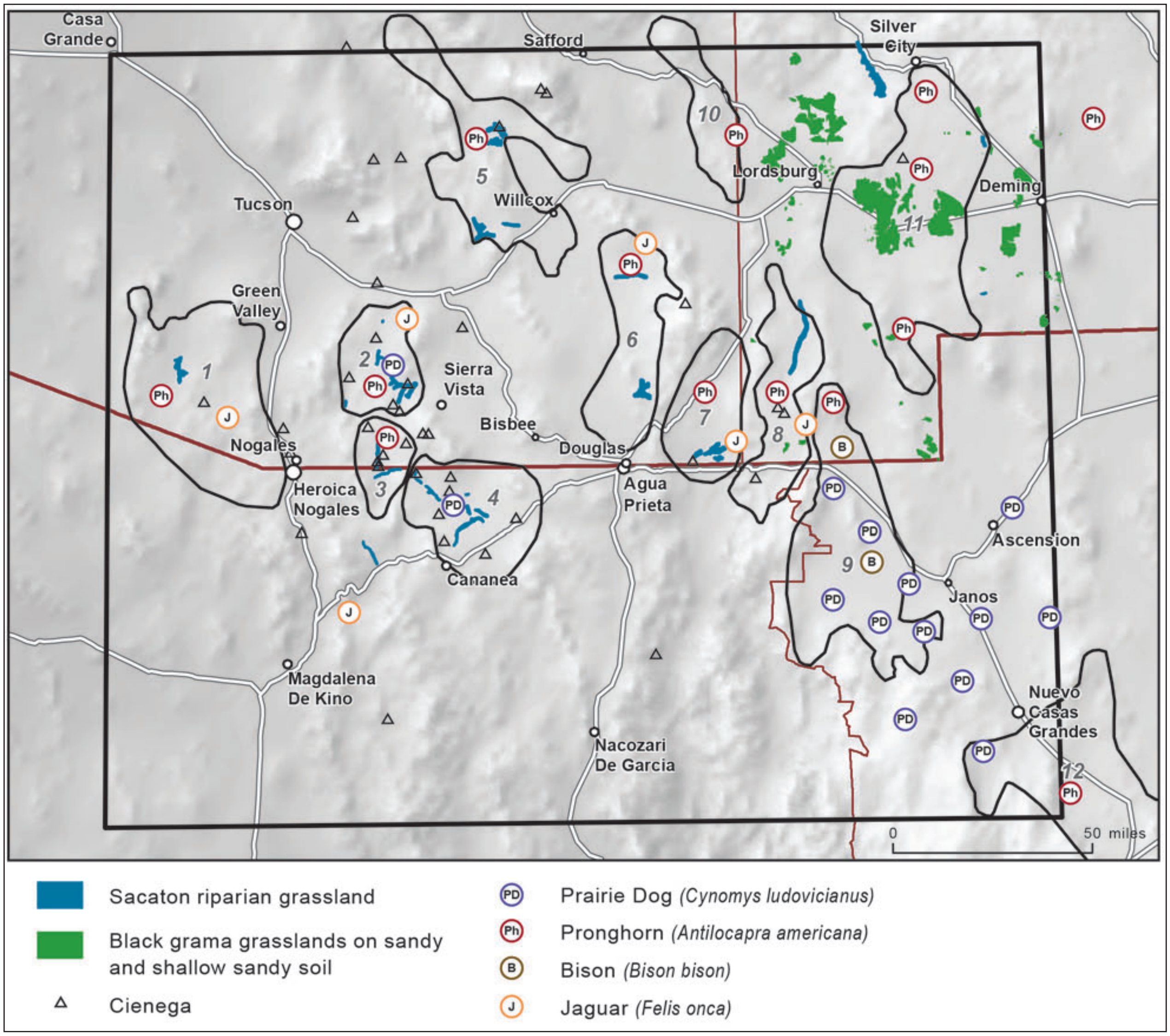

Figure 3—Priority grassland landscapes, showing select species and biological features of interest.

tion to prevent further fragmentation of the surviving grasslands, and (3) active ecological management to restore and maintain grassland health through time. These are addressed further in Gori and others (2012), highlighted below to show the broad utility of information presented here.

Overlaying polygons on land management highlights the role of particular institutions in sustaining grasslands across the region and within each individual landscape. For instance, these maps suggest that if the U.S. Forest Service wants to invest in maintaining open grasslands, this agency might focus on areas within the San Rafael polygon; if the agency's goal is to restore recoverable grassland, working in the Altar-Tumacacori might provide the best opportunities. Of federal agencies, BLM has a particularly large role to play across the U.S. portion of this region. While each of these landscapes includes a mix of public and private lands, success in landscapes like the Empire-Cienega-Sonoita depends heavily on management effects on BLM lands. By contrast, outcomes in landscapes such as the Animas-San Luis Valley depend almost entirely on the actions of private landowners.

