PERFORMANCE REPORT

As required by

ENDANGERED SPECIES ACT, SECTION 6

TEXAS

Project E-1-2

ENDANGERED AND THREATENED SPECIES CONSERVATION

Job No. 12: Texas Kangaroo Rat Habitat Mapping and Status

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December 20,

PERFORMANCE REPORT

STATE: Texas **PROJECT NO.:** E-1

PROJECT TITLE: Endangered and Threatened Species Conservation.

PERIOD COVERED: FY 1990; Study conducted during the spring, summer, and fall, 1990.

JOB NUMBER: 12

JOB TITLE: Texas Kangaroo Rat (*Dipodomys elator*) Habitat Mapping and Status

JOB OBJECTIVE: To map the habitat of the Texas Kangaroo Rat, determine threats to the habitat, and develop a predictive model for its occurrence.

ABSTRACT

See Attached Report

ACCOMPLISHMENTS

See Attached Report

SIGNIFICANT DEVIATIONS

The study conducted addressed all yearly objectives except mapping of the known range of Texas Kangaroo Rat through specimen records.

COST: $6000.00

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GIS AND REMOTE SENSING FOR

TEXAS KANG^ROO RAT HABITAT CHARACTERIZATION

PREPARED FOR TEXAS PARKS AND WILDLIFE DEPARTMENT

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1.0 INTRODUCTION

This report describes the development and results of an empirical model that was developed to utilize GIS and remote sensing to predict habitat suitability for the Texas kangaroo rat (**Dipodomys elator**) for a portion of their range. Specifically, three major objectives were identified. The first was the establishment of a spatial digital data base for the study area. This data base was comprised of the following: kangaroo rat collection sites; major soil associations; major geologic formations; slope description and landuse. A second objective was the evaluation of these data and subsequent development of a suitability map for kangaroo rat habitat, indicating areas most likely to contain kangaroo rats. The third objective was an evaluation of historic landuse information for the study area. These data were summarized to identify major landuse trends which may impact potential habitat for the Texas kangaroo rat.

1.1 Distribution

The current known range of the Texas kangaroo rat (Dipodomys elator) extends across nine counties in North-Central Texas (Fig. 1). Several old records exist from outside the range. From Oklahoma, the species is documented by three specimens, two from Chattanooga County, collected in 1904 and 1905, and one from Cotton County collected in 1969. From Texas, there have been no records from Clay County since early in this century (Martin and Matocha 1972), although there are specimens from Montague County, immediately east of Clay County (Cokendolpher et al. 1979). Martin and Matocha (1972) suggested the lack of recent records of Texas kangaroo rats from previously reported areas indicates some former habitat is no longer suitable. An additional record of the species exists from Coryell County, Texas (Blair 1949) but, according to several authors (Dalquest and Collier 1964; Martin and Matocha 1972), is subject to question.

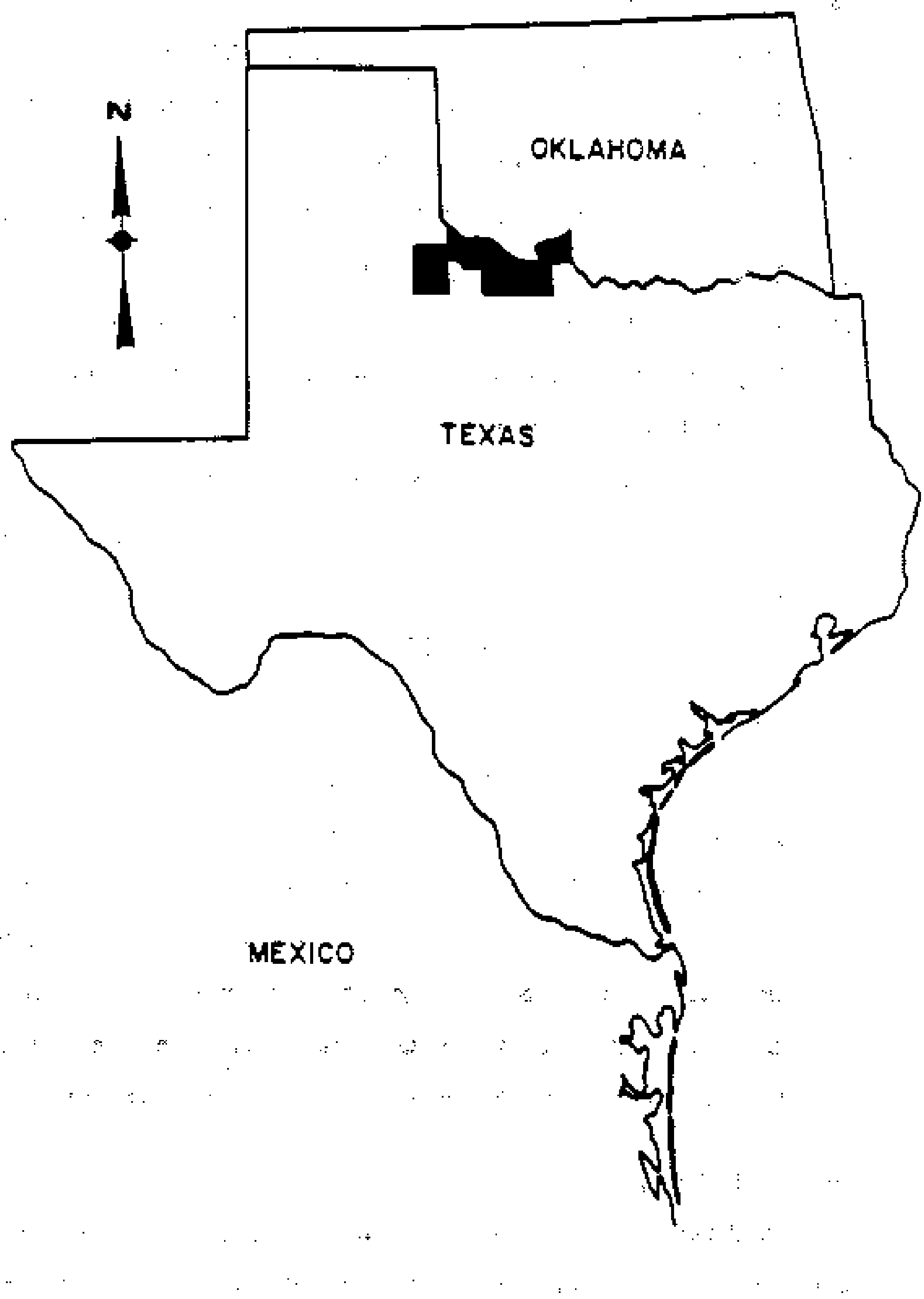


FIGURE 1. Current range of the Texas kangaroo rat.

1.2 Texas Kangaroo Rat Habitat

The historical range of the Texas kangaroo rat extends over portions of two major physiographic provinces, the Rolling Plains (eastern portion) and the Cross Timbers (western portion). Within the Rolling Plains, native vegetation includes prairie grasses, including bluestem (Schizachyrium scoparium), big bluestem (Andropogon gerrardii), sideoats gramma (Bouteloua curtipendula), Indian grass (Sorghastrum nutans), and dropseed (Sporobolus sp.). Invading plant species in this area, typical of overgrazed or disturb landscapes, include mesquite (Prosopis glandulosa), western ragweed (Ambrosia psilostachya), tumble grass (Schedonnardus paniculatus) and sandburrs (Cenchrus incertus).

The native vegetation of the Cross Timbers in north-central Texas includes grasses such as little bluestem, big bluestem, Canada wildrye (Elymus canadensis), tall dropseed (Sporobolus asper) and Texas wintergrass (Stipa leucotricha). Also characteristic are clusters of post oak (Quercus stellata) and blackjack oak (Q. marlandica).

1.3 Status

The Texas kangaroo rat is currently listed as threatened by the Texas Organization for Endangered Species and as protected by the Texas Department of Parks and Wildlife (Roberts and Mills 1983). It is listed as rare by the International Union for Conservation of Nature and Natural Resources (ICUN 1986). Habitat alteration, such as clear cutting and brush control for agricultural development, has reduced available habitat for the species (Hamilton et al. 1987). Martin and Matocha (1972) suggested the extensive modification of mesquite pastures or conversion of pastures to monoculture may adversely affect the kangaroo rat.

1.4 Remote Sensing

Analysis of digital remotely sensed data was conducted in order to classify major landuse or landcover categories within the study area. Remote sensing involves sampling of electromagnetic radiation (EMR) that is reflected or emitted from the earth's surface. Features on earth can be characterized by their pattern of spectral emittance (termed "spectral signature") across the electromagnetic spectrum. Figure 2 displays such spectral signatures for typical green vegetation, dry loam soil and clear water. Relative spectral differences between these materials are the basis for interpretation of satellite imagery.

The digital imagery used for the analyses for this study was collected by Landsat 4. Landsat orbits the earth at an altitude of 705 km in a sun synchronous near-polar orbit. Its repeat coverage is 16 days (Slater 1985). The spectral data were recorded by the MSS (Multi-spectral Scanner) which discriminates reflected and emitted energy in four bands, each band representing discrete portions of the electromagnetic spectrum. Resolution of MSS data is 80 meters.

The specific MSS image utilized for this work was obtained form the EOSAT Company in Sioux Falls, South Dakota. The image was recorded 18 July 1986 (scene ID 85085916364, Path 29, Row 36).

2.0 STUDY AREA

An area of 300,885 ha in north central Texas was selected as the study area (Fig. 3). This area is within the range of the Texas kangaroo rat and was chosen for of the availability of data pertaining to kangaroo rat collections and sightings. This area is within the Texas counties of Hardeman, Foard and Wilbarger. It is bounded by the Red River to the north, and by State Highways 283 and 70 to the west and south, respectively. The eastern limit of the study area is the eastern boundary of Hardeman county. The study area is within the Red River basin, in the north-central portion of the Rolling Plains ecological area of Texas The climate is subtropical subhumid, with dry winters and low summer humidity. Rainfall ranges from 56 to 67 cm annually. The regional topography is dissected by many narrow intermittent streams in the plains, and by undulating grasslands in nearly level valleys and prairies. Elevations range from 245 to 915 m (USACE 1976).

