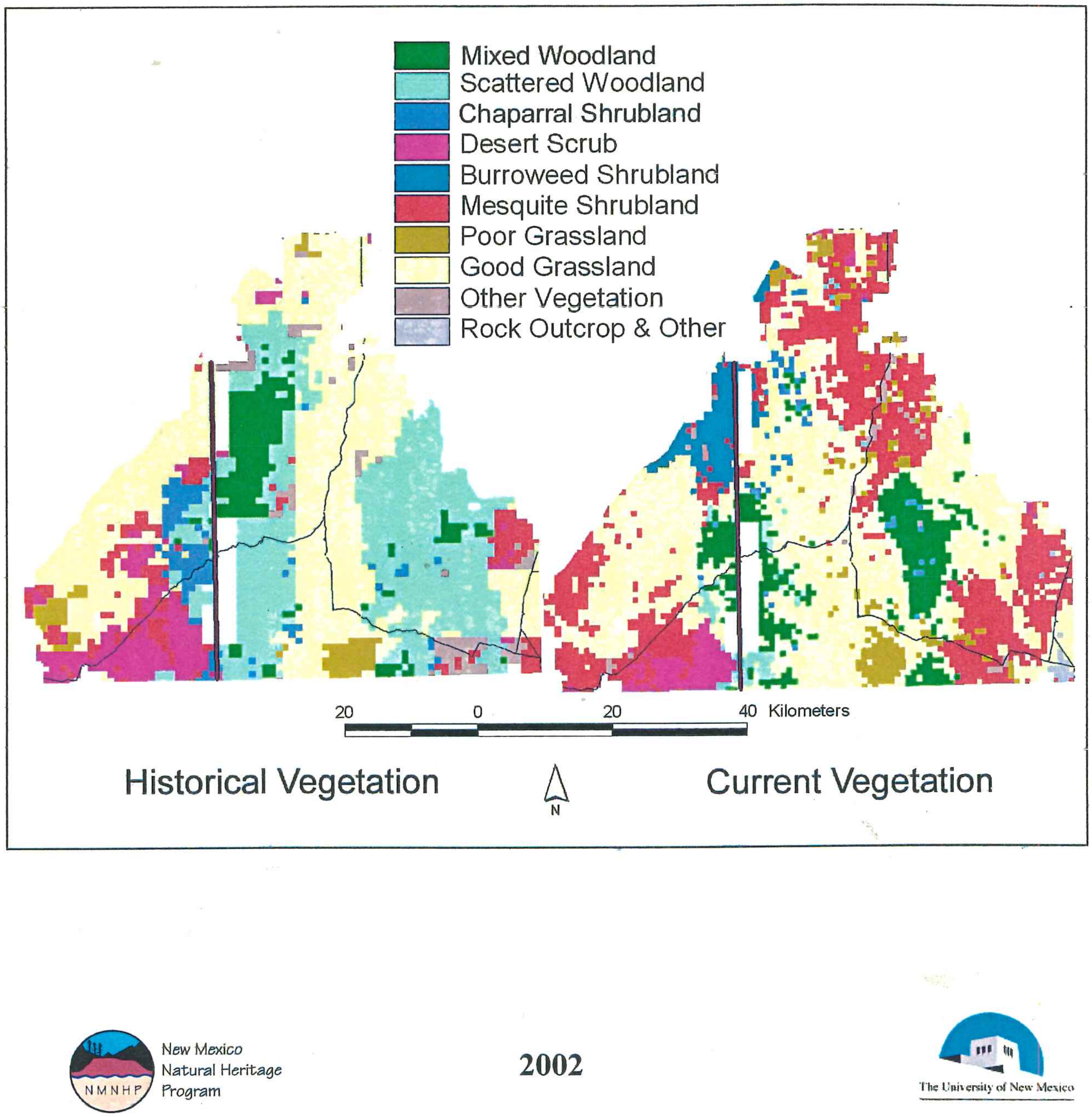
Soils, Geology and Vegetation Change in the Malpais Borderlands



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Soils, Geology and Vegetation Change in the Malpais Borderlands[1]

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INTRODUCTION

Recently, maps of current vegetation, soils, and geology have been completed within the Malpais Borderlands area of southeastern Arizona and southwestern New Mexico (Muldavin, Archer and Neville 1998, McGuire 1998, and Biggs et al. 1999). In addition, Rich, Muldavin and Valone (1999) completed a map of historical vegetation of the area based on reconstructing past vegetation patterns from the general land survey records dating back to the 1880s. Using these maps and associated databases, we evaluated the relationships between vegetation types, soils and geological substrates in a historical context. Of particular interest was the correlation between vegetation change and soil-geologic properties such as the substrate age, texture, and mineralogy, and to what degree changes might reflect a desertification process and a loss of productivity. Understanding the degree of change that has occurred over this 80-to-140-year time frame (desertification or not) can provide insight into the potential for restoration. In other words, determining the dynamic range of an ecosystem help to shape our management expectations with respect to long-term resource recovery and sustainability.

STUDY AREA

The Malpai Borderlands study area is located on either side of the border in southwestern New Mexico (the "Bootheel") and southeastern Arizona (Figure 1). This area has been the focus of an ecosystem management initiative by the US Forest Service that has led to an upgrading of resource maps of soils, geology and vegetation. The entire area was included for the development of the current vegetation map and subsequent historical reconstruction. Since soils and geology maps were only available for the San Bernardino Valley on the Arizona side, the analysis of vegetation, soils and geology correlations was restricted to this area.

METHODS

In order to make comparisons, the historical and current vegetation maps needed to be brought into some degree of congruity with respect to resolution and content. Our approach was to take the high-resolution current vegetation map of Muldavin, Archer and Neville (1998) that was derived from Thematic Mapper (TM) satellite imagery and generalize it to match the vegetation map units and ¼-square-mile (0.65 sq km) spatial resolution of the historical

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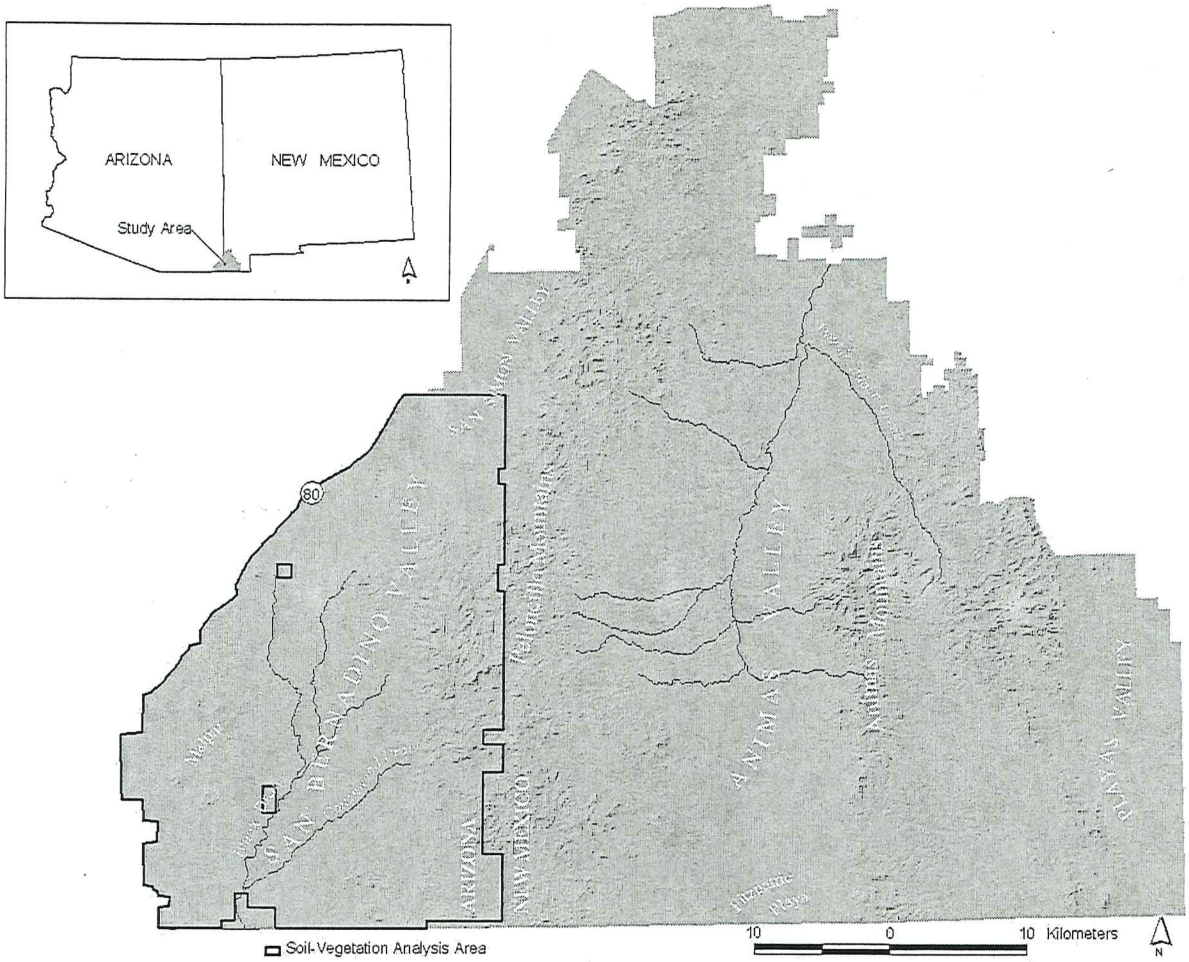

Figure 1. The Malpai Borderlands study area. The entire area was included for the historical vegetation reconstruction and current vegetation map. The soil, geology and vegetation analysis was restricted to the San Bernardino Valley on the Arizona side.

reconstruction of Rich, Muldavin and Valone (1999). The crosswalk between the modern units and the historical ones is given in Table 1. Spatially, a simple majority filter was applied to the current vegetation map wherein all 30m TM pixels within a given ¼ square mile (corresponding to the historical reconstruction) were assigned to the majority map class for that ¼ square mile (Figure 2). There are likely cases where differences between current and historical maps could be structural rather than representing real differences on the ground (such as differences in definition of what constitutes "sparse" woodlands). Hence, as a partial check on the map analysis, we used 384 ground plots with actual percent cover values and directly classified these plots according to the new, generalized map units. This generated a consistent and accurate data set for comparison to the historical map. The even more precise approach of ground truthing the actual land survey section lines was beyond the scope of this project.

