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Reinterpreting Historical Data for Evidence-Based Shrubland Management

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ABSTRACT

Long-term vegetation dynamics in the Chihuahuan Desert of southern New Mexico have been intensively studied for over a century, and interpretations of the broad scale drivers of these dynamics are numerous. We now understand that interpretation of spatially heterogeneous change requires a more nuanced, contextualized, and detailed understanding of edaphic features and landscape characteristics. Recently, state and transition models (STMs) have been employed to represent landscape-specific dynamics for each ecological site within a Major Land Resource Area (MLRA). We re-examined data characterizing vegetation across the public lands of the northern Chihuahuan Desert at two points in time, the 1930s and 2005. In this study, our objectives were to (1) develop geospatial data layers of historical and current vegetation states, (2) compare vegetation states between the 1930s and 2005 where the two data layers overlap, and (3) interpret any major vegetation state changes over this ~70 year period within the context of specific ecological sites. It was our hypothesis that ecological dynamics would vary in interpretable ways among ecological sites. Three primary observations are drawn from our results: (1) the bulk of the region was relatively stable during this period, (2) approximately the same amount of area experienced increased grass dominance as experienced increased shrub dominance, and (3) dynamics are strongly influenced by the properties of specific ecological sites. Major vegetation state changes, involving either increased grass dominance or increased shrub dominance, only occurred to any extent in 11 of 18 ecological sites within this study area. More important to management, significant increases in shrubs occurred within only four ecological sites. These sites were sandy, deep sand, shallow sandy, and gravelly sand. All other ecological sites within this region were relatively stable over the ~70 year period between observations. The obvious management implication is the importance of stratifying by ecological site prior to application of shrub control treatments.

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INTRODUCTION

Vegetation dynamics in the Chihuahuan Desert of southern New Mexico have been studied for over a century (Buffington and Herbel 1965; Gibbens and others 2005; Schlesinger and others 1990; Wootton 1908). These studies have produced a long-term record indicating significant and lasting vegetation change (Havstad and others 2006; Peters and others 2006). Though the interpretations of the broad scale drivers of these changes are numerous and diverse (Van Auken 2009; Yanoff and Muldavin 2008), ecologically-based principles with application to rangeland management have been drawn from these studies for decades (Herbel and Gibbens 1996; Jardine and Forsling 1922). Increasingly, though, we

have understood that interpreting land change requires a more detailed and location specific understanding of edaphic features and landscape characteristics that contribute to resistance and resilience of vegetation assemblages across this arid region (Bestelmeyer and others 2009).

Central to this improved approach to interpreting land change have been state and transition models (STMs), rooted in a thorough understanding of vegetation dynamics and linked to specific ecological sites and their descriptions (Bestelmeyer and others 2004). The Natural Resources Conservation Service (NRCS) has made recent advances in the development of rangeland ecological site descriptions

(ESDs) and the mapping of ecological sites, especially within Major Land Resource Area (MLRA) 42, which encompasses much of southern New Mexico (see: <http://www.cei.psu.edu/mlra>). The STMs embedded within these ESDs, when used either explicitly or implicitly, provide a mechanism to house and disseminate information including an understanding of current vegetation states (Bestelmeyer and others 2003), explanations of long-term dynamics (Yao and others 2006), and evaluations of management actions (Havstad and James 2010).

Techniques that utilize remotely-sensed imagery, including aerial photographs, to map vegetation states within this region are well established (Laliberte and others 2004). In fact, remotely-sensed imagery has been available since the 1930s in some areas for detection of vegetation states and recent dynamics (Browning and others 2009). In addition, detailed field observations of vegetation conditions have been available for this region since the establishment of the Grazing Service, the forerunner of the Bureau of Land Management (BLM), following passage of the Taylor Grazing Act by the US Congress in 1934 and subsequent establishment of public land grazing districts across the western US (Skaggs and others 2011, in press). Ground-based surveys conducted in conjunction with the establishment of public land livestock grazing districts in the 1930s provided systematic and geographically extensive records of historical vegetation conditions. These records can be extremely useful for tracking vegetation changes through time and placing these changes within the context of other relevant geospatial data.