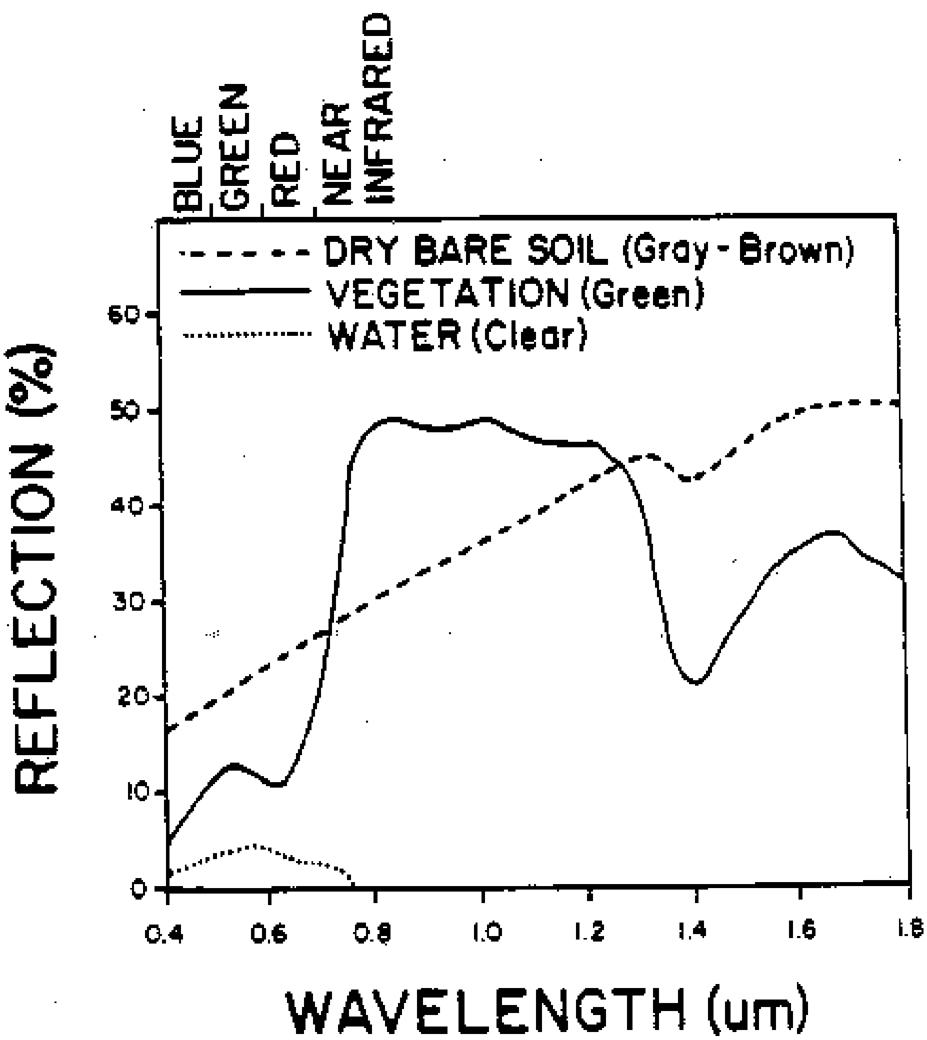


FIGURE 2. Typical spectral reflectance curves (from Swain and Davis 1978).

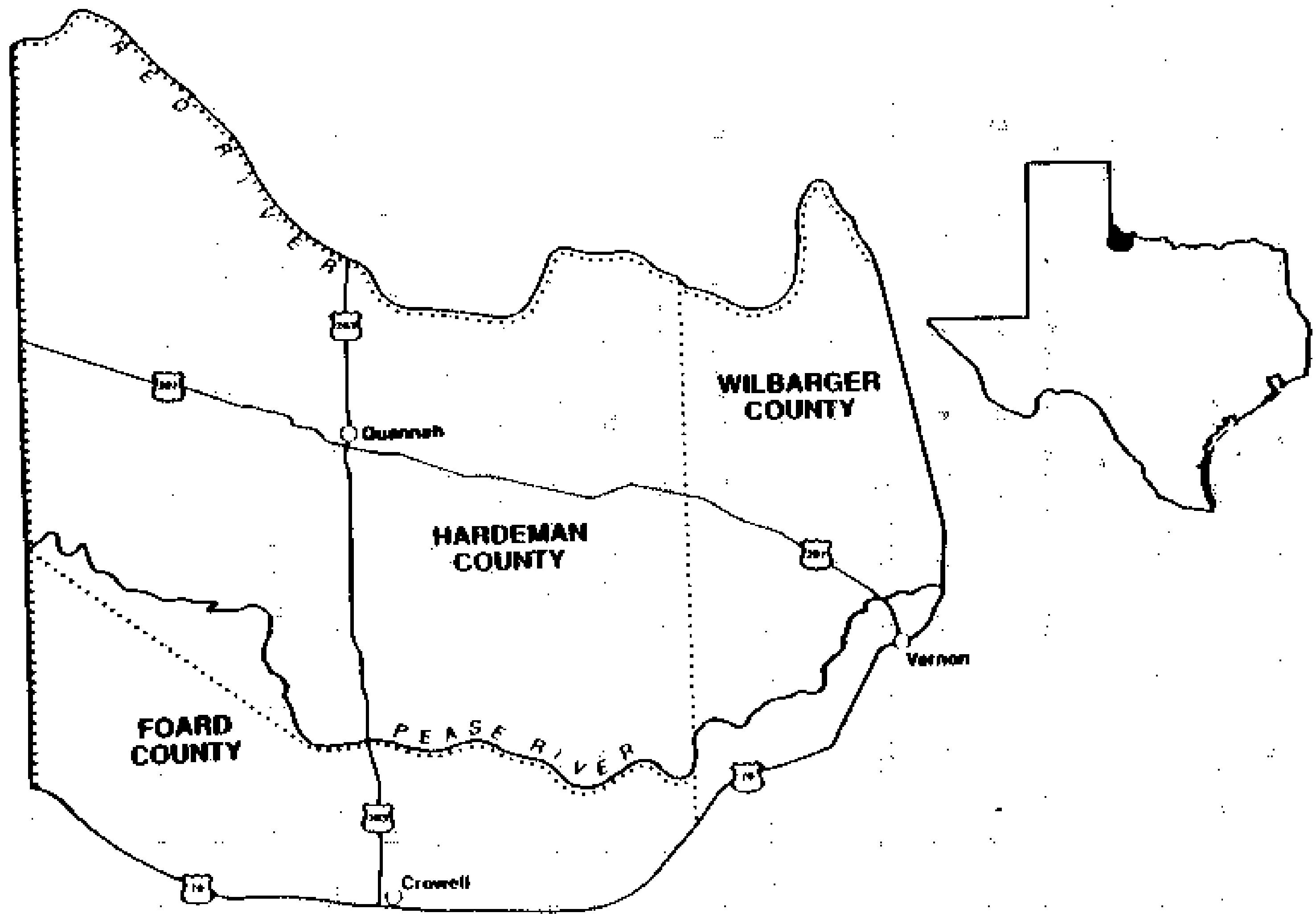


FIGURE 3. Location of the Texas kangaroo rat study area.

2.1 Soils and Geology

The study area is underlain by geology of the Permian Formation, consisting mainly of rocks of the Double Mountain Group. This group consists of interbedded gypsum, dolomite and red shale with layers of sandstone and shale in the lower parts. Permian rocks are exposed over portions of the central and southern parts of the study area. In the northern and east-central portions of the study area, a r .antle of outwash materials was deposited over the Permian Red Beds from the Pliocene to Pleistocene periods. These outwash deposits, the Seymour Formation, rest directly on top of the Permian Red Beds and vary from a few meters to about 15 m in thickness and range in texture from clayey to silty and sandy (Sellards et al. 1932). Soils in this area have developed from four types of parent material: residuum derived from Permian shale, (sandstone, limestone and gypsum); sandy to clayey outwash or old alluvium; recent alluvium and; recent eolian materials. Eolian materials are mostly along tributaries of the Red River. These materials were deposited in a relatively narrow band parallel to the river. Soils in the plains vary from sands to tight clays or red bed clays that are slightly acidic to moderately alkaline. Upland soils are composed of slightly acidic silty or sandy loam. These soils are usually deeper and have more distinct horizons than sloping soils on hilltops and ridges. The flatter soils receive additional water, have less runoff and are subject to less erosion (USDA 1972).

Due to the combination of climate and substrate, this area is subject to extensive soil erosion. Wind and water induced erosion have caused extensive soil loss and subsequent reduction in the productivity. Incidents of sheet erosion exceeding 5 tons/acre/year occur in the area, particularly on sandy soils. As much as 49 million tons of soil annually are moved by erosion for all of the Red River basin and over 120 ha are lost to streambank and gully erosion yearly (USDA 1977).

2.2 Vegetation

Five major vegetative groups are identified within the study area (McMahan et al. 1984). The most prominent is cropland. Major crops in this area are wheat, cotton and sorghum. The second largest vegetative type a mesquite-juniper brushland. The dominant species of this community are mesquite, Pinchot juniper (Juniperus pinchotii), lotebush (Ziziphus obtusifolia), sumac (Rhus sp.), Texas pricklypear (Opuntia lindheimeri), tasajillo (Opuntia kleiniae) and catclaw (Acacia greggii). This vegetative association is located predominately in the eastern and southeastern portions of the study area.

The third vegetative community is desc-ibed as a cottonwood-hackberry-saltcedar brush/woodlands. The common plants are cottonwood (Populus deltoides), black willow (Salix nigra), buttonbush (Cephalanthus sp.), rough-leaf dogwood (Cornus drummondii), Panhandle grape (Vitis acerifolia), and groundsel-tree (Baccharis sp.). This community is located primarily along the Pease River in the southern portion of the study area. The fourth community, a Mesquite-Lotebush Shrubland consists of mesquite (Prosopis glandulosa), yucca (Yucca sp.), skunkbush sumac (Rhus sp.), agarita (Berberis sp.), elbowbush (Forestiera pubescens), juniper (Juniperis sp.) and tasajillo. This community is located in the southeastern corner of the study area. The fifth vegetative community is a mesquite brushland, composed of mesquite, yucca, pricklypear and Pinchot juniper. This brushland community is located in the far northwest portion of the study area (McMahan et al. 1984).

3.0. METHODS

This section provides description of the GIS and digital image classification techniques employed to characterize habitat for the Texas kangaroo rat. All image processing and GIS analyses were conducted with the Earth Resources Data Analysis System (ERDAS) at the University of North Texas' Center for Remote Sensing and Landuse Analyses (CRSLA).

This section also describes the data sources for the digital data base which was generated for the GIS analyses. This data base was comprised of spatial information for five variables; locations of Texas kangaroo rat collection sites, major soil associations, major geologic formations, slope descriptions and landuse. These data were acquired in digital format or manually digitized (Appendix A).

3.1 Digital Image Analysis

Digital image data were obtained in computer compatible format on magnetic tapes. Digital analyses of these data involved the extraction of significantly different classes of data, termed clusters. These clusters were isolated on the basis of statistical differences in spectral reflectance. Each of the classes represent a category of interest, such as mesquite woodland, pasture or bottomland forest.

Prior to classification, several pre-processing steps were required, including georectification and signature extraction. Figure 4 illustrates these steps as part of the overall data analysis procedure.

