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INVENTORY AND MONITORING OF NATURAL VEGETATION AND RELATED RESOURCES IN AN ARID ENVIRONMENT

A Comprehensive Evaluation of ERTS-1 Imagery

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16. Abstract

A vegetation classification, with 31 types and compatible with remote sensing applications, has been developed for the test site. Some relationships between types and selected terrain features have been established. Terrain features can be used to discriminate vegetation types. Elevation and macrorelief interpretations were successful on ERTS photos, although for macrorelief, high sun angle stereoscopic interpretations was better than low sun angle monoscopic interpretations. Using spectral reflectivity, several vegetation types were characterized in terms of patterns of signature change. The ERTS MSS digital data was used to discriminate vegetation classes at the association level and at the alliance level when image contrasts were high or low, respectively. An imagery comparison technique was developed to test image complexity and image groupability. In two stage sampling of vegetation types, ERTS plus high altitude photos were highly satisfactory for estimating kind and extent of types present, and for providing a mapping base. Quality of inventory was affected by quality of space photography.

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LIST OF ABBREVIATIONS AND ACRONYMS*

ANOVA	Analysis of variance
CALSCAN	Discriminant analysis program at CRSR
CCT	Computer compatible tapes
CDC 7600	Control Data Corporation computer
CRSR	Center for Remote Sensing Research
$\hat{E}$	Mean errors
ERTS-1	Earth Resources Technology Satellite-1
EVGN	Evergreen
IR	Infrared
LARS	Laboratory for Applications of Remote Sensing
lsd	Least significant difference
Ly/min	Langley's per minute
MSEpps	Mean square errors for samples drawn proportionately
MSEeq	Mean standard errors for samples drawn with equal probability
MSS	Multi-spectral Scanning System
NASA	National Aeronautics and Space Administration
PSU's	Primary sampling units
$SE_{\hat{E}}$	Standard errors
SIPS	Statistical Interactive Programming System
spp.	Species
SSU's	Secondary sampling units
TAIL	Copper mine tailings pile
USDA	United States Department of Agriculture

* Four lettered alpha titles for plant species are given in Table 4-2, page 111.

USGS	United States Geological Survey
$\hat{V}$	Variance
V.I.	Vegetation index
WIND	Winter dormant
WISP	Winter-spring dormant

PREFACE

In 1966, Dr. Charles E. Poulton, Rangeland Resources Program, Oregon State University, and Mr. Edwin Roberts, University of California, Berkeley, examined a frame of Gemini IV photography of southeast Arizona and determined that natural vegetation and associated features could be related to space photo images. That effort resulted in a research grant at Oregon State University for studying, "The feasibility of inventorying native vegetation and related resources from space and high altitude photography." The remote sensing expertise and vegetation resources knowledge gained by the research team led to our ERTS-1 involvement. The following objective and scope of work statements reflect the problems and approaches which provided the basis for the ERTS research. Also included are succinct concluding and recommendation statements which resulted from the research activity. Our purpose was to examine the comparative feasibility of and develop procedures for utilizing ERTS and high altitude imagery in gathering vegetational resource information.

OBJECTIVES AND SCOPE OF WORK

Imagery Comparisons (Objective 1)

Compare the amount of vegetation pertinent information which is available on photographic ERTS, Apollo 6, and Gemini IV imagery. Compare the relative success of vegetation type interpretations from two kinds of intermediate scale aircraft photography that logically could be used in conjunction with space imagery.

The approach involved photo interpretation which was designed to minimize area familiarity and use of associated photo images as interpretive evidence. In the case of the space imagery, a single color photo of each type was chosen for comparison. From these, image samples representing known macrorelief classes were drawn for subsequent "interpreter" unrestricted (no image standards) and restricted (with image standards) sorting. For the aircraft imagery, a single date of black and white photography was compared to a single date of color infrared photography. Both were presented to interpreters as stereo pairs which represented known vegetation types. Sorting was restricted. The approach not only expedited the procedure for accomplishing the desired analysis, but provided test results that were more comprehensible than those which might have come from mapping comparisons.

Terrain Variable-Vegetation Relationships (Objective 2)

Continue ongoing terrain variable-vegetation relationship studies and compare the usefulness of ERTS photography with other available photography for identifying terrain features.

Data was collected from 250 field sites. Floristic data collected consisted of species cover and prominences. Terrain variable data included elevation, parent materials, macrorelief, landform type, slope, aspect, solar radiation index, and drainage density. Analysis involved graphic and tabular determinations of associations between species and terrain variables as well as between 25 vegetation types and the terrain variables. A stepwise discriminant analysis was used to show which species could best discriminate groups of terrain variables and which terrain variables could best discriminate the vegetation types.

Terrain Variables Interpretation Testing (Objective 3)

Determine the comparative accuracy with which interpreters can determine elevation and macrorelief from ERTS and other available imagery.

Monoscopic interpretability of elevation was tested for ERTS and high altitude photography. Interpreters established contour lines on the photography from a restricted number of known elevation points. Stereoscopic versus monoscopic macrorelief interpretation was conducted with Apollo 9 photography. Finally, macrorelief was interpreted on ERTS photography using a low sun angle stereoscopic format.

Seasonal Vegetation Change Detection (Objectives 4 & 5)

For selected vegetation types, determine patterns of signature changes apparent from a chronological sequence of ERTS imagery (Obj. 4), and evaluate multidate versus single data differentiations of types (Obj. 5).

Apparent spectral radiance of selected vegetation types was extracted from multidate ERTS imagery utilizing both digital processing and densitometric procedures. Three types were selected to typify patterns of signature change from summer, through winter, and into spring.

The three types were dissimilar in that one was composed of evergreens, another of winter dormant species, and the third of species dormant in the winter and spring. The multidate signature of each was unique. Several procedures for classifying representatives of the three types were explored including classification by spectral radiance, band ratios, ratios of band differences over band sums, date-to-date change factors of ratios, and direction of date-to-date changes. Standards based on these three vegetation types were not useful for successfully classifying other vegetation types having greater mixtures of species and much higher percentages of exposed ground. Alternative standards, more typical of the greater majority of vegetation types, were used in successful classification of test sample locations. Additionally, multidate signatures of 97 test sample locations representing 10 vegetation types were determined by densitometric sampling of ERTS reconstituted photographs. Classification was successful for the three categories, winter dormant, winter and spring dormant, and evergreen.

Two Stage Sampling (Objective 6)

Compare the use of ERTS-1 imagery to that of other available space photography for the first stage in a sampling technique.

As determined from results of Objective 1, the best non-ERTS space photography, Apollo 6, was compared to ERTS photography for relative suitability of vegetation sampling in a two stage probability scheme. Objective space photo stratification at the first stage was accomplished by "image pairings" of the unrestricted sorting done for Objective 1. Sampling was confined to the generally hilly and mountainous portions of the study area. The second stage, common to both space photos, was provided by two dates of high altitude, color infrared photography, on which image classes were developed. Proportional helicopter ground checking was used to identify image classes as to vegetation type. From this, vegetation areal estimates were made for the two space photo sampling schemes.

Digital Data Analysis (Objective 7)

Utilize selected digital MSS data for determining spectral signatures for some vegetation systems in an arid environment.

Activity was concentrated in a restricted portion of the study area where a detailed hierarchical vegetation classification existed. Data was analyzed with a maximum likelihood discrimination procedure (CALSCAN) which required training field establishment of vegetation classes before testing of the computer classification. The objective was extended by utilizing parts of the CALSCAN program to indicate the level of vegetation classification appropriate for ERTS digital data extraction.

CONCLUSIONS

Objective 1

An imagery comparison procedure was developed and tested for space and intermediate scale photography. In the space photo comparisons, image complexity was greater for Apollo 6 than for a single date ERTS-1 color reconstitution or Gemini IV. Greater ground subject detail is inferred from greater image complexity. Image grouping for macrorelief class discrimination was variable among the three, with Gemini usually worse than Apollo or ERTS. The imagery complexity procedure can be used as a base for objective photo stratification. The imagery comparison procedure was applied to an intermediate scale of panchromatic photography and to one of color infrared. Under conditions of the test, interpreters were better able to detect similar patterns of vegetation with the panchromatic photography. Results were believed to be adversely influenced by unusual test constraints; therefore, extreme caution is urged in any attempt to extrapolate beyond these test conditions.

Objective 2

Analysis showed that individual plant species had broader terrain variable amplitude than did vegetation types. Consequently, plant species are not as closely related to terrain variables as are vegetation types. A few species were closely related to terrain variables. Stepwise discriminant analysis revealed that vegetation types were more closely related to elevation and macrorelief than to the other terrain variables.

Objective 3

Elevation interpretations on ERTS photography and on high altitude photography were not statistically different. Differences were detected among interpreters. Macrorelief interpretations on ERTS photos revealed that low sun angle monoscopic interpretations were not as accurate as high sun angle stereoscopic interpretations. Macrorelief interpretations on space photography were successful, although from Apollo interpretations, stereoscopic enhancement was superior to monoscopic observations.

Objectives 4 & 5

Multidate spectral radiance from vegetation can be influenced by the phenological status of the plants. Some vegetation types can be characterized in terms of patterns of signature change. This attribute could be useful if utilized to produce a stratification of an ERTS scene into three groups of vegetation: (1) evergreen, (2) winter dormant, and (3) winter and spring dormant. The stratification could be accomplished with automatic data processing techniques, would provide an ecological grouping, and would be presumed useful for allocating samples in a procedure for inventorying natural vegetation.

Objective 6

Apollo 6 and ERTS-1 photos were compared for relative suitability as first stage strata bases in the two stage proportional probability sampling. Sampling efficiency gains over equal probability sampling were small; however, the three main benefits which resulted from the space photo stratification were that it (1) enabled high altitude photo image classification which was an integral part of the sampling scheme, (2) created a base suitable for small scale vegetation mapping, and (3) provided a means of cluster sampling which substantially reduced helicopter ground sampling expenses. Sampling variation was generally smaller for Apollo than ERTS sampling; however, both photo types were judged satisfactory. Mapping from Apollo-derived statistics provided greater information than from ERTS. Helicopter ground sampling was a highly satisfactory technique for gathering the type of information needed in the inventory.

Objective 7

The ERTS MSS digital data used in the CALSCAN program satisfactorily discriminated vegetation classes at the association level when these classes had high contrast images. For classes with low contrast, discrimination appeared possible at about the alliance level. The results suggest that the detailed hierarchical vegetation classification, which was based in part on annual species, may need to be reevaluated for some possible regrouping.

RECOMMENDATIONS

Based on results from Objectives 1 and 6, there is substantial evidence to suggest that the quality of vegetation resource information is positively and directly correlated with the quality of the space photography used to gather that information. This appears to be the case whether one is interested in directly interpreting subjects, or in using the space photography for sampling. Therefore, future earth resources satellites used for vegetation applications, should have photo resolution capabilities that equal or exceed those of ERTS-1.

Further use is encouraged for image complexity and groupability testing of space and aerial photography (Objective 1). However, considerable caution must be exercised in planning, conducting, and analyzing these tests.

Positive relationships were seen to exist between vegetation and terrain variables (Objective 2); because it was discovered in Objective 3 that two of the terrain variables employed in the research of Objective 2 could be accurately interpreted on space imagery, it is seen that an analysis of the interpretability of additional terrain variables could be conducted. A combination of several of those terrain variables might then be employed in determining their applicability in vegetation interpretations.

The technique of using spectral reflectance patterns which are influenced by plant phenological changes (Objectives 4 & 5) needs to be tested in the production of a natural vegetation inventory. Greatest applicability would likely result for vegetation types which characteristically have relatively high ground cover.

Based on the success of the vegetation inventory sampling (Objective 6), encouragement is extended for further use of space imagery in conjunction with aerial photography and ground sampling. Further refinement of the "image classification" approach in photo sampling is encouraged as an alternative to more traditional "subject interpretation" of photography.

From digital data analysis activity (Objectives 4, 5, and 7), digital tapes as originally received were thought to have some bad scan lines in the MSS. Bad lines interfered with training site selections, and may sometimes have resulted in spurious classifications. For subsequent systems, the desirability of having "clean" digital data is apparent.

CHAPTER 1

INTRODUCTION

HISTORICAL PERSPECTIVE[1-1]

In late 1965, the National Aeronautics and Space Administration (NASA) and the U.S. Department of Agriculture (USDA) entered into agreement to authorize the USDA to undertake remote sensing research in agriculture, forestry, and range management. Funding was from the Supporting Research and Technology Program of NASA, Contract Number R-09-038-002. The Forest Service was designated by the USDA to administer the research through the Pacific Southwest Forest and Range Experiment Station. As a result of that contract, personnel in the Rangeland Resources Program, Oregon State University, were funded to conduct vegetation resource research in southern Arizona. Dr. Charles E. Poulton was principal investigator. The major highlights of the research effort which contributed directly toward accomplishment of our subsequent ERTS-1 research follow.

(1) Using Gemini IV photography, rangeland ecosystem interpretability was determined for space photography (Carneggie, Poulton, and Roberts, 1967; and Poulton, Schrumpf, and Garcia-Moya, 1968).

(2) The value was recognized in having small scale photography for multistage use in vegetation resource inventory; conceptual approaches were developed for multistage sampling of vegetation types (Poulton, Schrumpf, and Garcia-Moya, 1971).

(3) The need for understanding the impact of seasonal vegetation changes on small scale imagery prompted investigations into plant phenological pattern analysis. This gave an insight into the usefulness of sequential imagery (Poulton, *et al.*, 1969).

(4) Because landforms are among the most salient features imaged in arid regions by small scale photography, an evaluation of landform-vegetation relationships was begun on Apollo 6 photography for the

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[1-1] Much of the information in this section was gleaned from Poulton (1972).

purpose of enhancing vegetation interpretations (Poulton, Johnson, and Mouat, 1970).

(5) A hierarchical legend system was developed for multiple levels of interpretation and mapping display. It included natural vegetation, land use, and selected physical features (Pettinger, 1970; and Poulton, 1972).

(6) For purposes of demonstrating compatibility with large scale imagery, a detailed natural vegetation classification was developed from numerical taxonomic-plant sociological considerations (Garcia-Moya, 1972).

(7) An ecological resource and land use inventory of Maricopa County, Arizona, was conducted by using the legend system with Apollo 9 and high altitude photography (Poulton, Johnson, and Mouat, 1970). Mapping was displayed on a mosaic of 1:120,000 high altitude photography. From this, the value was demonstrated for broad scale vegetation mapping in land use planning (Poulton, et al., 1970; and Poulton, Schrumpf, and Johnson, 1971).

(8) Photo interpretation accuracy checking was successfully accomplished by use of a helicopter. Unrestricted access was gained to photo selected sites for rapid vegetation type identification (Poulton, et al., 1971).

