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LANDFORM-VEGETATION RELATIONSHIPS IN THE NORTHERN CHIHUAHUAN DE--ETC(U)

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The description and monitoring of environmental resources in arid regions can be a formidabele undertaking requiring substantial resources. These efforts can be expedited by using remote sensing techniques. There remains, however, a need for correlating features that are readily extracted from the imagery with anticipated soil and vegetation conditions on the ground. Landform features provide a basis for the assessment of soil and vegetation conditions and these features can be readily identified from aerial photography and, to a certain extent, from Landsat imagery. The purpose of this study was to evaluate

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landform features as a basis for the assessment of soil and vegetation conditions. The study was conducted on 650,000 hectares in the northern Chihuahuan Desert (south-central New Mexico and western Texas).

Landform conditions and plant communities were identified from an analysis of stereo panchromatic aerial photography, and were evaluated in detail by intensive field investigations. Soil conditions of the various landforms identified from the imagery were established by the laboratory analysis of field samples. The distribution of the plant communities was closely correlated to landform conditions and the edaphic factors affecting plant-available soil-water, soil texture, soil depth, infiltration, and slope. The most frequent landform-soil-vegetation relationships in the study area were: (1) sand dunes and sand-covered alluvial fans with mesquite/broom snakeweed/grass and sand sage/grass; (2) washes, lower alluvial fans, and playas with tarbush/grass and burro grass/tobosa grass on deep clay, silty clay, and clay loan soils; (3) dissected limestone hills, mesa (limestone), and upper allucial fans with vreosote and grama grass/parthenium on shallow clay, sandy clay loam, clay loam, and silty loam soils; and (4) mesa (limestone), intermedaite and lower alluvial fans, and washes with grama grass/creosote/mesquite on deep loam, silty loam, clay, clay loam, and sandy clay loam soils. Establishment of landform-plant community-soils relationships such as these can facilitate environmental resource inventories and environmental monitoring activities.

LANDFORM-VEGETATION RELATIONSHIPS IN THE NORTHERN CHIHUAHUAN DESERT

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ABSTRACT

The description and monitoring of environmental resources in arid regions can be a formidable undertaking requiring substantial resources. These efforts can be expedited by using remote sensing techniques. There remains, however, a need for correlating features that are readily extracted from the imagery with anticipated soil and vegetation conditions on the ground. Landform features provide a basis for the assessment of soil and vegetation conditions and these features can be readily identified from aerial photography and, to a certain extent, from Landsat imagery. The purpose of this study was to evaluate landform features as a basis for the assessment of soil and vegetation conditions. The study was conducted on 650,000 hectares in the northern Chihuahuan Desert (south-central New Mexico and western Texas).

Landform conditions and plant communities were identified from an analysis of stereo panchromatic aerial photography, and were evaluated in detail by intensive field investigations. Soil conditions of the various landforms identified from the imagery were established by the laboratory analysis of field samples. The distribution of the plant communities was closely correlated to landform conditions and the edaphic factors affecting plant-available soil water; soil texture, soil depth, infiltration, and slope. The most frequent landform-soil-vegetation relationships in the study area were: (1) sand dunes and sand-covered alluvial fans with mesquite/broom snakeweed/grass and sand sage/grass; (2) washes, lower alluvial fans, and playas with tarbush/grass and burro grass/tobosa grass on deep clay, silty clay, and clay loam soils; (3) dissected limestone hills, mesa (limestone), and upper alluvial fans with creosote and grama grass/parthenium on shallow clay, sandy clay loam, clay loam, and silty loam soils; and (4) mesa (limestone), intermediate and lower alluvial fans, and washes with grama grass/creosote/mesquite on deep loam, silty loam, clay, clay loam, and sandy clay loam soils. Establishment of landform-plant community-soils relationships such as these can facilitate environmental resource inventories and environmental monitoring activities.

INTRODUCTION

Relationships between vegetation, soils, and landforms can be readily determined by using stereoscopic aerial photography and air photo interpretation techniques augmented by minimum field efforts. Although landforms can be readily characterized on most photography, and general soil conditions can be identified by photographic interpretation or by association with specific landforms, plant species often cannot be directly identified on aerial photography. Inferential determinations of plant communities, however, can be made on the basis of photo tone and photo texture differences. In arid lands where vegetation is closely adjusted to various edaphic conditions (soil texture, soil depth, soil water, salinity, and groundwater), the photo tone/photo texture relationship, used in conjunction with landform data, can facilitate predictions of plant community conditions.

The purpose of this study was to identify and describe the relationships between vegetation, landform, and soil conditions using manual photo analysis and interpretation techniques together with phytosociological techniques and to determine the extent to which one or more of these three factors can be used as an indicator of the other factors.

This study was conducted in south-central New Mexico and western Texas where the vegetation is largely dominated by shrub species (figure 1). These shrublands are thought to be disclimax communities that developed from the true climax desert grassland communities in response to man-induced changes in environmental conditions. The shrub and grass species, now adjusted to the new environmental conditions, from identifiable plant communities.