3.1.1 Georectification

Georectification was performed on the digital satellite image to provide spatial reference (to the Universal Transverse Mercator [UTM] coordinate system), and to correct for error produced by changes in satellite attitude (roll, pitch and yaw) and altitude. Georectification was accomplished in two steps. First, recognizable features on the image were matched with specific locations on U.S. Geologic Survey 1:24,000 scale maps form which precise coordinates were determined with a digitizing tablet. The second step of classification required the determination of a coefficient matrix describing the geometric relationship between image pixel locations and associated map coordinates for each GCP. To achieve this, the total root mean square (RMS) of the spatial error between the image locations and map coordinates were determined. The RMS attributable to each location was also calculated. GCPs contributing the greatest error were sequentially removed until the total RMS was less than or equal to 1.0. Remaining GCPs were used to calculate the final set of coefficients that model the geometric distortion of the image.

The final phase of rectification, resampling, involved the extraction of an individual pixel's value from its original location and placement of that value at the appropriate new coordinate location. Nearest Neighbor interpolation algorithm was used for all image resampling. After

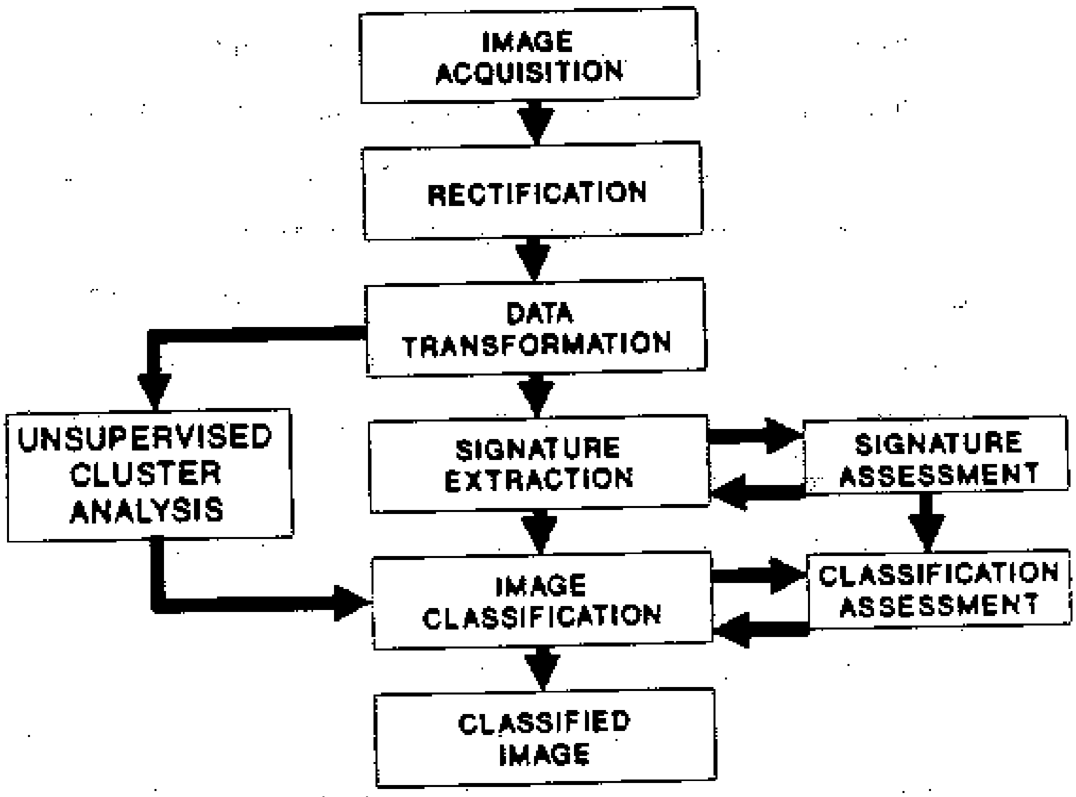


FIGURE 4. Basic steps for digital Landsat image classification.

rectification, resulting image pixels were referenced not only by row and column but also with respect to the UTM map projection system.

3.1.2 Image Classification

Classification of digital imagery is a means of spectral pattern recognition. Classification of the kangaroo rat image was accomplished with a combination of supervised and unsupervised classification techniques (Figure 5). This method provided the autonomy of unsupervised classification but allowed for the inclusion of signatures form specific training fields.

The first step of the classification process was an unsupervised classification algorithm used to extract signature statistics from the image based on spectral response variations within and among bands. The second step, supervised classification, involved the extraction of specific signatures from the MSS image (signatures for the various landuses were identified from field reconnaissance work). Signatures created from the unsupervised method and from the training samples were merged.

The final classification step was the application of a supervised classification algorithm. The algorithm analyzed the digital satellite data with respect to the catalogue of combined signatures. Each pixel is then assigned to the class to which it has the highest probability of belonging, based on statistical similarity. The output image was then generated in which every pixel from the input MSS image has been assigned to a particular class. Eight different landuse classes were identified from the satellite image; Agriculture, Mesquite-Juniper Woodland, Developed/Barren, Badlands, Water, Bottomland Hardwoods, Mesquite Grassland and Grasslands.

3.2 Geology and Soils

Geology data for the study area were manually digitized from the Texas Bureau of Economic Geology Wichita Falls/Lawton 1:250,000 sheet (BEG 1987). These maps provided locations and descriptions of the major geologic formations. Nine different formations were

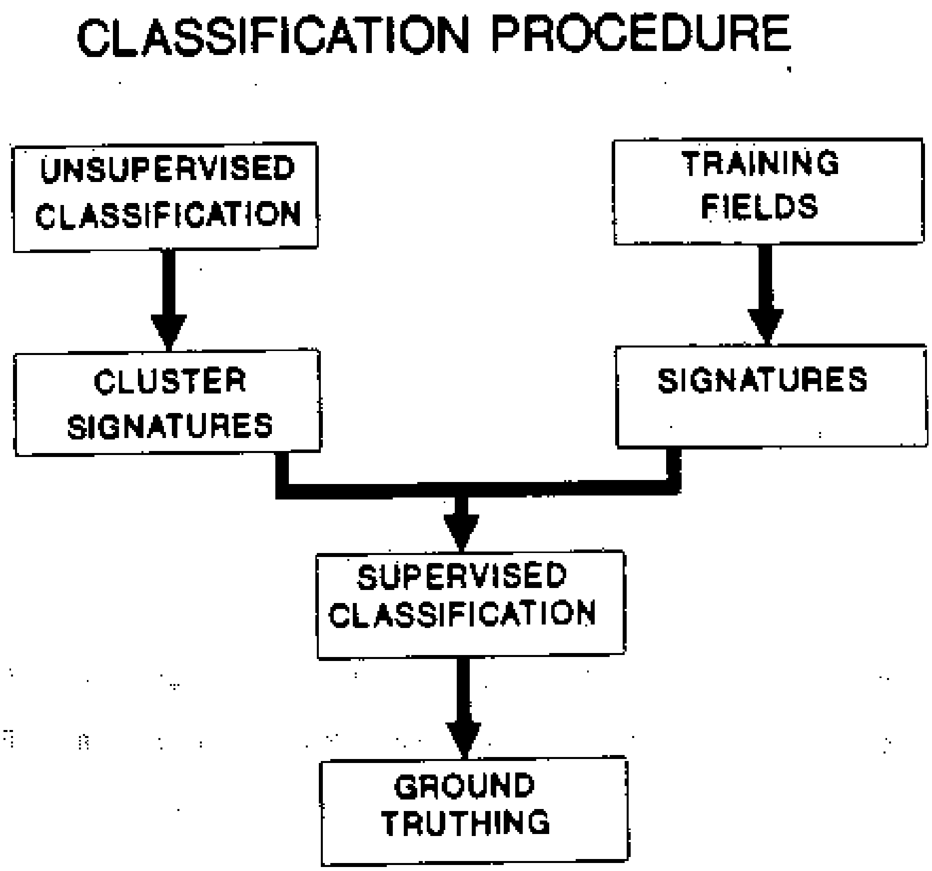


FIGURE 5. Procedure used for classification of digital Landsat data.

located in the study area. Brief descriptions of each of these are found in Appendix B. Soils information was manually digitized from Soil Conservation Service (SCS), general soil maps of Hardeman, Foard and Wilbarger Counties (USDA 1972, USDA 1961, USDA 1981). Only the 13 major associations were considered. Brief descriptions of these associations are provided in Appendix C.

3.3 Slope

Data for the factor were generated from U.S. Geological Survey (USGS) Digital Elevation Model data (DEM). The information provided land surface elevation values for each pixel in the study area. A slope value for each pixel was calculated by comparing each pixel's elevation to its neighbors' elevation, thus estimating "percent slope". The result of these calculations were a data base where the attribute is the percent slope for each pixel.

3.4 Texas Kangaroo Rat Locations

Locations of previously reported Texas kangaroo rats were provided by Texas Parks and Wildlife Natural Heritage Program and Robert Martin (Martin 1989). These data were originally collected from museum collections at Texas Tech University (Lubbock, Texas) and Midwestern University (Wichita Falls, Texas) (Appendix D). The data were collected from 1969 to 1974. Seventy-seven different collection points were identified in the study area. For several of these sites, more than one rat had been collected, but these sites were considered to be equal weight with the other points.

3.4 Suitability Model

The suitability of any portion of the study area for Texas kangaroo rats was determined from comparison of known kangaroo rat locations, to a combination of the previously described variables (i.e. slope, geology, soil and landuse). For this stage, the development of the model, 46 collections sites (60%) were randomly selected. The remaining 31 points were used to test the model. The development of the model was achieved in three steps. The first step was an assessment the actual distribution of the rats for each variable class (i.e. the number of rats reported from Quanah-Talpa soil formation). This was compared with the number of rats expected (per class), if this were a random distribution. For each variable, a chi-square test was employed to determine if there was a significant deviation from the expected distribution. If there was, the variable was included in the model. If there was not a significant deviation from a random distribution, the variable was not included.

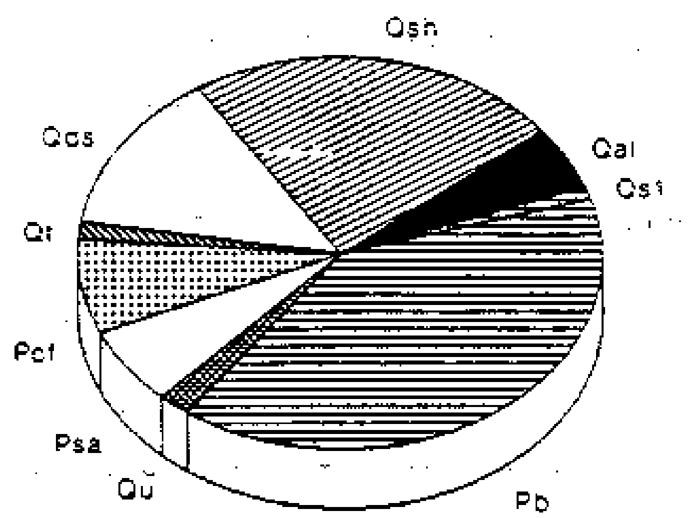
The second step for the development of the model was the assignment of weights to each variable class. The weight for each class was determined as the number of rats observed divided by the number of rats expected (for a given class). Each of these variable layers (composed of weighted classes) were added together in a pixel by pixel addition. The result was the generation of a habitat suitability map with the highest values indicating the most suitable habitat. The final step in the model development was a test of the suitability map with the remaining 31 points. This was done as a comparison of the collection sites with respect to the suitability value assigned to that location.