For the soils and geological analysis, the soil map units of McGuire (1998) were first correlated with geological-geomorphological units of Biggs et al. (1999) for the San Bernardino Valley. Then, using the geological-geomorphological map as the base, a more generalized geo-edaphic map incorporating geology and soils information was generated that was appropriate for the spatial and content scale of the historical vegetation analysis (Appendix A). The geological and soils characteristics of the new geo-edaphic units are provided in Table 2. The geo-edaphic map units fall into four broad categories that we refer to in the analysis: limestone derived soils (Table 2a); mostly Quaternary alluvial soils with mixed mineralogy (Table 2b); soils on or derived from Quaternary volcanic basalts of the "Malpai" (Table 2c), and soils of Tertiary rhyolytic and andesitic volcanics of the Peloncillo Mountains (Table 2d). All map layers were entered into an ArcView GIS and direct comparisons made between historical and current vegetation distribution with respect to geological substrate, soil characteristics, age and productivity.

RESULTS

General trends in vegetation change

From the1880s to the present there were significant changes in overall vegetation composition within the Malpai Boderlands area (Figure 3), but some portions of the landscape and particular vegetation types changed more dramatically than others. For example, large areas that were good grasslands in the 1880s changed to poor grasslands with shrubs (poor grasslands include burroweed shrublands). This is particularly evident along the alluvial fan piedmonts of the northern portion of the Animas Valley that were recorded by surveyors as good grass country with no mesquite in the 1880s that are now predominately poor grass with scattered to dense mesquite (Figure 2). In fact, according to Rich, Muldavin and Valone (1999) there is little or no mention of mesquite in the 1880s record throughout the study area (except in riparian draws); the first major upland record comes at 1900 in the southern San Bernardino Valley. The mesquite in the Playas Valley and in the foothills of the southern Animas Mountains does not appear in the record until the 1920s. Similarly, to the west in the San Simon Valley and north of the Malpai lava flow, good grasslands were recorded during the 1880s that are now predominantly burroweed shrubs with annual grasses. Overall, of the estimated 1,230 sq km of historical good grassland, over 30% (375 sq km) had significant mesquite encroachment and another 18% had

Table 1. Generalized vegetation map units derived through a crosswalk between the current vegetation map units of Muldavin, Archer and Neville (1998) and the historical vegetation reconstruction of Rich, Muldavin and Valone (1999). Map unit numbers or abbreviations are in parentheses.

Current Vegetation	New Map Unit	Historical Vegetation
Chihuahuan Pine, Ponderosa Pine, and Douglas-fir Montane Forest Mexican Pinyon Pine Montane Woodland [dense] Emory and Arizona White Oak Foothill Woodlands [medium]	Mixed Woodland (MW)	Woodland (59) Fair or Undefined Grass/Woodland
Alligator and Oneseed Juniper Foothill Woodlands [scattered]	Scattered Woodland (SW)	Good Grass/Scattered Woodland Fair or Undefined Grass/Scattered Woodland Poor Grass/Scattered Woodland Scattered Woodland
Toumey Oak, Pointleaf Manzanita and Mountain Mahogany Shrublands	Chaparral Shrubland (CS)	Poor Grass/Chaparral Good Grass/Scattered Chaparral Good Grass/Chaparral Fair or Undefined Grass/Scattered Chaparral Fair or Undefined Grass/Chaparral Scattered Chaparral Chaparral
Sandpaper Bush Foothill Desert Shrubland Viscid Acacia Foothill Desert Shrubland Viscid Acacia or Ocotillo Foothill Shrublands with Black or Sideoats Grama Creosote Bush Piedmont Desert Shrubland	Desert Scrub (DS)	Good Grass/Scattered Desert Scrub Good Grass/Scattered Unknown Shrubs Good Grass/Desert Scrub Fair or Undefined Grass/Scattered Desert Scrub Fair or Undefined Grass/Desert Scrub Poor Grass/Desert Scrub Desert Scrub

Table 1 (continued). Generalized vegetation map units derived through a crosswalk between the current vegetation map units of Muldavin, Archer and Neville (1998) and the historical vegetation reconstruction of Rich, Muldavin and Valone (1999). Map unit numbers or abbreviations are in parentheses

Current Vegetation	New Map Unit	Historical Vegetation
Honey Mesquite Desert Shrubland with Grama Grasses	Mesquite Shrubland (MS)	Good Grass/Scattered Mesquite
Honey Mesquite or Viscid Acacia Basin Shrubland with Tobosagrass [lava]		Good Grass/Mesquite
Blue Grama or Hairy Grama Piedmont Grasslands with Honey Mesquite		Fair or Undefined Grass/Scattered Mesquite
		Fair or Undefined Grass/Mesquite
		Poor Grass/Mesquite
		Scattered Mesquite
		Mesquite
Burroweed-Purple Threeawn Basin Shrubland	Poor Grassland (PG)	Poor Grass
Blue Grama-Purple Threeawn or Sparse Hairy Grama/Featherplume		
Purple Threeawn Basin and Piedmont Grassland		
Creeping Muhly, Annual Grasses, or Vine Mesquite Grasslands		
Hairy Grama and Sideoats Grama Foothill Grasslands	Good Grassland (GG)	Good Grass
Hairy Grama or Blue Grama Piedmont-Foothill Grasslands with Sacahuista		Fair or Undefined Grass
Rock Outcrop or Sparse Grama Foothill Grasslands		
Blue Grama or Hairy Grama Piedmont Grasslands		
Black Grama-Blue Grama Piedmont Grassland		
Black Grama Piedmont Grassland		
Black Grama or Tobosagrass Basin Grasslands		
Tobosagrass Lava Grasslands		
Tobosagrass or Tobosagrass-Blue Grama Basin Grassland		
Mesa Dropseed-Blue Grama Basin Grasslands		
Giant Sacaton or Alkali Sacaton Basin-Swale Grasslands		
Various riparian, rock outcrop, barren ground map units	Other (OT)	No Trees

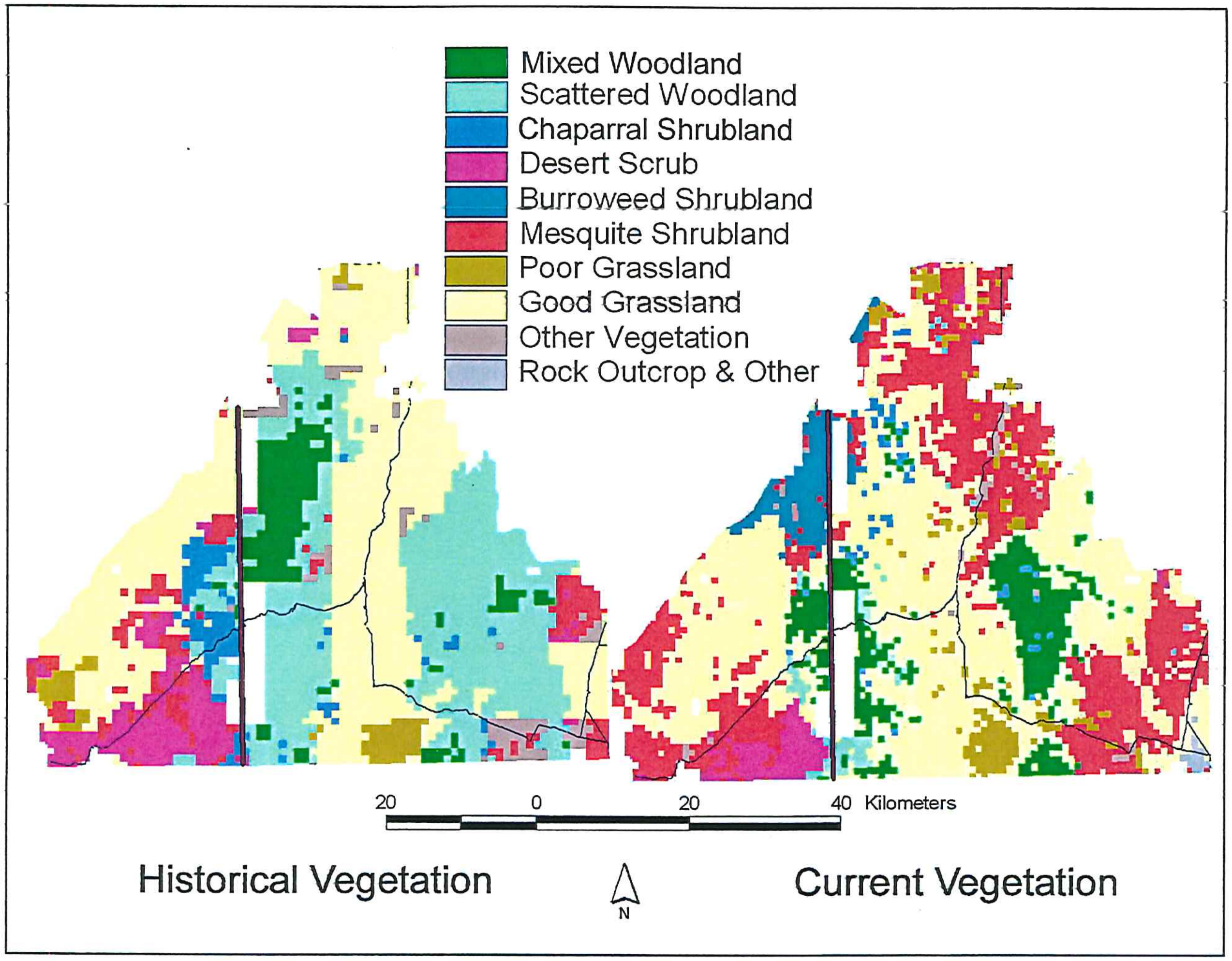

Figure 2. Malpai Borderlands historical vegetation (based on general land survey records from the 1880s through 1920s) compared to current vegetation (derived Thematic Mapper satellite imagery). Minimum polygon size is ¼ of a survey section (0.65 sq km).