OBJECTIVES

As a result of the above-mentioned research activity, the Arizona research team, (1) gained a considerable amount of knowledge about the vegetation resources of the area, (2) developed an understanding of remote sensing approaches in vegetation resource investigations, and (3) recognized resource problems that appeared solvable by remote sensing. The team had the desire to contribute to the evaluation of the, then, upcoming ERTS-A program through a continuation of our remote sensing research effort. The result was that we proposed a research package which was accepted and is the basis for this report. The scope of the research effort is shown in Figure 1-1. The need for working from an understanding of vegetation is illustrated. The three boxes

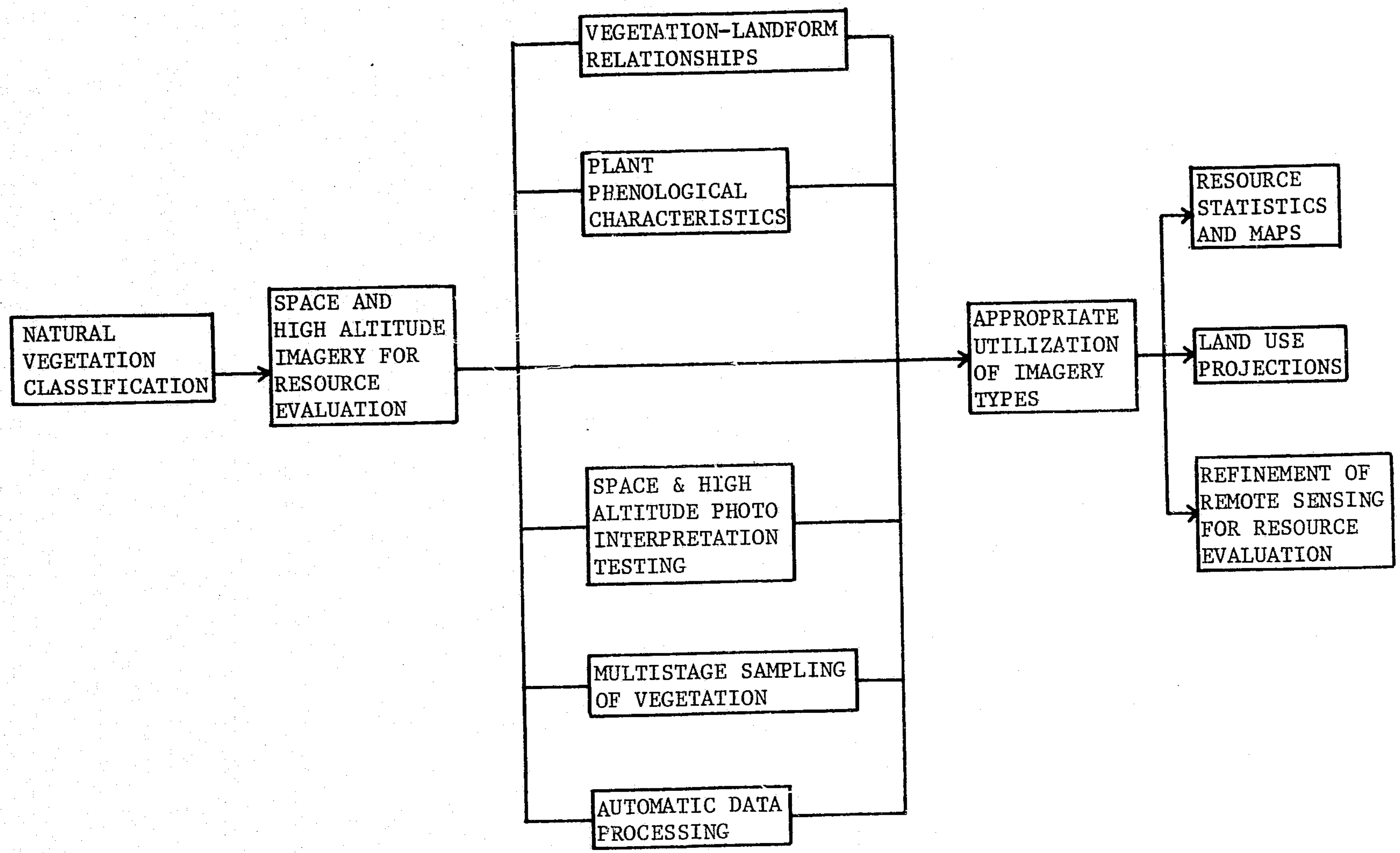

Figure 1-1. Interrelationships of tasks for research conducted in southern Arizona.

on the far right side of the figure are products or goals of operational remote sensing activities, and were not a part of this research. Some of the objectives and approaches, as originally accepted, were modified during the course of the research as provided in the contract (NAS 5-21831, Article I, Phase III-Continuing Data Analysis, b). However, the intent of the original objectives remained the same and the objectives were accomplished. The remote sensing technology which we are developing is intended to provide at least part of an ecological base suitable for many types of land use decisions. The research approach and objectives are consistent with those of the Earth Resources Technology Satellite Program which is ". . . designed as a research and development tool to demonstrate that remote sensing from space is a feasible and practical approach to efficient management of the earth's resources" (NASA, 1972, p. 2-1).

Objective 1: Imagery Comparisons

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Objective 2: Terrain Variable Relationships

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Objectives 4 & 5: Seasonal Vegetation Change Detection

For selected vegetation types, determine patterns of signature changes apparent from a chronological sequence of ERTS imagery (Obj. 4), and evaluate multidate versus single date differentiations of types (Obj. 5).

Objective 6: Two Stage Sampling

Compare the use of ERTS-1 imagery to that of other available space photography for the first stage in a sampling technique.

Objective 7: Digital Data Analysis

Utilize selected digital MSS data for determining spectral signatures for some vegetation systems in an arid environment.

THE STUDY AREA

The region between latitudes of about 32°N and 32°S was first imaged from space platforms. The study area (Figure 1-2) is a part of Arizona that has been photographed frequently from space. Boundaries of the 3,200 square mile area are approximately 32°05'N latitude on the north, 31°30'N on the south, 111°10'W longitude on the west, and 109° 50'W on the east. The towns of Tucson, Willcox, Bisbee, and Nogales lie just outside the four corners of the area as indicated in the figure. The historic community of Tombstone falls within the boundary, as do several small communities, notably Benson, St. David, Ft. Huachuca-Sierra Vista, Sonoita, and Patagonia. Parts of three counties are in the area. They are Cochise, Pima, and Santa Cruz.

The general region of the study area was chosen because it represents an extremely good example of diverse environments in a semiarid region characterized by the Basin and Range physiographic province (Fenneman, 1931). Few other spatially restricted areas in the United States possess as much diversity in physiography, climate, and vegetation in such a small area as does the study area. The economy of the area is based chiefly upon agriculture, cattle ranching, mining, retirement communities, tourism, defense, and astrophysics (the clear air of the desert combined with a low regional population have resulted in the region's being a major center for the location of astronomical observatories.)

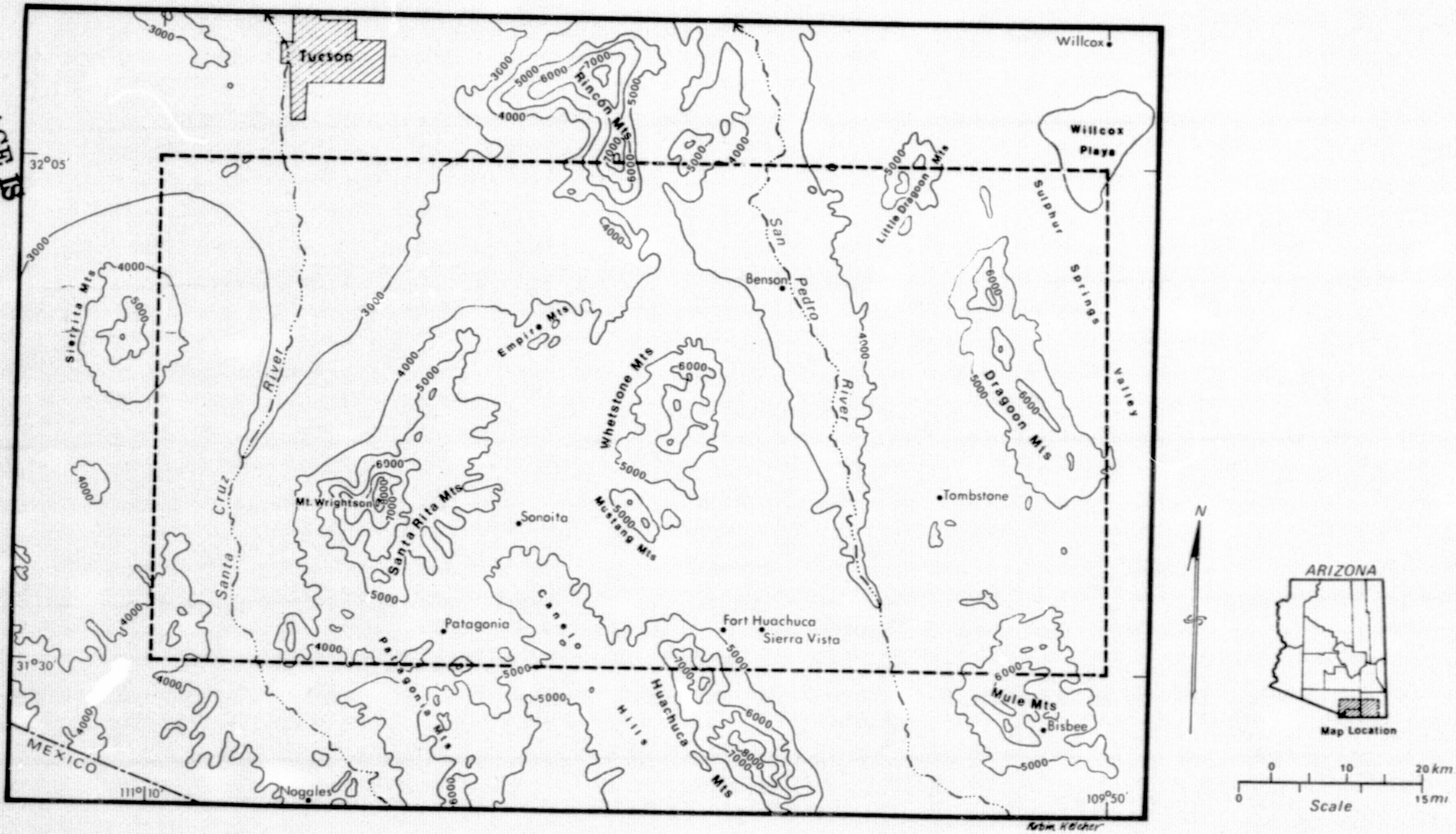


Figure 1-2. Map of the study area. Features on this map may be compared with the photographic images produced from the electronic sensors of the Earth Resources Technology Satellite. (Fig. 6-3)

Climate

The importance of the influence of climate on vegetation of arid and semiarid regions was summarized well by Hastings and Turner (1965, p. 10):

> Climate remains the single most important determinant for the plant life of an arid region, and to climate one must look to explain the uniqueness of the Sonoran vegetation: to precipitation, its amount, its variability, its spatial and temporal distribution; to temperature; to the various components of the heat balance.

The study area occupies a unique climatic situation in that it is affected by two quite different and distinct air masses and wind circulation systems. In winter, the area is influenced by the southward migration of the westerlies, bringing with them frontal precipitation. The high pressure known as the "Pacific high" produces an extreme drought in late spring and early summer. By the end of May, however, a tongue of warm moist air intrudes into northeast Mexico occasionally reaching as far as southeast New Mexico. Toward the beginning of July, a global readjustment of the subtropical highs occur. Moisture-laden winds coming clockwise around these highs from the Gulf of Mexico intrude into southeast Arizona and the Sonoran Desert bringing with them the summer monsoons (Hastings and Turner, 1965). Occasionally, tropical storms spawned in the east Pacific Ocean off Mexico veer northward and move up the Gulf of California. These storms can bring extremely heavy rains to southeast Arizona in late summer and early fall.

Because of the altitude of the study area, ranging from 2500 feet to 9500 feet, temperatures are moderated somewhat compared to those of the lower desert to the northwest. In addition, annual precipitation figures are higher in the study area than in the lower desert region (Green and Sellers, 1964). Both rainfall and snowfall amounts increase significantly with an increase in elevation. These amounts are most noticeable in the isolated mountain blocks or ranges (the "island mountains") that are interspersed throughout the study area.

The low latitude of the study area affects the region in two ways: it moderates the region's temperature regime on an annual basis, and situates the study area under the influence of the subtropical highs - the effects of which have already been discussed.

A final climate control, continentality, affects the study area quite markedly. The study area is approximately 400 miles from the Pacific Ocean. Thus, storm systems occasionally coming in off the California coast are greatly dissipated by the time they reach the study area. The great distance from the ocean tends to produce a greater seasonal temperature variation. Temperatures of the study area are quite moderate. The hottest temperatures occur on the low desert floor in the vicinity of Tucson. There, daily maxima during the summer frequently exceed 100°F and may exceed 110°F. The average daily maxima in July at Tucson are near 100°F. Those temperatures, though, are ten degrees cooler than stations located further to the west and northwest (for example, Gila Bend). Winter temperatures are mild with warm days and cool nights, resulting in an extremely popular climate during the winter months. Only a vague relationship exists, though, between elevation and temperature in the winter. Generally, temperature decreases with elevation; however, many stations have warmer temperatures (both mean monthly and mean monthly minima during January) than stations at lower elevations.

Precipitation is generally lowest in the low elevations of the northwest (Tucson has 10.91" annually) and highest in the higher elevations of the southeast (Bisbee has 18.44" annually). There exists a biseasonal distribution in the annual precipitation regime of climate stations within the study area. The principal peak occurs in the middle to late summer, while a lesser but still pronounced peak occurs in winter. The summer rain occurs usually as mid- to late afternoon thundershowers, small in areal extent (one or two miles across) and of short duration. These rains are generally associated with the warm, moist unstable air which circulates about the Bermuda high emanating from the Gulf of Mexico. Orographic lifting typically increases the amount. The winter rains are normally lighter in intensity, of longer duration, and generally cover a much wider area. The main cause of the winter precipitation is frontal. It generally comes from the cyclonic systems which are brought over southeastern Arizona by the westerlies.

While precipitation in desert areas is often thought of as being extremely intense on occasion, with very high amounts during a 24-hour period once every several years, maximum 24-hour rainfall totals are not very great. For the entire state of Arizona, the maximum 24-hour total is less than 6 inches. Within the study area, Bisbee received 4.25" on July 22, 1910, between 4 P.M. and 5:10 P.M.

Landforms, Geology, and Soils

The general topographic character of the study area is one of short, narrow, isolated mountain ranges (or "island mountains") scattered over extensive basins or bolsons consisting of bajadas, valley fill, and occasional lacustrine deposits. With the exception of the northeast corner of the study area where a portion of the Sulphur Springs Valley drains into Willcox Playa, drainage is external. Figure 1-2 illustrates major topographic features of the study area. The major mountain systems are the Santa Rita, Whetstone, Huachuca, and Dragoon mountains, while the major drainage networks are the Santa Cruz and San Pedro rivers. The topography of the study area is extremely varied. Maximum local relief is over 5,000 feet within a horizontal distance of less than two miles. In other areas, the topography is essentially level and smooth with local relief less than one foot. General geomorphic descriptions of the study area region usually distinguish four broad geomorphic surfaces: mountains, old alluvial surfaces, young alluvial fans, and river floodplains (for example, Hendricks and Havens, 1970). Pediment surfaces should be added to that list.

We recognize that edaphic factors comprise an integral part of physical environmental interrelationships. For this research, soil properties were not directly employed to assess relationships between vegetation and related factors, such as terrain variables. Soils in the rugged terrain areas are often thin and poorly developed; on more gentle slopes, soils are sometimes deeply developed. Parent materials in the area include igneous, sedimentary, and metamorphic types, further contributing to diversity. In the drier reaches, soil development is often minimal; except that petrocalcic accumulations are common. In more moist areas, organic matter influences and clay movement are apparent in upper horizons.

Vegetation

A single reference, Interagency Technical Committee, Range (1963), provided the information necessary to give a perspective of the vegetation-topographic-soils relationships in the area. Information from that report was used to prepare the following descriptions. Occasional reference was made to Western Land Grant Universities and Colleges (1964). Inferences for soil orders come from the Soil Survey Staff (1960).