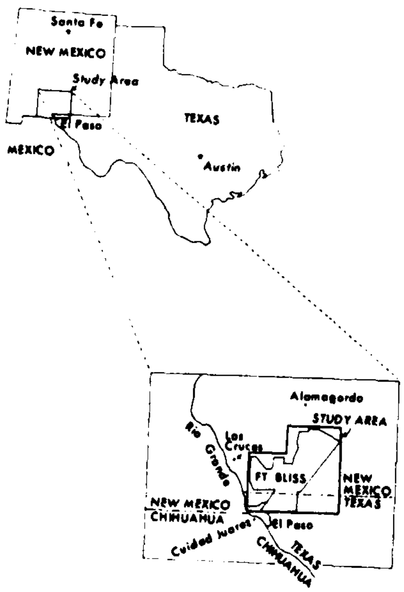


Figure 1: Location of the Study Area

PROCEDURES

The aerial photography used was panchromatic 22.9-x 22.9-cm (9-x 9-in.) 1:50,000 scale stereo aerial photography laid as three 102-x 152-cm uncontrolled photomosaics. Landform units were identified and described from the three-dimensional characteristics of shape, relief, slope, arrangement, and orientation; the drainage characteristics of pattern, density (spacing of drainageways), gulley cross sections, gulley gradient (uniformity and steepness), and degree of incision; and the bedrock characteristics of rock layering, dip, type, and structure. Four major landform categories (mountains/hills, alluvial fans, basin areas, and washes) were divided into 14 landform units. The percentage of the study area occupied by each landform unit was determined using a grid sampling technique. Soil samples were collected at selected sites and were analyzed in the laboratory for textural and moisture conditions.

Plant communities were identified from phytosociological data collected at 298 sites. These were representative of the plant community and associated conditions found in the land cover mapping units. Species composition, species percent ground cover, and ancilliary data representative of the plant community were collected using a 20-x 20-m quadrant. Perennial grass species and woody plants provided the basis for the plant community descriptions because of their constant presence and reoccurring nature.

The tabular comparison method was used to cluster the phytosociological data and to assist in the identification of plant communities (Mueller-Dombois and Ellenberg, 1974; Kuchler, 1967). The phytosociological data were partially analyzed using the automated clustering technique developed by Lieth and Moore (1971).

Three major land use categories (grassland, shrubland, and forestland) and 22 land cover mapping units were identified from the phytosociological data. For each species, the ground cover class, absolute frequency, relative frequency, and an important coefficient [(cover x frequency)/2], were determined. The procedures followed for characterizing each community and for assigning botanical names to the plant communities are discussed in Satterwhite and Ehlen (1980). Coefficients of similarity were calculated between all the plant communities.

Probable plant communities were mapped on the aerial photography by evaluating the photo tone and photo texture differences and plant physiognomic characteristics. Relationships between the plant communities and the photo mapping (land cover) units were identified by evaluating these same characteristics at each sample site and from numerous random observations made en route between sample sites. Consequently, an association can be made between the plant communities described from the phytosociological data and the photo patterns mapped from the aerial photography.

The relationships between the plant communities and specific landform units were determined by using the data collected in the field together with data collected by simultaneous sampling of the landform and land cover maps. Data from the maps were collected at 6,033 sample points using the grid point sampling techniques. The frequency of each relationship was calculated as a percentage of the total sample.

RESULTS

Landform and land cover units were mapped on three photo mosaics; for convenience, only one photo mosaic is presented here. All three photo mosaics and their accompanying landform and land cover maps are reported elsewhere (Satterwhite and Ehlen, 1980). Geographic names are shown on figure 2.

Landforms

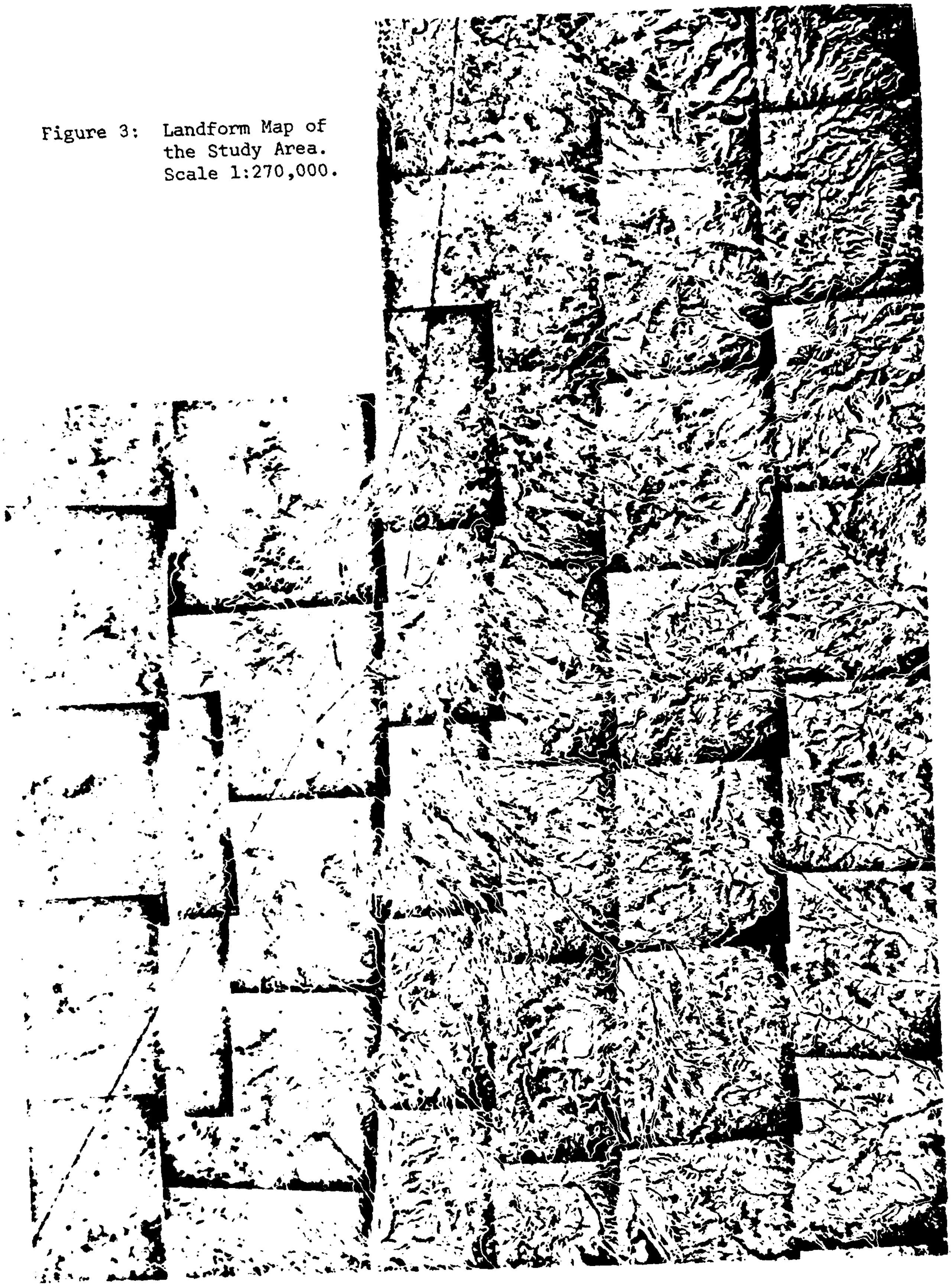
The relative percentages of the major landforms and their subunits within the study area are shown in Table I. Figure 3 illustrates the spatial distribution of the landform subunits on one of the photo mosaics.