Table 2a. Geo-edaphic (GE) map units of the San Bernardino Valley – limestone bedrock-derived soils. GE units correspond spatially to one or more geologic units of Biggs et al.(1999) and are named accordingly. The dominant soils correlated with the GE units are indicated along with a suite of edaphic characteristics: soil subgroup and family texture class based on the soil taxonomy; depth class (D); available water capacity class (W); general landform; generalized potential and current vegetation class, and normal average annual vegetation production (lbs/ac) for the soil unit (see McGuire (1998) for details).

GE MU No.	GE Map Name.	Geologic Unit Symbol	Soil MU No.	Dominant Soil Associations	Soil Subgroup	Texture Class	D[1]	W[2]	Landform	PV[3]	CV[3]	Prod. lbs/ac
1 L	Limestone Mesozoic & Paleozoic bedrock	MPz, Kb, Kl, Km, Kc, Kcc, Kcl, Pe, Pc, P^{3}e, P^{3}eh	1080	Yarbam Rock Outcrop	Lithic Haplustoll	Loamy-skeletal	5	1	Hills	GG	GG	1100
			1220	Mabray Rock Outcrop	Lithic Ustic Torriorthent	Loamy-skeletal	4-5	1	Hills	GG	GG/ PG	900
			1215	Maybray	Lithic Ustic Torriorthent	Loamy-skeletal	4-5	1	Hills	GG	GG/ DS	900
				Chiricahua Rock Outcrop	Ustic Haplargid	Clayey						
10 LC	Limestone colluvium	Qcl	1230	Sutherland Mule	Calcic Petrocalcid Ustic Haplocalcid	Loamy-skeletal	5 1	1 2-3	Fan terraces	DS	DS	400

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[1] 1=Very Deep (>60 in), 2=Deep (40-60 in),3=Moderately Deep (20-40 in), 4=Shallow (10-20 in), 5=very shallow (<10in)

[2] 1=Very Low (0-3 in/60 in soil profile), 2=Low (3-6 in/60 in), 3=Moderate (6-9 in/60in), 4=High (9-12 in/60in), 5=Very High (>12/60 in soil profile)

[3] GG = goodgrass, PG = poor grass, DS = desert scrub, MS = mesquite scrub, SW = scattered woodland, and MW=mixed woodland, and OV=other vegetation

Table 2b. Geo-edaphic (GE) map units of the San Bernardino Valley – alluvial soils.

GE MU No.	GE Map Name.	Geologic Unit Symbol	Soil MU No.	Dominant Soil Associations	Soil Subgroup	Texture Class	D[1]	W[2]	Landform	PV[3]	CV[3]	Prod. Ibs/ac
4 TQA	Late Tertiary to Quaternary alluviual deposits, basin fill	Tsy, TQo	23	Stronghold Bernardino	Ustic Haplocalcid Ustic Calciargid	Coarse-loamy; fine	1 1	1-2	Fan terraces	GG	PG	900 850
			1110	Blakeney Luckyhills	Ustic Petrocalcid Ustic Haplocalcid	Loamy Coarse-loamy	1-2 5	1 3-4	Fan terraces	DS	DS	500 500-600
12 EPA	Early to Middle Pleistocene alluvial fan deposits	Qm, Qm$_1$, Qmo	1265	Kahn Zapolote	Ustic Haplocalcid Usteric Calciargid	Fine-loamy; fine	1	3 4	Relict basin floors and alluvial fans; low fan terraces	DS GG	DS GG	300 500
			1235	Eloma Caralampi White	Ustic Haplargids	Clayey-skeletal; loamy-skeletal; fine	1	1-2 2 2-3	Fan terraces	GG	MS	1000
5 MPA	Middle to late Middle Pleistocene alluvial deposits	Qm$_2$	271	Sasabe	Ustic Paleargid	Fine	1	5	Fan terraces; swales	GG	MS	1200 - 2000
15 LPA	Late Pleistocene alluvial deposits	Qml, Ql	1320	Mallet Hooks	Ustic Haplocambid Ustic Camborthid	Coarse-loamy fine-loamy	1	2 4-5	Stream terraces; alluvial fans	GG	PG	1000 1200
7 HOA	Holocene to Recent alluvial deposits, including active channels	Qly, Qy	1100	Guest Riveroad	Usteric Torrifluvents Ustic Torrifluvents	Fine fine-silty	1	3-4	Flood plains; stream terraces	GG	MS GG	2000 – 3000
			21	Riverwash Bodecker	Ustic Torriorthent	Sandy-skeletal	5	1	Flood plains	GG	DS MS OV	

Table 2c. Geo-edaphic (GE) map units of the San Bernardino Valley –basalt volcanic soils.

GE MU No.	GE Map Name.	Geologic Unit Symbol	Soil MU No.	Dominant Soil Associations	Soil Subgroup	Texture Class	D[1]	W[2]	Landform	PV[3]	CV[3]	Prod. Ibs/ac
6 HB	Holocene to Recent playa lake deposits	Qyp	672	Guest	Ustertic Torrifluvents	Fine	1	4	Floodplain	GG	GG	2000
2 LPV	Late Pleistocene alluvial veneer over basalt flows	Qli	1290	Eloma	Ustic Haplargid	Clayey-skeletal	1	1	Fan terraces	GG	DS MS	1100
			1305	Elgin Outlaw	Calcic Paleargid Typic Calcictorrert	Fine	1	4	Fan terraces	GG	PG GG	1000
13 MPV	Middle Pleistocene alluvial veneer over basalt flows	Qm$_2$, Qmi, Qm$_{1i}$	1305	Elgin Outlaw	Calcic Paleargid Typic Calcictorrert	Fine	1	4	Fan terraces	GG	PG GG	1000
			7	Elgin Stronghold	Calcic Paleargid Ustic Haplocalcid	Fine Coarse-loamy	1	4	Fan terraces	GG	PG	1000 900
9 QF	Quaternary basalt lava flows, tuff and dikes	Qbf, Qbpt, TQbf, Tb, Qcb, Qab, Tc	1190	Outlaw Epitaph Paramore	Typic Calcitorrert Petrocalcic Calcitorrert Leptic Haplotorrert	Fine	1 3 3	3-4 2 1-2	Lava flows	GG	GG	1000
8 QCC	Quaternary volcanic vent deposits (cider cones)	Qbp, Qbvl, Qbpc, Qbpb	1195	Boss Krentz Paramore	Lithic Ustic Haplargid Vitrandic Haplocambid Leptic Haplotorrert	Clayey loamy-skeletal fine	4-5 1 3	1 2-3 2	Cinder cones	GG	GG MS	700 - 1000
14 QS	Surge pyroclastic deposits around maar craters	Qps	1310	Surge	Lithic Ustic Torriorthent	Loamy	4-5	1	Volcanic surge conglomerate rings	GG	PG	400
3 HC	Holocene to Recent colluvial deposits	Qc		Not defined								

Table 2d. Geo-edaphic (GE) map units of the San Bernardino Valley – rhyolite and andesite volcanic soils.