Succulent Desert Shrub: In the lowest and one of the drier reaches of the study area (northwest corner, less than 3,000 feet), vegetation from the Sonoran Desert has its greatest impact. The unit is found on upper, middle, and lower bajadas. Complex soil patterns consist of zonal and azonal Red Desert, Reddish Desert soils, and Lithosols (Aridisols and probably Entisols). Soils are generally deep, gravelly to cobbly, moderately coarse to medium textured with fine textured subsoils. Some are underlain by indurated caliche. The aspect of the unit is microphyllous shrub with cacti. Characteristic species are littleleaf paloverde, brittlebush, creosotebush, mesquite, burroweed, cholla, prickly pear, and saguaro.

Coronado Coniferous Forest: This unit is restricted to the highest elevations (6,500-9,500 feet) in the Santa Rita and Huachuca mountains. The unit normally occurs on steep, stony mountain slopes. Soils have not been classified. This representative of the montane forest is primarily characterized by ponderosa pine, but also by Chihuahua pine, Mexican white pine, and *Ceanothus* spp., among many other woody and herbaceous representatives.

Coronado Chaparral: Foothills and lower mountain slopes (4,000-6,500 feet) provide the habitat for this broadly described unit. It occurs in the Santa Rita Mountains, extending south and east in a broad belt to the Huachuca Mountains. Elsewhere, examples occur in the Rincon, Whetstone, and Dragoon mountains. Slopes are generally steep. Granite, schist, basalt, and limestone provide the parent material and contribute to the stony and rocky nature of the shallow soils. The generally neutral soils are classified as Reddish Browns and Lithosols (mostly Aridisols although some Mollisols may be present on alluvium of the more gently sloping drainageways). This heterogeneous unit has an aspect of mixed large shrubs and trees, but often with such openness as to create a savanna-like appearance. Trees of the unit include Arizona white oak, Emory oak, alligator juniper, and Mexican pinyon. Grasses, especially the grama grasses, are well represented as are some of the acacias.

Sonoita Desert Grassland: The Sonoita Desert Grassland occurs primarily in the 4,500-5,500 feet range of a basin surrounded by mountains--namely, the Santa Ritas on the west, the Canelo Hills on the south, the Whetstones on the east, and the Huachucas on the southeast. An arm of the grassland extends along the eastern flank of the Huachucas. The general occurrence is on gently rolling to hilly valley fill and sometimes on deeply dissected alluvial fans. The often deep soils are mostly moderately fine to fine textured representatives of Reddish Brown and Reddish Chestnut soils (probably mostly Aridisols) although in localized areas, Calcisols (Calciustolls) occur. The vegetational aspect is one of a mid-grass prairie, dotted with mesquite, and local patches of beargrass and soaptree yucca. The grasses are prominently gramas, although other genera, especially threeawns, common to the region, are well represented.

Apache Desert Grassland: This "grassland," for the portion which occurs in the study area, is primarily on alluvial fans and upper to mid-bajadas in a band that stretches from near Benson to the southwest, around the western fringe of the Whetstone Mountains, then southeast through the middle of the San Pedro basin between Ft. Huachuca and Bisbee. Thus it flanks the Sonoita Grassland along its eastern boundary. In the northeast corner of the study area, north of the Dragoon Mountains, the unit is again present. Elevation ranges 4,000 to 5,000 feet. Most of the area is gently sloping, with minimal dissection; however, on the west side of the Whetstones, parallel drainageways are deeply entrenched. Soils are deep, medium to fine textured and mostly Reddish Browns (Aridisols), often highly calcareous and with indurated pans. Physiognomy of the unit is mostly that of a grassland with scattered large and small shrubs, although that portion in the San Pedro River basin takes on a grass-shrub aspect with influences from

Chihuahuan shrubs. Characteristic grasses are rothrock grama, black grama, sacaton, tobosa grass, curly mesquite, and Lehmann lovegrass. Whitethorn, soaptree yucca, ocotillo, and prickly pear are common.

Sonoran Desert Grassland: This unit is found in the 3,000-4,000 feet range along the western edge of the study area, from Nogales to the Rincon Mountains, and flanking the Santa Rita Mountains to the north, west, and south. In the study area portion of Arizona, this unit represents the eastern-most extension of primary Sonoran Desert influence. The unit is found throughout the valley fill, adjacent bajadas, and hills of the Santa Cruz Valley. Valley soils are deep with coarse to medium textured topsoils. Some soils are highly calcareous. Most are Reddish Browns (Aridisols). The aspect of the type is a mixed shrub-scrub grassland. Characteristic shrubs include mesquite, burroweed, and ocotillo. The common succulents are prickly pear and cholla. Several grama grasses, threeawns, dropseed, and curly mesquite are also present.

Chihuahuan Desert Shrub: This unit occupies practically all of the San Pedro River basin between 3,500 and 4,500 feet. In fact, in the study area it has greater occupancy (ca. 25 percent) than any other unit. The valley fill and bajadas on which it occurs are severely dissected and moderately to strongly sloping. Except for vegetation of mountainous areas, the unit is bordered primarily by the Apache Desert Grassland. Soils are complex, deep, mostly moderately fine and fine textured, and often highly calcareous. They are generally classified as Reddish Browns and Calcisols (Aridisols). Vegetation physiognomy is shrub-scrub with the characteristic shrubs being whitethorn, tarbush, creosotebush, mortonia, mesquite, ocotillo, and catclaw. Grasses are common, but not prominent.

CHAPTER 2

VEGETATION CLASSIFICATION

There is no single "best" vegetational classification and legend system. Classifications and legends are developed for utilitarian purposes; that is, there must be some reason to classify or it would not be done. No classification system of natural vegetation can suit all needs, thus numerous classifications exist - each with its own set of merits. All of these thoughts are clearly illustrated in the book by Küchler (1967) and probably more thoroughly and emphatically expressed than in any other English publication. Culver and Poulton (1968), Poulton and Isley (1970), and Martin (1970) found that it was necessary to develop natural classifications and legends in eastern Oregon vegetation resource research. This resulted from a lack of information relating to vegetation and, therefore, a lack of existing classifications amenable for use with remote sensing techniques.

From the wealth of Poulton's and associates' experiences, it was evident that legend development would be of fundamental importance as others of his associates began to use remote sensing for "ecological resource inventory" in southern Arizona. A few references (Humphrey, 1963; Interagency Technical Committee, Range, 1963; Küchler, 1964; Shreve, 1942; and Shreve and Wiggins, 1964) provided descriptive insights to the vegetation of southern Arizona. These works served only as a starting point for our research, generally because the available vegetation descriptions and maps were highly generalized. For example, Shreve (1942) described nine types of vegetation for the entire state and Küchler's map (Küchler, 1964) showed six types within the study area boundaries. Another map, which by contrast to Küchler's is limited to the State, showed seven "vegetative units" for the study area (Interagency Technical Committee, Range, 1963). From the beginning, Poulton, Schrumpf, and Garcia-Moya (1968) found it necessary to develop a legend system compatible with information needs and remote sensing in southern Arizona. As the bank of resource information grew, the vegetation classification and legend was progressively improved (Poulton, et al., 1969). By late 1970, a degree of maturity had been achieved (Poulton, et al., 1970) and in 1973 the vegetation classification for the study area was finalized (Schrumpf, Johnson, and Mouat, 1973).

Details of association table preparation and discussion relating to table validity in vegetation classification are expressed by Becking (1957), Moore (1962), and Küchler (1967, p. 227-256) in their explanation of the classification procedure used by Braun-Blanquet. According to Moore (1962, p. 761-762), the approach is widely used in continental Europe, at least as to basic principles; "Only the Anglo-American ecologists have stood aloof, although there is developing desire to understand and learn." The ease with which the approach is applied in the field made it an extremely attractive choice in Arizona where several people were involved in gathering information. Quadrats were located

> . . . in what seemed to be a typical portion of the community; (with) atypical sections . . . carefully avoided. The size of the quadrat should be large enough to encompass all species which belong to the particular community . . . (Küchler, 1967, p. 227).

Further, the stands were considered for classification in a straightforward manner; that is ". . . units of vegetation are obtained solely on the basis of comparing the tables on which the species (for each stand being compared) are listed. Hence, this is a purely floristic procedure" (Küchler, 1967, p. 246). The reason this approach was particularly desirable for the southern Arizona research is because it did not require a thorough knowledge of successional seres and climax representatives as a prerequisite to vegetation classification. Daubenmire, who relies heavily on a climax approach to the understanding of vegetation, has stated that,

> . . . it is usually possible to construct a useful key to ecosystems or habitat types (which, by necessity, infers that some speculation relative to climax is operative) based on a few readily observable features of vegetation and environment . . . (Daubenmire, 1968, p. 267).

It is our belief that the vegetation classification we have developed does serve, in fact, a useful function - especially in that we were able to use it to demonstrate the potential applicability of remote sensing to the natural vegetation resource with which we were working.

FIELD APPROACH

Sample locations in the field were to represent photographic image classes recognized on Gemini IV (Poulton, Schrumpf, and Garcia-Moya, 1968), and later on Apollo 6, and NASA high altitude aircraft photography (Schrumpf, Johnson, amd Mouat, 1973). Similar techniques were employed and refined in the Phoenix, Arizona, area as well (Poulton, Johnson, and Mouat, 1970) where some of the same vegetation systems occur as are found in the Southern Arizona Test Site. Choice of sample locations was somewhat restricted as a result of inadequate accessibility. This was especially true for rough terrain areas. However, this was partially overcome by use of several reconnaissance flights with fixed wing aircraft, and to a more limited extent by helicopter reconnaissance (Poulton, et al., 1971).

Throughout the history of the project, several personnel gathered vegetation information that was used in developing the vegetation classification. Through field training sessions, observers learned to "read the vegetation" in acceptably similar fashions. Details of these techniques are to be found in Poulton, Faulkner, and Martin (1971). At each location, plant species characteristics were recorded, as well as other relevant features of the landscape. Species information was taken in an area of indefinite size (ca. 100-300 feet in diameter) in an attempt to adequately represent the major species in the stand being sampled. Care was taken to avoid "edge effect." Aspect photographs were obtained for most locations. Information was presented on record cards, including for each species: relative prominence, cover, and sociability or gregariousness. Least prominent species were indicated by 1, ranging to most prominent, 4 or 5. Cover classes range from 50-75 percent cover (class 4) to 0-5 percent cover (class 1). Species approaching random distribution were indicated by sociability class 1. Details of these expressions are presented in Appendix A. This type of information was often necessary in legend development and identification of specific vegetation-soil systems by legend class. A total of about 500 field location samples were used in developing the vegetation classification for the study area.

LABORATORY PROCEDURE

Classification of vegetation was undertaken in an attempt to create ecologically similar vegetation classes. The classification procedure was described by Schrumpf, Johnson, and Mouat (1973) and is reproduced here with little alteration:

> A first approximation of a vegetation classification was based on a reconnaissance of the area and a review of literature (Darrow, 1944; Humphrey, 1960a,1963; Interagency Technical Committee, Range, 1963; Lowe, 1964; Nichol, 1952; Pond and Bohning, 1971; Shreve, 1942; Shreve and Wiggins, 1964). On the basis of that review, short lists were compiled of those plant species which seemed to best typify the broad vegetation classes [Sonoran and Chihuahuan Desert shrub, grassland, chaparral, mixed needleleaf and broadleaf woods, and needleleaf forests]. Approximately 500 field samples were then sorted into those six broad classes as appropriate according to the match of species listed in each sample with those in the short list for each class. In this manner, the total number of samples were divided into more manageable groups for analysis, and the sorting brought similar samples together. When warranted, samples were further sorted within the six broad classes to produce subgroups by the similarities and differences among the samples. The criteria for sorting were species presence and species prominence. Woody species tended to receive greater consideration than succulent or herbaceous species; however, there are some notable exceptions to this (*Cereus giganteus*, *Ferocactus wislizenii*, *Opuntia* spp., *Nolina microcarpa*, *Yucca baccata*, *Y. elata*, *Sporobolus wrightii*, and *Hilaria mutica*). Vegetation classification work by Garcia-Moya (1972), for a small portion of the test site, provided some useful guidelines for this sorting activity. During this process, several field samples were shifted from one broad class to another. As subgroups became evident, association tables were prepared which provided the means for finalizing decisions about the validity of the subgroups. The resulting classification is based primarily upon the presence or absence of the more common plant species and, secondarily, on the prominence of those species. Each association table showed the species present and their prominence ratings for all field samples belonging to one subgroup. These tables provided the compiled data for the vegetation descriptions which follow. The subgroups established in this manner number 31 and are called vegetation types. The name of each type is part of a "technical vegetation legend" for the test site; each description is a part of the "descriptive legend" (Poulton, Johnson, and Mouat, 1970; Poulton, *et al.*, 1970; Poulton, Faulkner, and Martin, 1971).

THE VEGETATION TYPES

The classification has been published previously (Schrumpf, Johnson, and Mouat, 1973) and is presented here as Figures 2-1 through 2-31 with minor revision. Table 2-1, which precedes the figures, is intended as a reference table for later discussion. The type descriptions conform to a format of elaborated discussions about the plant species. The physiognomy of a group is given first, followed by a discussion of the primary character species. The physiognomic terms are from a technical legend provided in Appendix B. A list of scientific and common names is presented in Appendix C.

Table 2-1. Reference table of vegetation types and corresponding figure numbers.

Figure Number	Type Number	Abbreviated Alpha Title	Figure Number	Type Number	Abbreviated Alpha Title
2-1	1	Latr-annuals	2-17	17	Bout-Arist
2-2	2	Latr-Prju	2-18	18	Prju-Bout
2-3	3	Atca-Prju	2-19	19	Bout-Arist-Nomi
2-4	4	Cemi-Cegi-Enfa	2-20	20	Prju bosque
2-5	5	Coca-Zipu-Fosp	2-21	21	Himu-Prju
2-6	6	Acve-Latr	2-22	22	Spwr-Prju
2-7	7	Acve-Latr-Rhmi	2-23	23	Prju-Quercus-Jude
2-8	8	Alwr-Fosp-Acco	2-24	24	Come
2-9	9	Mosc	2-25	25	Quercus-Nomi
2-10	10	Mosc-Rhch	2-26	26	Quercus-Mimosa
2-11	11	Prju-Hate-Cholla	2-27	27	Quercus-Arpu-Mibi
2-12	12	Prju-Hate	2-28	28	Quercus-Arpu-Pice
2-13	13	Acco-Prju	2-29	29	Cebr
2-14	14	Caer-Acco-Prju	2-30	30	Pofr, Plwr, Chli
2-15	15	Caer-Prju-Mimosa	2-31	31	Pinus
2-16	16	Caer-Eptr-Yucca			

The "vegetation types," as they are called, are not structured in this presentation by a hierarchical arrangement. Hierarchical considerations become necessary as vegetation is coordinated throughout a region (Küchler, 1967, p. 252). Thus no attempt has been made to assign them to a rank. For purposes of orientation, it is worthwhile to consider likely ranking of some of the types. The Prju-Hate Types (11 and 12 from Table 2-1) might well be at the habitat-type level of Daubenmire (1968, p. 259) or the association level of Braun-Blanquet (Schallig, ca. 1970). Based on the discussions by Schallig, the Mosc

Types (9 and 10) might be subassociations of the same association while the Pinus Type (31), as a more generalized type, probably represents an alliance.