Combining historical field data, remotely-sensed imagery, state and transition models, ecological site descriptions, and knowledge of broad scale drivers allows for spatially-explicit interpretations of vegetation dynamics across the region. Our objectives were to (1) develop geospatial data layers of historical and current vegetation states, (2) compare vegetation states between the 1930s and 2005 where the two data layers overlap, and (3) interpret any major vegetation state changes over this ~70 year period within the context of specific ecological sites. It was our hypothesis that patterns of state change would vary among ecological sites.

METHODS

Study Region

This study was mostly confined to public lands within MLRA 42 administered by the BLM. The specific area of study was a region of approximately 8000 km² (2 M surface acres) across six counties in southern New Mexico (figure 1). Land use within this region has been dominated by cattle ranching over the past 125 years. Although livestock numbers are greatly reduced from those recorded in the early part of the 20th Century, the BLM Las Cruces District Office currently manages 603 grazing allotments. The region is characteristic of the northern extent of the Chihuahuan Desert (Havstad and others 2006) with its arid climate (long-term average annual precipitation <250 mm primarily as convective storms in the summer months) and elevations above 1100 m (3600 ft). The area considered for analysis was necessarily restricted to regions of overlap between historical and modern datasets. More specifically, the study area was defined by those historical 1930s-era map polygons more than 70 percent covered by our current vegetation state map (see below).

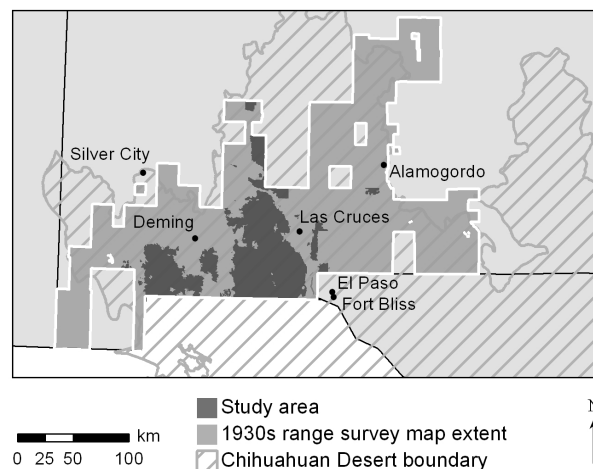


Figure 1. Extent of study area within southern New Mexico.

Current Ecological Site and State Mapping

In our approach to contemporary ecological site and state mapping, the basic stages are: (1) identify soil map units, (2) digitize vegetation states based on shrub cover/density and perennial grass cover/presence, and (3) attribute each polygon with

an ecological site and state. Ecological states were manually delineated in ArcGIS (Esri 2008) using color infrared, 1-m resolution 2005 Digital Ortho Quarter Quads (DOQQs), ground-based observations, and other geospatial reference layers. Soil Survey Geographic Database (SSURGO) soil map unit polygons were clipped to produce sub-polygons (child polygons) representing an ecological state or complex of ecological states based upon the state and transition model (STM) for the correlated ecological site (figure 2). Child polygons created in this manner differed from one another in the presence/absence or cover/density of perennial grasses and shrubs. Polygons were attributed with generic, three-digit state codes using ground-based spatial data, reference layers, photo-interpretation, and the associated ecological site description's STM. The dominant state was recorded as the first number in the state code. Where more than one state occurred within a polygon, the other two were recorded sequentially based on area. Otherwise, zeros followed the first (or second) number in the three-digit state code.

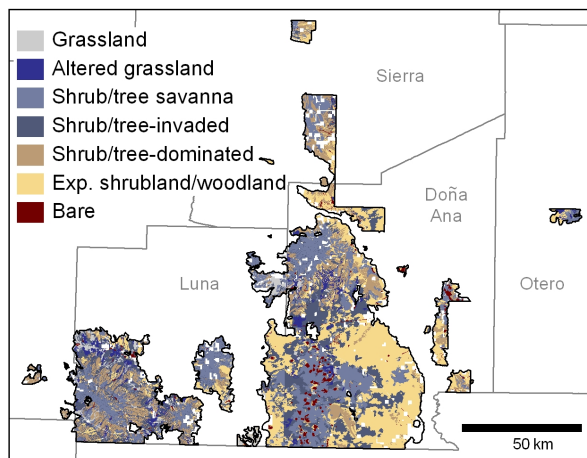


Figure 2. Dominant ecological states of the 2005 state map in regions of sufficient overlap (>70 percent) between historical and contemporary map polygons.