4.0 RESULSTS

4.1 Geology and Soils

Nine specific geologic formations were identified within the study area, the proportions of each are illustrated in Figure 6. The comparison of the spatial geologic data with 46 randomly selected records of the kangaroo rat found they had been observed or collected in only three of the nine formations, Qds, Psa and Pb. Forty-three (93.5%) of the rats were reported from Permian Blain Formation (Pb). The formation comprises 39.4% of the study area (118,965 ha), and is typified by mudstone, gypsum, dolomite and sandstone deposits. One observation was reported from the Quaternary dune sands (Qds), which accounts for 13.3% of the study area (40,042 ha). Qds is characterized by eolian sand and silt and sheetwash slope deposits.

Two of the 46 (4.3%) kangaroo rat records were reported from the Permian sandstone



Formation	%	ha.
Qal	5.3	16097
Qsh	23.2	69669
Qds	13.3	40042
Qt	1.4	4150
Pcf	7.8	23491
Psa	6.5	19396
Qu	2.0	6007
Qsl	1.0	3060
Pb	39.5	118973

FIGURE 6. Major geologic formations within the Texas kangaroo rat study area.

Formation (Psa). The formation comprises 6.5% of the study area (19396 ha). Psa is characterized by mudstone, sandstone, siltstone and gypsum (BEG 1987). This distribution of kangaroo rats was significantly different from random ($x^2 = 36.3, P < 0.001$). This was determined from a comparison of observed versus the expected rats normalized for formation area (Fig. 7). If there was no relationship between the distribution and a particular formation, there would not be a significant difference between the observed and expected.

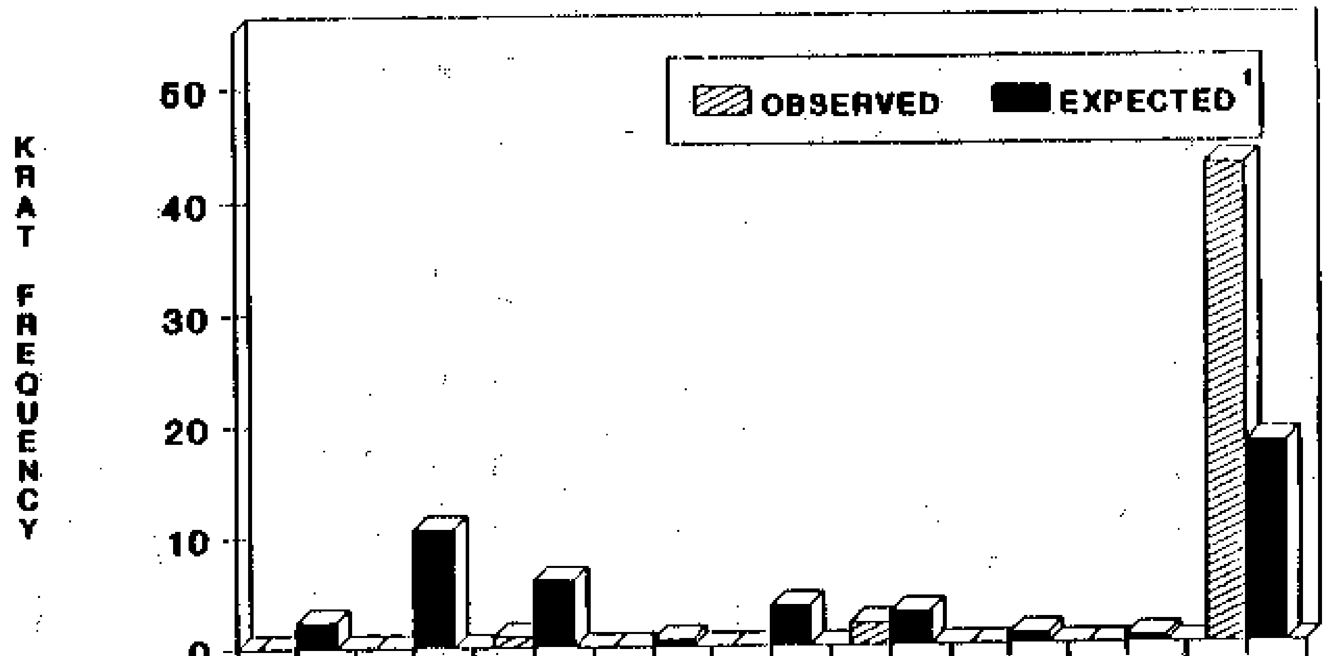
Fifteen major soil categories were identified in the study area. Figure 8 illustrates their proportion in the study area. Of these, six associations with were combined into a category "other". No rats were reported from these relatively small areas. Kangaroo rats had been collected in five of the fifteen soil associations. Thirty-five (76%) were reported from areas underlain by the Tillman-Vernon-Weymouth soil association. The association comprises 24.6% of the study area. Another soil association in which kangaroo rats were reported was the Hollister-Abilene. Four kangaroo rats (8.7%) were reported from the association. The association represents 9.7% of the study area. Five rats (10.9%) were located on the Quanah-Talpa soil association. This represents 4.7% of the study area. One rat was located in each of the Cobb-Cosh and Badlands-Vernon-Cottonwood associations (1.1 and 18.1% of the area respectively).

As with geologic formations, in a comparison of observed versus expected, the distribution of kangaroo rats was significantly different than a random (proportional) distribution of rats across all soil associations ($x^2 = 52.7, P < 0.001$) (Fig. 9).

4.2 Slope and Landuse

Slope was calculated for the study area and compared to the locations of the kangaroo rats. Within the study area, slope ranged from 0 - 15% (Fig. 10). A comparison of observed and expected kangaroo rats found no significant difference in the distribution of kangaroo rats and distribution of slope ($x^2 = .56$) (Fig. 11). For this reason slope was not considered as a variable in the suitability model.

Eight major landuse categories were identified within the study area. With respect to

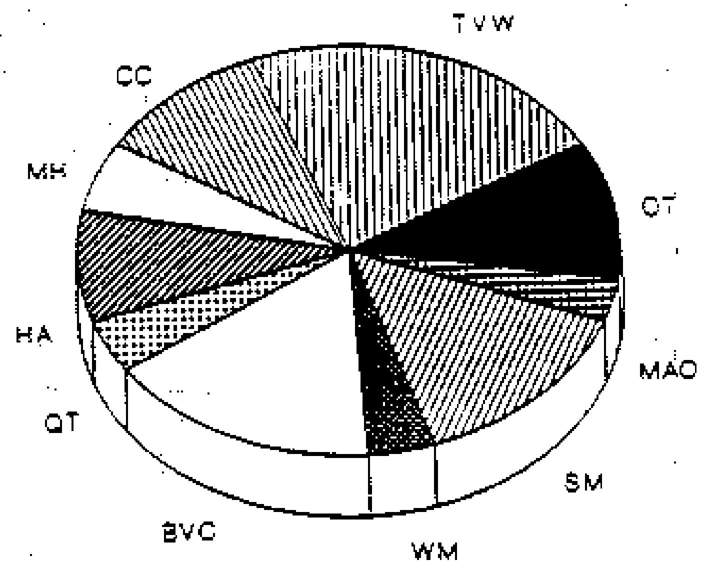


	Qal	Qsh	Qda	Qt	Pcf	Psa	Qu	Qs1	Pb
OBSERVED[1]	0	0	1	0	0	2	0	0	43
EXPECTED	2.4	10.7	6.1	0.6	3.6	3	0.9	0.6	18.1

FORMATION

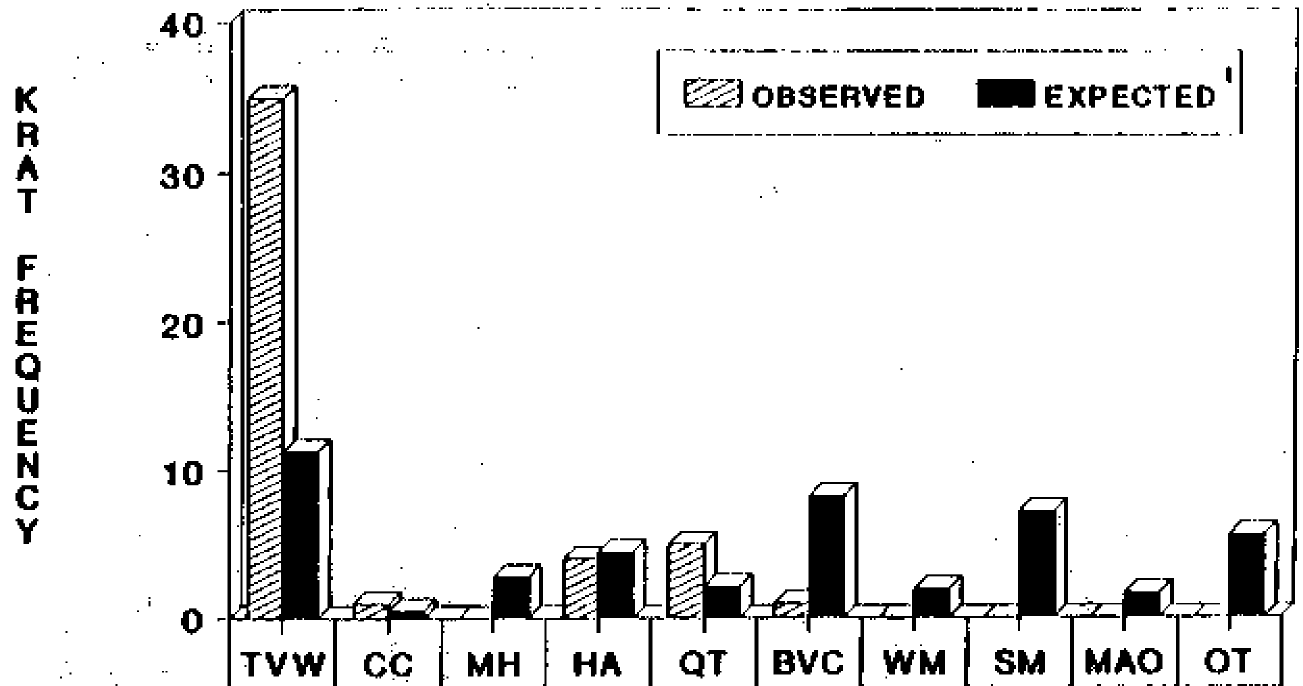
[1] Assuming a random distribution

FIGURE 7. Observed and expected distribution of Texas kangaroo rats with respect to major geologic formations.