Table I: Landform Units and Their Percentages of the Study Area

Major Landform Unit	Map Symbol	Landform	Percentage of the Study Area
Mountains/hills	A1	Mesa	15.8
	A2	Highly dissected hills	16.1
	A3	Rugged, sharp-crested mountains	2.3
Alluvial Fans	B1	Primary, high elevation fans	10.8
	B2	Secondary, high elevation fans	1.2
	B3	Mottled, intermediate elevation fans	6.8
	B4	Dark-toned, lowest elevation fans	3.6
	B5	Fans covered with aeolian sand	3.5
	B6	High elevation, anomolous fans	0.7
Basin Areas	C1	Light-toned, speckled sand dunes	30.2
	C2	Dark-toned, rough-textured sand dunes	2.6
	C3	Low, smooth areas	2.5
	C4	Small, dark-toned depressions	1.5
Washes	D	---	2.0
		Total:	99.6

Figure 2: Geographic Names in the Study Area

Figure 3: Landform Map of the Study Area. Scale 1:270,000.



The mountains/hills landform comprises 34 percent of the study area and was identified by its three-dimensional shape in the stereo images. These areas are the highest and most rugged parts of the study area. Drainage patterns are dendritic and a high degree of structural control is often exhibited locally. The drainageways are usually incised, and density is generally high. Three subunits were identified in this landform category: (1) large, flat-topped mesas (A1) that are composed of gently dipping limestone with minor sandstone and shale; (2) large, highly dissected rock masses (A2), primarily interbedded limestones or limestones and shales, along with many relatively small, isolated rock bodies (inselbergs); and (3) large areas of rugged, sharp-crested mountains (A3) composed of coarse-grained, intrusive, igneous rocks, which also include some inselbergs.

The alluvial fans comprise 27 percent of the study area. They were identified by their distinctive fan shape, distributary drainage pattern, moderate slope (1 to 5 percent), and topographic position between the mountains and hills and the low, flat basin areas. Relief and drainage characteristics on the alluvial fans very with topographic position and the degree of fan development. Fans occur as individuals and as broad aprons (bajadas). The alluvial fans were separated into six discrete subunits.

Flat, with little relief, and occupying the lowest elevations, the basin areas comprise 37 percent of the study area and are the largest landform units. Coppice sand dunes are common in this landform. Few drainageways can be seen, although some channel-like depressions were identified on the air photos. The gentle regional slope of the basin areas is to the north in the Tularosa Basin, and to the south in the Hueco Bolson (figure 2). The boundary between these basins is difficult to identify on the air photos. The basin areas were divided into four discrete units.

The washes (the major stream channels upstream from where the drainage pattern becomes distributary or where the major channels enter the lowest alluvial fans) comprise 2 percent of the study area. Washes include the immediate overflow areas associated with the channels. Distinct, steep-sided channels were occasionally noted on the alluvial fans. Most of the drainageways in these areas, however, lacked distinct channels and were identified by tonal pattern. This pattern consists of very dark and very light tones caused by the contrast between dense vegetative cover and bare soil. Washes in the mountains/hills landform have either U-shaped or V-shaped cross sections, whereas in the alluvial fan complex, the cross sections are box-shaped.

Soils

Soil texture and soil depth data, summarized in Table II, were collected in the field for most of the landform subunits. The soil conditions form four groups defined by textural and depth differences: (1) sand, loamy sand, and sandy loam soils more than 30 cm deep; (2) clay, clay loam, loam, gravelly loam, and gravelly clay loam soils less than 15 cm deep; (3) clay loam, clay, sandy clay, and sandy clay loam soil 15- to 30- cm deep; and (4) clay loam, silty clay loam, clay, and sandy clay soils more than 30 cm deep. Group 1 was associated with the

Table II: Landform, Soil Texture, and Soil Depth Relationships

Landform	Soil Texture	Soil Depth
A1	Clay loam with 10-20% gravel, < 2.5 cm in diameter; silty loam with pebbles in the drainageways	Up to 45 cm where the slope is < 3%; up to 30 cm on steeper slopes
A2	Colluvial on shale: silty loam, silty clay, gravelly silty clay	Usually > 30 cm, but sometimes < 15 cm
	Residual on shale: clay, clay loam, gravelly clay, gravelly clay loam; shale fragments < 1.5 cm in diameter	< 30 cm
	Residual on bedded limestones: gravelly loam with gravels 2.5- to 5- cm in diameter	Usually < 15 cm, but up to 30- to 45- cm or more
A3	Residual: loamy gravel, sand	< 15 cm
	Colluvial: loamy gravel	15- to 20- cm
B1	Gravelly loam, gravelly clay loam, gravelly silt loam, clay, gravelly clay, gravelly sand loam, sandy clay loam, gravelly sandy clay loam; 10-40% gravel	15- to 45- cm
B2	NO SOIL SAMPLES	
B3	Clay loam, sandy loam, loamy sand, < 10% gravel at the surface, 10-30% at depth	> 30 cm, sometimes >100 cm
B4	Clay, gravelly clay, gravelly clay loam, clay loam, silty clay, sandy clay loam	30- to 60- cm or more; precipitated carbonates may occur at 30 cm
B5	Sandy clay loam, loamy sand	30- to 45- cm or more