Reinterpretation of Historical Data

Detailed vegetation maps were produced in the 1930s by trained field personnel working for the Grazing Service. These maps, often referred to as "adjudication" or "range survey" maps because they indicated private and public land ownership boundaries, landscape features, and vegetation

related to newly established Department of Interior grazing districts, were based on ground observations directed by specific protocols. Skaggs and others (2011 in press) have detailed the procedures used to create the original 1930s maps and to convert the physical maps into a digital form for the portion of southern New Mexico studied here. Like the modern state map, the 1930s maps are object-based representations that segment the landscape into discrete vegetation polygons. Data recorded for each polygon include a list of up to five plant species. 1930s map polygons are, however, on average much larger (1392 hectares) than state map polygons (32 hectares) within our study area. Thus, two primary steps were taken to facilitate comparisons between the 1930s range survey maps and 2005 ecological state map.

These steps included (1) reclassification of map content to a compatible thematic format and (2) generalization of thematic information to a consistent spatial resolution. The modern state map provided the thematic template for the analysis, while the historical maps defined the spatial template. A rule set was developed to assign each 1930s map polygon to one of nine classes using the species listed for that polygon (table 1). This algorithm took into account the functional importance of different species and was meant to align the historical data as closely as possible with contemporary ecological state definitions. Five of the new classes developed for this study had a single equivalent class in the modern ecological state map. One new class, grass-dominated, included both shrub/tree savanna and shrub/tree invaded categories of the modern map, while three others had no counterpart in the modern classification scheme. In reclassifying the 1930s range survey maps, it was necessary to assume that plant species recorded for each polygon were the dominant species, listed in the order of their dominance, and that the protocol for recording species was regionally consistent. These assumptions appear reasonable given range survey methods of the time (USDA 1940). Nevertheless, a small change in species ordering could mean assignment of a polygon to a different generalized state (table 1). While up to three classes are recorded for each polygon of the modern state map, these polygons were reclassified to the new format using only that state indicated as dominant.