GE MU No.	GE Map Name.	Geologic Unit Symbol	Soil MU No.	Dominant Soil Associations	Soil Subgroup	Texture Class	D[1]	W[2]	Landform	PV[3]	CV[3]	Prod. Ibs/ac
11 TV	Tertiary rhyolite and andesite volcanics	Tru, Tr, Ttr, Tt, Tsc, Tscn, Tdc, Tdm, Tco, Tql, Tdx, Tro, Tax, Ttax, Ttx, Ttu, Ttun, Ttw, Tto, Ta, Tai, Tfi	1270	Cherrycow Magoffin Rock Outcrop	Aridic Argiustols; Lithic Haplustolls	Fine loamy	3/4 5	2 1	Hills and mountains	GG SW	GG SW	900 - 1100

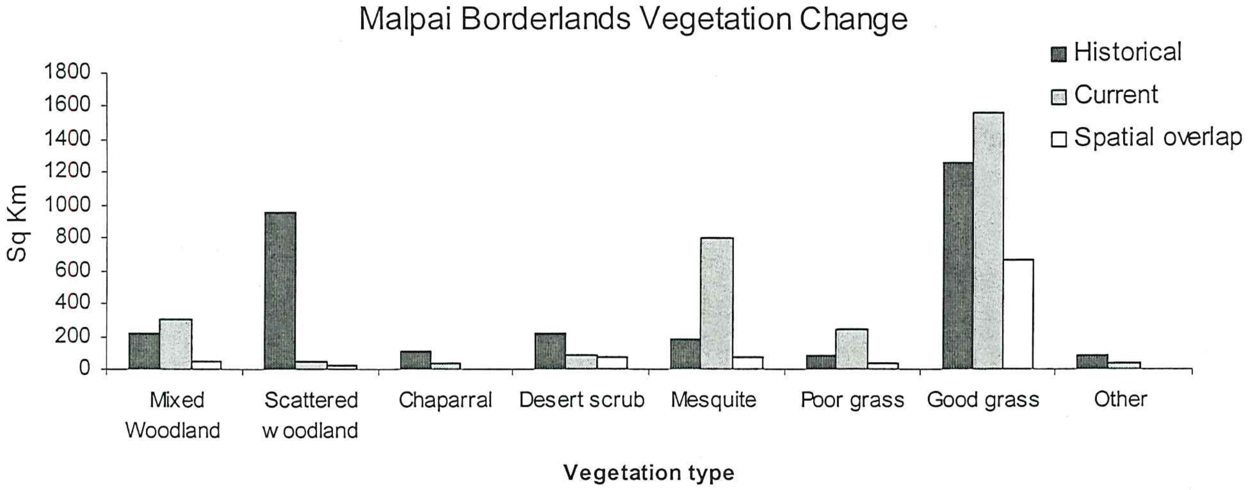

Figure 3. Vegetation change by major vegetation type in the Malpai Borderlands (poor grass includes burroweed shrublands). Overlap indicates the degree of spatial one-to-one correspondence between the historical and modern vegetation on a ¼ section basis (0.65 sq km).

been degraded to poor grassland (Figure 4a). That is to say, over 60% of what is now poor grassland was good grassland in the past (Figure 4b). Similarly, over 50% of current mesquite shrublands were mapped as good grasslands historically (Figure 5b). In contrast, there is some suggestion that historical mesquite, while limited in extent, had undergone a transition to good grassland (Figure 5a). This might represent mesquite treatments by mechanical, herbicidal or fire means, or, alternatively, an under representation of mesquite in the modern map (low densities of trees and shrubs are often difficult to detect with TM satellite imagery). This aside, an overall desertification trend in grasslands seems apparent, and is corroborated by field plot data. Of the133 plots that were mapped historically as good grass, over 45% have shifted to mesquite, desert scrub or poor grass (Table 3).

There were still significant amounts of mapped current good grass, in fact more now than registered in the historical map (1541 sq km), yet only 43% of this overlapped the historical distribution (Figure 3). Most of the additional "new" good grassland came from what was mapped historically as woodland, scattered woodland or chaparral (Figures 5b and 7a). This may reflect an opening up of the woodlands by fire or woodcutting, as suggested by the ground data where nearly 60% of current good grass points were recorded as scattered or mixed woodland in the historical map (Table 3). But woodland dynamics are complex. Over 20% of the historical scattered woodland is now mapped as the denser mixed woodland and over 70% of the current mixed woodland was scattered woodland in the past (Figure 6). This suggests a lack a fire and a closing in of the woodlands. Both processes may be happening simultaneously, but in different parts of the landscape over long time periods. In addition, some of this "change" may be a function of resolution and definition error, i.e., the question of what constitutes significant tree cover in this transitional grassland-woodland class, both now and in the past. Overall, woodlands and chaparral shrublands in the foothills and mountains appear to form a shifting mosaic over the past 120 years with a trend towards increased tree density.

Desert scrub exhibited much more restricted dynamics, and most of the change was associated with mesquite encroachment (Figure 5a). Desert scrub is defined here as a mixture of creosotebush (*Larrea tridentate*), acacia (*Acacia neovernicosa*), sandpaper bush (*Mortonia scrabella*) and tarbush (*Flourensia cernua,)* without significant amounts of mesquite. With mesquite encroachment there is now less desert scrub than there was in the past, but as is not the case with grasslands, when mesquite entered the desert scrub stands, it is likely that neither the structure nor overall composition of the stands was significantly altered. As with historical mesquite, some historical desert scrub transitioned to good grass, which may similarly reflect mechanical/herbicide treatments or fire (this pattern is also apparent in the transition of historical desert scrub ground points in Table 3). In contrast, most areas that were mapped as desert scrub today were desert scrub in the past (Figure 5b). This would suggest that factors such as underlying substrate and long-term geomorphic processes are strong controls in the dynamics of these sites (as opposed to short-term climatic flux or landuse history). The ground points are more equivocal on this point (Table 3). Although over 65% of current desert scrub plots were desert scrub in the past, 33% were also poor grassland, suggesting grassland desertification processes.

Table 3. Field plot current vegetation classes cross-tabulated by percent with historical vegetation class derived from the historical reconstruction map. Total *n* = 384.

	n	Historical vegetation (%)								% of Current
		Woodland	Scattered woodland	Chaparral shrubland	Desert scrub	Mesquite shrubland	Poor grass	Good Grass	Other	
n		27	121	9	43	19	12	133	20	384
Curent vegetation (%)										
Woodland	21	11.1	12.4	11.1	0.0	0.0	0.0	1.5	0.0	5.5
Scattered Woodland	48	29.6	24.0	44.4	0.0	5.3	0.0	3.8	5.0	12.5
Chaparral	17	22.2	7.4	11.1	0.0	0.0	0.0	0.8	0.0	4.4
Desert Scrub	46	3.7	2.5	0.0	51.2	15.8	33.3	7.5	15.0	12.0
Mesquite	64	3.7	8.3	11.1	32.6	26.3	16.7	21.1	15.0	16.7
Poor Grass	47	7.4	2.5	11.1	2.3	21.1	25.0	22.6	15.0	12.2
Good Grass	129	22.2	36.4	11.1	14.0	26.3	25.0	41.4	45.0	33.6
Other	11	0.0	5.8	0.0	0.0	5.3	0.0	1.5	5.0	2.9
% of Historical	384	7.0	31.5	2.3	11.2	4.9	3.1	34.6	5.2	100.0

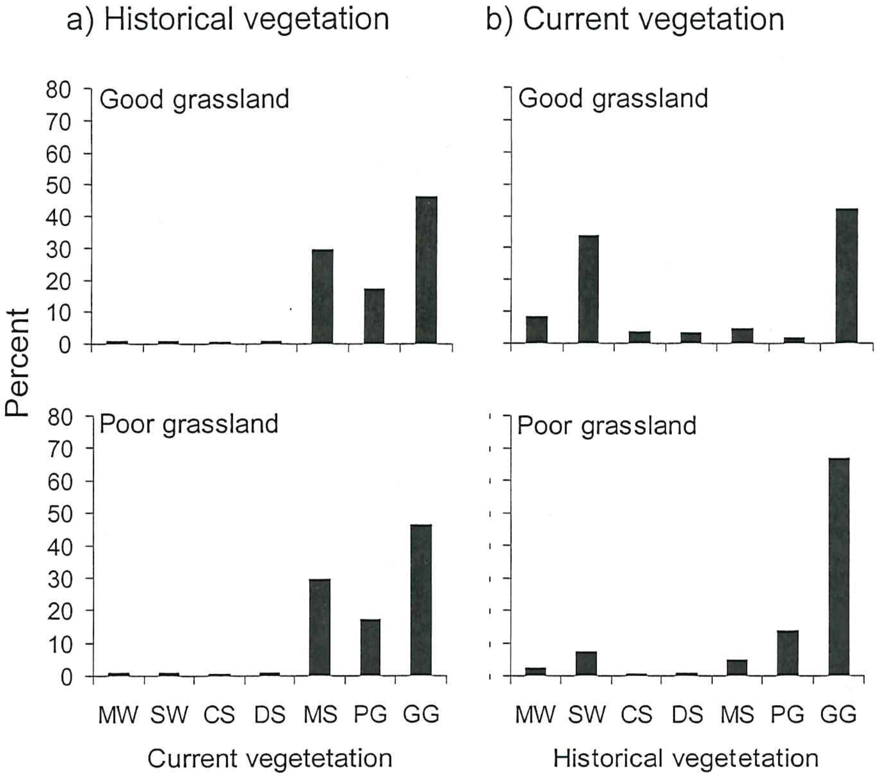

Figure 4. Changes in composition on a percentage basis between historical and current vegetation in good grass and poor grass vegetation types. The dynamics can be viewed from the perspective of (a) how mapped historical vegetation changed, or (b) what the historical distribution was among the currently mapped vegetation types. MW = mixed woodland, SW = scattered woodland, CS = chaparral shrubland, DS = desert scrub, MS = mesquite shrubland, PG = poor grass (including burroweed shrublands), and GG = good grass.