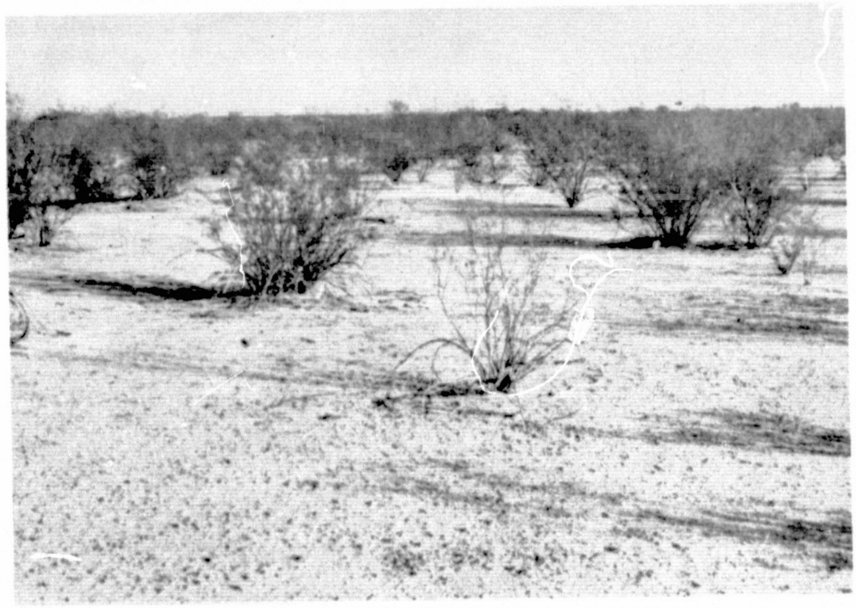


Figure 2-1. Larrea tridentata with or without annuals.

This vegetation type has a "shrub-scrub" physiognomy, specifically "microphyllous, non-thorny scrub, generally with succulents."

Larrea tridentata occurs regularly spaced in nearly pure stands, giving a uniform appearance. However, annuals may be present during periods when sufficient moisture is available. Zinnia pumila and Tridens pulchellus may be present in low prominence.

This vegetation type appears closely related to the "Larrea tridentata with Prosopis juliflora and/or Opuntia (cholla)" type. The two are often found in close proximity.

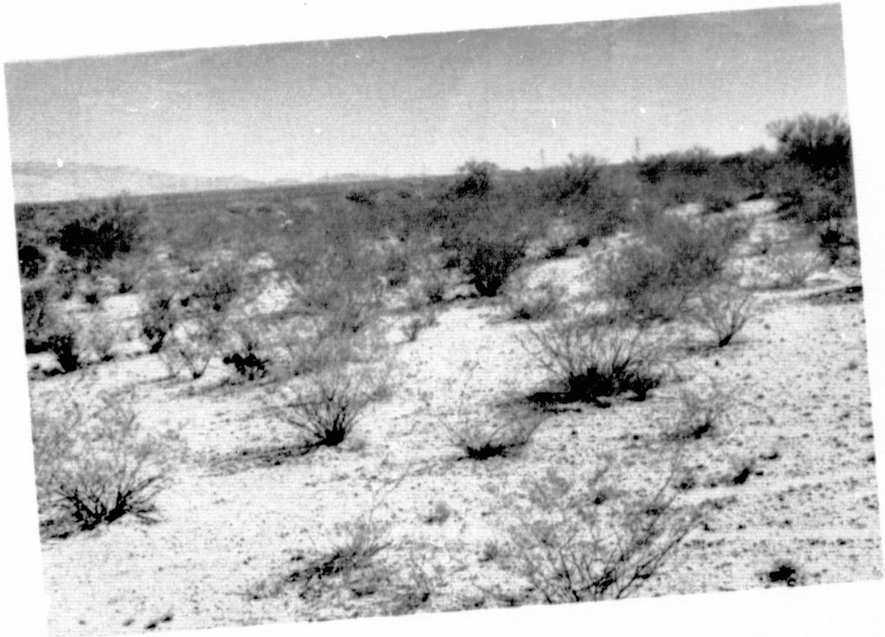


Figure 2-2. Larrea tridentata with Prosopis juliflora and/or Opuntia (cholla).

The physiognomy of the type is described in general as "shrub-scrub" and in specific as "microphyllous, non-thorny scrub, generally with succulents."

Larrea tridentata almost always maintains a high prominence value (5) in this type; however, other species of similar stature are present and often conspicuous. Prosopis juliflora is one of these. Cacti, especially cholla (mostly Opuntia fulgida) are also usually present and occasionally high in prominence.

Other tall shrub species are commonly present, but generally in low prominence (1-2). These include Fouquieria splendens, Acacia constricta, Cercidium floridum, and C. microphyllum, among others. The low statured Zinnia pumila is nearly ubiquitous and is often joined by Haplopappus tenuisectus and/or Coldenia canescens.

Stem succulents, as previously mentioned, are a characteristic feature of the type. The chollas (Opuntia fulgida and/or O. spinosior) are usually present in mid-prominence (2-3). Ferocactus wislizenii is also common, but in low prominence (1-2).

Grasses are a conspicuous component of most stands. Tridens pulchellus is normally present and in substantial prominence (3-4), while Muhlenbergia porteri is common and has low to mid-prominence (1-3).

The type appears related to "Larrea tridentata with or without annuals."

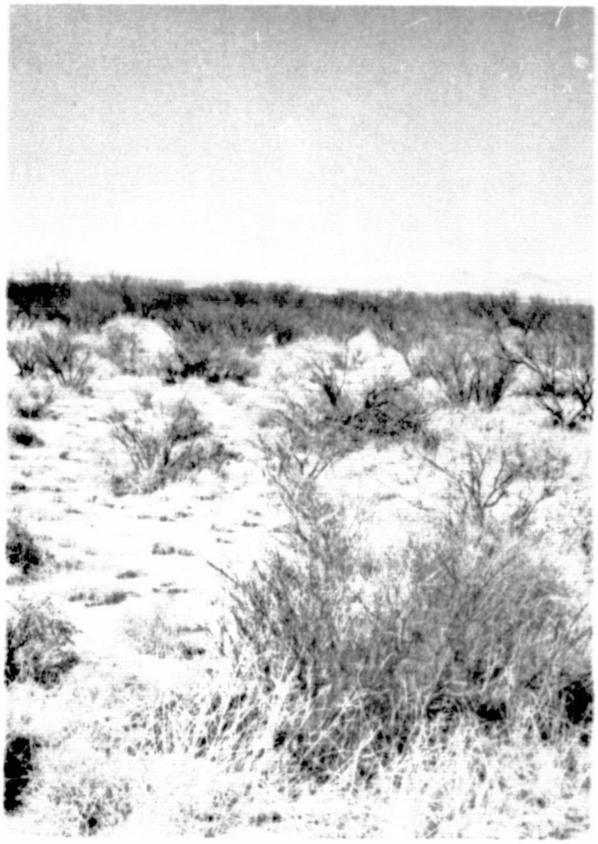


Figure 2-3. Atriplex canescens and Prosopis juliflora.

The physiognomy of this vegetation type is "shrub-scrub," especially "microphyllous saline tolerant and related scrub types."

Atriplex canescens and Prosopis juliflora occur together in restricted areas. The prominence values of the two species are quire variable (2-5), but in general one or the other or both tend to rank highest in prominence values.

The variety of other shrub species is generally limited, but may include Larrea tridentata, Haplopappus tenuisectus, Zinnia pumila, cholla (Opuntia spp.), and Fouquieria splendens among others. Grass prominence generally is not high, but several genera are often represented including Muhlenbergia, Sporobolus, and Andropogon.

Figure 2-4. Cercidium microphyllum and Cereus giganteus often with Encelia farinosa and Opuntia spp., and without Franseria deltoidea.

This vegetation type has a "shrub-scrub" physiognomy, specifically, "microphyllous, non-thorny scrub, generally with succulents."

Cercidium microphyllum is usually prominent or coprominent (4) and is generally accompanied by Cereus giganteus, Encelia farinosa, and a variety of cacti. For purposes of type recognition, the absence of Franseria deltoidea need also be recognized.

A variety of shrub species may be present in this rather floristically rich type including Prosopis juliflora, Acacia constricta, Celtis pallida, Zinnia pumila, and Larrea tridentata. Most do not occur with high prominence values, but Larrea can achieve a high rank (4) in a few stands.

Several cacti species contribute to the type, with at least one occurring in each stand. Prominence values rate mid to low. From most to least common, the cacti are Opuntia spp. (prickly pear, cholla), and Ferocactus wislizenii.

An immense variety of forbs and grasses, both annuals and perennials, make a marked seasonal floral impression.

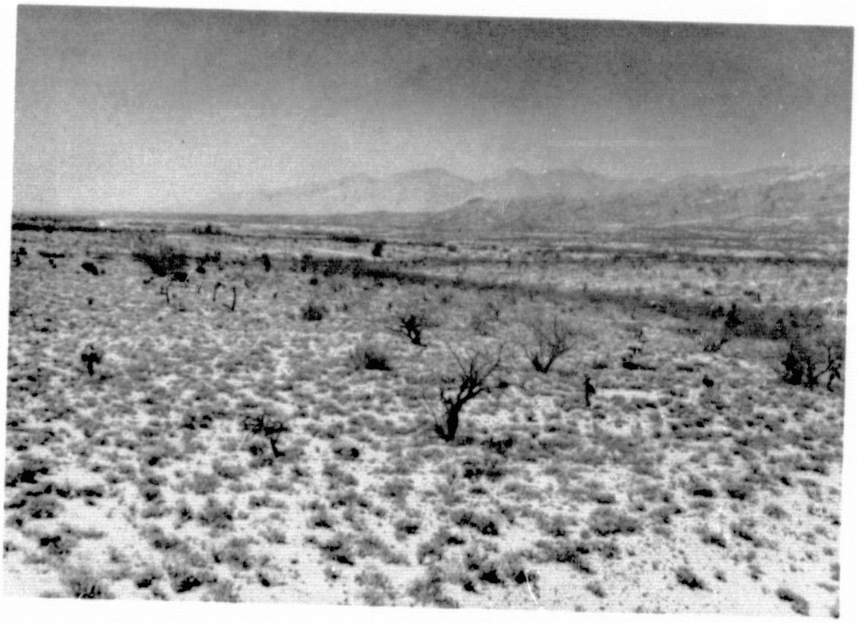


Figure 2-5. Coldenia canescens, Zinnia pumila, Fouquieria splendens, and Tridens pulchellus.

The vegetation of the type has a "shrub-scrub" physiognomy. Coldenia canescens and Zinnia pumila clearly are the prominent shrubs in this type giving a low shrub aspect. Other low shrubs that may be present include Calliandra eriophylla, Ephedra trifurca, Psilostrophe cooperi, and Condalia lycioides. Their prominences tend to be low. Taller shrubs are common, particularly Fouquieria splendens, Prosopis juliflora, and Acacia constricta, but they are never abundant enough to create a tall shrub aspect.

Succulents are also common including some or all of the various Opuntia (chollas and prickly pear) and Yucca. Grasses, other than Tridens pulchellus and Muhlenbergia porteri are noticeably sparce.

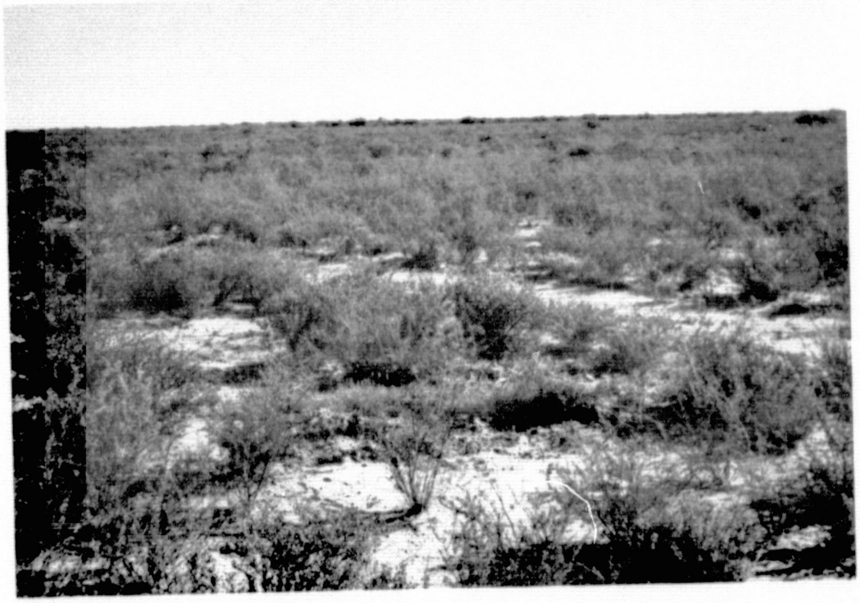


Figure 2-6. Acacia vernicosa, Flourensia cernua, and Larrea tridentata, without Rhus microphylla and Dalea formosa.

The physiognomy of this type is "shrub-scrub," specifically "microphyllous thorn scrub."

The three species which characterize the type are the shrubs, Acacia vernicosa, Flourensia cernua, and Larrea tridentata. All three are usually present with one of the three being most prominent or at least two of the species sharing prominence. The absence of Rhus microphylla and Dalea formosa needs to be recognized to prevent confusion with a similar type.

In addition to the shrub species mentioned, several others may be present including, but not limited to, Zinnia pumila, Parthenium incanum, Fouquieria splendens, and Prosopis juliflora. These species usually have mid- to low prominence values.

The primary leaf succulent is Yucca elata which is present only occasionally. Stem succulents are not common in the type, with Opuntia phaeacantha most often present.

Perennial grasses are usually present, and usually in mid-prominence. Bouteloua eriopoda and Muhlenbergia porteri are usually present, and ocaasionally, Hilaria mutica. The biennial grass, Tridens pulchellus, usually is present.

This vegetation type is closely related to the one identified as "Acacia vernicosa, Flourensia cernua, Larrea tridentata, and Rhus microphylla."

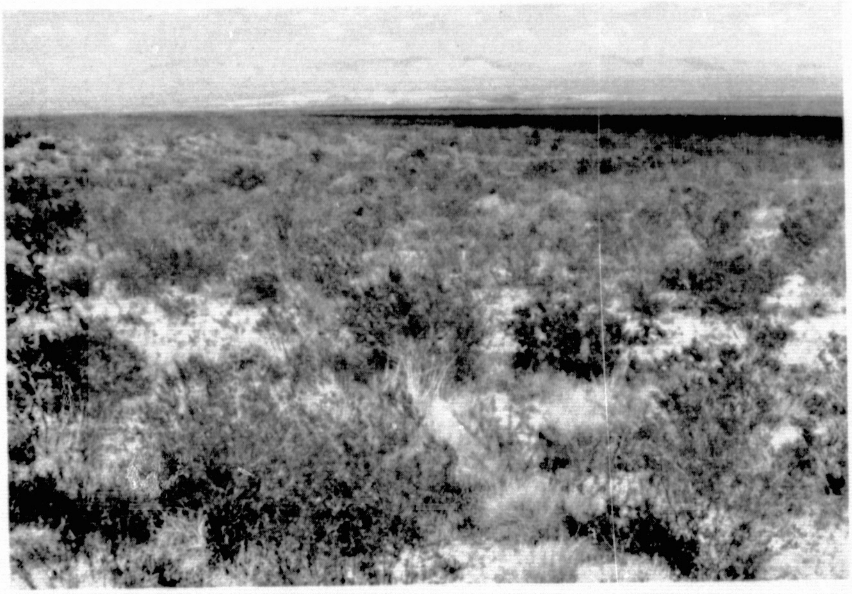


Figure 2-7. Acacia vernicosa, Flourensia cernua, Larrea tridentata, and Rhus microphylla.

"Shrub-scrub" ("microphyllous thorn scrub") is the physiognomy of this vegetation type.