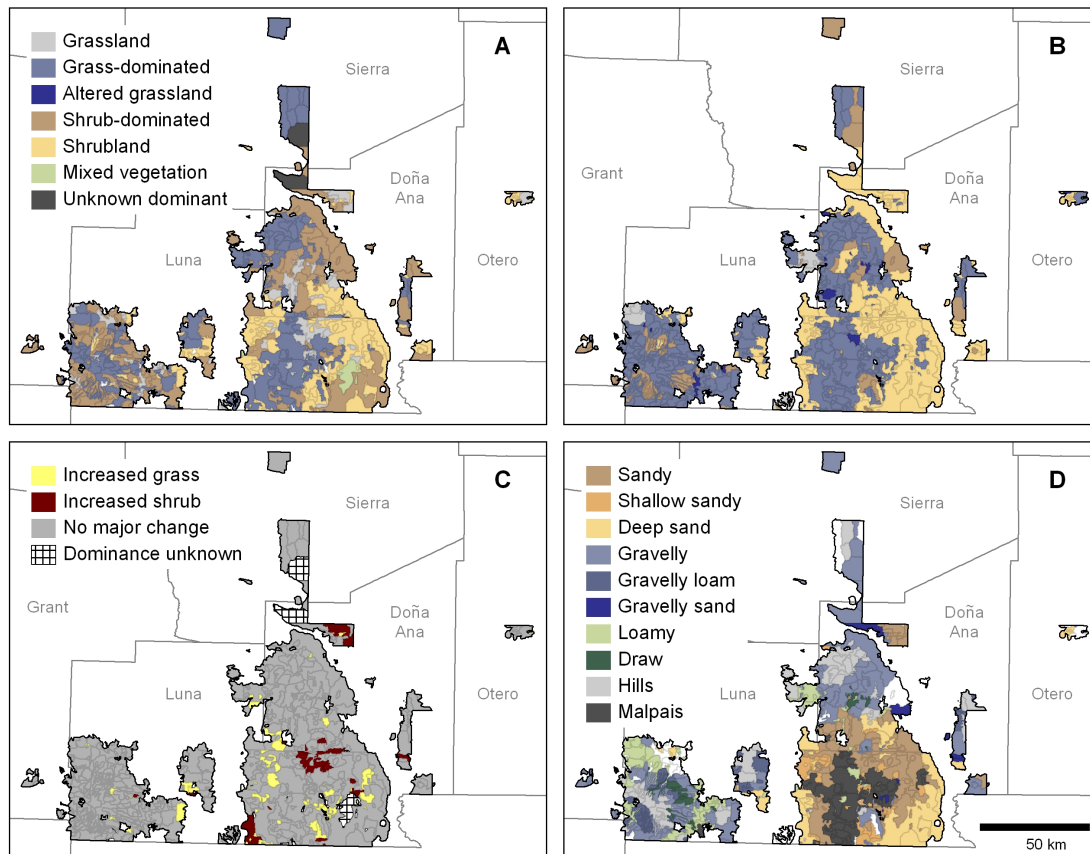


Figure 3. 1930s range survey map polygons classified by **A** generalized ecological state based on 1930s data, **B** generalized ecological state based on 2005 data, **C** major state changes (a departure of 2 or more generalized states) between the 1930s and 2005, and **D** dominant ecological site.

A second major step in facilitating comparisons between historical and modern datasets was to generalize the modern data to the coarser scale of the 1930s maps. This step was accomplished by merging the two datasets in a geographic information system (GIS) and calculating the area of each 1930s range survey map polygon intersected by contemporary ecological site and state classes. Each 1930s map polygon was subsequently assigned the generalized state and ecological site occupying the greatest proportion of the polygon (figure 3). A considerable amount of information was lost in the process. Yet, 1930s map data were interpreted as describing the predominant character of the landscape, and generalization of the state map was expected to produce a similar result. Grassland and altered grassland are not states recognized in the STMs of some of the ecological sites studied here, including deep sand, gravelly, gravelly loam, gravelly sand, hills, limestone hills, limy, and malpais. These ecological sites tend to feature scattered shrubs at

potential as described in current ecological site descriptions. Therefore, once 1930s map polygons were assigned a dominant ecological site, a final historical state classification was determined (table 1). Even if perennial grasses and no invasive shrubs were recorded for a particular 1930s map polygon, this polygon was classified as grass-dominated if it predominantly encompassed one of the ecological sites listed above, the presumption being that areas without shrubs were likely not at equilibrium and would eventually progress to a grass-dominated state, or that scattered shrubs might have been ignored by the recorder. This final step helped to further align the historical and modern classification schemes.

State changes between the 1930s and present were visualized by mapping the historical and modern states attributed to each 1930s map polygon (figure 3). The prevalence of different states was also examined by ecological site class for the two time periods. The percentage of an ecological site class

covered by each state was calculated using the equation

$$P = (\sum A_{\text{state}} / \sum A_{\text{ecological site}}) \times 100$$

where $\sum A_{\text{state}}$ is the area of all 1930s map polygons attributed with the generalized state and ecological site of interest and $\sum A_{\text{ecological site}}$ is the area of all

polygons attributed with the ecological site of interest. Because of the various assumptions, generalizations and considerable spatial data manipulations involved in this project, we focused on major vegetation changes and placed low confidence in interpretations involving ecological sites represented by few polygons (table 2).

Table 1. Rule set used to reclassify modern and historical maps.