B6	Gravelly loam, gravelly clay loam	> 45 cm
C1	Sandy loam, sandy clay loam, sandy clay, silty clay loam; < 3% gravel	> 75 cm on dunes, can be < 15 cm in interdunal areas
C2	Loamy sand, sandy loam, > 75% sand	> 100 cm
C3	NO SOIL SAMPLES	
C4	Sandy loam, loamy sand, sandy clay loam, clay; usually < 5% gravel	> 60 cm
D	Upper reaches: gravel, cobbles, boulders	---
	Middle and lower reaches: clay, clay loam, silty clay; little or no gravel	---

basin area landforms; group 2, with the uppermost alluvial fan unit and the moutains/hills units; group 3, with the lower and sand-covered alluvial fans and the washes; and group 4, with the mesa and the upper and sand-covered alluvial fan units.

Plant Communities

The spatial distribution of the land cover units on one photo mosaic is shown in figure 4. The statistics describing the areal extent of each of the 22 land cover units are presented in Table III.

Grasslands and grass-shrublands occupy 37 percent of the study area, are widely distributed, and occur on most landform units. Five discrete grassland communities were identified: (1) Bouteloua eriopoda - Bouteloua curtipendula, (2) Bouteloua curtipendula - Bouteloua uniflora, (3)Scleropogon brevifolius - Hilaria mutica, (4) Sporobolus cryptandrus - Sporobolus flexuosus, and (5) Sporobolus giganteus. These communities were mapped as undifferentiated grassland (10) because of their small size and the difficulty in differentiating them at the 1:50,000 photographic scale. The shrub species, Acacia constricta, Artemisia filifolia, Flourensia cernua, Larrea tridentata, Parthenium incanum, or Prosopis glandulosa, can occur as scattered individuals with 1 to 5 percent cover in the grassland areas.

Shrublands, the major physiognomic group, occupy 58 percent of the study area. The major shrub species are Acacia constricta, Artemisia filifolia, Flourensia cernua, L. tridentata, Parthenium incanum, and Prosopis glandulosa. Less frequent shrub species, Chilopsis chiliensis, Falligua paradoxa, and Thelesperma longipes can form dense stands along some drainageways. These species were rarely observed in the upland areas. The grasses commonly forming the understory in these shrub communities are B. eriopoda, B. gracilis, H. mutica, Muhlenbergia spp., Scleropogon brevifolius, or Sporobolus flexuosus.

The distribution of forestlands is very limited. For all practical purposes, the forested areas of any size (more than 5 hectares) are in the Sacramento and Organ Mountains in the northeastern and northwestern parts of the study area (figure 2). The major tree species, Juniperus monosperma, Pinus edulis, and Quercus undulata are limited to these areas and to isolated draws along the Otero Mesa escarpment. The associated shrub species in the forestlands are Agave sp., Cercoparpus montanus, Chrysothamnus sp., Nolina sp., and Xanthocephalum Sarothrae. Acacia sp., Celtis sp., Populus sp., Prosopis glandulosa, Tamarix ramosissima, and Ulmus sp. are associated with some cattle watering tanks (ponds). Prosopis glandulosa occurs as a small tree in these areas, but its normal stature is a short- to medium-sized shrub. Chilopsis chiliensis occasionally occurs as dense stands of tall shrubs and small trees in major drainageways.

Figure 4: Land Cover Map of the Study Area. Scale 1:270,000.