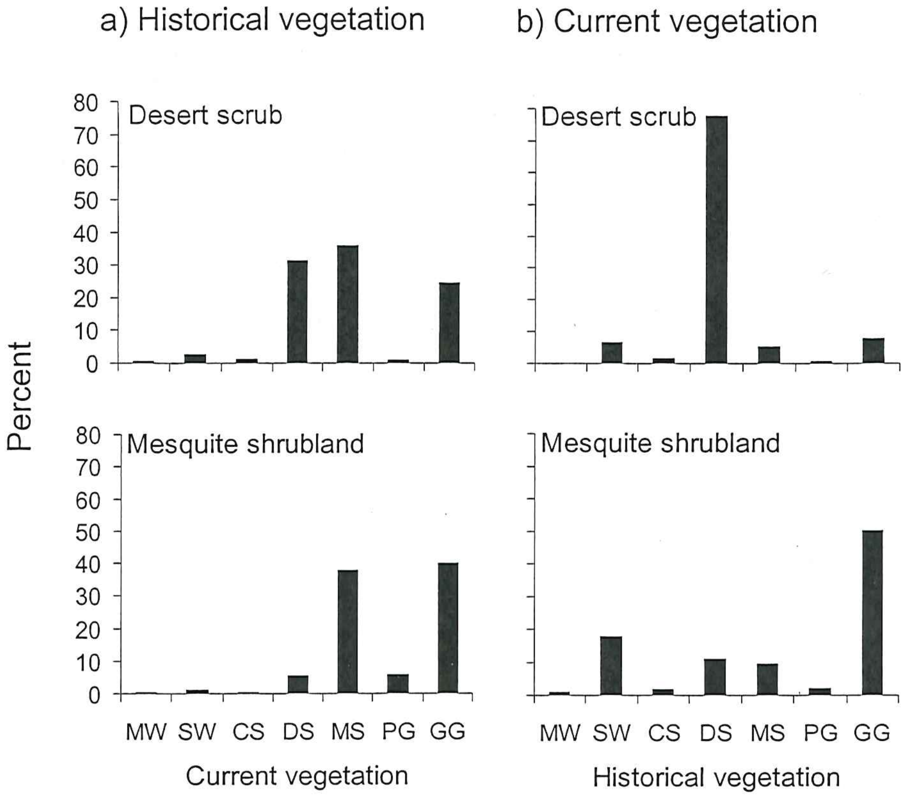

Figure 5. Changes in composition on a percentage basis between historical and current vegetation in desert scrub and mesquite shrubland vegetation types. The dynamics can be viewed from the perspective of (a) how mapped historical vegetation changed, or (b) what the historical distribution was among the currently mapped vegetation types. MW = mixed woodland, SW = scattered woodland, CS = chaparral shrubland, DS = desert scrub, MS = mesquite shrubland, PG = poor grass (including burroweed shrublands), and GG = good grass.

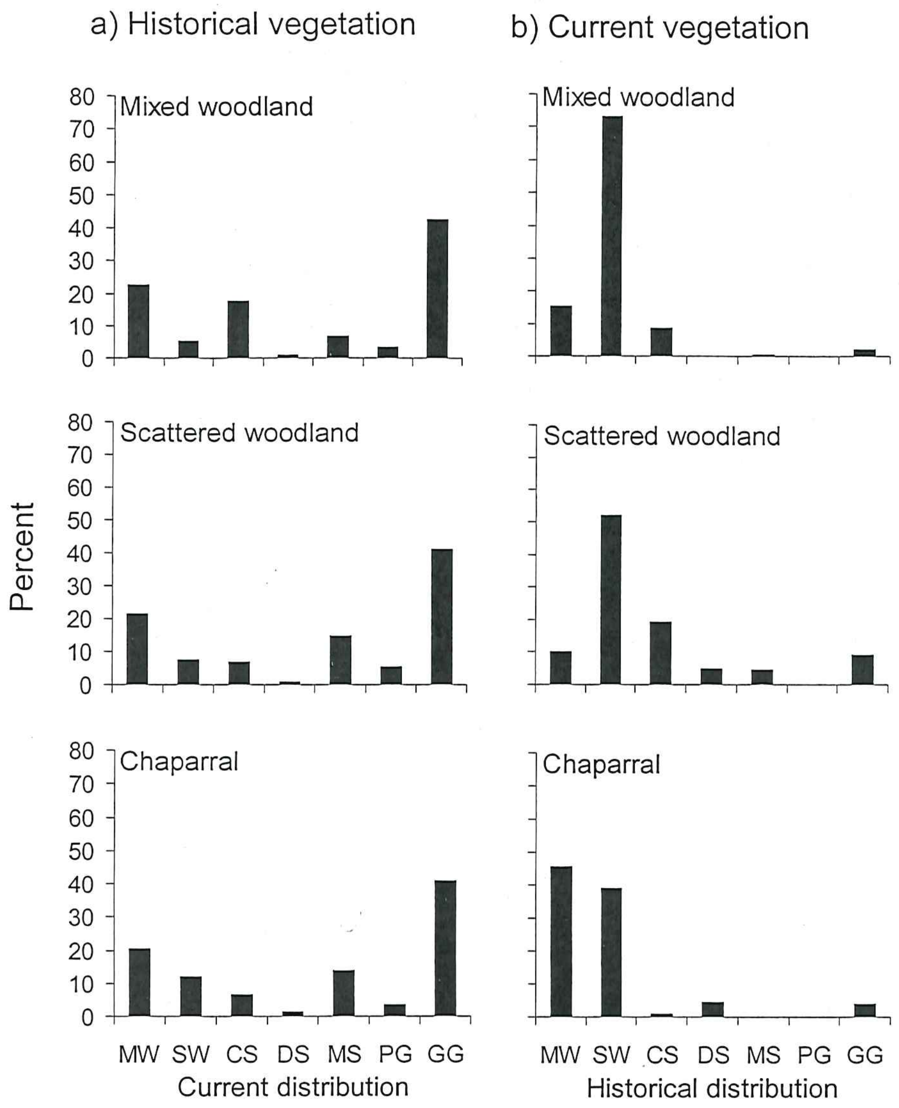

Figure 6. Changes in composition on a percentage basis between historical and current vegetation in mixed woodland, scattered woodland and chaparral vegetation types. The dynamics can be viewed from the perspective of (a) how mapped historical vegetation changed, or (b) what the historical distribution was among the currently mapped vegetation types. MW = mixed woodland, SW = scattered woodland, CS = chaparral shrubland, DS = desert scrub, MS = mesquite shrubland, PG = poor grass (including burroweed shrublands), and GG = good grass.

Vegetation change, soils and geology in the San Bernardino Valley

There were definite patterns of vegetation change in the San Bernardino Valley that were associated with substrate type, age of the soils and the corresponding landforms. The most dramatic changes occurred in areas surrounding the "malpai" lava flows (QF) in the center of the valley (Figure 7). There was also a tendency for greater dynamics with decreasing soil age (Figure 8). The least dynamic soils were the shallow Yarbam and Mabray soils developed on Paleozoic limestone bedrock (L). These soils almost exclusively supported desert scrub communities in the past and continue to do so now (Figure 9). The closely associated Sutherland and Mule soils of limestone colluvium (LC) also remained relatively stable except for encroachment by mesquite.

On mixed alluvial soils, the degree of vegetation change tended to increase with the youth of the soils, culminating with the Late Pleistocene (LPA) and Holocene (HOA) geo-edaphic units (Figure 8). The LPA and HOA soils (Mallet-Hooks-Sasabe association and Guest-Riveroad-Boedecker association, respectively) historically supported a significant amount of good grass, but now they have large components of poor grass and mesquite scrub (Figure 10). These young soils are associated with arroyo terraces, floodplains and alluvial fans, and the degree of change may be associated with direct disturbance from flooding. The older units (TQA, EPA and MPA) are erosional alluvial fans not subject to flooding. The oldest soils (Caralampi, White, Zapolote, Kahn, Bernardino, Blakeney, Lucky Hills and Stronghold) also have some degree of caliche (calcic horizon) development. As with the limestone soils, they tended to be historically dominated by desert scrub, and the main change was an increase in mesquite shrubland.

On soils underlain by lava flows or derived from cinder deposits there was a similar trend of decreasing change with increasing age of soils (Figure 8). Aside from the Tertiary volcanic soils (TV), the Holocene and Pleistocene aged soils (Guest, Eloma, Elgin-Outlaw and Elgin-Outlaw-Stronghold soil associations) were the most dynamic with most of the change reflected in increased mesquite and desert scrub, and a decline in good grass (Figure 11). The older Quaternary soils (Outlaw-Eitaph-Graham, Boss-Krentz-Parmore, and Surge soil associations), which dominate the "malpai" in the center of the San Bernardino Valley were strongly dominated by grass in the past and continue to be so today (mostly by tobosagrass [*Pleuraphis mutica*]).

The tertiary volcanics (TV) of the Peloncillo Mountains are relatively old compared to the basalt lava flows of the basin. The soils (Cherrycow and Magoffin) of this unit are well-developed mollisols, yet they have undergone a significant amount of historical change (Figure 11). Most of this change has centered on shifts in woodland composition and structure as opposed to a shift from desert grassland to scrub, as in other units. Historically, chaparral and scattered woodlands dominated the hillslopes, but now there is more mixed woodland (denser canopy) as well as an increase in good grassland. The increase in grassland may be more a matter of differences in definition of woodland versus grassland, both historically and currently.