	Association	%	ha.
TVW	Tillman-Vernon-Weymouth	24.6	73721
CC	Cobb-Cosh	1.1	3451
MH	Miles-Hardy	6.0	18065
HA	Hollister-Abilene	9.7	29056
QT	Quanah-Talpa	4.7	14001
BVC	Badlands-Vernon-Cottonwood	18.1	54517
WM	Wichita-Miles	4.3	13213
SM	Springer-Miles	15.7	47099
MAO	Miles-Acuf-Olton	3.7	11042
OT	Other:		
	Yomont-Lincoln	1.1	3525
	Rotan-Hollister	3.0	9116
	Tivoli-Enterprise	0.5	1480
	LaCasa-Ector	2.6	7859
	Tivoli-Hardeman	2.6	7916
	Enterprise-Tipton	2.3	6824
	TOTAL	100.0	300885

FIGURE 8. Major soil associations within the Texas kangaroo rat study area.

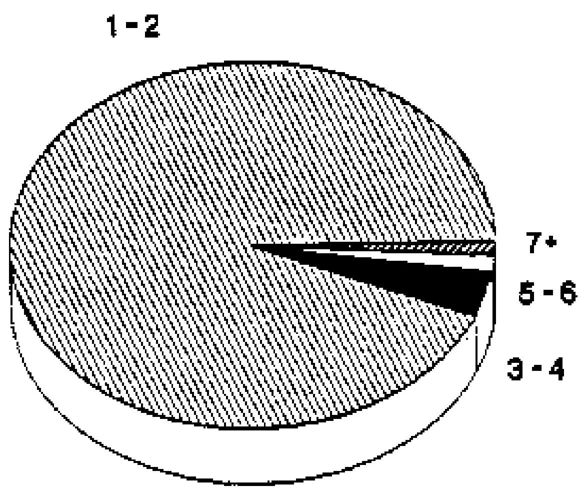


	TVW	CC	MH	HA	QT	BVC	WM	SM	MAO	OT
OBSERVED	35	1	0	4	5	1	0	0	0	0
EXPECTED[1]	11.3	0.5	2.8	4.5	2.1	8.3	2	7.2	1.7	5.6

SOIL ASSOCIATION

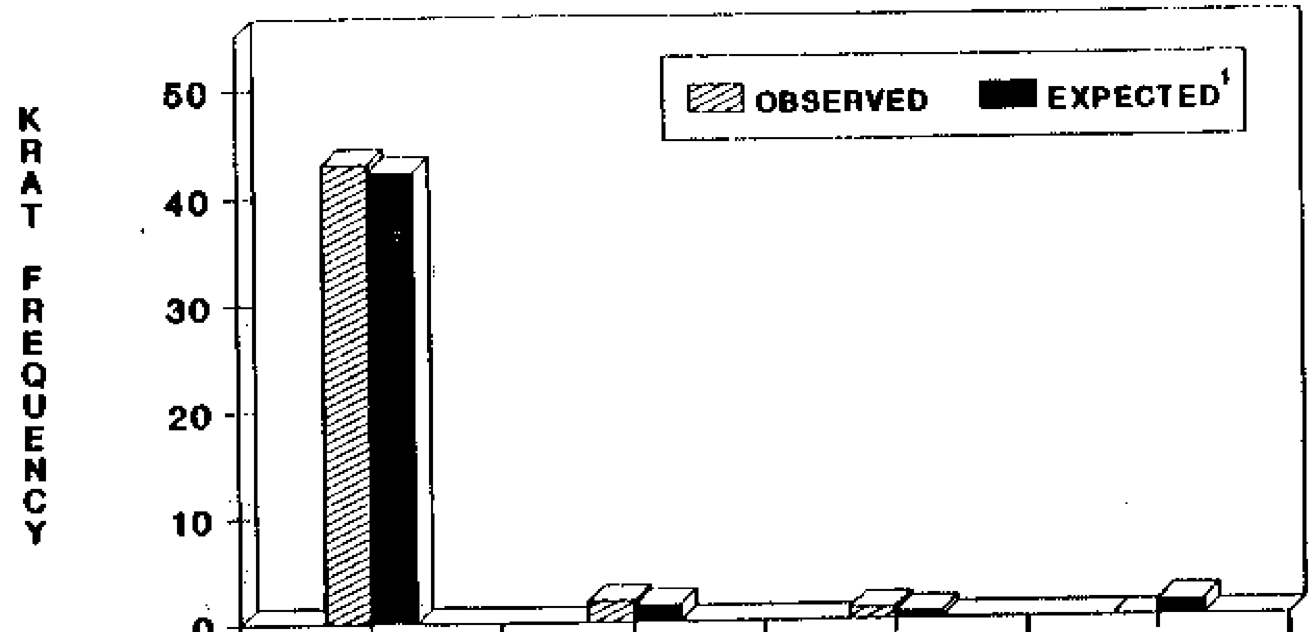
[1]Assuming a random distribution

FIGURE 9. Observed and expected distribution of Texas kangaroo rats with respect to major soil associations.



Slope	%	ha.
0 - 2	91.9	276513
3 - 4	3.5	10531
5 - 6	1.3	3912
7+	3.3	9929
TOTAL	100.0	300885

FIGURE 10. Distribution of slope within the Texas kangaroo rat study area.



	0-2	3-4	5-6	7+
OBSERVED	43	2	1	0
EXPECTED[1]	42.3	1.6	0.6	1.4

SLOPE (PERCENT)

[1] Assuming a random distribution

FIGURE 11. Observed and expected distribution of Texas kangaroo rats with respect to slope.

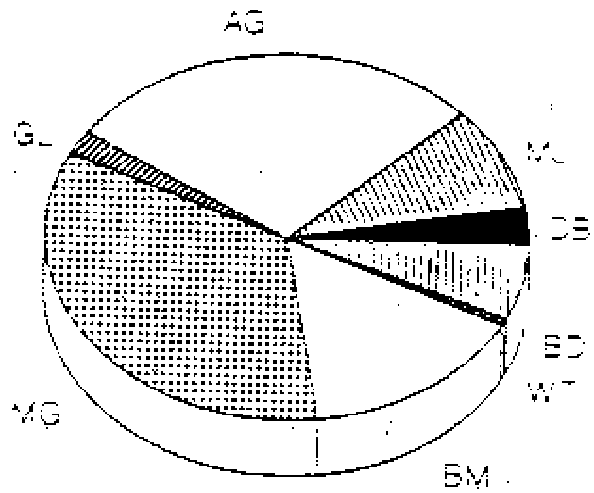
coverage they ranged from 34.5% of the area (mesquite grassland) to 0.6% of the area (water) (Fig. 12). A comparison of the kangaroo rat collection sites found their distribution to be significantly different from a random, with respect to these landuse categories (x^2 = 14.5, P < 0.05) (Fig. 13).

4.3 Habitat Suitability Map

The variables in the model (geology, soil and landuse) were equally weighted, and each was considered to have the same importance for the distribution of the Texas kangaroo rat. The justification for this was that there was not sufficient information with which to weight the variables. Within each of the variables, the value assigned to individual classes (e.g. specific soil formations) was determined as the number of observed rats divided by the number of expected rats. For example, in the HA (Hollister-Abilene) soil association, four rats were observed, based on proportional area and a random distribution, 4.5 rats would be expected. The value assigned to the HA association was .89 (4/4.5). Using the GIS capabilities of the ERDAS software, these layers of variables were added together. The values of the resulting suitability map was condensed to 5 categories, where 1 was least and 5 most likely to contain kangaroo rats (Fig. 14). Specifically, 18.1% (53283 ha) of the study area was rated as 'most likely' (to contain kangaroo rats) (5), 3.17% (9329 ha) was rated as 'likely' (4), 19.7% (57951 ha) was rated as 'less likely', 15.7% (46409 ha) as 'unlikely' and 43.3% (127756 ha) were rated as 'least likely'.

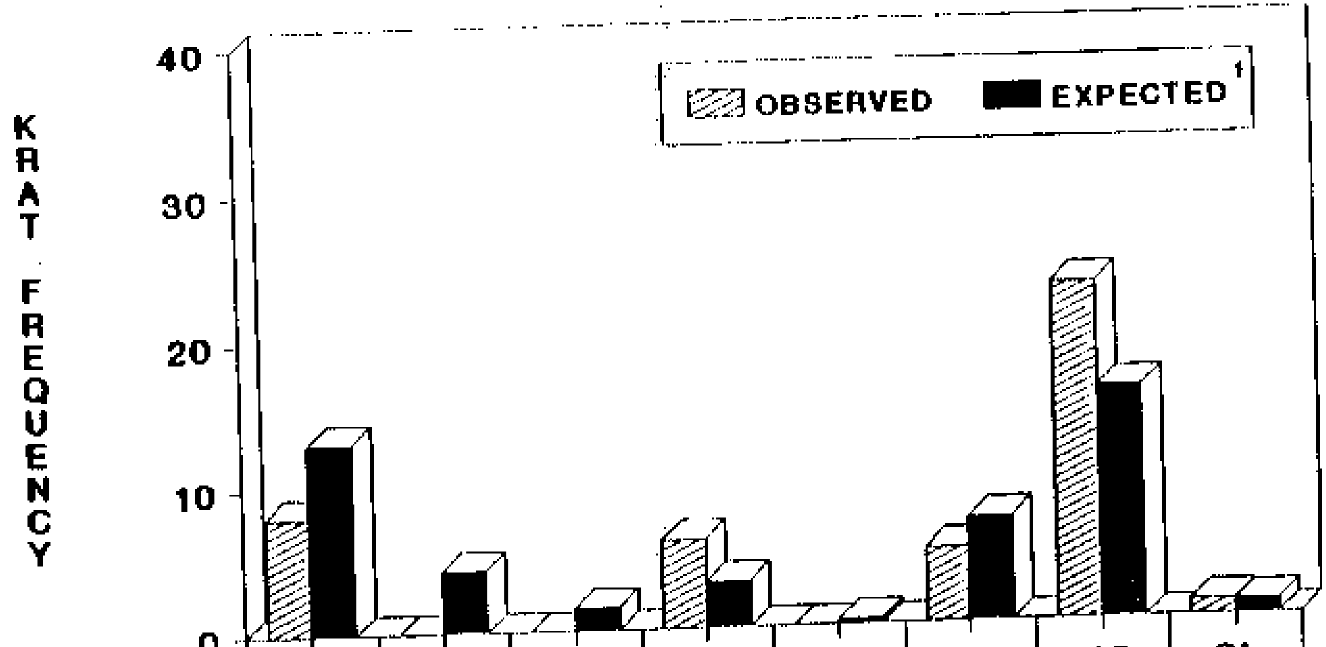
When the suitability map was tested with the 31 additional locational points, results supported the validity of the model for the variables tested. Fifty-five percent (17) of the rat locations were within the 'most likely' areas, 6 (19%) were located in areas classified as 'likely', 5 rats were located within areas designated as 'less likely', and 3 were located in 'unlikely' areas. No rats were reported from the 'least likely' areas (Fig. 15). A Chi-square test (normalized for area) found the distribution of kangaroo rats was significantly different than the distribution of habitat categories (x^2 = 62.3, P < .001).