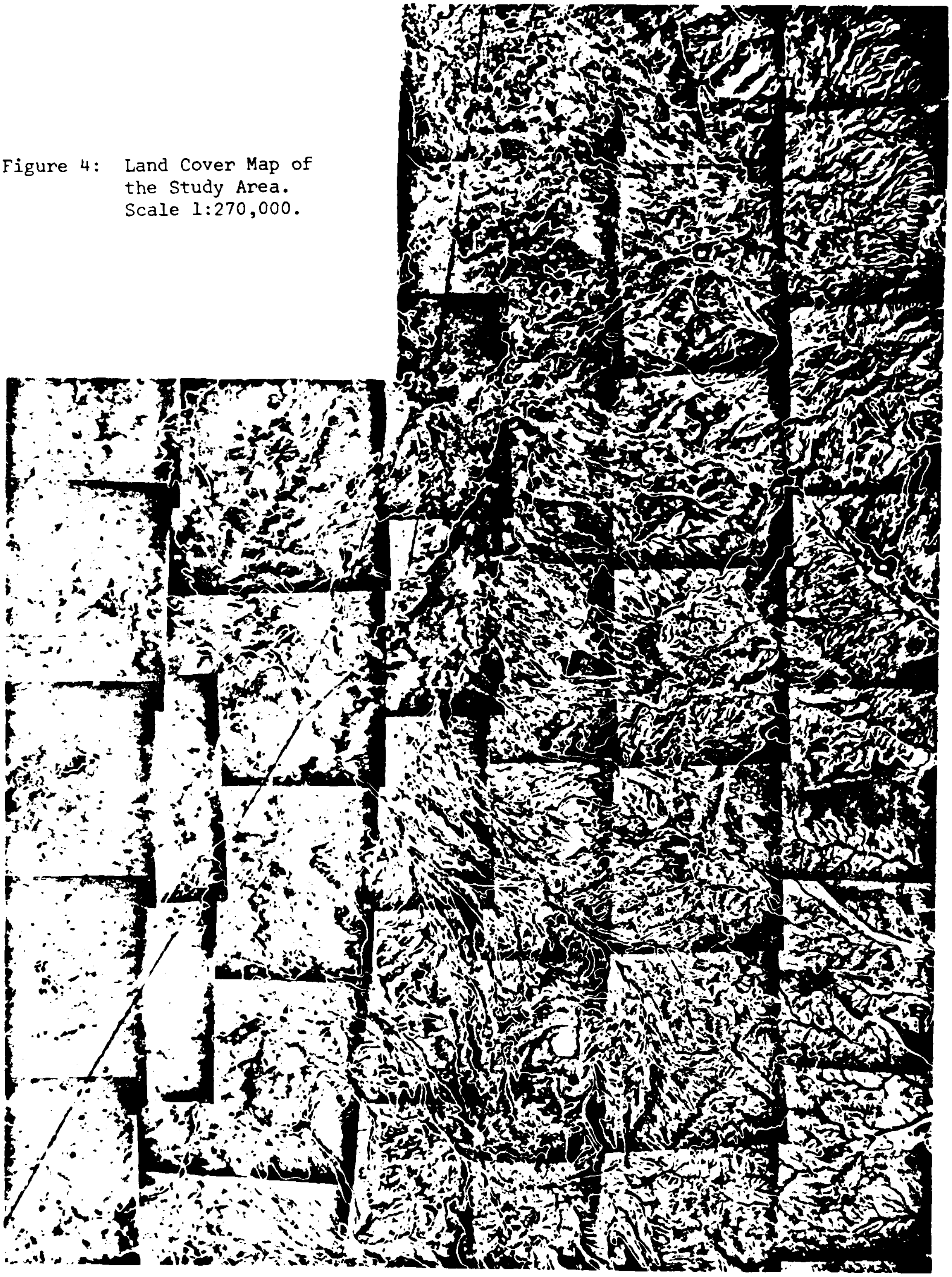


Table III: Land Cover Mapping Units and Their Percentages of the Study Area

Physiognomic Group	Group Percent of Area	Land Cover Unit	Percent of Area
Grassland	37.4		
		Grassland (10)	21.1
		Grass - *Larrea tridentata* (11)	0.7
		Grass - *Flourensia cernua* - *Larrea tridentata* (12)	1.3
		Grass - *Acacia constricta* (13)	<0.1
		Grass - *Artemisia filifolia* (14)	0.7
		Grass - *Prosopis glandulosa* (15)	2.2
		Grass - *Parthenium incanum* (16)	11.3
Shrubland	58.2		
		Larrea tridentata (20)	9.6
		Larrea tridentata - Grass (21)	4.6
		Larrea tridentata - *Parthenium incanum* - Grass (22)	0.6
		Larrea tridentata - *Prosopis glandulosa* - *Xanthocephalum Sarothrae* (23)	4.1
		Larrea tridentata - *Flourensia cernua* - Grass (25)	2.4
		Acacia constricta - Grass (30)	1.2
		Acacia constricta - *Larrea tridentata* - Grass (31)	0.8
		Flourensia cernua - Grass (40)	<0.1
		Flourensia cernua - *Larrea tridentata* - Grass (41)	2.2
		Prosopis glandulosa - *Xanthocephalum Sarothrae* - *Atriplex canescens* - Grass (50)	27.5
		Prosopis glandulosa - *Larrea tridentata* (51)	0.9
		Prosopis glandulosa - *Artemisia filifolia* (52)	0.7
		Artemisia filifolia - Grass (60)	2.8
		Artemisia filifolia - *Prosopis glandulosa* (61)	0.7
Forestland	2.2		
		Juniperus monosperma - *Quercus undulata* (70)	2.2
Other	2.3		
Total	100.1		100.1

Landform/Soils/Plant Community Relationships

The relationships between landform and land cover show that landform can be used as an indicator of both vegetation and soil conditions. Data describing the associations between the plant communities and landform units are summarized in Table IV. The value given at the intersection of a row and a column is the percentage of the study area occupied by a particular landform/plant community association. The Chi square test (95 percent level of confidence) confirmed what the frequency table shows: there is a relation between the plant communities and landform units. Figure 5 illustrates the association of the major and minor plant communities with a landform unit.

Mountains/Hills Plant Communities. The plant communities associated with the mesa landform are primarily grassland communities (10A and 10B); the *Bouteloua eripoda* - *Bouteloua curtipendula* grassland (10A) is the most common. Soils are silty clay loam, loam, and gravelly clay loam in texture and are generally more than 30 cm deep. In some swales, the soil depth is 60 cm or more to a petrocalcic horizon or bedrock. The mesa soils in some areas, however, are less than 15 cm to bedrock or a petrocalcic horizon and contain substantial amounts of gravel.

The plant community most commonly associated with the highly dissected hills is the Grass - *Parthenium incanum* community (16), which occurs primarily on this lanform unit. Grassland communities are limited, with *Bouteloua curtipendula* - *Bouteloua uniflora* (10B) the most common. Grass-*Acacia constricta* (13), *Acacia constricta* - Grass (30), and *Acacia constricta*-*Larrea tridentata* - Grass (31) communities occur almost exclusively on this landform unit. The *Juniperus monosperma* -*Quercus undulata* community (70) occurs on this landform unit along the southern flanks of the Sacramento Mountains. Soils are shallow (less than 15 cm) and their textures are clay and clay loam. Grass species in the *Acacia constricta* communities are *H. mutica* and *Scleropogon brevifolius*, which occur on clay soils 15- to 30- cm deep.

Bouteloua curtipendula - *Bouteloua uniflora* (10B) and *Juniperus monosperma* - *Quercus undulata* (70) communities are commonly found on the rugged, sharp-crested mountains. The latter community occurs in the Organ Mountains. *Larrea tridentata* - *Parthenium incanum* - Grass (22) is a minor associated community. Soils are shallow (less than 15 cm), and their textures are gravelly loam and sandy.