With respect to productivity, there was an indication of greater productivity with increasing dynamics, and younger soils (Figure 12). The most productive soils were in Holocene

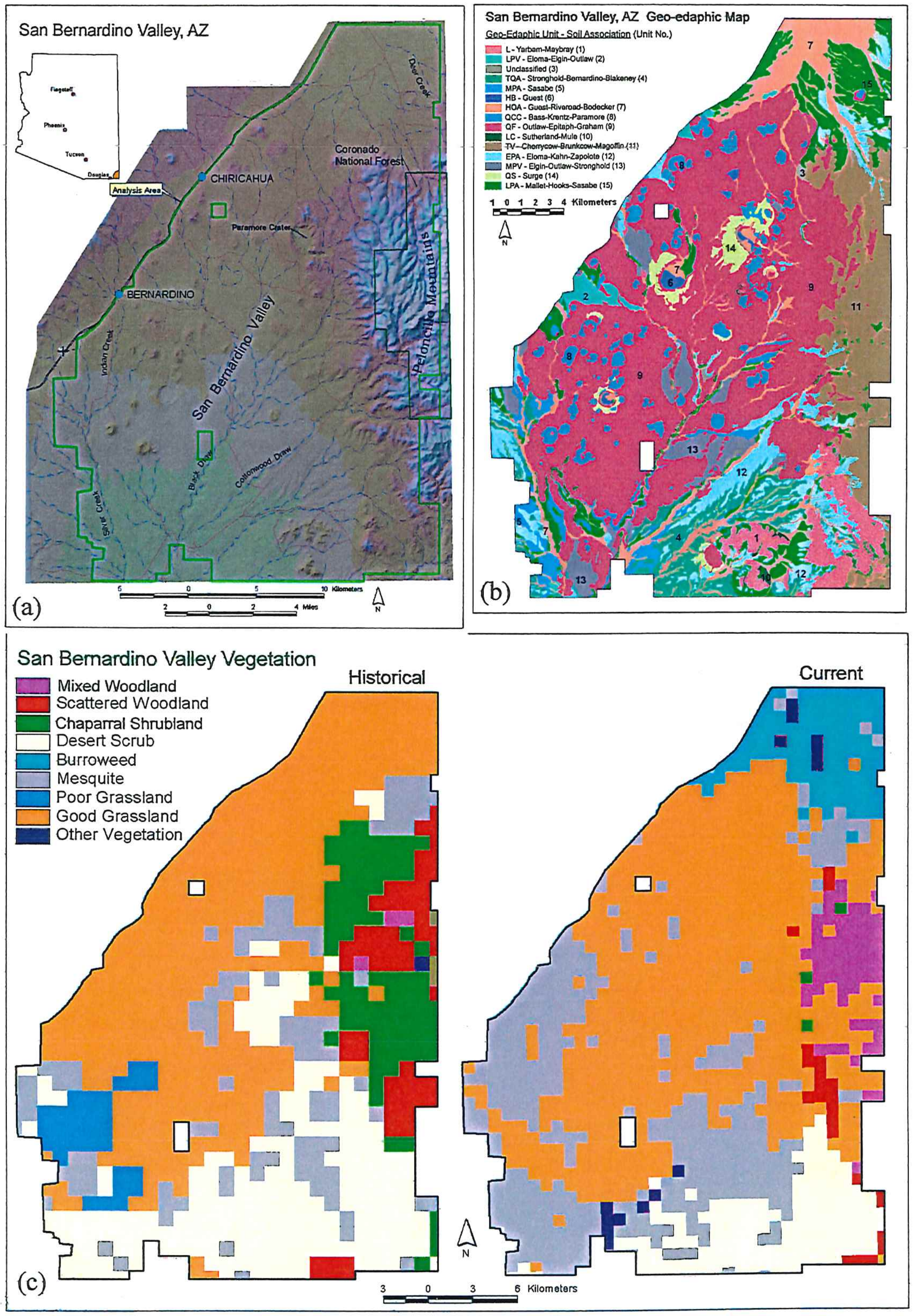

Figure 7. (a) Shaded relief map of the San Bernardino Valley; (b) Geo-edaphic map (see Table 2); (c) historical and current vegetation (burroweed and poor grass are considered together in the analysis).

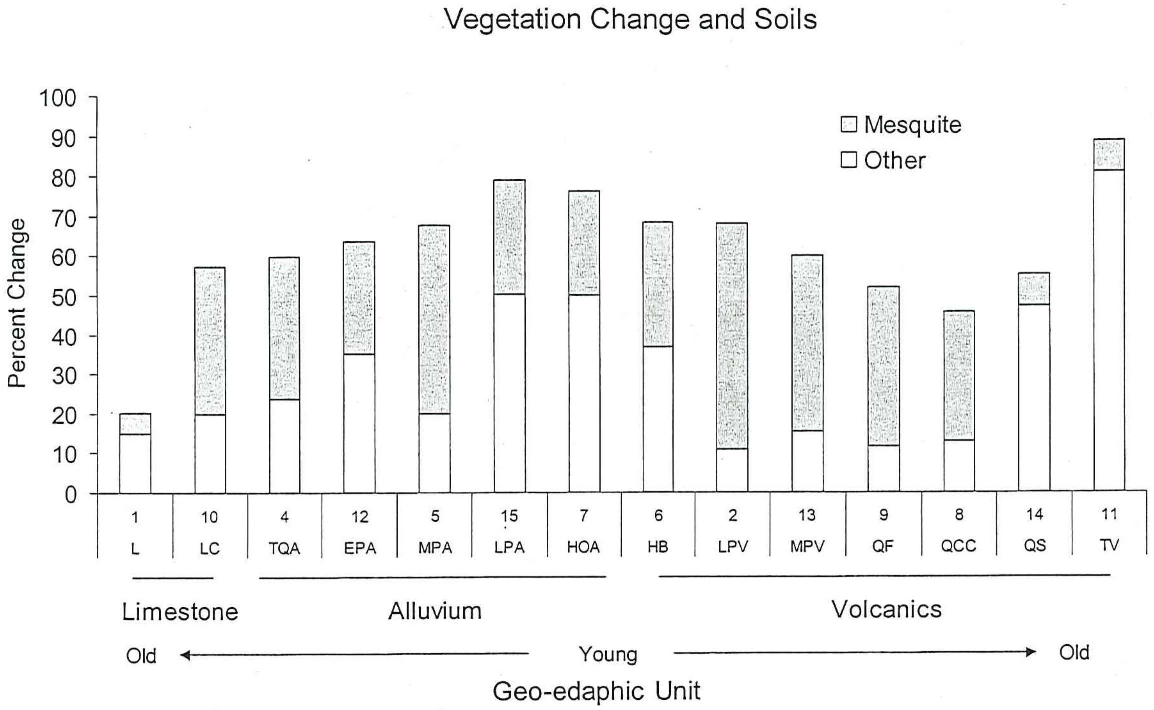

Figure 8. Percent vegetation change by geo-edaphic unit (see Table 2). Units are ordered by substrate and approximate age. Mesquite refers to the amount of mesquite shrubland encroachment.

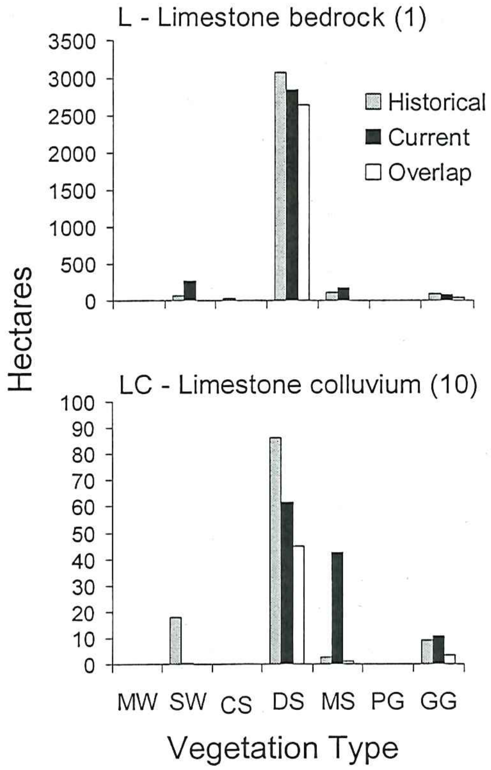

Figure 9. Historical and current vegetation on Cretaceous and Paleozoic limestone substrates. Overlap refers to spatial concordance through time within a given vegetation type. L includes Yarbam and Maybray soils; LC , Sutherland and Mule soils. MW = mixed woodland, SW = scattered woodland, CS = chaparral shrubland, DS = desert scrub, MS = mesquite shrubland, PG = poor grass (including burroweed shrublands), and GG = good grass.