The areas rated highest for Texas kangaroo rats were located on soils of the TVW



	Landuse	%	ha.
AG	Agriculture	28.2	84895
MJ	Mesquite-Juniper Woodland	9.2	27681
DB	Developed/Barren	3.3	9898
BD	Badlands	6.8	20576
WT	Water	0.6	1996
BM	Bottomland Hardwoods	15.3	45878
MG	Mesquite Grassland	34.5	103730
GL	Grassland	2.1	6231
	TOTAL	100.0	300885

FIGURE 12. Distribution of landuse categories within the Texas kangaroo rat study area.



	AG	MJ	DB	BD	WT	BM	MG	GL
OBSERVED	8	0	0	6	0	5	23	1
EXPECTED[1]	13	4.2	1.5	3.1	0.3	7	15.8	0.9

LANDUSE

[1]Assuming a random distribution

FIGURE 13. Observed and expected distribution of Texas kangaroo rats with respect to landuse categories.

FIGURE 14. Location of the 31 Texas kangaroo rat test locations on the habitat suitability map.

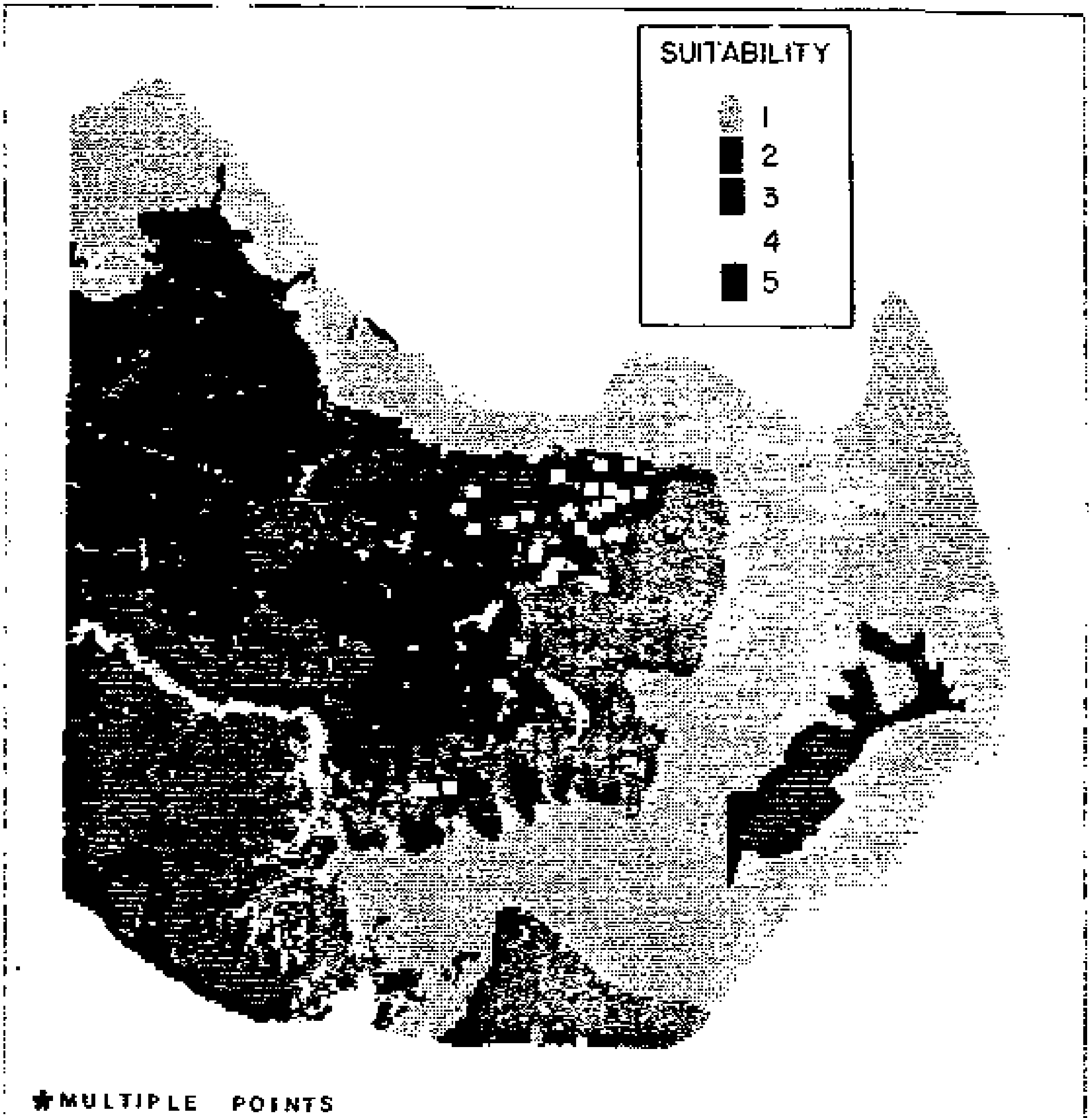
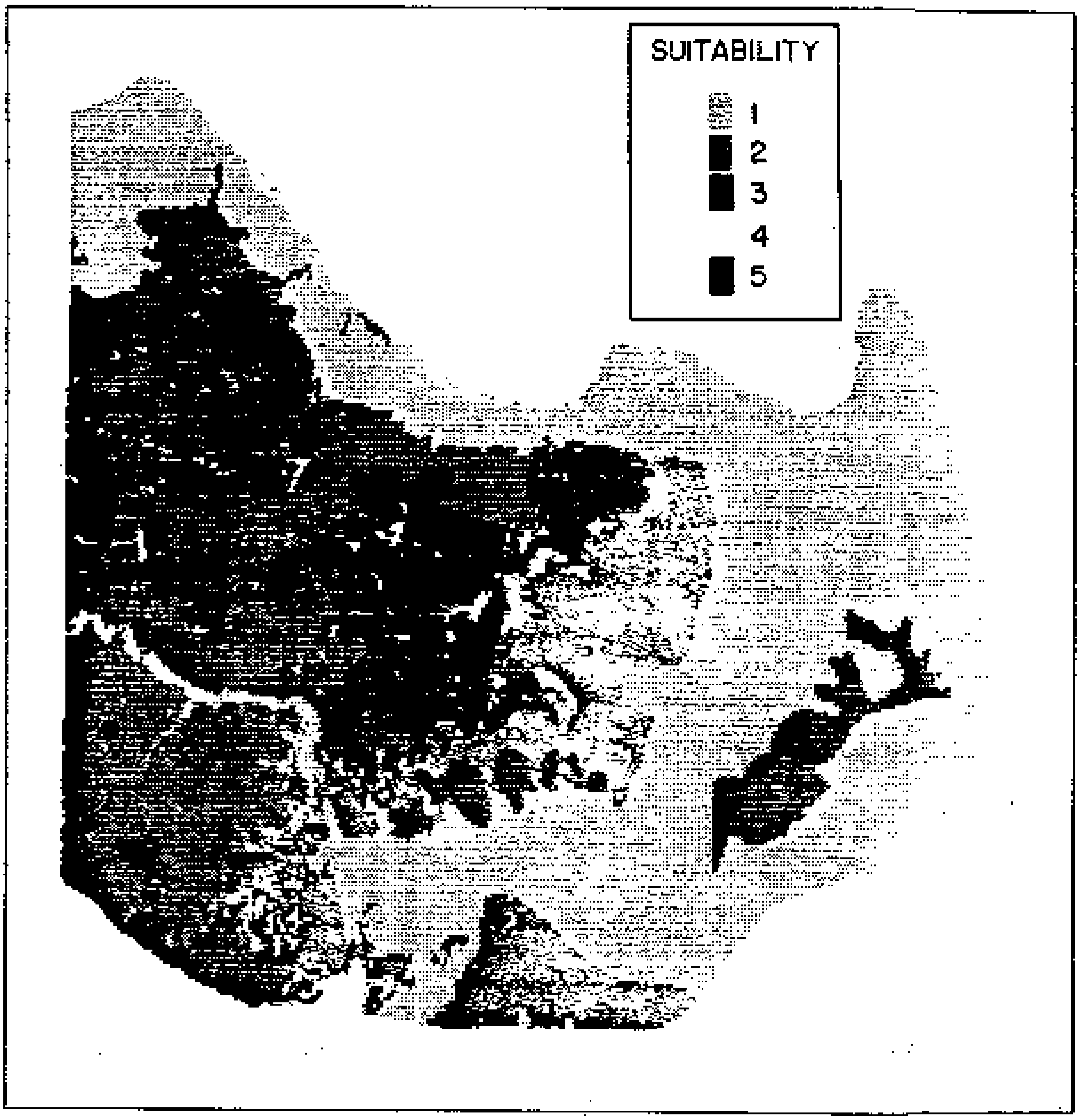

SUITABILITY
1
2
3
4
5
*MULTIPLE POINTS

FIGURE 15. Texas kangaroo rat habitat suitability map. Habitat suitability ranked 1-5; Areas designated as 1 are least likely, areas of 5 are most likely to contain Texas kangaroo rats.


SUITABILITY
1
2
3
4
5

(Tillman-Vernon-Weymouth association). Tillman series soils are typically deep, nearly level to gently sloping, composed of reddish-brown to brown clay loams with a slowly permeable lower layer. Vernon series soils consist of well-drained calcareous soils that are clayey below the surface layer. Weymouth soils consist of well-drained sloping calcareous soils on uplands. They formed from calcareous moderately fine textured red beds or in old alluvium that contains red-bed material consisting primarily of clay loam (USDA 1972). The geology underlying the best habitat is primarily of the Pb (Permian-Blaine) formation. The formation is composed primarily of mudstone, gypsum, dolomite and sandstone. The landuse of the highest rated region is a mesquite-grassland.

4.4 Landuse change

Most of the land within in the study area is privately owned and has been modified for agricultural production and grazing. Cultivation was introduced to this area about 1880, prior to this most of the area was native rangeland (USDA 1974). Over the past 30 years there has been a trend away from agriculture and towards rangeland (Fig. 16) (USDA 1974). This trend may benefit the kangaroo rat, given the prevalence of the rat in rangeland (mesquite grassland) as opposed to agricultural areas. Hamilton et al. (1987) suggested that habitat alteration such as clear cutting and brush control for agricultural development, may reduce available habitat for the species. Additionally, Martin and Matocha (1972) suggested the extensive modification of mesquite pastures or conversion of pastures to monoculture may adversely affect the kangaroo rat. However, Martin and Matocha (1972) pointed out agricultural practices need not limit the distribution of the kangaroo rat if cultivated areas are interspersed with mesquite pastures and shrubby fence rows. Aside from agricultural impacts, tolerance of the Texas kangaroo rat to land development with regards to buildings and roadway impacts are not known, although Martin and Matocha (1972) suggested that urbanization and cultivation apparently limit the habitat available to the species.