Comparing polygons to maps of land management and protection status (Gori et al 2012) highlights places where grassland blocks are vulnerable to fragmentation by human infrastructure and disturbance, as well as key opportunities to protect long term connectivity of natural vegetation for the many wildlife species that are affected by more dramatic landscape changes such as proliferation of roads, houses, mines, or intensive agriculture. Several jurisdictions, for instance, combine to provide protection across nearly the entire San Rafael Valley in the United States; adding easements or other conservation status to the last remaining large block of unprotected private land at the top of the valley would secure the ongoing value of these previous investments. Successfully completing long-standing efforts to bring publicly identified parcels of Arizona State Trust land into

Table 5—Species of concern identified in NFWF (2009) that occur in priority grassland landscapes. Target species are designated as Type = A, and high-priority species likely to benefit from grassland conservation and restoration as Type = B. An "X" indicates that species has been recorded at the site. Data used to populate the table came from Natural Heritage Program (NHP) databases for Arizona, New Mexico and Sonora, gray-literature reports, and expert knowledge. Six species on NFWF's list were not included in the table because NHP is not tracking them and summary information from other sources was not readily available. In general, the lack of records for a species at a site may not mean that the species is absent but may be a function of insufficient survey effort.

		Priority Grassland Landscape[a]											
Common Name	**Type**	**A-T**	**EV-S**	**SR**	**U. SP**	**A-M-W**	**S. SS**	**SB**	**A-SL**	**PV-JP**	**NP**	**BC-H**	**BV**
Jaguar	A	X	X					X	X				
Bison	A								X	X			X
Pronghorn	A	X	X	X		X	X	X	X	X	X	X	X
Black-tailed prairie dog	A		X		X				X	X			X
Chiricahua leopard frog	A	X	X	X	X	X	X	X	X	X		X	
Aquatic Amphibians & Reptiles													
Sonoran tiger salamander	B			X	X								
Lowland leopard frog	B	X	X	X		X		X	X	X			
Mexican garter snake	B	X	X	X				X					
Native Fish													
Gila topminnow	B	X	X	X								X	
Gila chub	B		X	X		X							
Yaqui topminnow	B						X	X					
Yaqui chub	B						X	X					
Yaqui catfish	B							X					
Mexican stoneroller	B						X	X					
Yaqui longfin dace	B						X	X					
Beautiful shiner	B							X					
Gila longfin dace	B	X	X	X	X	X							
Desert sucker	B		X	X		X							
Sonoran sucker	B	X	X	X		X							
Desert pupfish	B		X			X							
Sonora chub	B	X											

		Priority Landscapes[a]											
Common Name	**Type**	**A-T**	**EV-S**	**SR**	**U. SP**	**A-M-W**	**S. SS**	**SB**	**A-SL**	**P-JP**	**NP**	**BC-H**	**BV**
Roundtail chub	B					X							
Spikedace	B					X							
Loachminnow	B					X							
Speckled dace	B		X			X							
Grassland Reptiles													
Desert massasauga	B						X	X					
Grassland Birds													
Aplomado falcon	B								X			X	
Grasshopper sparrow	B	X	X	X	X		X	X	X	X			
Baird's sparrow	B	X	X	X				X	X	X			
Western burrowing owl	B			X		X			X	X			
Mammals													
White-sided jackrabbit	B								X	X			

[a]Priority landscape abbreviations are: A-T = Altar Valley-Tumacacori; E-C-S = Empire-Cienega-Sonoita; SR = San Rafael Valley; U.SP = Upper San Pedro, MX; A-M-W = Aravaipa-Muleshoe-Willcox; S. SS = Southern Sulphur Springs Valley; SB = San Bernardino; A-SL = Animas Valley-Sierra San Luis; P-JP = Playas Valley-Janos Plains; NP = Northern Peloncillos; BC-H = Burro Cienega-Hachita; BV = Buenaventura.

conservation status would greatly benefit five of the 12 priority grassland landscapes identified here. Conserving these State Trust lands would, for example, safeguard the grassland block in the center of the Empire-Cienega-Sonoita, and secure wildlife connectivity across the I-10 corridor, Catalina-Rincon Mountains, and the San Pedro River to the Aravaipa-Muleshoe-Willcox landscape.