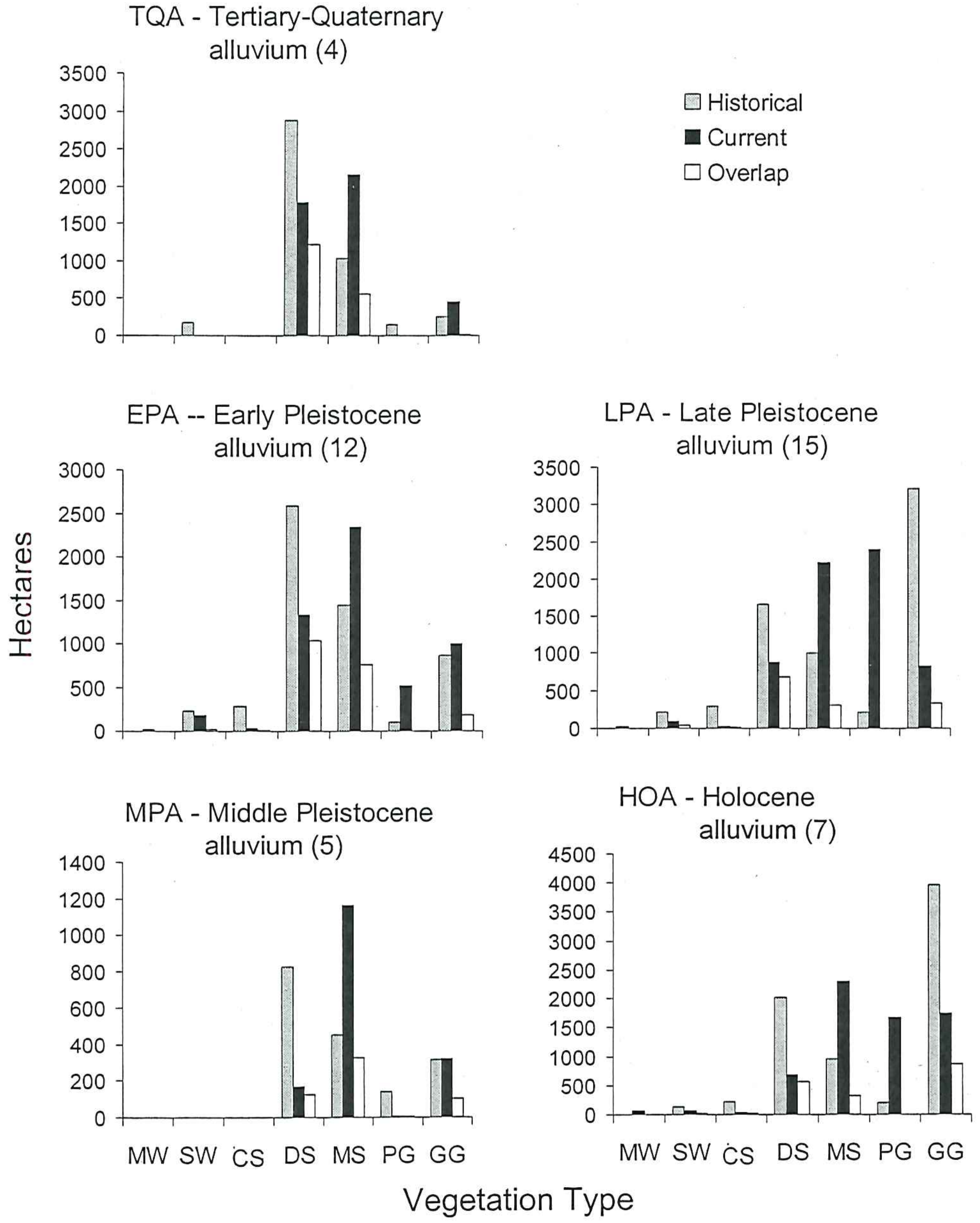

Figure 10. Historical and current vegetation on mixed alluvial soils. Overlap refers to spatial concordance through time within a given vegetation type. See Table 3 for geo-edaphic unit descriptions. MW = mixed woodland, SW = scattered woodland, CS = chaparral shrubland, DS = desert scrub, MS = mesquite shrubland, PG = poor grass (including burroweed shrublands), and GG = good grass.

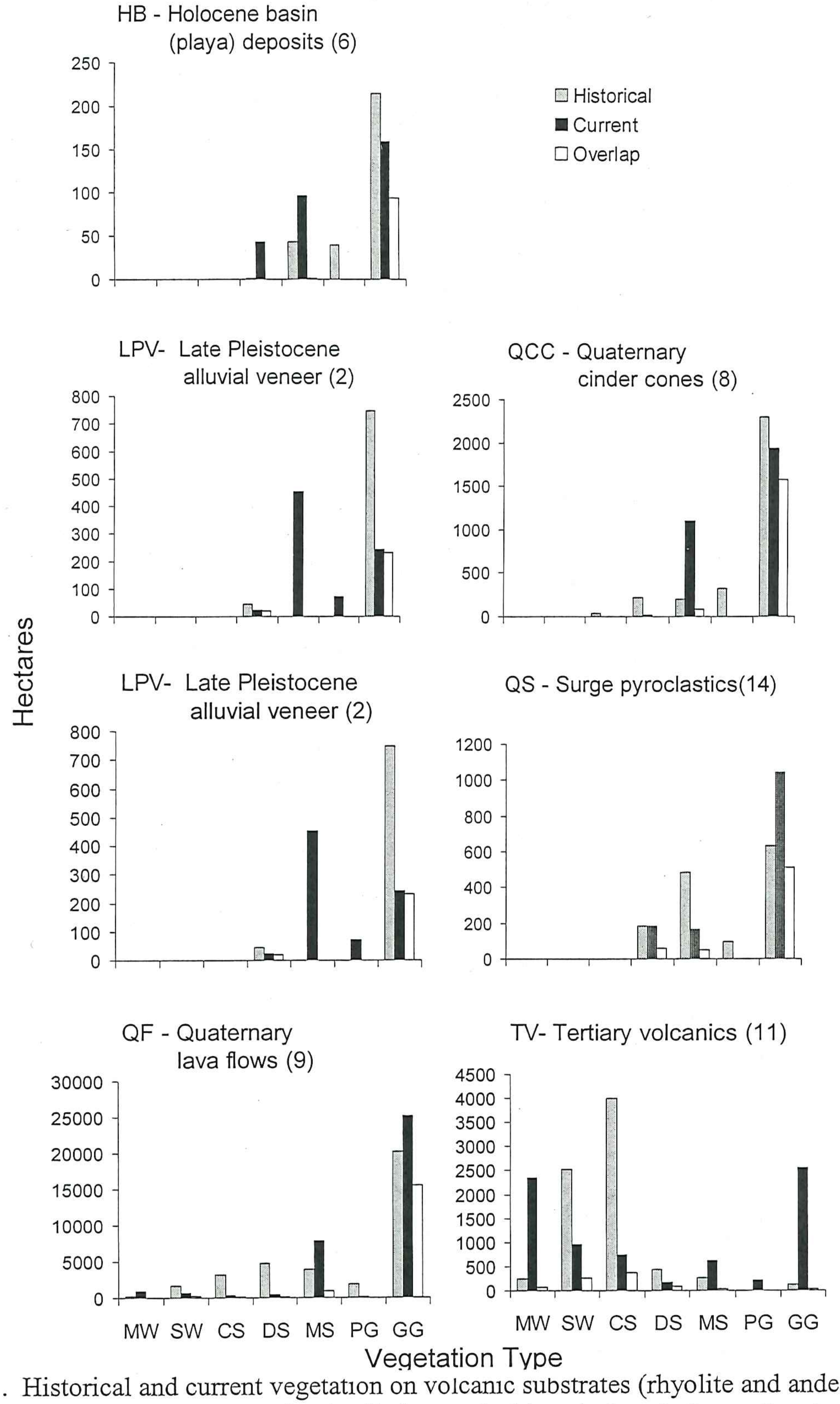

Figure 11. Historical and current vegetation on volcanic substrates (rhyolite and andesite for TV, basalt for all others). See Table 3 for detailed geo-edaphic unit descriptions. Overlap refers to spatial concordance through time within a given vegetation type. MW = mixed woodland, SW = scattered woodland, CS = chaparral shrubland, DS = desert scrub, MS = mesquite shrubland, PG = poor grass (including burroweed shrublands), and GG = good grass.

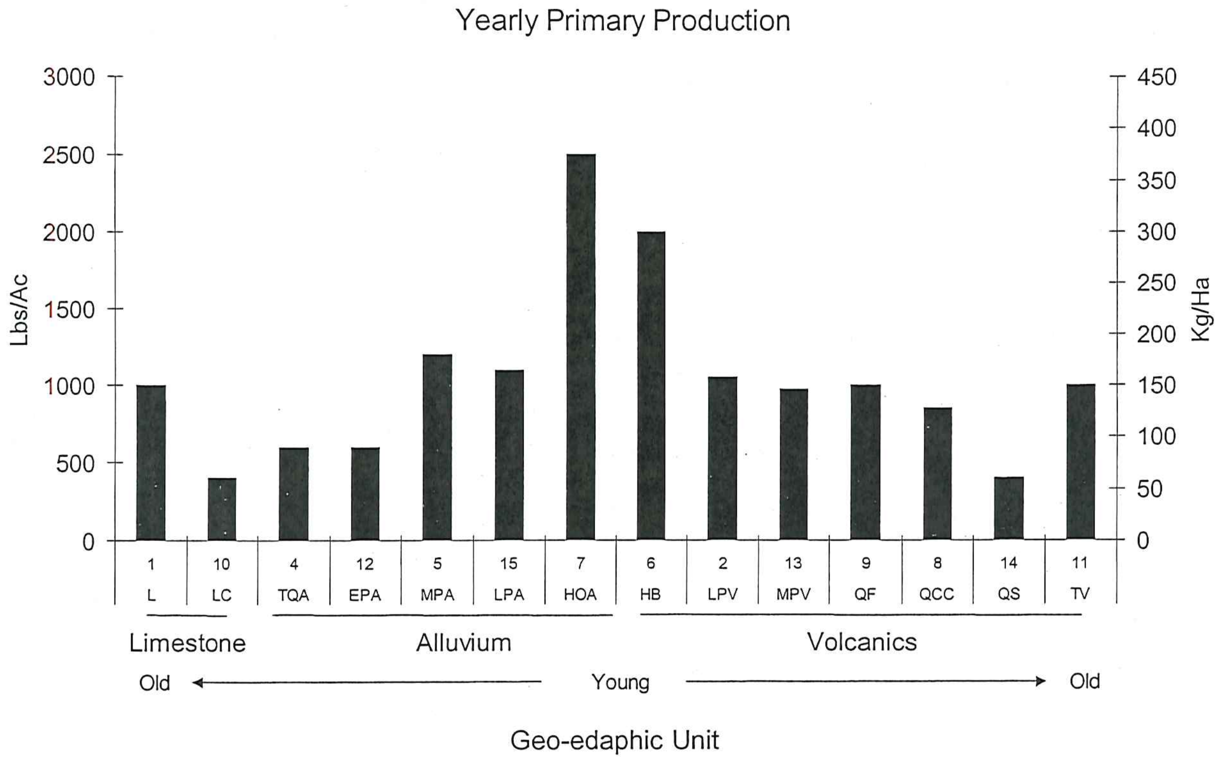

Figure 12. Average primary production by geo-edaphic unit as estimated for each soil type by McGuire (1999). See Table 3 for details by soil series. Geo-edaphic units are ordered by substrate and approximate age.

to Recent alluvial channels and bottoms (HOA and HB), and these were among the most dynamic (Figure 8). The earlier Quaternary soils, both mixed alluvium and those on the lava flows, were much less productive and somewhat less dynamic. Productivity was particularly low on limestone colluvium (LC) soils, which is reflected in the dominance of desert scrub through time in this part of the landscape.