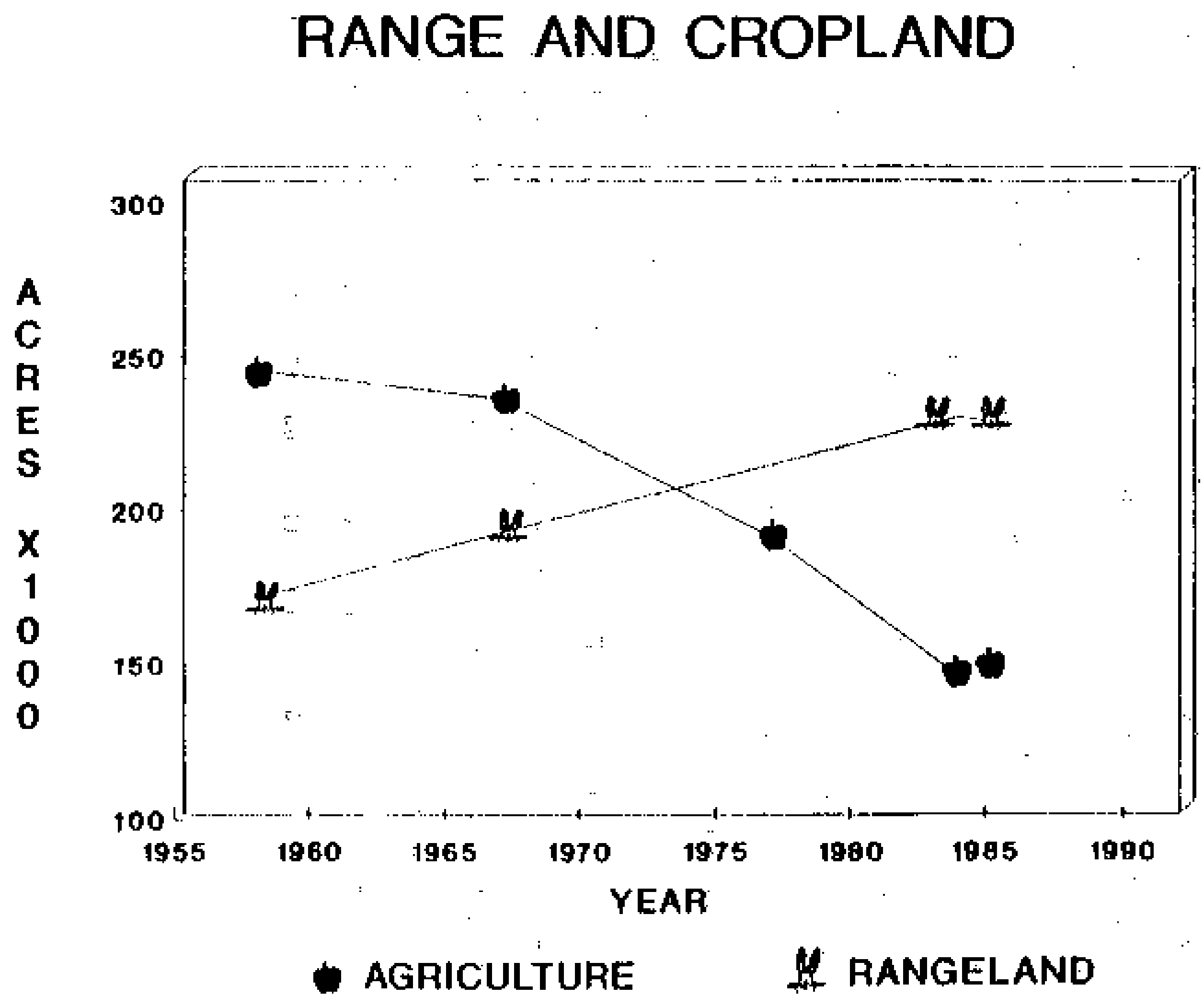


FIGURE 16. Trends in agriculture and rangeland for the past 30 years in the Texas kangaroo rat study area.

5.0 DISCUSSION

Several difficulties were encountered in the course of the research. First, with respect to the sample points. There was a bias with respect to locations. The study area was not randomly sampled for presence or absence of kangaroo rats. The data points that were used were areas known to have kangaroo rats, therefore individuals interested in collecting kangaroo rats returned to these sites. Second, with respect to landuse classification, during June (when the image was taken) many of the agricultural fields were fallow. These were difficult to classify. Another difficulty encountered with the collection sites was that most sites were located near the boundary of two landuses (i.e. roads and agriculture). Because of the resolution of the Landsat MSS data (80 m), and the spectral variation of these areas, these areas may have been misclassified with respect to landuse.

This habitat model was developed and implemented to identify areas of suitable habitat for the Texas kangaroo rat. Results from the test of this model indicate that the model provides a good appraisal of the suitability of Texas kangaroo rat habitat for the study area. Through the development and implementation of the model, variables (i.e. geology, soils and landuse) were identified which appear to be correlated spatially with the current distribution of the Texas kangaroo rat. More research is needed to investigate these relationships. The research has also established a digital data base for the study area which may be used for future research in the area.

APPENDIX A

TEXAS KANGAROO RAT

LAYER	SOURCE	SCALE	ENTRY	DESCRIPTION
COUNTY	USGS	1:250000	DIGITIZED	COUNTY BOUNDARIES
SLOPE	USGS	1:250000	DIGITAL	SLOPE PERCENT
LANDUSE	MSS	1:24000	DIGITAL	CLASSIFIED IMAGE
GEOLOGY	BEG	1:250000	DIGITIZED	MAJOR FORMATIONS
KRATS	MARTIN	1:24000	DIGITAL	KRAT SITES
SOILS	SCS	1:163000	DIGITIZED	SOIL TYPES
STUDAR	USGS	1:250000	DIGITIZED	STUDY AREA
ROADS	USGS	1:250000	DIGITIZED	STUDY AREA ROADS

KEY FOR DATA DICTIONARY	
USGS	U.S. Geologic Survey
TP&W	Texas Parks and Wildlife
BEG	Texas Bureau of Economic Geology
USACOE	U.S. Army Corps of Engineers
TM	Thematic Mapper Landsat Data
MSS	Multispectral Scanner Landsat Data
GCW	Golden-cheeked Warbler
BCV	Black-capped Vireo
KRAT	Texas Kangaroo Rat

APPENDIX B

Description of Major Geologic Formations*

Qal - (Quaternary, Holocene) Floodplain and channel deposits: sand, silt, clay and gravel near floodplain levee. Locally developed eolian dunes of sand and silt, bedrock locally in stream channels. Thickness of alluvium of to 30 feet.

Qsh - (Quaternary Holocene and/or Pleistocene) Windblown deposits, dunes and dune ridges; sand, silt and clay, orange-brown, massive with crude vertical joints and buried soils. Thickness of sheets up to 20 feet.

Qds - (Quaternary Holocene and/or Pleistocene) Windblown deposits, dunes and dune ridges; sand and silt, orange-brown, massive, local low-angle crossbeds; best developed on floodplains, fluviatile terraces and Seymour Formation. Thickness of dune ridges up to 25 feet.

Qt - (Quaternary Holocene and/or Pleistocene) Fluviatile terrace gravel, sandy lenticular, stratified, crossbedded, locally cemented by calcite, clasts granule to cobble-size, well-rounded to subangular, composed of quartzite and other metamorphic rocks, milky quartz, chert and fine grained igneous rocks from westerly sources.

Pcf - (Permian) Mudstone, siltstone, dolomite, limestone and gypsum. Mostly mudstone, commonly silty, brownish-red, minor gray and green, calcareous nodules abundant in lower part. Siltstone in units 1 to 3 feet thick distributed throughout.

Psa - (Permian) Mudstone, sandstone, siltstone and gypsum. Thickness of formation 90 to 120 feet.

Qu - (Quaternary) Alluvium surficial deposits; sand, clay, silt, caliche and gravel; includes thin remnants of older terraces, lag gravel, windblown sand and silt, residual soil and colluvium commonly cemented by caliche. Thickness of surficial deposits up to 10 feet.

Qsl - (Quaternary Pleistocene) Surficial deposits, thin deposits; sand, silty orange-brown massive; thin gravel locally in basal part, generally massive to crudely stratified, rarely crossbedded, locally cemented by calcite; clasts granule to pebble-size, angular to rounded, composed predominately of limestone with minor clasts of quartzite, milky quartz, sandstone and siltstone. Thickness of deposits 1 to 10 feet.

Pb - (Permian) Mudstone, gypsum, dolomite and sandstone; laterally persistent and prominent dolomite beds. Mudstone, locally silty, brownish-red and gray -green. Gypsum typically of nodular alabaster, friable, white, dolomitic beds; units pinch out locally in outcrop owing to dissolution.

* From BEG 1987

APPENDIX C

Soil Association Descriptions*

Tillman-Vernon-Weymouth - This association is a large, irregular shaped, nearly level to sloping, upland plain. It is on a broad divide between the rivers and adjoins most of the other associations. It is characterized by deep to shallow, nearly level to gently sloping soils that have a surface layer of clay loam and slowly to moderately permeable lower layers.

About 70% of this association is cultivated, 30% is in native range. Wheat, cotton and sorghum are the principal crops. This association covers about 34% of the total study area. Tillman soils make up about 38%, Vernon soils about 15% and Weymouth soils 11%. The remaining soils are scattered areas of Hollister, Olton, Colorado, Spur and Mangum soils.

Tillman soils are deep, nearly level to gently sloping, reddish-brown to brown clay loams with a slowly permeable lower layer. They are usually found on smoother ridges and upland divides. Vernon soils are gently sloping, reddish brown with a slowly permeable clayey lower layer. They are shallow and underlain by redbed clay or shale. Weymouth soils are deep, gently sloping, brown to reddish-brown clay loams with a moderately permeable clay loam lower layer. Weymouth and Vernon soils are found on the more prominent ridges, hilltops and side slopes flanking creeks and natural drains.

Badland-Vernon-Cottonwood - This association consists of very shallow rough lands in breaks lying below the adjoining soil associations. The topography of this associations is steep escarpments and benchlike areas dissected by drainage channels and gullies. The soil is characterized as nearly barren red-bed shale and clay with shallow to very shallow soils with a clay or clay loam surface layer and lower layers of clay or gypsum.

This association is approximately 18% of the study area. Little of this association is cultivated, it is used mainly for range.

Springer-Miles - These soils form an undulating to hummocky sandy plain that covers about 16% of the study area. These soils are deep, neutral and have a very friable fine sandy loam lower layer. The underlying material is loamy fine sand to fine sand.

About 75% of this association is cultivated and about 25% is in native range. The principal crops are wheat, cotton, guar and sorghum. These soils are susceptible to wind erosion.

Hollister-Abilene - These soils form a nearly level to gently sloping upland plain that occupies about 10% of the study area. The association is characterized by deep nearly level to gently sloping soils that have a clay loam surface layer and lower layers of clay, silty clay, or silty clay loam.