The shrub, Rhus microphylla, is always present in the type, usually with mid-prominence values. In most stands, two or more of the other three characteristic shrub species (Acacia vernicosa, Flourensia cernua, and Larrea tridentata) are present, and one of these will occupy the position of highest prominence. Any of several other shrub species may be present, but they usually have mid- to low prominence values (3-1). Zinnia pumila and Parthenium incanum are very common. Some of these other species which are occasionally present include Condalia spathulata, Ephedra trifurca, Fouquieria splendens, Koeberlinia spinosa, and Krameria parvifolia.

Leaf succulents may be present, but usually in low prominence. The more common species are Yucca baccata, Y. elata, and Nolina microcarpa. Stem succulents are rare.

Perennial grasses are common with the genera, Aristida, Bouteloua, and Muhlenbergia most frequently represented. Tridens pulchellus is the most common grass species and it is usually present. Prominence values of individual grass species cover the range (5-1), but most are mid- to low range (3-1).

The type is related to and resembles "Acacia vernicosa, Flourensia cernua, and Larrea tridentata without Rhus microphylla and Dalea formosa.

Figure 2-8. Aloysia wrightii usually with Fouquieria splendens, Acacia constricta, and Opuntia (prickly pear).

This vegetation type has a "shrub-scrub" physiognomy and varies from "microphyllous thorn scrub" to "microphyllous, non-thorny scrub, often with succulents."

The most prominent species generally vary among Fouquieria splendens, Aloysia wrightii, and Acacia constricta and their combinations, although the latter is frequently absent. Grass prominence, especially Bouteloua, can be high (4-3). Opuntia (prickly pear), although rarely prominent (mostly 3), is the remaining species which serves best to characterize the type.

Type variation can be regionally correlated. Toward the southeast portion of the study area Parthenium incanum, Flourensia cernua, Larrea tridentata, Mimosa dysocarpa, Acacia vernicosa, and Dasylirion wheeleri may be included in the type although they are by mo means always present or abundant. Cercidium floridum, when present in this type, is confined to the western portion of the area. In addition, Lycium spp. and Celtis pallida, although only occasionally present, are confined to the west. Shrubs common throughout include Calliandra eriophylla, Prosopis juliflora, and Zinnia pumila. Common succulents include Opuntia (cholla), Agave palmeri, and A. parryi.

Grasses tend to be more common and prominent eastward, but most are found throughout. Species of Bouteloua are the most common. Aristida and Muhlenbergia are also well represented as is Tridens pulchellus.

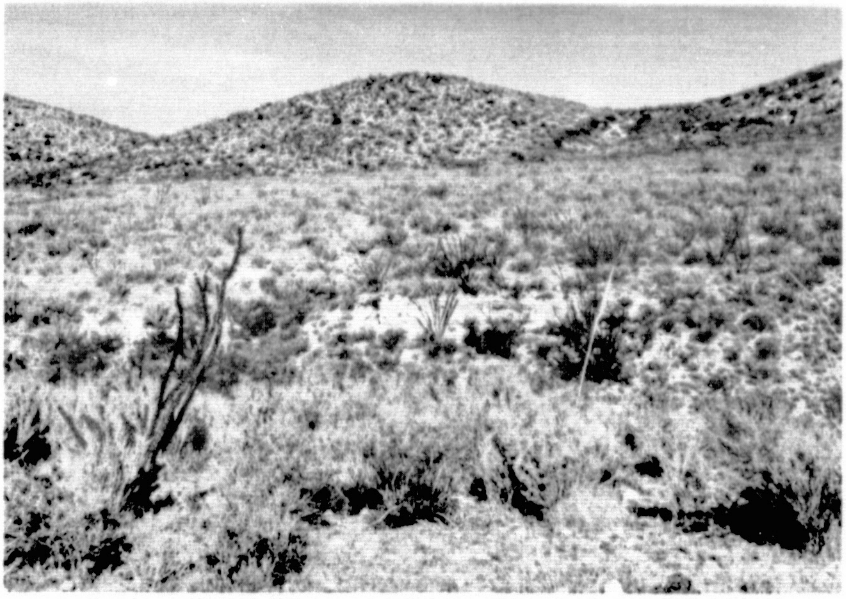


Figure 2-9. Mortonia scabrella without Rhus choriophylla.

Stands of this vegetation type have a "shrub-scrub" physiognomy.

Vegetation of this type is identified by the presence of Mortonia scabrella. However, the absence of Rhus choriophylla is also required for complete characterization.

In most stands, Mortonia has the highest prominence value (5), but several other shrub species can also be present, and quite abundant (prominence 5-4). The more common species are Fouquieria splendens, Parthenium incanum, Zinnia pumila, Larrea tridentata, Acacia vernicosa, Calliandra eriophylla, and Rhus microphylla.

Succulents are also common, especially Dasylirion wheeleri and Nolina microcarpa. Agave spp., Opuntia (prickly pear) spp., and Yucca spp. occur in fewer stands.

Grasses are abundant, especially species of Bouteloua and Aristida and Tridens pulchellus. Although grass prominence values can be high, stands normally maintain a shrub aspect.

This type is well defined and occurs in close proximity to a related and similar appearing type, "Mortonia scabrella with Rhus choriophylla."

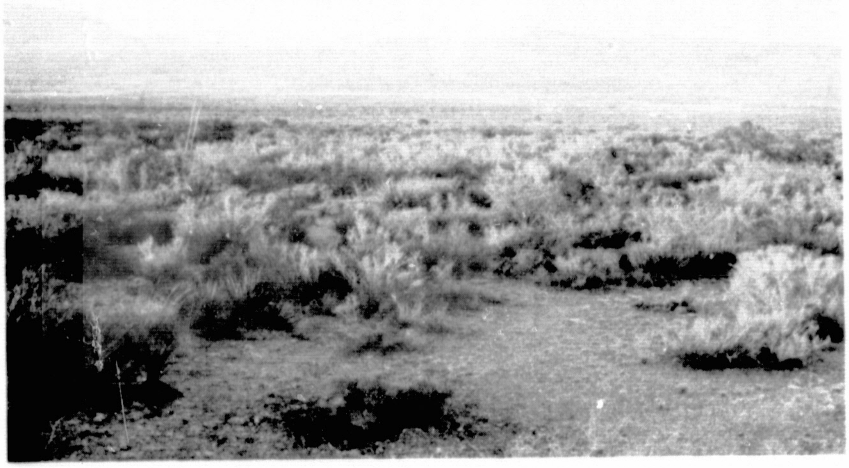


Figure 2-10. Mortonia scabrella with Rhus choriophylla.

Representatives of this type usually have a "shrub-scrub" aspect.

Mortonia scabrella and Rhus choriophylla when found in combination are the only species that need be recognized to identify this vegetation type. In most stands, Mortonia has the highest prominence (5), yielding a shrub aspect. Other shrubs are normally not abundant, but may include Cercocarpus breviflorus, Fouquieria splendens, and Aloysia wrightii. A shrubby Quercus and Pinus cembroides may also be present.

Leaf succulents are common to most stands and most frequently exhibit mid-prominence values. The more common species are Nolina microcarpa, Dasylirion wheeleri, and Yucca.

Grasses are most commonly represented by Aristida and Bouteloua. In some stands, grass prominence values rank high enough to give a shrub-grass aspect.

This vegetation type is well defined, occurs in limited habitats, and is found adjacent to and is closely related to the other Mortonia type, "Mortonia scabrella without Rhus choriophylla."

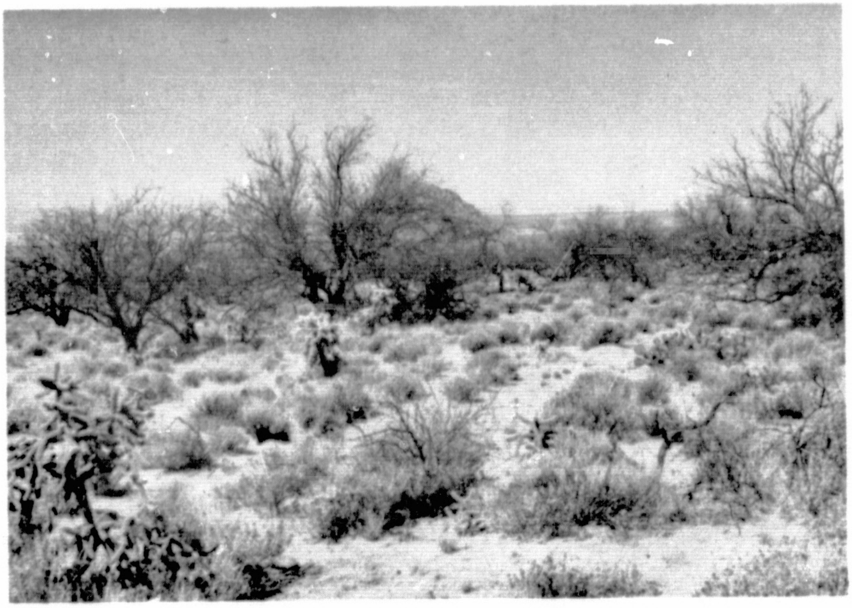


Figure 2-11. Prosopis juliflora and Haplopappus tenuisectus with Opuntia (cholla) and without Acacia constricta and Calliandra eriophylla.

This vegetation type is classified as "shrub-scrub" and "microphyllous, non-thorny scrub, generally with succulents."

Prosopis juliflora and Haplopappus tenuisectus are the usual prominent (4-5) species of the type, with Prosopis the more common sole prominent (5) when the two are not coprominent (4). The consistent occurrence of Opuntia [cholla and prickly pear in mid- to low prominence (3-1)] and frequent occurrence but low prominence (2-1) of Ferocactus wislizenii further characterize the type. To distinguish from other types, the absence of Acacia constricta and Calliandra eriophylla needs to be noted. For the same reason, the low presence of Yucca elata is important.

Several shrub species, in addition to those mentioned above, are found in many of the stands, but none of these species occur frequently or with high prominence values. The more common ones are Acacia greggii, Atriplex canescens, Cercidium floridum, Celtis pallida, Ephedra trifurca, and Fouquieria splendens.

Although grasses are common and fairly prominent (4-2), primarily Aristida and Bouteloua, they are always decidedly subordinate to the shrubs.

This vegetation type is related to "Prosopis juliflora and Haplopappus tenuisectus; without Acacia constricta, Opuntia (cholla) and Calliandra eriophylla."

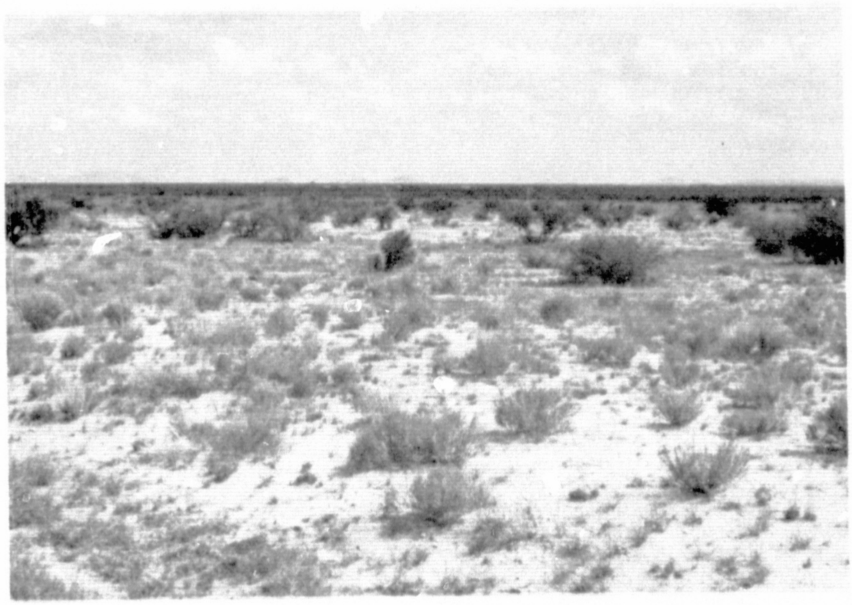


Figure 2-12. Prosopis juliflora and Haplopappus tenuisectus; without Acacia constricta, Opuntia (cholla), and Calliandra eriophylla.

The physiognomy of the type is "shrub-scrub" specifically "microphyllous, non-thorny scrub, generally with succulents."

In this type, which usually has a tall shrub or low shrub aspect, Prosopis juliflora is the most common tall shrub while Haplopappus tenuisectus is the most common small shrub. In most stands, these species are either prominent (5) or coprominent (4) with grasses (Bouteloua and/or Aristida). One of the characteristic features of the type is that it has very few shrub species other than those mentioned, and in particular, it never has Acacia constricta or Calliandra eriophylla. Furthermore, cacti are nearly absent, especially Opuntia (cholla) and Ferocactus wislizenii. Opuntia (prickly pear), when present, has low prominence values. Yucca elata is common with mid- to low prominence values.

A vast variety of grasses are found in the type. Occasionally, individual grass species will rank highest in prominence values. The most common species are Bouteloua rothrockii, B. curtipendula, B. eriopoda, Andropogon barbinodis, Muhlenbergia porteri, and several species represented by the genera, Aristida, Eragrostis, and Setaria.

A related type is "Prosopis juliflora and Haplopappus tenuisectus with Opuntia (cholla) and without Acacia constricta and Calliandra eriophylla."

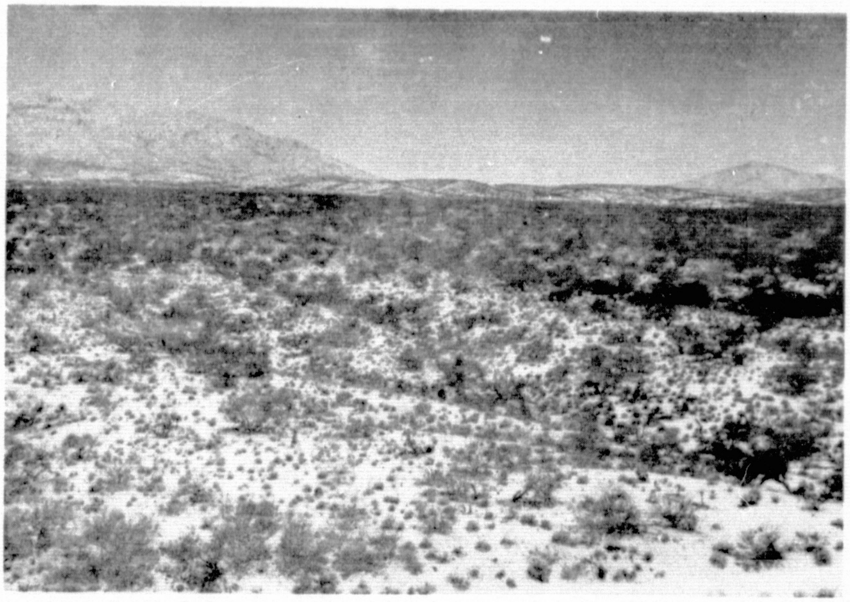


Figure 2-13. Acacia constricta and Prosopis juliflora usually with Opuntia; without Calliandra eriophylla.

The physiognomy of this type is "shrub-scrub."

Acacia constricta is always present in this type which is further characterized by almost always having Prosopis juliflora. These two species are generally the most prominent. Opuntia (cholla and/or prickly pear) contribute to the type. The absence of Calliandra eriophylla needs to be recognized to distinguish this type from some similar types.

A notable feature of the type is its extreme floristic diversity, particularly among shrubs. Some of these are Acacia greggii, Celtis pallida, Cercidium floridum, C. microphyllum, Ephedra trifurca, Fouquieria splendens, and Larrea tridentata. In most cases, these species are present and have mid- to low prominence values (3-1).