Overlaying polygons on maps of grassland habitat condition highlights key opportunities to protect or restore connections for species such as pronghorn whose movements are affected by habitat changes such as shrub encroachment (Brown and Ockenfels 2007). However, for planning and implementing restoration or management interventions, more information is needed. Closer examination of Ecological Site maps (Bestelmeyer and others 2009) can provide many insights into conservation value and management options within landscapes. Finer-scale mapping of ecological condition (e.g. by ecological state) can then inform selection of project locations, treatment methods, and monitoring (Tiller and others 2012).

Future efforts to gather information from additional experts would no doubt improve the resolution, accuracy, and richness of the regional picture presented here. We recognize, for example, that challenges of collecting data across state and international boundaries create inconsistent coverage for some communities and species, and welcome refinements. The large proportion of grasslands in Mexico currently depicted as "unknown condition," for example, highlights the need to compile consistent information about these areas. We encourage readers to treat this assessment, and others like it, as living documents to be modified and added to as time goes on, as ecological and social conditions change, as species ranges shift, and as we learn more about all these factors.

In reviewing the status and trends of Sky Island grasslands, it is clear that maintaining them as functioning systems represents one of the greatest needs, and greatest challenges, of any conservation issue in the borderlands. These grasslands are an essential link that sustains the wildlife in the mountains and the perennial waters in the valley bottoms. Yet successful grassland conservation is complex, requiring simultaneous progress on several fronts: protecting the land from fragmentation, managing the land to control shrubs and maintain grass cover, and supporting community organizations and other partnerships that get the work done. We hope that this analysis, combined with efforts to make progress on these fronts and evaluations of what is working best, helps us all rise to this challenge.

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References

Albrecht, Eric W.; Geiger, E.L.; Litt, A.R.; McPherson, G.R.; Steidl, R.J. 2008. Fire as a tool to restore biodiversity in ecosystems dominated by invasive grasses. Unpublished report on file at: U.S. Department of Defense, Legacy Resource Management Program.

Archer, Steve. 1989. Have southern Texas savannas been converted to woodlands in recent history? American Naturalist. 134: 545-561.

AZGFD (Arizona Game and Fish Department). 2011. Arizona statewide pronghorn management plan. 101 p. Report available online: http://www.azgfd.gov/h_f/documents/2011%20Pronghorn%20Management%20Plan%20-%20December%203%202011.pdf [April 27, 2012]

Bahre, Conrad J. 1985. Wildfire in southeastern Arizona between 1859 and 1890. Desert Plants. 7: 190-194.

Bahre, Conrad J. 1991. A legacy of change: historic human impact on vegetation of the Arizona borderlands. Tucson: University of Arizona Press. 231 p.

Bahre, Conrad J., 1995. Human impacts on the grasslands of southeastern Arizona. In: Mitchel P. McClaran; Van Devender, T.R., eds. The desert grassland. Tucson: University of Arizona Press, Tucson, AZ: 230-226.

Bestelmeyer, Brandon T.; Tugel, A.J.; Peacock, G.L.; [and others]. 2009. State-and-Transition models for heterogeneous landscapes: A strategy for development and application. Rangeland Ecology and Management. 62(1): 1-15.

Bock, Carl E.; Bock, J.H.; Jepson, K.L.; Ortega, J.C. 1986. Ecological effects of planting

African lovegrasses in Arizona. National Geographic Research. 2 (1986): 456-463.

Brown, David E.; Ockenfels, R.A. 2007. Arizona's pronghorn antelope: a conservation legacy. Phoenix: Arizona Antelope Foundation. 190 p.

Brown, James H.; Valone, T.J.; Curtin, C.G. 1997. Reorganization of an arid ecosystem in response to recent climate change. Proceedings of the National Academy Sciences. 94: 9729-9733.

Buffington, Lee C.; Herbel, C.H. 1965. Vegetational changes on a semidesert grassland Range from 1858 to 1963. Ecological Monographs. 35: 139-164.

Cable, Dwight R. 1967. Fire effects on semidesert grasses and shrubs. Journal of Range Management. 20: 170-176.

Ceballos, Gerardo; Davidson, A.; List, R.; [and others]. 2010. Rapid decline of a grassland system and its ecological and conservation implications. PLoS One 5:1-12.

Cox, Jerry R.; Ruyle, G.B. 1986. Influence of climatic and edaphic factors on the distribution of *Eragrostis lehmanniana* Nees in Arizona, USA. Journal Grassland Society of South Africa 3: 25-29.

Emmerich, William E.; Cox, J.R. 1992. Hydrology characteristics immediately after seasonal burning on introduced and native grasslands. Journal Range Management. 45.5 (1992): 476-479.