Alluvial Fan Plant Communities. *Larrea tridentata* is either the dominant or the major associate species in plant communities on the alluvial fans. The major plant communities on the upper alluvial fans (B1 and B2) are *Larrea tridentata* (20) and *Larrea tridentata* - Grass (21). Soils on these fans are less than 15 cm to bedrock or a petrocalcic horizon. Soil textures are clay, clay loam, and loam. Some soils contain substantial amounts of gravel.

TABLE IV Frequencies of Plant Community and Landform Relationships (Percent Basis)

PCN	Landform Unit A1	A2	A3	B1	B2	B3	B4	B5	B6	C1	C2	C3	C4	D	Total
10	13.3	2.2	.7	.4	.1	.7	.1	.3	.7	.4	.3	1.0	.2	.8	21.2
11	.2	.1	0.0	.0	.1	0.0	.1	.0	0.0	.1	0.0	0.0	.1	.0	.7
12	.0	.1	0.0	.2	.1	.0	.4	0.0	0.0	.0	0.0	0.0	.1	.3	1.2
13	0.0	.0	0.0	0.0	.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.0
14	0.0	0.0	0.0	0.0	0.0	0.0	.2	.0	0.0	.3	.0	.0	.1	0.0	.6
15	0.0	0.0	0.0	.0	0.0	0.0	.0	.1	0.0	1.3	.4	.2	.1	0.0	2.1
16	2.0	8.5	.1	.4	.1	.0	.0	.0	0.0	0.0	0.0	0.0	0.0	.2	11.3
20	.0	1.2	.3	4.6	.1	2.1	.5	.3	0.0	.1	.0	0.0	.1	.2	9.5
21	.0	.4	.1	2.8	.2	.4	.3	.0	0.0	.2	0.0	0.0	0.0	.1	4.5
22	0.0	.2	.3	.1	0.0	0.0	.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.6
23	0.0	.0	0.0	.6	.1	1.2	.3	.8	0.0	.7	.1	.0	.1	.1	4.0
25	.0	.2	0.0	.7	.1	.1	.4	.2	0.0	.0	0.0	0.0	.4	.2	2.3
30	.0	.9	0.0	.2	.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2
31	.0	.6	.0	.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.7
40	0.0	0.0	0.0	0.0	0.0	0.0	.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.0
41	0.0	.3	0.0	.2	.1	.3	.9	.0	0.0	0.0	.0	0.0	0.0	.3	2.1
50	0.0	.1	0.0	.1	0.0	.1	0.0	.9	0.0	25.8	.3	.2	.1	0.0	27.6
51	0.0	0.0	0.0	.1	0.0	.1	.0	.3	0.0	.1	.1	.0	.0	0.0	.7
52	0.0	.0	0.0	0.0	0.0	.0	.0	.0	0.0	.4	.1	.1	.0	0.0	.6
60	.2	.0	0.0	.1	0.0	.0	.3	.2	.0	.2	1.0	.6	.2	.0	2.8
61	0.0	.0	0.0	0.0	0.0	.0	.0	.0	0.0	.4	.1	.1	0.0	0.0	.6
70	0.0	1.3	.7	.1	.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2
90	0.0	.0	.1	.0	0.0	0.0	0.0	.0	0.0	.0	0.0	0.0	0.0	0.0	.1
91	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.1	0.0	0.0	0.0	0.0	.1
92	0.0	0.0	0.0	0.0	.1	1.6	.0	0.0	0.0	.0	.1	.1	.1	0.0	2.0
Total	15.7	16.1	2.3	10.7	1.3	6.8	3.5	3.1	.7	30.1	2.5	2.3	1.6	2.2	98.7

PCN = Plant Community Number

.0 = Frequencies < 0.1%

0.0 = No Observations

○ = Frequency ≥ 1.0 percent (circled values)