Grasses, like the shrubs, are present in variety, but generally not in high prominence. The genera Aristida and Bouteloua are best represented along with the species Tridens pulchellus and Muhlenbergia porteri.

This vegetation type is similar to "Calliandra eriophylla usually with Acacia constricta, Fouquieria splendens, and Prosopis juliflora and without Coldenia canescens."

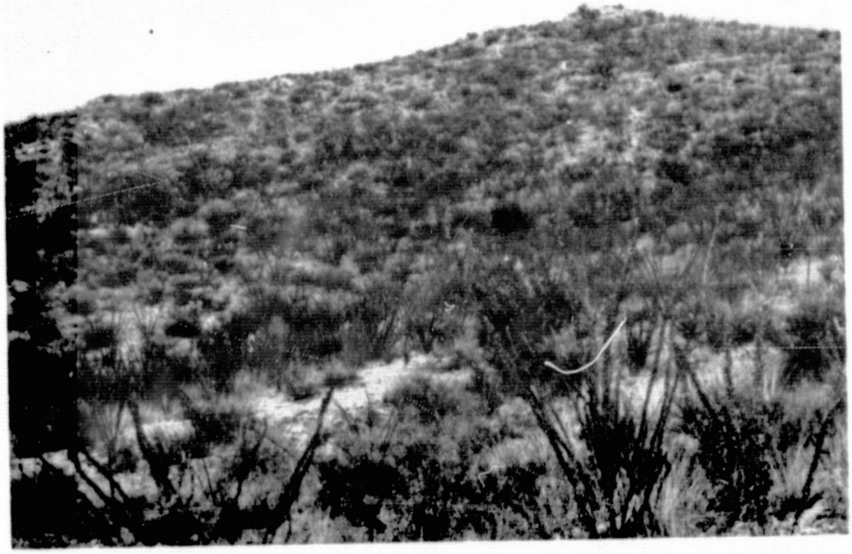


Figure 2-14. Calliandra eriophylla usually with Acacia constricta, Fouquieria splendens, and Prosopis juliflora and without Coldenia canescens.

Stands of this type always have a "shrub-scrub" physiognomy. Although this type is characterized by Calliandra eriophylla, this species is seldom prominent and, in fact, may occupy a position of low prominence. The aspect of the type is most often one of mixed tall shrubs. Acacia constricta, Fouquieria splendens, and occasionally Prosopis juliflora share, or alternately solely occupy, the most prominent position. In some stands, any one of the three species can be absent. Except for the species mentioned above, few other shrub species contribute substantially to the type, although several can be present. The more common of these are Zinnia pumila, Acacia greggii, and Lycium spp. The near absence of Haplopappus tenuisectus and complete absence of Coldenia canescens aid in distinguishing this type from others.

Opuntia spp. (primarily prickly pear and some cholla) is the primary succulent. Prickly pear is present in most stands in mid-prominence. Ferocactus wislizenii, although in low prominence, is commonly a component.

Grasses are common, and frequently challenge the shrubs for highest prominence ratings. As is often the case, species from the genera Aristida and Bouteloua are abundant. Two of the most common species are Bouteloua curtipendula and Hilaria belangeri.

This type is closely related to "Acacia constricta and Prosopis juliflora usually with Opuntia; without Calliandra eriophylla." It is also considered similar to the other two types which have Calliandra eriophylla as a character species.

Figure 2-15. Calliandra eriophylla and Bouteloua usually with any or all of Fouquieria splendens, Acacia greggii, Mimosa biuncifera, M. dysocarpa, Ferocactus wislizenii, and without Acacia constricta.

The structural characteristic of the type is primarily an intergradation of "scattered tall shrubs over herbs."

This vegetation type tends to be three layered with tall shrubs, low shrubs, and grasses all in high prominence. Calliandra eriophylla is always present in the type in widely fluctuating prominence (5-1). The most conspicuous shrub is normally Prosopis juliflora which is usually present in mid- to high prominence. Acacia greggii, Fouquieria splendens, Haplopappus tenuisectus, Mimosa biuncifera, and M. dysocarpa are present in a number of stands in mid- to low prominence. The presence of any or all of these five species in conjunction with the other character species suggests the type. Acacia constricta is not a component. Relatively few other shrub species are found in the type.

Some succulents are represented in rather low prominence in the type. One, Ferocactus wislizenii, is fairly common and is useful in distinguishing this type from a similar one which also contains Calliandra.

Of the grasses, Bouteloua is best represented, often with high prominence values (5-4). B. curtipendula is the most common grass species. The genera, Aristida and Andropogon, are also well represented.

The other vegetation types containing Calliandra are considered similar to this type, especially "Calliandra eriophylla and Bouteloua with any or all of Ephedra trifurca, Yucca baccata, Y. elata, Prosopis juliflora, and without Acacia constricta."

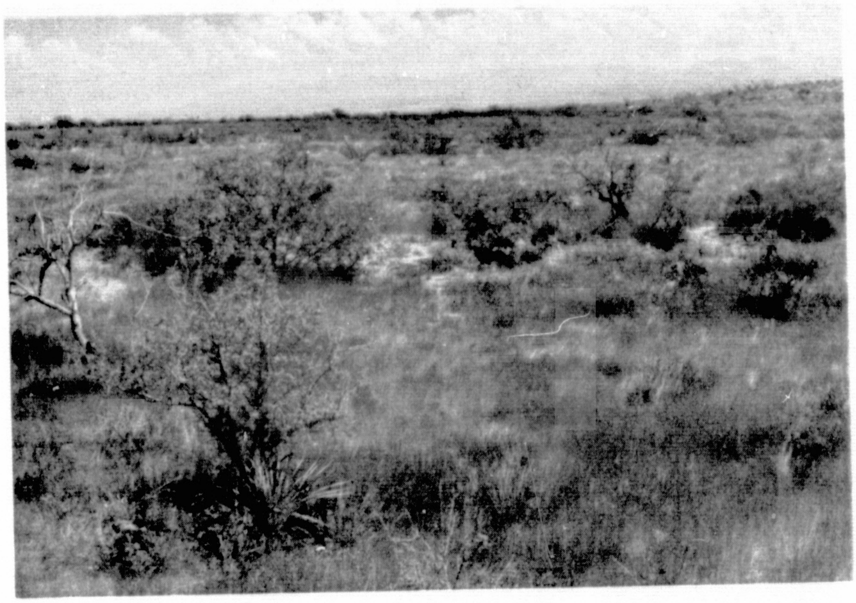


Figure 2-16. Calliandra eriophylla and Bouteloua with any or all of Ephedra trifurca, Yucca baccata, Y. elata, Prosopis juliflora, and without Acacia constricta.

The physiognomy of the type fluctuates between "herbaceous" types and an intergradation of "scattered tall shrubs over herbs."

As in some other types, Calliandra eriophylla and Bouteloua are present and substantially contribute to the herbaceous aspect of the type, even though Calliandra is not herbaceous. Prosopis juliflora is the most common tall shrub species, and when present it too influences the aspect of the type. Haplopappus tenuisectus and Ephedra trifurca are important in type identification. Noting the absence of Acacia constricta, and near absence of Acacia greggii, Fouquieria splendens, Mimosa biuncifera, and M. dysocarpa is important for the same reason. The latter group, when present, has low prominence values.

Yucca elata and Y. baccata are important succulents. The near absence of Ferocactus wislizenii is also characteristic. Several other stem and leaf succulents occur in the type.

Grasses abound and usually have high prominence (5). The genus, Bouteloua, has many species represented including B. curtipendula, B. eriopoda, and B. rothrockii. Aristida and Andropogon rank next to Bouteloua in frequency of occurrence and prominence followed closely by Muhlenbergia and Panicum.

In addition to being related to other herbaceous types, this vegetation type is similar to the others with Calliandra, especially "Calliandra eriophylla and Bouteloua, usually with any or all of Fouquieria splendens, Acacia greggii, Mimosa biuncifera, M. dysocarpa, Ferocactus wislizenii, and without Acacia constricta."

Figure 2-17. Bouteloua and Aristida without large shrubs, Nolina microcarpa, Yucca, and Calliandra eriophylla.

This "herbaceous" vegetation type fits into the class of "sodgrass and mixed sodgrass-bunchgrass steppe and prairie."

Perennials of Bouteloua and Aristida combine to give this type its herbaceous (grassland) aspect. However, presence of the grasses alone is not sufficient to separate the type from others. In addition to the general observation that there are nearly no large shrubs or succulents, it is meaningful to specifically notice that there is an absence or near absence of Prosopis juliflora, Calliandra eriophylla, Haplopappus tenuisectus, Nolina microcarpa, and Zinnia pumila in addition to species of the genera Acacia, Agave, and Yucca. Small shrubs are often present in high prominence, but because of their low stature they do not interrupt the grass aspect of the type. Mimosa biuncifera and M. dysocarpa are the small shrub species most often present.

As a group, perennial Bouteloua usually has the highest prominecce value (5). The most common species are Bouteloua curtipendula, B. gracilis, B. chondrosioides, and B. eriopoda. Perennial Aristida is is present in nearly all stands, but highly variable in prominence. Although other perennial grass species can be occasionally abundant, the only one consistently present in Andropogon barbinodis.

Several types are similar to this one with the major distinguishing features being the presence of absence of associated shrubs.

Figure 2-18. Prosopis juliflora and Bouteloua without Nolina microcarpa, Quercus, and Juniperus.

The physiognomy of the type is best expressed as an intergradation between a "shrub-scrub" and "herbaceous" type.

Grasses and Prosopis juliflora combine to create the herbaceous or grass-shrub aspect of the type. Thus, Prosopis normally is not in high prominence (mostly 3) and other tall shrubs and trees are nearly absent. The succulent, Nolina microcarpa, is also absent in the type. Two low shrubs, Haplopappus tenuisectus and Calliandra eriophylla, are also absent.

Mimosa biuncifera is occasionally present and sometimes in high prominence, but because of its stature, it does not interrupt the aspect. The only succulent which is fairly common is Yucca elata. Opuntia (prickly pear and cholla) when present is in low promiennce (2-1).

Species of Bouteloua generally rank highest in prominence in the stands of the type, with B. eriopoda, B. curtipendula, B. gracilis, and B. hirsuta being the most prominent and common. Aristida is normally present and sometimes ranks highest. Occasionally, stands can have unusually high prominences of Eragrostis, Hilaria belangeri, and Andropogon barbinodis.

There appear to be several types to which this vegetation type is related. They include the grasslands without shrubs as well as other Prosopis-Bouteloua types.

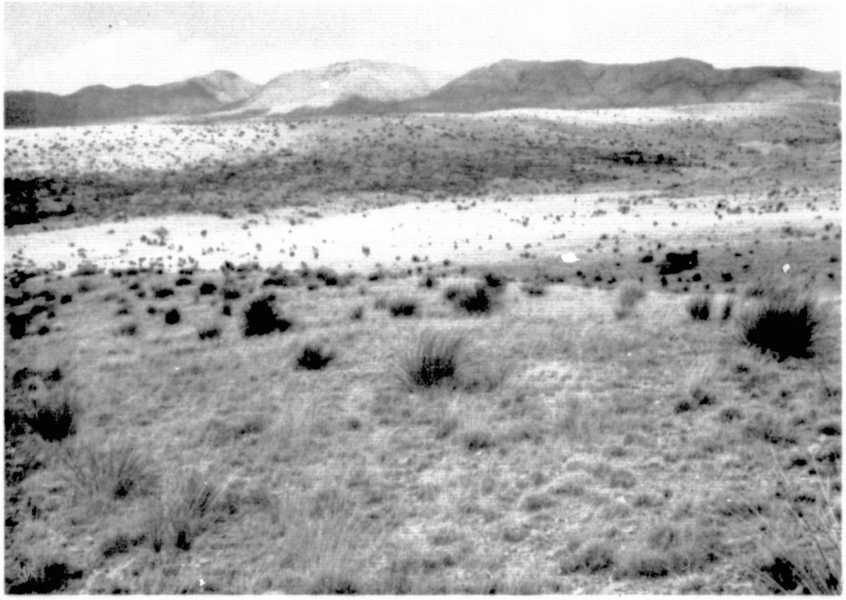


Figure 2-19. Bouteloua, Aristida, and Nolina microcarpa without Calliandra eriophylla.

Even though a few tall shrubs may be present in the type, the physiognomy is "herbaceous." The vegetation subclass is "sodgrass and mixed sodgrass-bunchgrass steppe and prairie."

The type is characterized primarily by the presence of Nolina microcarpa in either the most prominent position or coprominent with grasses. Thus, although some shrubs can be present, they do not contribute greatly to the aspect because of their rather low abundance. The more common shrub species are Prosopis juliflora, Ephedra trifurca, Baccharis pteronioides, and Rhus microphylla. Calliandra eriophylla is absent.

Succulents other than Nolina which are commonly present include Yucca baccata, Y. elata, and Dasylirion wheeleri.

Bouteloua curtipendula, B. hirsuta, and B. eriopoda, in that order, tend to be the most common and abundant grama grasses. As a group, perennial species of Aristida tend to rank second. Although several other grass species can be present, they are seldom abundant.

This vegetation type is similar to other herbaceous types which have an abundance of Bouteloua. The differentiating features are primarily based on associated shrubs, trees, or succulents.

Figure 2-20. Prosopis juliflora bosque.

Prosopis juliflora is the most prominent species along some major drainageways, attaining tree-like proportions of 30 feet near the primary river channels and becoming smaller on the floodplains. However, the stature of Prosopis on the floodplains qualifies the type as a "woods." Although associated shrubs and understory vegetation may be present in the bosque, the aspect is completely dominated by Prosopis.

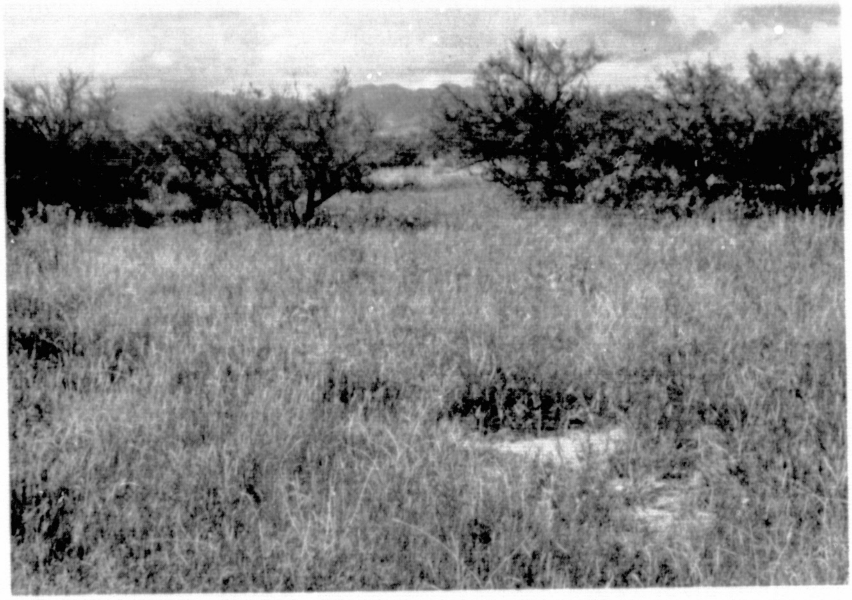


Figure 2-21. Hilaria mutica and Prosopis juliflora.

The physiognomic characteristic for most stands of the type is an intergradation of "scattered tall shrubs over herbs."

Hilaria mutica occurs as the prominent or coprominent species with Prosopis juliflora usually in and along drainageways. Although several other species can be present in the type, these two completely control the aspect. Some of the more common shrub species that occur, but generally in low prominence, are Acacia constricta, Haplopappus tenuisectus, Ephedra trifurca, and Zinnia pumila. A few succulents can also be present, especially Yucca and Opuntia (cholla and prickly pear). The most common associated grass genera are Bouteloua, Aristida, Muhlenbergia, and Eragrostis.