1930s map species list ^a	Generalized state	2005 state map class ^b	Generalized state
2GRAM, ARDI5, ARIST, ARPU9, ARPUF, BOCU, BOER4, BOGR2, BOHI2, BOUTE, MUPO2, PLMU3, SCBR2, SPAI, SPCR, SPGI or SPORO listed first. FLCE, JUMO, LATR2, PRGL2, QUERC, QUTU2 or browse not listed. ATCA2 and ARFI may be present.	Grassland ^c , Grass-dominated ^d	Grassland	Grassland
2GRAM, ARDI5, ARIST, ARPU9, ARPUF, BOCU, BOER4, BOGR2, BOHI2, BOUTE, MUPO2, PLMU3, SCBR2, SPAI, SPCR, SPGI or SPORO listed first. FLCE, JUMO, LATR2, PRGL2, QUERC, QUTU2 and/or browse also listed.	Grass-dominated	Shrub/tree savanna or Shrub/tree-invaded	Grass-dominated
Perennial grass species other than those above listed first and not DAPU7.	Altered grassland ^c , Grass-dominated ^d	Altered grassland	Altered grassland
ARFI, ATCA2, FLCE, JUMO, LATR2, PRGL2, QUERC, QUTU2 or browse listed first. 2GRAM, ARDI5, ARIST, ARPU9, ARPUF, BOCU, BOER4, BOGR2, BOHI2, BOUTE, PLMU3, SCBR2 and/or SPAI also listed.	Shrub-dominated	Shrub/tree-dominated	Shrub-dominated
ARFI, ATCA2, FLCE, JUMO, LATR2, PRGL2, QUERC, QUTU2 or browse listed first. 2GRAM, ARDI5, ARIST, ARPU9, ARPUF, BOCU, BOER4, BOGR2, BOHI2, BOUTE, PLMU3, SCBR2 or SPAI not listed. MUPO2, SPCR, SPGI and SPORO may be present.	Shrubland	Expansion shrubland/woodland	Shrubland
Vegetation number 8 and no species listed.	Bare	Bare/annuals	Bare
Assemblage of shrubs, grasses and/or succulents not representing one of the above classes.	Mixed vegetation	N/A	N/A
The code listed first could not be translated to a modern species code.	Unknown dominant	N/A	N/A
Areas are delineated on the map but not surveyed.	Undefined	N/A	N/A

^aPlant species recorded for each historical map polygon were assumed to be the dominant species, listed in the order of their dominance. Species are referenced here by their current USDA plant symbol. In assessing species order, we ignored those shrub and succulent species not specifically referenced by their symbol in one of the above rule descriptions. Polygons whose species list included only these “not functionally important” shrub or succulent species were assigned the mixed vegetation class.

^bThe 2005 ecological state map was reclassified based on the dominant state within each polygon.

^cClass assigned to polygons dominated by bottomland, clayey, draw, loamy, loamy-gypsum upland-gypsum, salt flats, salty bottomland, sandy, or shallow sandy ecological site.

^dClass assigned to polygons dominated by deep sand, gravelly, gravelly loam, gravelly sand, hills, limestone hills, limy, or malpais ecological site.

Table 2. Percentage of area covered by each generalized state in the 1930s and 2005, by ecological site.

Generalized state	1930s						2005					
	Sandy ecological sites			Gravelly ecological sites			Sandy ecological sites			Gravelly ecological sites		
	Shallow sandy	Deep sand	Gravell y	Gravell y loam	Gravell y sand	Shallow sandy	Deep sand	Gravell y	Gravell y loam	Gravell y sand		
Grassland ^a	20.1	31.5	N/A	N/A	N/A	N/A	0	2.1	N/A	N/A	N/A	N/A
Grass-dominated	13	0	6.8	19.8	23.7	18.7	31.3	43.4	1.3	38.6	63.4	9.1
Altered grassland ^a	0	0	N/A	N/A	N/A	N/A	1.9	2.4	N/A	N/A	N/A	N/A
Shrub-dominated	9.8	0.6	50.2	58.8	64.4	69.6	0	0	0.3	33.5	30.7	0
Shrubland	50.7	66.7	42.7	12	10.1	11.7	66.8	52	98.4	27.9	5.9	90.9
Mixed vegetation ^b	6.3	1.2	0	0.1	0	0	N/A	N/A	N/A	N/A	N/A	N/A
Unknown dominant ^b	0.1	0	0	9.3	0	0	N/A	N/A	N/A	N/A	N/A	N/A
Undefined ^b	0	0	0.3	0	1.7	0	N/A	N/A	N/A	N/A	N/A	N/A
Total area (km ²)	1331	268	972	1877	328	121	1331	268	972	1877	328	121
Polygon count	83	37	36	111	42	9	83	37	36	111	42	9

^aGrassland and altered grassland are not considered stable states in the modern classification scheme for deep sand, gravelly, gravelly loam, and gravelly sand ecological sites.