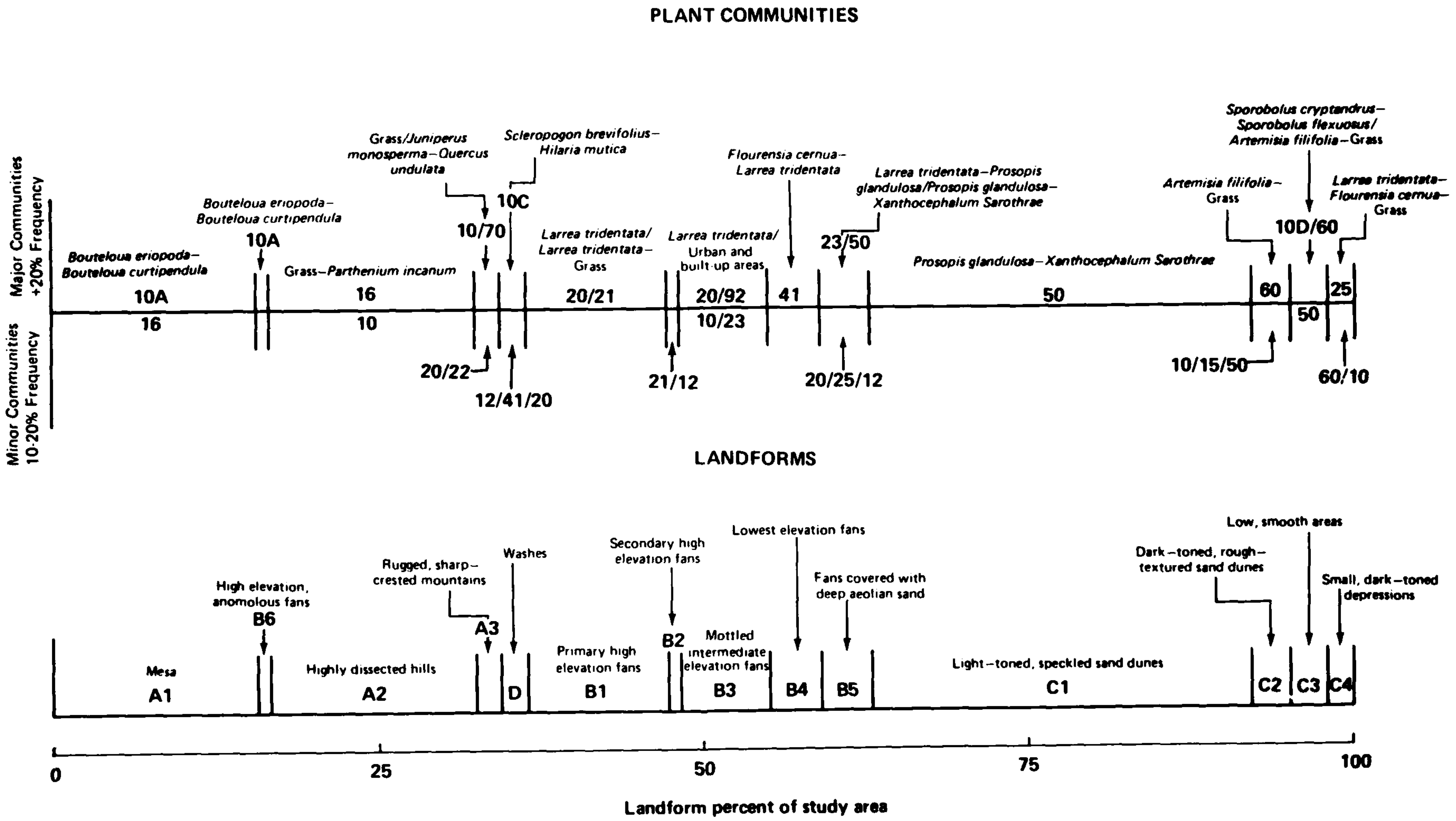


Figure 5: Plant Community Associations with Specific Landforms. The Width of each Landform Unit is Proportional to its Relative Percentage of the Study Area. The Frequencies of Major and Minor Plant Communities Reflect the Relative Percentage that that Community Occurs on the Landform. For example, the Bouteloua Grassland (10A) Occurs on More Than 20% of Landform A1 and is the Major Plant Community.

The major plant communities on the mid-elevation alluvial fans (B3) are Larrea tridentata (20) and Larrea tridentata - Prosopis glandulosa - Grass (23). The lower alluvial fans are dominated by Flourensia cernua - Larrea tridentata - Grass (41), Larrea tridentata - Flourensia cernua - Grass (25), Grass - Flourensia cernua - Larrea tridentata (12) and Scleropogon brevifolius - Hilaria mutica (10C) in addition to the two L. tridentata communities, 20 and 21. The Flourensia cernua - Grass community (40) is found only on the lowest alluvial fan unit. This community covers large areas of these fans but its frequency is low in regard to the total study area. The grass species commonly found on these landforms are H. mutica, M. Porteri, or Scleropogon brevifolius. Soil textures are clay loam, silty clay loam, clay, and sandy clay; soil depth is more than 30 cm.

The major plant communities found on the sand-covered alluvial fans (B5) are the Larrea tridentata - Prosopis glandulosa - Xanthocephalum Sarothrae (23) and the Prosopis glandulosa - Larrea tridentata (51) communities. The presence of Prosopis glandulosa-dominated communities indicates a change in soil conditions compared to the other alluvial fans. Where substantial amounts of sand occur, the L. tridentata shrubs, and other shrubs incapable of tolerating partial or complete burial, are eliminated and P. glandulosa is becoming established. P. glandulosa is capable of adventitious root growth and rapid establishment on active fan areas. The Larrea tridentata - Prosopis glandulosa - Xanthocephalum Sarothrae community (23) occupies sites where aeolian deposition is active, i.e., between the upper alluvial fan communities dominated by L. tridentata (20 and 21) and the P. glandulosa communities (50) of the basin areas. Soil textures on the B5 landforms are sandy clay loam and loamy sand and soil depths are 30- to 45- cm or more.

The alluvial fans on the Otero Mesa (B6) are vegetated almost exclusively with Bouteloua spp. grassland communities, particularly Bouteloua eriopoda-Bouteloua curtipendula (10A). Two isolated areas of Artemisia filifolia - Grass community (60) were found. Soil textures are gravelly loam and gravelly clay and soil depth is more than 45 cm.

Basin Area Plant Communities. The most prevalent plant community on the light-toned, speckled sand dunes is the Prosopis glandulosa - Xanthocephalum Sarothrae - Atriplex canescens - Grass community (50). Other communities dominated by Prosopis glandulosa, Artemisia filifolia or the Sporobolus spp. grasses, Grass - Prosopis glandulosa (15), Grass - Artemisia filifolia (14), Prosopis glandulosa - Artemisia filifolia (52), and Artemisia filifolia - Prosopis glandulosa (61), occur on limited areas. Soils in these dune areas are sandy loams, loamy sands and sands. Soil depth is normally more than 2 m on the dunes, but is less than 30 cm in the interdunal areas.

The major plant community associated with the large, dark-toned sand dunes (C2) is the Artemisia filifolia - Grass community (60). Minor plant communities are the Sporobolus cryptandrus - Sporobolus flexuosus grassland (10D), Grass - Prosopis glandulosa (15), and Prosopis glandulosa - Xanthocephalum Sarothrae - Atriplex canescens - Grass (50). The sand and loamy sand soils in these areas are more than 2 m deep.

The plant communities in the low, smooth areas (C3) are mostly Sporobolus cryptandrus - Sporobolus flexuosus grassland (10D) and the Artemisia filifolia - Grass shrubland (60). Sporobolus cryptandrus and S. flexuosus are the dominant grass species in both communities. Soils are similar in texture to those in the C1 and C2 landforms, but are 1.0 meter or more in depth.