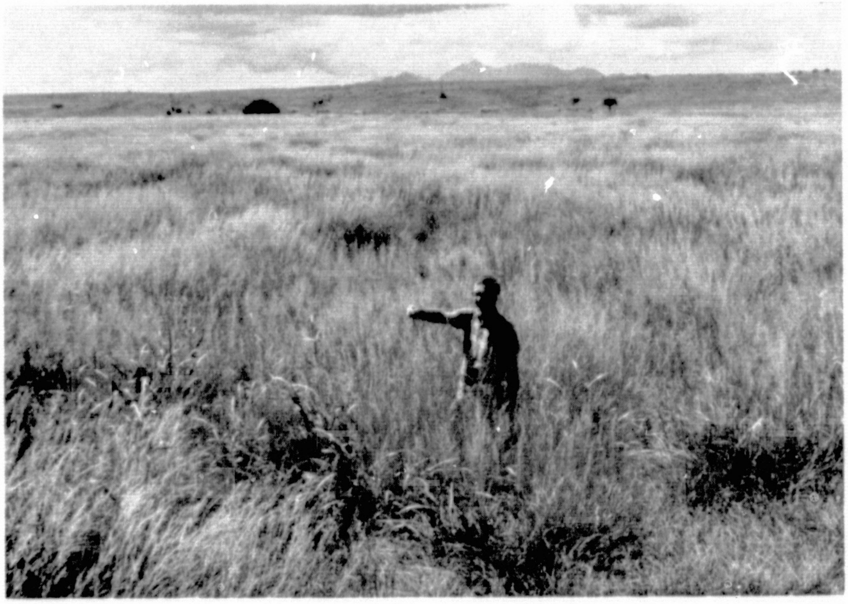


Figure 2-22. Sporobolus wrightii often with Prosopis juliflora.

When Prosopis is present, the physiognomy of the type is an intergradation of "scattered tall shrubs over herbs." When absent, the physiognomy is "herbaceous."

Sporobolus wrightii holds the most prominent or coprominent position in this vegetation type which is confined to drainageways. When coprominent, the other species is Prosopis juliflora. Thus, depending on the presence or absence of Prosopis, the type has a grassland aspect or shrub-grass aspect. Few other shrubs contribute consistently to the type, and succulents, when present, are sparse. In addition to Sporobolus, Aristida and Bouteloua are common grass components.

Figure 2-23. Prosopis juliflora and Bouteloua with Quercus (usually Q. oblongifolia) and/or Juniperus deppeana.

The vegetation type is represented by a variety of physiognomic forms, primarily undifferentiated intergradations. The most consistent structural characteristic is the presence of a well developed herbaceous layer.

The character species of the type are Prosopis juliflora, Bouteloua, and Quercus oblongifolia or Juniperus deppeana. Prominence ratings vary greatly for these species from stand to stand. However, in most stands, one species is either prominent or at least one shares prominence with other species.

In addition to the Quercus mentioned, Q. emoryi may be present. Mimosa biuncifera and/or M. dysocarpa are often present, and the genus represents the only shrub form other than Prosopis that is commonly present.

Leaf succulents (Agave palmeri and/or A. parryi, Dasylirion wheeleri, Nolina microcarpa, and Yucca spp.) are frequently present as are stem succulents of the genus, Opuntia (cholla and prickly pear). Agave schottii is seldom present.

There are several other vegetation types involving Prosopis and Bouteloua to which this type appears closely related. The presence of an overstory of Quercus and/or Juniper is the most distinguishing characteristic. There are, however, less consistent characteristics which support the distinction. These other characteristics consist of the less commonly associated plant species which are more common in the forest and wood physiognomic type.

Figure 2-24. Cowania mexicana usually with Juniperus.

This type usually has the appearance of an "intergrade type" of "scattered tall shrub over herbs" or "evergreen sclerophyll shrub" ("shrub-scrub").

Cowania mexicana is the species which determines the character of this vegetation type. In most cases, Cowania ranks high in prominence (5-4).

Trees are common to the type but seldom in high prominence. Juniperus spp. (Juniper) and several species of Quercus are about equally common with both genera occasionally represented in a stand.

In addition to Cowania, several shrubs contribute to the type mostly in mid- to low prominence. The more common being Cercocarpus breviflorus, Mimosa spp., and Rhus choriophylla.

Succulents are a very common component, especially Agave spp. (other than A. schottii), Dasylirion wheeleri, and Nolina microcarpa.

The herbaceous layer is generally well developed and usually includes Andropogon barbinodis, Aristida spp., Bouteloua curtipendula, Hilaria belangeri, and Muhlenbergia spp.

This type is not taxonomically closely related to other types in the area.

Figure 2-25. Quercus and Nolina microcarpa; without Cercocarpus breviflorus, Arctostaphylos pungens, and Mimosa biuncifera.

The physiognomy of this vegetation type is usually that of "woods" or occasionally, "intergrades."

Oaks are the most conspicuous genera of the type and are generally prominent (5-4). Nolina microcarpa is the other characteristic species; it has a wide range of prominence values. Shrubs not present in the type include Cercocarpus breviflorus, Arctostaphylos pungens, and Mimosa biuncifera.

The usual oak species is Quercus emoryi. Others are not frequent, but include Q. arizonica, Q. hypoleucoides, Q. oblongifolia, and Q. reticulata. Juniperus deppeana is occasionally present but normally in mid- to low prominence.

Shrubs may be present, but usually with low prominence values and number of species.

Other than Nolina, Yucca schottii is the only other leaf succulent consistently present, although occasional species of Agave do occur. Stem succulents are not common.

The herbaceous layer is usually well developed. The most common genera are Andropogon, Aristida, Bouteloua, Eragrostis, and Muhlenbergia.

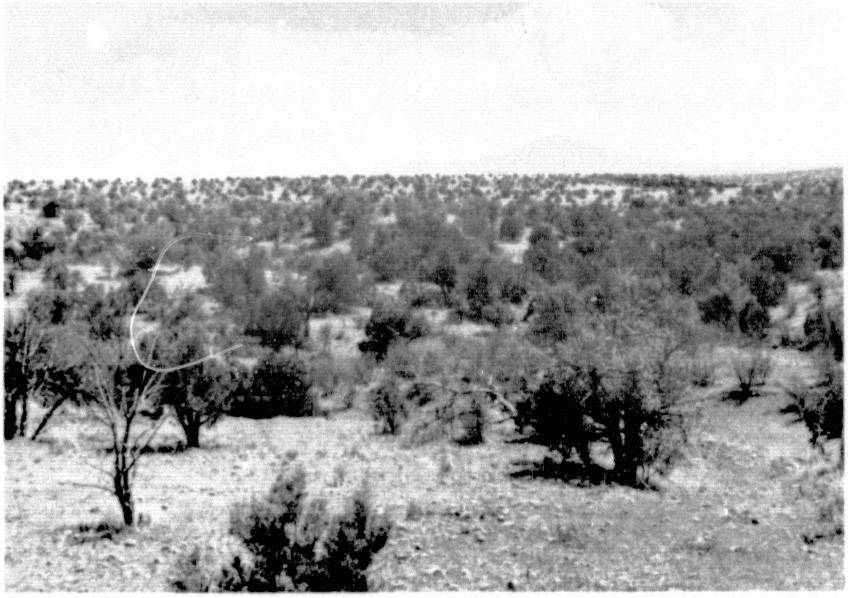


Figure 2-26. Quercus and Mimosa without Arctostaphylos pungens and Cercocarpus breviflorus.

Representatives of this type are either "woods" or "intergrades" having "scattered trees over an herbaceous layer." In either case, the herbaceous layer is well developed.

The oak, Quercus emoryi, is the most characteristic tree species of the type, being almost always present and with a high prominence value (5-4). Mimosa biuncifera is the usual Mimosa present and it has widely varying prominences. To distinguish from other types, the absence of Arctostaphylos pungens and Cercocarpus breviflorus is noteworthy.

Other tree species which are common include Quercus arizonica and Q. oblongifolia, although evidence suggests that they are not found together. Juniperus deppeana and J. monosperma may also be present.

Shrubs, other than Mimosa, are not an important component. Leaf succulents, however, are common in most stands. The more common succulents are Agave spp. (other than A. schottii), Dasylirion wheeleri, Nolina microcarpa, and Yucca schottii.

Figure 2-27. Quercus and Arctostaphylos pungens usually with Mimosa biuncifera; without Pinus cembroides.

This vegetation type is expressed in several physiognomic forms including "intergrades" (both scattered tree and shrub over grass), "shrub-scrub," and "woods."

The most characteristic oak is Quercus emoryi (prominence values mostly 5-3) and it is almost always present. Arctostaphylos pungens is always present most often in mid-prominence. Mimosa biuncifera and/or M. dysocarpa are also normally present and contribute to the characterization of the type even though they have low prominence. The absence of Pinus cembroides further distinguishes this type.

Juniperus deppeana occurs frequently in mid-prominence in several stands of the type and J. monosperma in a few. Two additional oaks are not frequently present, but they can be conspicuous. They are Quercus oblongifolia and Q. arizonica. Several shrub species can also be present, but none of them are consistent and they seldom exhibit high prominence values.

Leaf succulents are usually present in mid- to low prominence. Dasylirion wheeleri and Nolina microcarpa are most common. Agave species including A. schottii are also common. Yucca schottii is seldom present.

Perennial grasses are usually present, frequently in high prominence. Bouteloua curtipendula and species of Andropogon, Aristida, and Muhlenbergia are the most conspicuous.

Figure 2-28. Quercus, Arctostaphylos pungens, Pinus cembroides, Juniperus deppeana; without Mimosa biuncifera.

The physiognomy of the type is generally that of woods, but some stands may have a "shrub-scrub" or "intergrade" aspect of "scattered trees over shrubs."

The trees of the type include Pinus cembroides in mid- to low prominence and Juniperus deppeana with mid-prominence. Quercus emoryi and Q. arizonica are the most common oak species and they usually exhibit mid- to high prominence. The characteristic shrub of the type is Arctostaphylos pungens. It exhibits mid- to high prominence (3-5). Other shrub species are only occasionally present and usually do not exhibit high prominence. For purposes of type recognition, the absence of Mimosa biuncifera needs to be noted.

Two leaf succulents are common to the type. They are Nolina microcarpa with mid-prominence and Yucca schottii which usually has low prominence. Agave spp. and Dasylirion wheeleri are only occasionally present. Stem succulents are uncommon.

Perennial grasses are usually present although the herbaceous layer is seldom strongly expressed.

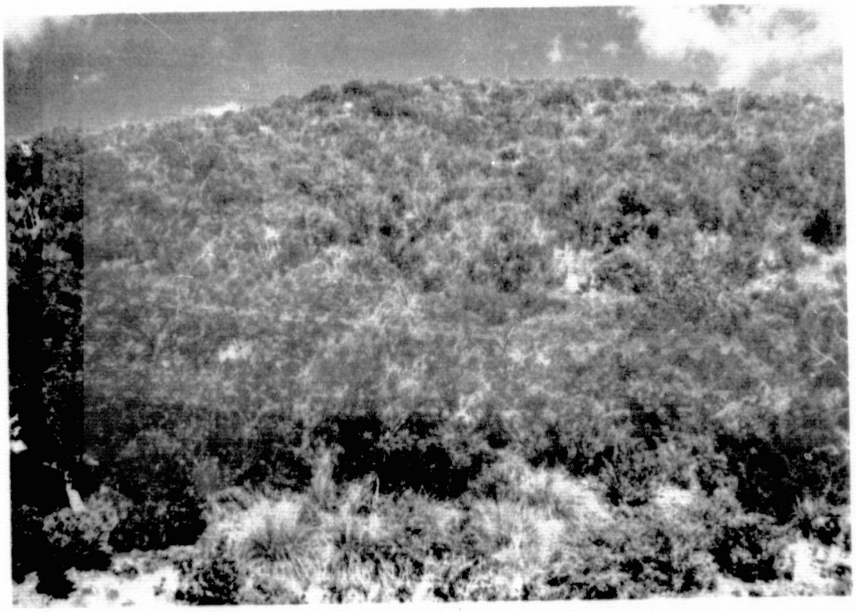


Figure 2-29. Cercocarpus breviflorus with Juniperus deppeana and/or Pinus cembroides and usually with Quercus.

The physiognomic expression of this type is quite variable. Stands appear as "forest and woods," "shrub-scrub," and "intergrades" of several types.

An overstory is always present although it sometimes consists of widely scattered trees over tall shrubs and may be quite inconspicuous. The more common oaks are Quercus arizonica, Q. emoryi, and Q. reticulata. Juniperus deppeana is usually present with Pinus cembroides and is nearly always present when the pine is absent. The character species, Cercocarpus breviflorus, usually has a prominence value of 5-3.

Garrya wrightii, Rhus choriophylla, and R. trilobata are frequently associated shrub species. Species of Ceanothus, in addition to Cercarpus breviflorus, may also be present.

Leaf succulents are always present; Nolina microcarpa and Yucca schottii are the most consistent. When present, Dasylirion wheeleri and Pinus cembroides usually occur together in this type. Agave spp. are only occasionally present.

Perennial grasses are always present; Bouteloua curtipendula is the most common.

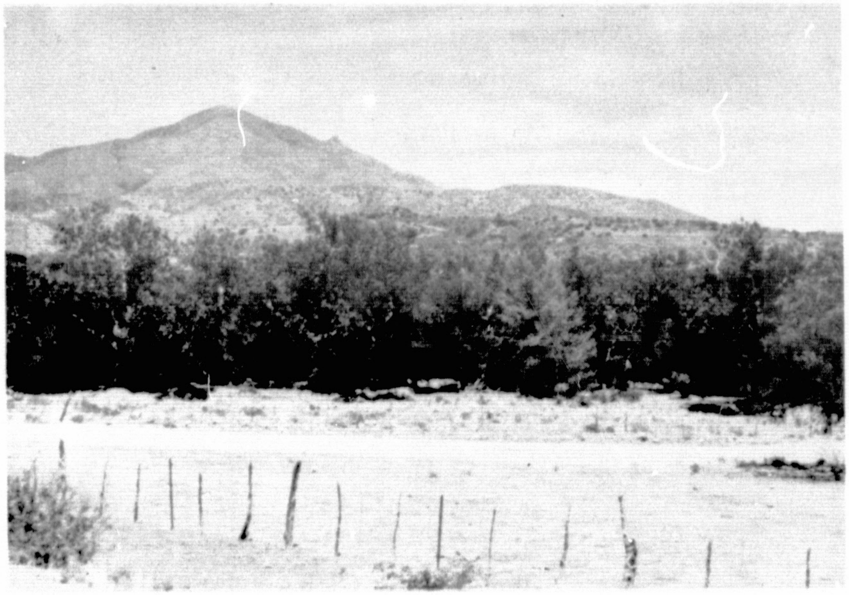


Figure 2-30. Populus fremontii, Fraxinus velutina, Platanus wrightii, and/or Chilopsis linearis.

Stands of the type normally have a "forest and woods" physiognomy. The type is riparian. The more common trees are Populus fremontii, Fraxinus velutina, Platanus wrightii, and Chilopsis linearis. They do not, however, necessarily occur together as the type is broadly defined. Several species of oak (Quercus arizonica, Q. emoryi, Q. hypoleucoides, and Q. reticulata) and Juniperus deppeana may also be found in the type. Shrub and tree forms of Prosopis juliflora are also present. This type is unique to riparian situations and is not closely associated with other types described.