^bThese states have no equivalent class in the 2005 classification scheme.

RESULTS AND DISCUSSION

State Changes 1930s to 2005

Our analyses worked from a fairly simple, but historically referenced model of vegetation states and transitions for this region. In general, the predominant ecological sites across the study area are characterized by five vegetation states: a grassland state dominated by historically dominant grass species (grassland), a grassland state dominated by grass species not considered to be historically dominant (altered grassland), a grass/shrub savanna (grass-dominated), a shrub-dominated state with some cover of historically dominant grass species and large unvegetated gaps (shrub-dominated), and a shrubland state lacking historically dominant grass species (shrubland). This generalized state model can be applied to nearly 95 percent of the study area (> 7500 km²) and at least 10 of the 18 main ecological sites within the region, including the area's six sandy and gravelly type ecological sites that are common across MLRA 42.

In characterizing vegetation dynamics using this generalized state model, we acknowledged two major differences between the historical and contemporary datasets: (1) differences in the spatial scale of the two state maps, and (2) differences in precision between

the modern state map attributed through photo interpretation, field observations and geospatial data layers and the historical state map derived from simple species lists recorded in the field. We thus focused on vegetation dynamics involving major state changes between the 1930s and 2005. These "major" changes were defined as a departure of two or more vegetation state classes over time based on our generalized state and transition model for the region. Considering, for example, a map polygon characterized as being predominantly grassland in the 1930s, a "major departure" would require that the polygon be characterized in 2005 as predominantly shrubland with some historically dominant grasses and large unvegetated areas (shrub-dominated), or predominantly a shrubland lacking historically dominant grasses (shrubland). If the polygon in 2005 was characterized as a grassland with shrubs present (grass-dominated), even though this designation might reflect a vegetation state less dominated by perennial grasses than in the 1930s, this would not be characterized as a major state change and would not be reflected in this analysis as having changed over the ~70 year period. The same required degree of departure would also apply to changes from shrubland or shrub-dominated states in the 1930s to grassland, altered grassland, or grass-dominated states in 2005. In applying this algorithm, altered grassland and grass-dominated states were given the same rank.

Based on these protocols, major state changes from the 1930s to 2005 are illustrated in figure 4. Three primary observations are drawn from these results: (1) the bulk of the region was relatively stable during this period, (2) approximately the same amount of area experienced increased grass dominance as experienced increased shrub dominance, and (3) dynamics differ strongly among ecological sites. To a great extent, these observations are counter to conventional interpretations of vegetation dynamics for this region drawn from anecdotal data. First, following the droughts of the 1930s and 1950s, it is typically assumed that major state changes occurred widely across the region. Second, it is usually assumed that most state changes were an increasing dominance of shrubs and that there has been a widespread loss of perennial grasslands. Third, it is generally assumed that these changes have occurred rather uniformly across diverse ecological sites.

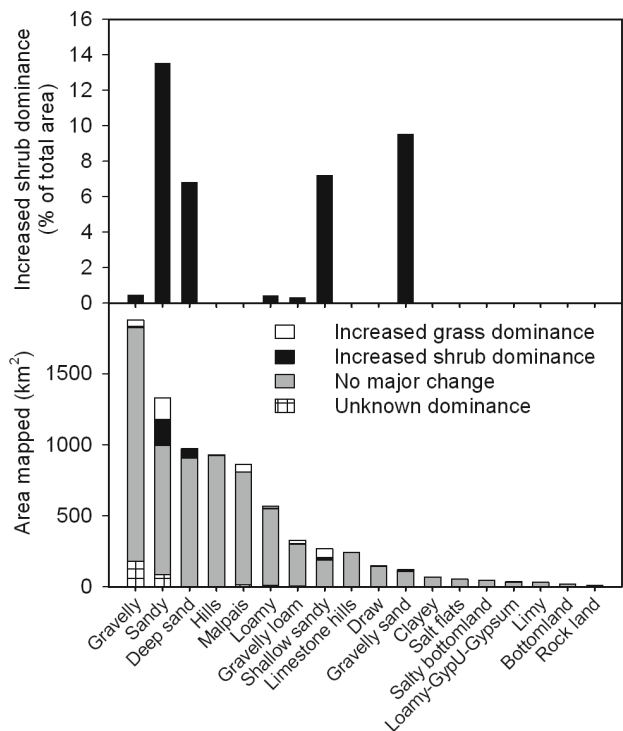


Figure 4. Major vegetation state changes (a departure of 2 or more generalized states) between the 1930s and 2005 delineated by the 18 major ecological sites within the study area.