The major plant community in the small depressions (C4) is Larrea tridentata - Flourensia cernua - Grass (25). The minor communities associated with this landform are the Sporobolus cryptandrus - Sporobolus flexuosus grassland (10D) and the Artemisia filifolia - Grass community (60). In the almost circular depressions, or playas, the grass communities are dominated by Scleropogon brevifolius and H. mutica. The soils in the depressions contain more silt and clay than the other basin area soils and are more than 1.0 meter in depth.

Wash Plant Communities. Along the major drainageways, several plant communities were encountered which had common species, but which differed in dominant species. The major plant community is the Scleropogon brevifolius - Hilaria mutica grassland (10D). The Sporobolus giganteus community (10E) is also present on small areas of the upper reaches. Minor plant communities are Grass - Flourensia cernua - Larrea tridentata (12), Flourensia cernua - Larrea tridentata-Grass (41), and Larrea tridentata (20). Soils are more than 30 cm deep and are clay loam, silty clay loam, clay, and sandy clay in texture.

DISCUSSION

Five major plant communities that covered 94 percent of the study area were associated with specific landform-soil conditions that in turn accounted for 80 percent of the landform areas: (1) mesa with the grassland community Bouteloua eriopoda - Bouteloua curtipendula on clay loam, clay, and sandy clay soils more than 30 cm deep; (2) the interbedded limestone and shale member of the highly dissected hills landform with the Bouteloua curtipendula - Parthenium incanum community on loamy and silty loam soils less than 15 cm deep; (3) the upper and intermediate alluvial fans with the Larrea tridentata and the Larrea tridentata-Grass communities on sandy clay loam and clay loam soils more than 15 cm deep; (4) the light-toned, speckled sand dunes (coppice dunes) with the Prosopis glandulosa - Xanthocephalum Sarothrae - Atriplex canescens - Grass community on loamy sand, sandy loam and sandy clay soils more than 30 cm deep; and (5) the dark-toned, rough-textured sand dunes with the Artemisia filifolia - Sporobolus spp. community on sandy, sandy loam, and loamy sand soils more than 65 cm deep.

The field and laboratory data show that soil depth and soil textural conditions vary with landform; each of the twenty-two plant communities is associated more frequently with one particular landform unit. The variation in these edaphic factors determines the moisture retention characteristics of a soil (Satterwhite, 1979) and the potential soil-water-holding capacity is the factor controlling plant community distribution. These relationships permit landforms to be used as an indicators of plant communities and soil conditions.

Species growing on the different soils throughout the study area tend to reflect these edaphic differences. For example, the drought-tolerant species occur on the more xeric sites where soils are shallow and coarse textured. Acacia constricta, Fouquieria splendens, Opuntia spp., and Nolina sp. are routinely found on the dissected, interbedded limstones where soils are very shallow or non-existent. The amount of plant-available water held in these soils is very small.

Other species exhibit similar edaphic relationships. L. tridentata, Parthenium incanum, Viguieria stenoloba, B. curtipendula, M. arenacea and Sporobolus Wrightii are found on the dissected limestone hills and the upper alluvial fans where soil depth is 3- to 30-cm and soil textures are gravelly clay loam and gravelly loam. These soils are capable of holding substantial plant-available water; once the soil water is depleted, they can remain droughty throughout the summer and fall growing season. Only the surface decimeter(s) may be wetted by the high-intensity, short-duration summer rains. The steep slopes of these landforms, combined with slow infiltration and percolation rates, prevent recharge of the soil-water reservoir during this period. Less intense precipitation events recharge surface and subsurface soil horizons during the late fall and winter months.

Even though the relationships between plant communities and edaphic conditions on the lower alluvial fans and washes are similar, the species on these landforms can be less drought tolerant. The soils in these areas often receive surface runoff from the upper slopes. The shrubs Atriplex canescens, Flourensia cernua, Prosopis glandulosa, Rhus aromatica, and R. mycrophylla and the grasses H. mutica, M. Porteri, Scleropogon brevifolius, and Panicum obtuscum are most common.

For example, Prosopis glandulosa encroaches along the thread of small drainageways on the mid-elevation alluvial fans on the eastern slopes of the Franklin Mountains. L. tridentata, the dominant species on these alluvial fans, occurs at slightly higher elevations (less than 0.3 m) on the coarse-textured, shallow soils that form the interfluvs. These occurrences of the two species on dissimilar microhabitats on the same landform illustrate their relative drought tolerances and water requirements.

Prosopis glandulosa and L. tridentata also occur in limited areas of the coppice dune region (C1). P. glandulosa occupies the dunes where soil depth can be 2 m or more, and L. tridentata occurs as a rare-to-infrequent species in the dunal areas where soil depth to the petrocalcic horizon is generally less than 0.5 m. These two species occupy basin sites comparable to those on the mid-elevation alluvial fans. L. tridentata occupies the shallow, droughty soils and P. glandulosa occupies soils of greater depth and a potentially greater soil-water reservoir.

CONCLUSIONS

Aerial photography and conventional air photo interpretation techniques can provide a successful way to obtain information about soils, landform, and vegetation. These relationships can permit the most easily determined factor on aerial photography, soils, landforms, or vegetation, to be used as an indicator of the other two factors. Because landforms are directly observable on stereo aerial photography, they can be used more easily than either vegetation or soil conditions as an indicator.

Extrapolating these relationships to other areas is a matter for continued investigation. Observations made adjacent to the study area show these relationships are applicable to those areas where the same species occur. Problems can arise when extrapolating to other regions, however, because species ecotypical differentiation can change tolerance limits, and hence, landform and soil relationships, even when comparable landform units and soil conditions are encountered.

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