DISCUSSION

There have been many studies that have addressed historical vegetation change in southeastern Arizona and southwestern New Mexico, with a wide variety of opinions on the causes of such change (see Bahre and Shelton 1993). Since some areas changed and others did not, some landscapes are more stable than others with respect to vegetation composition, regardless of climate fluctuations. Therefore, where change has occurred, it is likely to be a function of landuse history, possibly coupled with climatic extremes on sensitive soils with sensitive plants.

In the Borderlands, landuse and associated impacts have varied since the 1880s. The northern San Bernardino and southern San Simon Valleys were historically heavily grazed by sheep and goats, and that likely led to the shift from good grass to poor grass and desert scrub. In contrast, the tobosagrass-dominated soils of the San Bernardino lava flows have undergone little change in the past 100+ years. Whether these sites were once dominated by grama grasses (*Bouteloua* spp.) instead of the more grazing tolerant tobosagrass is unknown. Grazing had less impact on the limestone soils at the southern end of the valley where desert scrub was dominant before heavy grazing became the norm of the 1880s, and most change is related to mesquite invasion into already shrub-dominated systems.

The major changes in the study area were the influx of mesquite and the degradation of historical good grasslands to poor ones. This is in keeping with many reports of this desertification process in the Southwest (see Bare and Shelton 1993; Wilson, Webb and Thompson 2001 for detailed reviews). From a management perspective, the control of mesquite and restoration of poor grass grasslands is problematic. Typical restoration measures often involve some sort of root plowing followed by burning of debris. The younger, more productive soils (HB and HOA) that appear to be more dynamic may respond best to this type of treatment. But most of the other soils are shallow, poorly developed and may effectively be further desertified by the additional disturbance. Disturbance in the past has generated a shift to poor grass with mesquite, and new disturbance is unlikely to remedy the productivity loss.

Some current mesquite shrublands and poor grasslands may have potential for recovery with long-term relief from grazing, coupled with the restoration of a natural fire regime. Wilson, Webb and Thompson (2001) suggest that prescribed programs involving repeated high frequency fire may be the only way to keep mesquite at acceptable levels. Other types of current poor grasslands, such as those found in the low lying Fitzpatrick Playa in the southern Animas Valley, were predominantly poor grasslands in the 1880s (their low status may be a function of periodic flooding), and they are likely to remain poor grasslands into the future, barring a change in hydrological regime.

There is an indication that woodlands have changed significantly, and this may be a function of altered fire regimes since the turn of the century. On the Tertiary volcanic (TV) soils of the Peloncillo Mountains there has been an increase in mixed woodland and a significant drop in chaparral and scattered woodlands suggesting that fire suppression has led to denser canopies and a general shifting of the landscape towards woodland. But simultaneously there has been an increase in good grassland that indicates an increase in fire. This may be the result of mapping error where current savannas are being misclassified or differently classified as good grasslands in the modern map i.e., modern good grasslands are actually scattered woodlands. Yet this is not supported by our field validation data, where many field-verified grasslands were historically mixed and scattered woodlands. An alternative view is that these woodlands may go through transitions over longer time periods beyond the small window of the 130 years examined here. This suggests that the woodland landscape is made up of a shifting mosaic of dense and scattered woodlands, chaparral and grasslands predicated on long fire intervals, perhaps greater than 100 years.

Historical analyses of this sort have their limitations, both in terms of accuracy and precision, and to the degree historical dynamics are or are not relevant to future conditions. In our GIS approach we have attempted to maximize the quantitative attributes of the U.S. General Land Office surveys and current vegetation maps while maintaining a conservative viewpoint with respect to vegetation change, i.e., vegetation changes must be well marked to be considered in the discussion. We see this approach as complementary to other data types with good geographical references such as long-term transects, ground repeat photography or aerial photo time series. These approaches in combination can significantly enhance our understanding of the vegetation history of a landscape. In addition, we think that the linkage to soils and geomorphology has helped put some of the vegetation changes in perspective with the long-term evolution of the landscape, as reflected in soil properties and with respect to climate change. In some portions, vegetation has changed dramatically, while in other it has not, and this likely is a reflection of the degree of soil development coupled with long-term geomorphic processes as they have been affected by short-term historical degradation and climate flux. The relationship of productivity and change is interesting, but there is a need for more quantitative data to confirm production information from the soil survey. Overall, we think this historical analysis approach with its connection to geology and soil characteristics can aid in framing future experiments on vegetation dynamics and help guide ecological restoration in these ecosystems.

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Appendix A

Geo-edaphic map of the San Bernardino Valley, Arizona

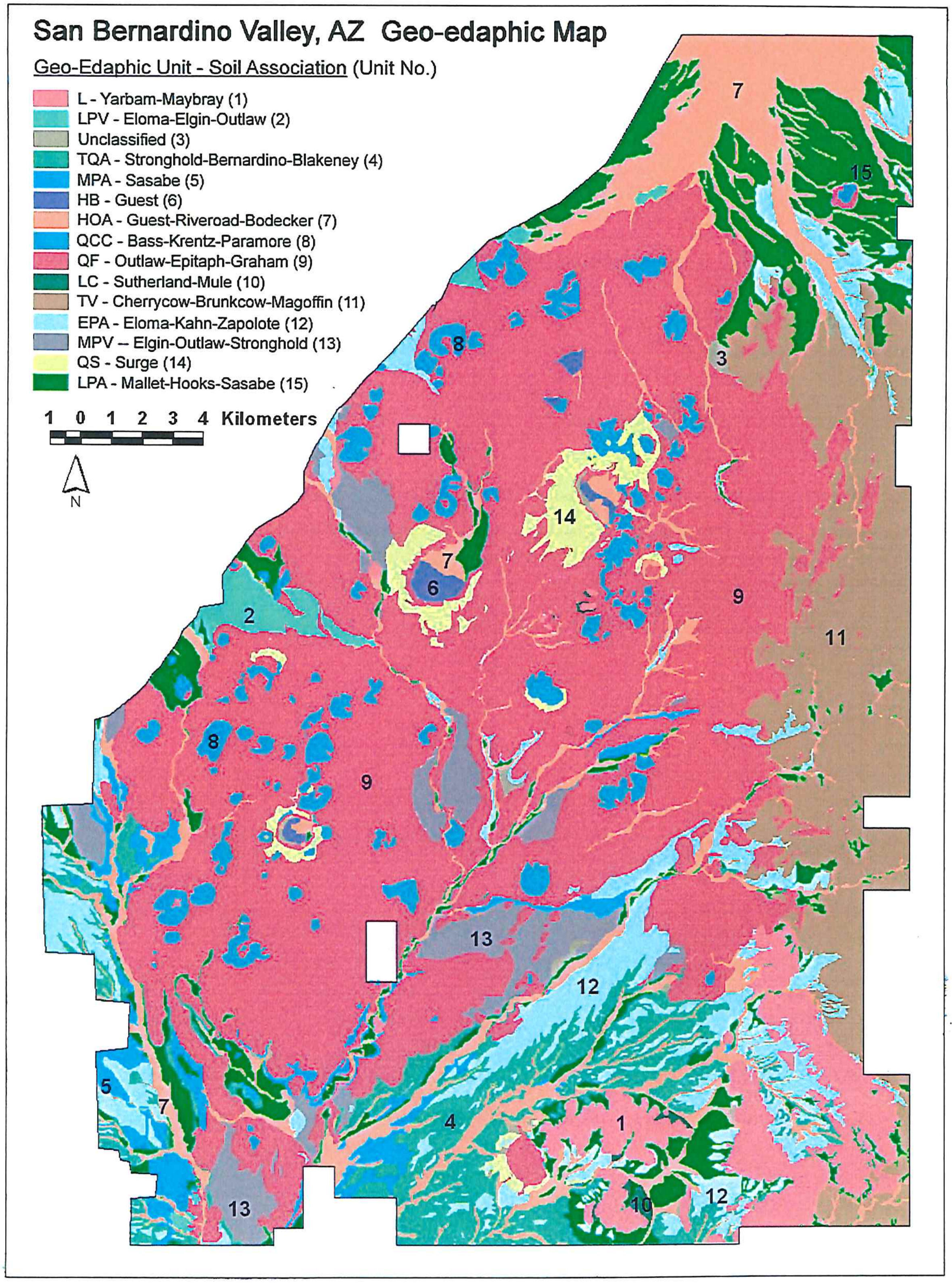

Figure A-1. Geo-edaphic map of the San Bernardino Valley in southeast Arizona derived from Biggs et al. (1999) and McGuire (1999). See text Table 2 for definition of units.