About 90% of this association is cultivated; 10% is in native range. Wheat, sorghum and cotton are cultivated on this association.

Miles-Acuff-Olton - This soil comprises about 8% of the study area and occupies nearly level to gently sloping uplands. The soils are characterized by deep, nearly level to gently sloping soils that have a surface layer of loam to clay loam and lower layers of sandy clay loam and clay loam to silty clay loam.

About 85% of this association is in cultivation and about 15% is native range. The major crops are wheat, sorghum and cotton.

Quanah-Talpa - This soil occupies about 7% of the study area. It is about 56% gently sloping Quanah soils and about 30% gently sloping to steep Talpa soils. The association is characterized by deep and very shallow, gently sloping to steep soils that have a surface layer of clay loam over moderately permeable layers.

About 10% of this association is cultivated, and about 90% is native range. Cultivation is primarily on the Quanah soils, Talpa soils are too shallow and stony.

Tivoli-Hardeman - These soils are duny and undulating. They comprise about 5% of the study area. The association is characterized by deep, nearly undulating, dunned and steep soils that have a surface layer of fine sand to fine sandy loam and lower layers of fine sand and fine sandy loam. The Tivoli soils (50%) are deep duned soils of the uplands. They are rapidly permeable fine sand throughout. They are generally adjacent to flood plains. The Hardeman soils are deep, nearly level to steep soils with fine sandy loam throughout.

About 30% of this association is cultivated and 70% in native range. Cultivated areas are confined almost entirely to the Hardeman soils. Wheat and cotton are the principal crops.

Cobb-Cosh - This association occupies gently sloping uplands and comprises less than 2% of the study area. The soils are characterized by moderately deep to shallow, gently sloping soils that have a surface layer of fine sandy loam and lower layers of sandy clay loam over sandstone.

About 80% of this association is cultivated and 20% is in native range. Wheat and sorghum are the principal crops.

* From USDA 1972

APPENDIX D

COLLECTION SITES FOR KANGAROO RATS

RAT NUMBER	CATALOG #	UTM X COORD.	UTM Y COORD.	YEAR	MON	DAY
1	24798	431916.00	3779073.00	69	10	9
2	13532	432720.65	3787119.50	69	10	9
3	13535	433525.30	3788510.20	69	10	9
4	13534	434329.95	3787119.50	69	10	9
5	13536	435134.60	3777463.70	69	10	9
6	13533	435134.60	3777463.70	69	10	9
7	8824	433536.93	3799189.25	69	7	15
8	24793	435939.25	3787119.50	69	10	9
9	9610	435939.25	3797579.95	69	12	17
10	11434	435939.25	3797579.95	70	4	4
11	13547	435939.25	3797579.95	70	6	5
12	11780	435939.25	3797579.95	70	7	1
13	11435	435939.25	3797579.95	70	4	4
14	11430	435939.25	3797579.95	70	2	11
15	24756	435939.25	3797579.95	70	1	8
16	9926	435939.25	3797579.95	70	2	10
17	11429	435939.25	3797579.95	70	2	11
18	24744	435939.25	3797579.95	69	11	6
19	9758	435939.25	3797579.95	70	1	13
20	24747	435939.25	3797579.95	70	7	1
21	9571	435939.25	3797579.95	69	12	17
22	24748	435939.25	3797579.95	69	11	7
23	24764	435939.25	3797579.95	70	4	4
24	12080	435939.25	3797579.95	70	5	9
25	24742	435939.25	3797579.95	69	11	6
26	9608	435939.25	3797579.95	69	12	17
27	11779	435939.25	3797579.95	70	7	1
28	10275	435939.25	3797579.95	70	5	9
29	24750	435939.25	3797579.95	70	7	2
30	24739	435939.25	3797579.95	70	1	13
31	24737	435939.25	3797579.95	70	2	11
32	24757	435939.25	3797579.95	70	1	8
33	24804	435939.25	3797579.95	70	2	11
34	11781	435939.25	3797579.95	70	7	2
35	24746	435939.25	3797579.95	69	11	6
36	24751	435939.25	3797579.95	70	2	10
37	9612	435939.25	3797579.95	69	12	17
38	24741	435939.25	3797579.95	70	1	12
39	24805	435939.25	3797579.95	70	4	4
40	9759	435939.25	3797579.95	70	1	12
41	24762	435939.25	3797579.95	70	4	4
42	9609	435939.25	3797579.95	69	12	17
43	24738	435939.25	3797579.95	70	2	11
44	24754	435939.25	3797579.95	70	5	9
45	9573	435939.25	3797579.95	69	12	17
46	24765	435939.25	3797579.95	70	4	4
47	9611	435939.25	3797579.95	69	12	17
48	24752	435939.25	3797579.95	70	2	10
49	11431	435939.25	3797579.95	69	11	6
50	24806	435939.25	3797579.95	70	6	5
51	10194	435939.25	3797579.95	70	5	9
52	9572	435939.25	3797579.95	69	12	17
53	10195	435939.25	3797579.95	70	5	9

54	24755	435939.25	3797579.95	70	5	9
55	11778	435939.25	3797579.95	70	7	1
56	24743	435939.25	3797579.95	69	11	6
57	11782	435939.25	3797579.95	70	7	2
58	11647	435939.25	3797579.95	70	7	2
59	24766	435939.25	3797579.95	70	4	4
60	11777	435939.25	3797579.95	70	7	1
61	11785	435939.25	3797579.95	70	7	2
62	12079	435939.25	3797579.95	70	5	9
63	10196	435939.25	3797579.95	70	5	9
64	24749	435939.25	3797579.95	70	7	2
65	10274	435939.25	3797579.95	70	5	9
66	24761	435939.25	3797579.95	70	4	4
67	11425	435939.25	3797579.95	70	5	9
68	24758	435939.25	3797579.95	70	1	12
69	9760	435939.25	3797579.95	70	1	9
70	24763	435939.25	3797579.95	70	4	4
71	11448	435939.25	3797579.95	70	7	2
72	24743	435939.25	3797579.95	69	11	6
73	24740	435939.25	3797579.95	70	1	13
74	24760	435939.25	3797579.95	70	6	4
75	11444	435939.25	3797579.95	70	7	1
76	11632	435939.25	3797579.95	69	11	6
77	24759	435939.25	3797579.95	70	1	13
78	10276	435939.25	3797579.95	70	5	9
79	9570	435939.25	3797579.95	69	12	17
80	11428	435939.25	3797579.95	70	2	11
81	11427	435939.25	3797579.95	70	2	11
82	11433	435939.25	3797579.95	69	11	6
83	11426	435939.25	3797579.95	70	5	8
84	11445	435939.25	3797579.95	70	7	1
85	11446	435939.25	3797579.95	70	7	2
86	24768	436743.90	3796936.23	69	7	14
87	13545	437076.94	3795222.39	69	9	19
88	13527	437146.23	3799189.25	69	7	15
89	13521	437237.87	3795383.32	69	9	19
90	24794	437548.55	3787119.50	69	10	9
91	13546	438203.45	3795544.20	69	9	19
92	13548	438353.20	3785510.20	69	10	9
93	13537	438353.20	3785510.20	69	10	9
94	13538	438486.24	3795544.25	69	9	19
95	24795	439157.85	3787119.50	69	10	9
96	13520	439490.89	3795544.25	69	9	19
97	11440	439540.18	3795959.03	70	6	5
98	13526	439540.18	3799189.25	69	7	15
99	13550	439962.50	3778268.35	69	10	10
100	24797	439962.50	3785510.20	69	10	9
101	24727	440344.83	3799189.25	70	2	5
102	13542	440617.40	3798762.85	69	9	19
103	13551	440767.15	3787119.50	69	10	9
104	24796	440767.15	3787119.50	69	10	9
105	13549	442376.45	3780279.98	69	10	9
106	13525	442376.45	3799189.25	69	7	15
107	24726	442698.31	3799350.18	70	2	5
108	24728	443583.43	3799189.25	69	7	15
109	12078	443836.00	3795544.20	69	9	19

110	11443	443836.00	3795344.25	70	6	5
111	24801	443836.00	3796509.83	69	7	14
112	13544	443836.00	3799084.70	69	9	19
113	24792	443985.75	3794763.68	69	8	11
114	24772	443985.75	3796775.30	69	7	14
115	24771	443985.75	3796775.30	69	7	14
116	13539	443985.75	3798786.93	69	9	19
117	13528	443985.75	3799189.25	69	7	15
118	13530	443985.75	3800798.55	69	11	7
119	24788	444388.08	3795568.33	70	6	5
120	13540	444962.51	3796670.76	69	9	19
121	24773	445192.73	3796775.30	69	8	11
122	24774	445273.19	3796775.30	69	7	14
123	24775	445273.19	3796775.30	69	7	14
124	11441	445445.30	3796670.76	70	6	5
125	24789	445595.05	3795166.00	69	7	14
126	24776	445595.05	3796775.30	69	7	14
127	24777	445595.05	3796775.30	69	8	11
128	24784	445755.98	3796614.37	69	8	11
129	11442	445767.16	3796670.76	70	6	5
130	24800	445767.16	3796670.76	69	7	15
131	24802	445928.09	3796509.83	69	7	14
132	24790	445997.38	3795166.00	69	8	11
133	24778	445997.38	3796775.30	69	8	11
134	24767	445997.38	3797177.63	69	8	11
135	24731	445997.38	3798384.60	69	7	5
136	24729	445997.38	3798786.93	70	2	6
137	24734	446077.84	3797740.88	69	7	15
138	24735	446077.84	3797740.88	69	7	15
139	24736	446077.84	3797740.88	69	7	15
140	24791	446399.70	3795166.00	69	8	11
141	24779	446399.70	3796775.30	69	8	11
142	24780	446399.70	3796775.30	69	8	11
143	24781	446399.70	3796775.30	69	8	11
144	24803	446571.81	3796509.83	69	7	14
145	24769	446721.56	3796934.23	69	7	14
146	13522	446732.74	3796670.76	69	9	19
147	24782	446802.03	3796775.30	69	8	11
148	24730	446802.03	3798786.93	69	8	11
149	11436	446893.67	3796348.90	69	11	7
150	13519	446893.67	3796670.76	69	9	19
151	13541	446893.67	3796670.76	69	9	19
152	24808	447204.35	3794341.35	70	6	5
153	24787	447204.35	3795970.65	69	8	11
154	24786	447204.35	3796372.98	69	8	11
155	24785	447204.35	3796372.98	69	8	11
156	24783	447204.35	3796775.30	70	6	5
157	24807	447204.35	3797579.95	70	6	5
158	24732	447204.35	3798384.60	69	7	15
159	24733	447204.35	3798384.60	69	11	7
160	13531	447204.35	3799591.58	69	9	19
161	13543	447204.35	3800396.23	69	9	19
162	24799	447215.53	3798280.06	69	9	19
163	24770	447365.28	3796934.23	69	7	15
164	12077	447376.44	3798280.06	69	9	19

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