Enquist, Carolyn A.F.; Gori, D.F. 2008. Application of an expert system approach for assessing grassland status in the U.S.-Mexico borderlands: implications for conservation and management. Natural Areas Journal. 28(4): 414-428.

Gori, David F.; Enquist, C.A.F. 2003. An assessment of the spatial extent and condition of grasslands in central and southern Arizona, Southwestern New Mexico and Northern Mexico. The Nature Conservancy of Arizona. 28 p. Report available on line: http://azconservation.org/dl/TNCAZ_Grasslands_Assessment_Report.pdf [April 27, 2012]

Gori, David F.; Bodner, G.; Sartor, K.; Warren, P.; Bassett, S. 2012. Sky Island grassland assessment: Identifying and evaluating priority grassland landscapes for conservation and restoration in the borderlands. 60 p. Report available online: http://azconservation.org/downloads/category/grassland [October 1, 2012]

Hastings, James R.; Turner, R.M. 1965. The changing mile. Tucson: University of Arizona Press. 317 p.

Hendrickson, Dean A.; Minckley, W.L. 1984. Ciénegas-vanishing climax communities of the American Southwest. Desert Plants. 6(3): 130-175

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

Humphrey, Robert R. 1960. Forage production on Arizona ranges. V. Pima, Pinal and Santa Cruz Counties. University of Arizona Agricultural Experiment Station Bulletin. 302: 1-138.

Humphrey, Robert R. 1987. 90 years and 535 miles: Vegetation changes along the Mexican border. Albuquerque: University of New Mexico Press. 448 p.

McClaran, Mitchel P.; Van Devender, T.R., eds. 1995. The desert grassland. Tucson: University of Arizona Press. 346 p.

McPherson, Guy R. 1995. The role of fire in desert grasslands. In: Mitchel P. McClaran; Van Devender, T.R., eds. The desert grassland. Tucson: University of Arizona Press: 130-151.

McPherson, Guy R.; Weltzin, J.F. 2000. Disturbance and climate change in the United States/Mexico borderland plant communities: a state-of-the-knowledge review. Gen. Tech. Rep. RMRS-GTR-50. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research and Experiment Station. 24 p.

Minckley, Thomas A.; Turner, D.; Weinstein, S.R., *in review*. The relevance of wetland conservation in arid regions: A re-examination of vanishing climax communities in the American Southwest. Journal of Arid Environments.

NFWF (National Fish and Wildlife Foundation). 2009. Sky Island grassland business plan. 34 p. Report available online: http://www.nfwf.org/AM/Template.cfm?Section=Wildlife_and_Habitat12andTEMPLATE=/CM/ContentDisplay.cfmandCONTENTID=14106 [April 27, 2012].

NRCS (U.S. Natural Resources Conservation Service). 2009. Homepage of the Ecological Site Information System, U.S. Department of Agriculture, U.S. Natural Resources Conservation Service, [Online]. Available: http://esis.sc.egov.usda.gov/ [April 27, 2012].

Rosen, Philip C.; Wallace, E. J.; Schwalbe, C. R. 2001. Resurvey of the Mexican Garter

Snake (*Thamnophis eques*) in Southeastern Arizona. Unpublished report on file at: Arizona Game and Fish Department and U.S. Fish and Wildlife Service, Phoenix, Arizona. 64 p.

Sundt, Peter. 2009. Rangeland monitoring of the Diamond A Ranch: Western, Central, and Eastern Divisions, 1993-2008. Unpublished report on file at: The Nature Conservancy in New Mexico, Santa Fe, NM.

Schussman, Heather; Geiger, E.; Mau-Crimmins, T.; Ward, J. 2006. Spread and current potential distribution of an alien grass *Eragrostis lehmanniana* Nees., in the southwestern USA: comparing historical data and ecological niche models. Diversity and Distributions. 12: 582-592.

Swetnam, Thomas W., 1990. Fire history and climate in the southwestern United States. In: Krammes, J.S., tech. coord. Effects of fire management of southwestern natural resources. Gen. Tech. Rep. RM-191. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 6-16.

Wright, Henry A. 1980. The role and use of fire in the semidesert grass-shrub type. Gen. Tech. Rep. INT-85. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 24 p.

Yanoff, Steven; McCarthy, P; Bate, J.; Miller, L.W.; Bradley, A.; Gori, D. 2008. New Mexico rangeland ecological assessment. 73 p. The Nature Conservancy in New Mexico. Report available online: http://nmconservation.org/projects/rangeland_ecological_assessment/ [April 28, 2012].

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