It is certainly possible that much of the area shown as stable from the 1930s to 2005 in figure 3 actually experienced substantial vegetation state changes prior to the 1930s. Pre-1930s pressures, such as overgrazing by livestock and lengthy drought periods in the late 19th and early 20th centuries, are well

documented (Havstad and others 2006). However, the distribution of vegetation states in the 1930s, when stratified by ecological site, indicate site heterogeneity in resistance and resilience to disturbance factors, and it would be inappropriate to assume prior broad scale disturbances had resulted in uniform and widespread vegetation state changes, or that those changes would reflect universal degradation (figure 3). One conclusion that we can draw from these historical and quantitative perspectives is that there has been considerable spatial heterogeneity in response to broad scale drivers, such as regional multi-year droughts.

Vegetation Dynamics of Sandy Soil Textured Ecological Sites

There are three ecological sites characterized by sandy textured soils within MLRA 42 – deep sand (ref #R042XB011NM), sandy (ref #R042XB012NM), and shallow sandy (ref #R042XB015NM). These ecological sites are common across the northern Chihuahuan Desert, occupying nearly 15 percent of the region and about 30 percent of the area studied here. Our results for vegetation dynamics across these three sandy type ecological sites are presented in figure 5.

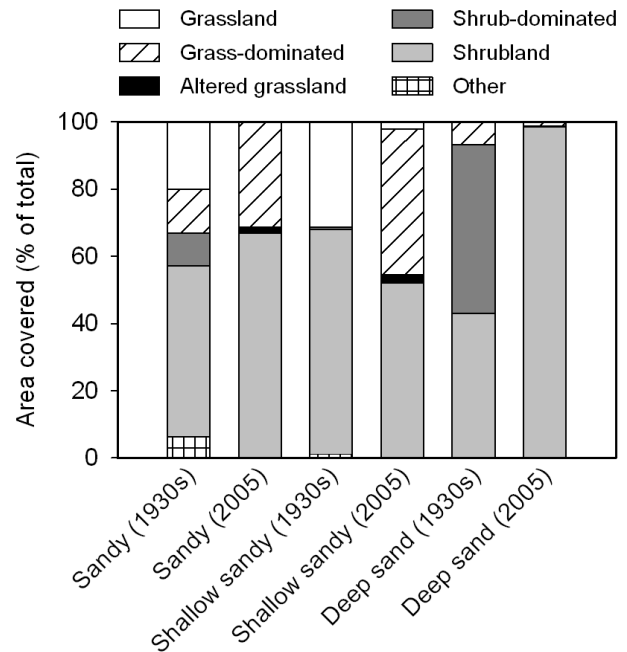


Figure 5. Vegetation state changes between the 1930s and 2005 delineated by the three principal sandy soil type ecological sites within the study area.

The deep sand ecological site was predominantly in either a shrub-dominated or shrubland state by the 1930s. By 2005 this ecological site was almost completely in a shrubland state across the study area. We conclude that this ecological site has poor resistance to extended drought, a conclusion recently supported by quantitative measures of relatively low plant available water in deep sandy soils lacking a calcium carbonate-cemented layer near the soil surface (Duniway and others 2010). This would support the observation of extensive shrubland and shrub-dominated states present across this ecological site prior to the 1930s. In addition, the poor resilience of this ecological site attributed to poor soil water retention features would help explain a near complete lack of the grass-dominated state in 2005 despite the implementation of various management practices, including more conservative livestock stocking rates, across this region since the 1930s.

Conversely, both shallow sandy and sandy ecological sites frequently exhibited grassland or grass-dominated states both in the 1930s and in 2005. The relative proximity of a calcium carbonate-cemented layer and/or a clay rich argillic horizon near the soil surface contributes to relatively high plant available water later within the growing season (McAuliffe 1994; Duniway and others 2010), and is likely one contributing factor to the resistance and resilience exhibited by these two ecological sites. However, it should also be noted that a large percentage of these sites were in the shrubland state by the 1930s, and these states appear to have been fairly stable for the ensuing ~70 years.

Vegetation Dynamics of Gravelly Soil Ecological Sites

There are three ecological sites characterized by gravelly surface textured soils within MLRA 42 – gravelly (ref #R042XB010NM), gravelly loam (ref #R042XB035NM), and gravelly sand (ref #R042XB024NM). Like the sandy textured ecological site group, these three ecological sites are fairly common across the northern Chihuahuan Desert, occupying nearly 20 percent of the region and about 30 percent of the area studied here. Our results for the vegetation dynamics across these three gravelly type ecological sites are presented in figure 6.

The gravelly sand ecological site has exhibited dynamics similar to the deep sand ecological site within this study area in MLRA 42. Vegetation states

across this site were predominantly either shrub-dominated or shrubland in the 1930s, and by 2005 most states were shrubland. Conversely, both the gravelly and the gravelly loam ecological sites exhibited an increase in the grass-dominated state from the 1930s to 2005. Although shrubland states are thought to be very stable, (Havstad and others 1999), we uncovered evidence of substantial grass recovery. These dynamics could be attributed to a combination of factors, including implementation of management practices such as shrub control, or the occurrence of climatic events that promoted successful grass regeneration. Our approach to reclassifying the 1930s map may also give the impression of state changes where no real changes have occurred, since small differences in the ordering of plant species listed for a polygon could mean the difference between a grass-dominated or shrub-dominated classification. It is also possible that map producers in the 1930s and 2005 used somewhat different parameters for defining species dominance. Because of these uncertainties in how the historical data were created, the line separating the grass-dominated and shrub-dominated states is likely less well defined than those separating other pairs of classes. The opportunity exists to further examine responses of specific areas within these sites to historical landscape treatments where records of treatment and response are available.

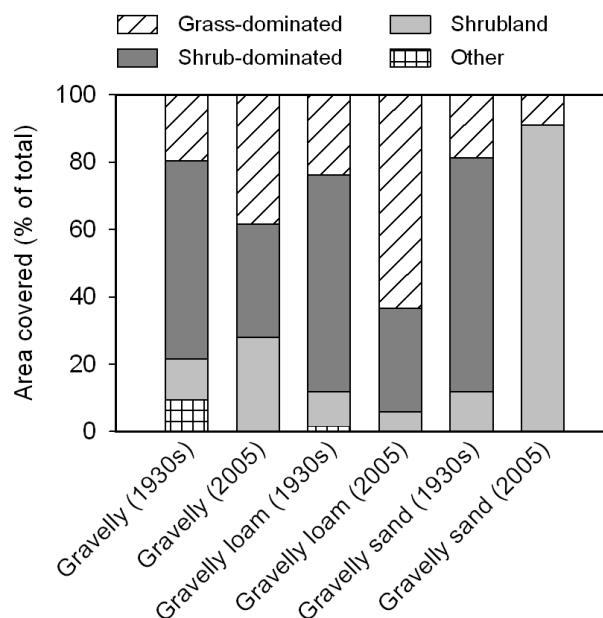


Figure 6. Vegetation state changes between the 1930s and 2005 delineated by the three principal gravelly type ecological sites within the study area.

MANAGEMENT IMPLICATIONS

There are 18 principal ecological sites within the study region. Major state changes between the 1930s and 2005, involving either increased grass dominance or increased shrub dominance, occurred in 11 of these ecological sites. Significant increases in shrubs occurred in only four ecological sites (figure 4). These sites were sandy, deep sand, shallow sandy, and gravelly sand. All other ecological sites within the region were relatively stable over the ~70 year period between observations. Although more detailed, site-specific studies are needed to reinforce the conclusions of this broad scale analysis, one clear management implication is the importance of stratifying by ecological site for application of shrub control treatments and in prioritizing management interventions or monitoring.

ACKNOWLEDGMENTS

Dr. Caiti Steele played a central role in developing the contemporary state map for MLRA 42. Zach Edwards supervised and provided technical guidance for the digitization of hardcopy 1930s range survey maps.

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