Figure 2-31. *Pinus*, with or without *P. cembroides*, often with *Pseudotsuga menziesii*, *Quercus hypoleucoides*, and *Q. gambelii*.

Physiognomically, representatives of this type are members of "mixed forests of needleleaf-broadleaf."

Several species of pine may be present in a stand of this broad type, although pines do not have to hold positions of highest prominence. Either *Pinus ponderosa* or *Quercus hypoleucoides* is usually the most prominent species. Other species which may be most prominent or co-prominent are *Pinus engelmannii*, *P. strobiformis*, *Quercus arizonica*, *Q. emoryi*, and *Q. reticulata*. Other pines and common tree species include *Pinus cembroides*, *P. leiophylla*, *Pseudotsuga menziesii*, *Juniperus deppeana*, and *Quercus gambelii*. Scattered shrubs and grasses, especially *Muhlenbergia*, can be common in the understory.

This broadly described type is found in the highest elevations of the study area and on a site-to-site basis may be related to any of the generally lower elevation vegetation types which commonly contain oak and juniper. Included within this type may be inclusions of vegetation types which contain the species *Populus tremuloides*, *Robinia neomexicana*, *Quercus gambelii*, and species commonly found in mountain meadows.

CHAPTER 3

IMAGERY COMPARISONS

OBJECTIVE 1

INTRODUCTION

> Because photo interpretation often involves a considerable amount of subjective judgment, it is commonly referred to as an art rather than an exact science . . . the interpreter must know how to use the scientific tools of methodology of the photogrammetric engineer; yet these objective findings must often be supplemented with deductive reasoning . . . the skilled interpreter must have a large store of information at his fingertips to adequately perform his exacting task . . . he should have a sound general background in geography, geology, forestry, and other disciplines . . . the value of experience and imagination can hardly be overemphasized . . . (Avery, 1968, p. 65).

The above quoted excerpts give an insight into the difficulty, or impossibility, of isolating the human factor when the goal is to compare different types of imagery. By minimizing the amount of image-subject judgments, it would seem that the reliability of imagery comparisons would improve. However, if we remove the interpreter altogether, we are left only with differences in photograph quality; namely, tone (or color) contrast, sharpness, and stereoscopic parallex (Colwell, 1960, p. 52). With no inferences, we have lost the ability in image comparisons to consider the "interpretable" features of an image, that is, the characteristics of the subjects (shape, height, relative position, etc.) which go to make up the image. It should follow that in order to compare images (or imagery) with the intent of having that comparison bear directly on the subjects in the imagery, the interpreter must play a role.

On the thought of being able to interpret natural vegetation from ERTS, Nichols (1973, p. 1205) stated:

> The human has the ability to quickly delineate gross differences in land classes, such as wildland . . . in the wildland areas, delineations can also be made, based on tone and texture, which represent general vegetation systems, such as grasslands, brush, trees, and barren areas.

In more directly addressing the question of image comparisons, Lauer and Krumpe (1973, p. 98-99) first conducted a quantitative interpretation of ERTS-1 imagery and showed that vegetation type identification could be made at 65-70 percent accuracy for features in the northern California Feather River Watershed. The resource types they were looking at were coniferous forests, hardwood forests, mountain chaparral, xeric grassland, etc. In another test for ERTS imagery in the Watershed, they performed a quantitative interpretation on several ERTS-1 color composite frames (scene-dates) and one single black and white (band 5) ERTS-1 frame.

> In no case were interpretation results derived for the three vegetation types significantly different than from those derived from another for the three vegetation types identified (conifers, brush, and dry site hardwoods).

This contrasted to their Northern Coastal Zone Test Site results where 23 resource mapping units were delineated by photo interpretation on the ERTS color composite as compared to five mapping units interpreted on the ERTS band 5 imagery. Details of the test procedures were not given in the report, nor was an explanation offered for differences in test results between the two sites.

"An objective evaluation of stratification boundaries in a wildland environment is often impossible," (Lauer, Goehring, and Benson, 1972, p. 73). This, the authors explain, is a result of gradual boundary changes between types. They further report that one of the more objective ways of evaluating boundary placement (stratification) is by comparing variances in timber volume estimates when the stratification is related to timber volume. As a means of evaluating the boundary placement problem, they conducted a forest type identification experiment where the identifications were made on two types of aerial photography of the same scale. By selecting a large number of points from a grid, they were able to compare the forest type identifications at each point for the two interpretation jobs. By inference, accuracy in boundary placement corresponded to accuracy of type identification as determined by point checking. This enabled a relative evaluation of boundary placements for the two tasks.

One means of objectively evaluating interpretation testing is through tables of commission-omission (Carneggie, 1971; Poulton, et al., 1971; and Schrumpf, Johnson, and Mouat, 1973). The concept is directly analogous to that in statistics where outcomes of decisions represent (1) no error; (2) a wrong decision, Type I error (omission); or (3) a wrong decision, Type II error (commission). A Type I error is made when the experimenter rejects the null hypothesis and it is true. A Type II error is made when the experimenter accepts the null hypothesis and the alternative is true (Steel and Torrie, 1960, p. 70). As applied to interpretation testing, comparisons are made between interpretation (expected units) and some standard (observed units). The manner in which calculations are made is given in Poulton, et al. (1971, p. 19):

> Interpreted units (denoted A) are compared to the standard units (denoted B) with the following calculations:
>
> Correct (no Error) = A agrees with B
>
> Omission (Type I Error) = A is like B, but it was rejected as B
>
> Commission (Type II Error) = A is not like B, but it was accepted as B
>
> $$\% \text{ Correct} = \frac{\text{Number of A's that agree with B's}}{\text{Total number of B's}} \text{ X } 100$$
>
> $$\% \text{ Errors of Omission} = \frac{\text{Number of A's like B's that were rejected}}{\text{Total number of B's}} \text{ X } 100$$
>
> $$\% \text{ Errors of Commission} = \frac{\text{Number of A's not like B's but were accepted}}{\text{Total number of A's}}$$

SPACE PHOTO IMAGE CONTENT COMPARISON

Photo Selection and Preparation

Prior to the advent of ERTS, two cloud free space photographs imaged the Southern Arizona Test Site (Table 3-1). Both of these photographs, Gemini IV and Apollo 6, were chosen for photo image content comparisons with an ERTS-1 photographic reconstitution.

The decision as to which ERTS-date (or dates) to use was based on several considerations. First, it was necessary to give as fair a representation of ERTS as was practical. Second, at the time the comparison was initiated, three dates of ERTS cloud free imagery were

Table 3-1. Space photo images available for comparison in the Southern Arizona Test Site prior to January 1973. Those with asterisks were used in the comparison.

Satellite name	Image date	Image I.D.	Type of image
*Gemini IV	Jun 65	S-65-34681	Photographic, color
*Apollo 6	Apr 68	AP6-2-1442	Photographic, color
ERTS-1	22 Aug 72	1030-17271	Photographic reconstitutions, 4 bands, & simulated color infrared
ERTS-1	2 Nov 72	1102-17280	
*ERTS-1	26 Dec 72	1156-17280	

available. This compelled a consideration of the use of more than one date of ERTS imagery because of the potentially greater information content of multidate imagery versus single date imagery. Third, an image format which could be obtained easily and rapidly was necessary. The format also needed to be compatible with those of the other space imagery types in order to conduct uniform comparisons. Fourth, following a visual comparison of color composites for the three available dates of ERTS imagery, the need for color was apparent if maximum information content were to be made available.

In consideration of all these factors, it was decided that a meaningful comparison could be made by using a single date diazo composite accompanied by a black and white photo print of ERTS band 5 of the same date. The reason for utilizing a black and white print in addition to the diazo composite was to provide a format with near maximum visual resolution potential. Diazo composites suffer some resolution loss.

Photographic methods of producing color composites are also available, and they produce composites of higher resolution than is possible with a diazo process. However, it was judged that the expediency of composite production via diazo, including the generally greater availability of diazo equipment, plus the additional judgments that the diazo composites were of acceptable quality, prompted use of diazo composites over the more sophisticated photographically produced composites.

To minimize scale variation, all three space photo images were photographically reproduced to give working copies at a scale of about 1:1,000,000. The reproduction process was intended to maximize working copy resolution, and in the case of Gemini and Apollo, this approximated the color balance and resolution of early generation, NASA produced, photographic prints.

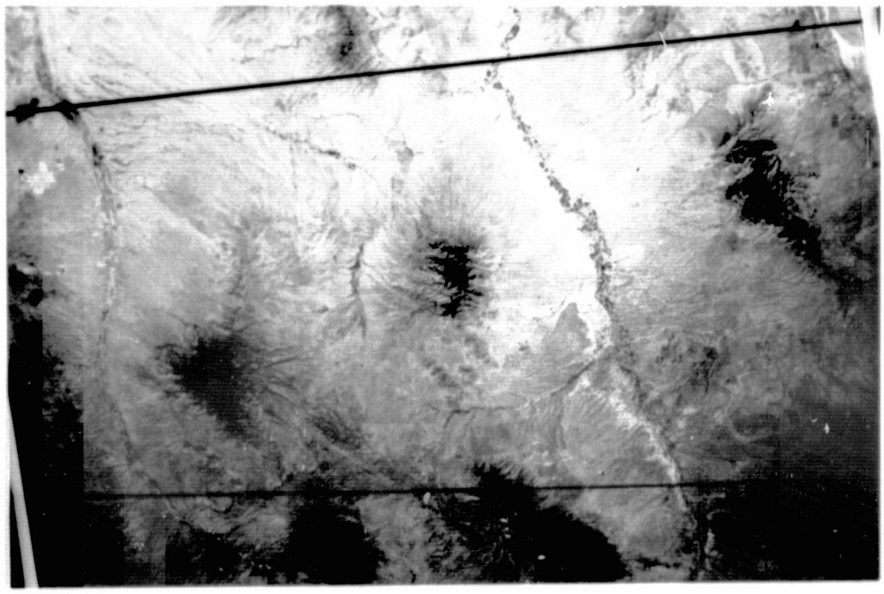
For the ERTS working copies, a simulated color infrared transparency (composite) was first produced from three multispectral ERTS transparencies using diazo film transparencies as intermediates. A commercial diazo machine was used to prepare the transparencies. The diazo transparencies were yellow, magenta, and cyan. They were formed respectively by exposure from ERTS bands 4 (green), 5 (red), and 7 (infrared) of the electromagnetic spectrum. When simultaneously registered, they produced a simulated color infrared composite.

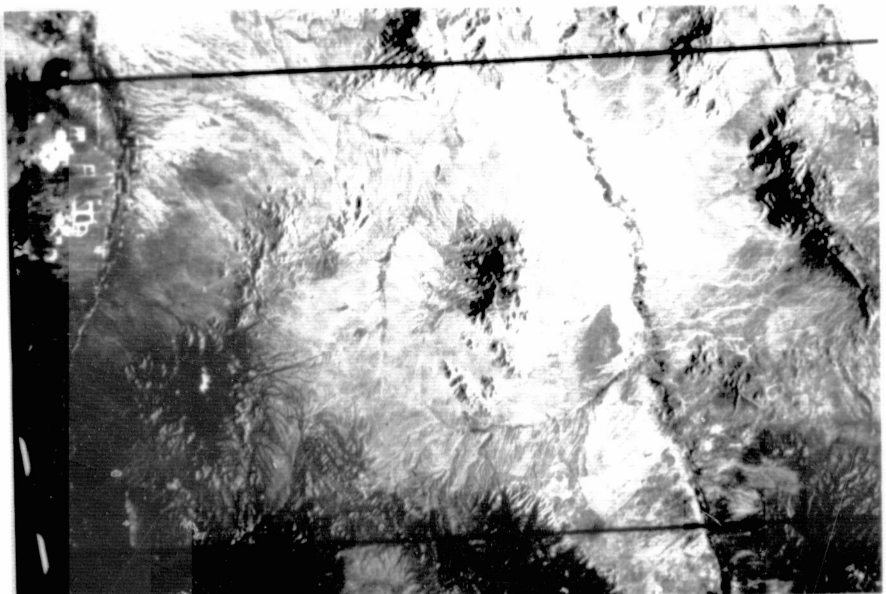
For all three space images, color working prints were prepared by a commercial photo laboratory from 120 mm Kodacolor-x negatives. The negatives were produced with a Polaroid MP-3 copy camera having a built-in strobe as the light source. Similarly prepared reduced scale prints are shown in Figure 3-1. The purpose of the figure is to give a visual impression of the nature of the photographs compared.

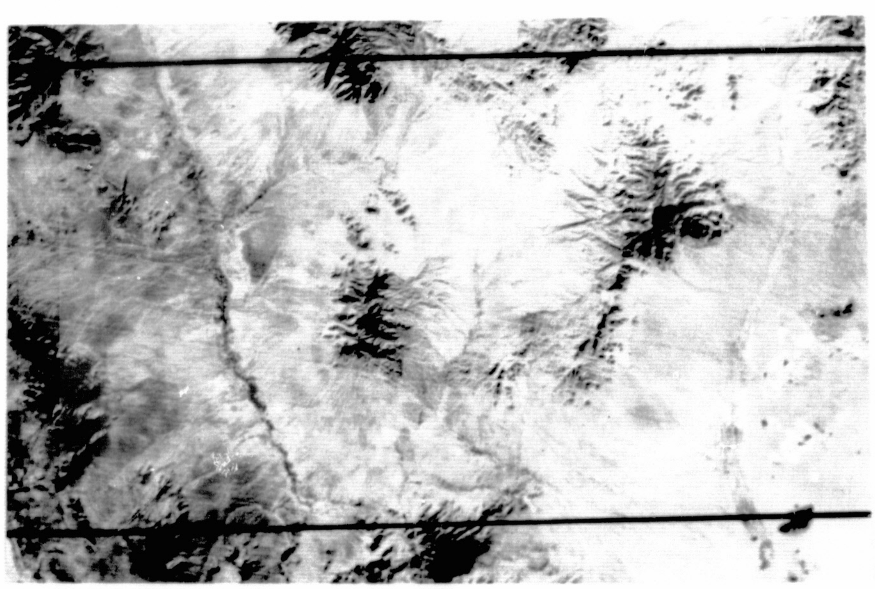
Test Material Preparation

As pointed out in the introduction, the development of the space photo testing procedure constitutes a major achievement of the research. Detailed discussion of the effectiveness of the procedure is reserved for the "Results and Discussion" section except as necessary in this section to describe methodology. The method, which might be called

Figure 3-1. Reduced scale (1:1,066,000 copies from top to bottom of Gemini IV, Apollo 6, and 26 Dec 72 ERTS-1 space images. Relative differences in quality are comparable to quality differences of the test materials. Test materials were in color at scales of about 1:1,000,000.







"image groupability"[3-1/] testing was designed to (1) minimize human interpretation induced error; and (2) enable effective statistical analyses of apparent information content among photographs being compared.

Three basic requirements of photo image selection had to be met in order to conduct the image groupability testing. First, an objective means had to be achieved for selecting image samples of the study area. Within this requirement was the need to have images which represented a reasonably complete range of subjects. Each image sample needed to represent a single subject. Second, each image sample had to be of sufficient size to permit unmagnified visual inspection. Third, image samples from each space photo type necessarily represented the same pieces of land.

The outgrowth of these requirements was that image selection was based on a macrorelief mapping job which earlier had been conducted for the study area. The mapping was displayed on a 1:120,000 scale high altitude photo mosaic. A mock-up of that display is shown as a part of Figure 3-2. The mapping was done by David A. Mouat, a student of geomorphology, by using a three way combination of stereo photo interpretation, ground observations, and high rèliance upon his ability to "read" 1:120,000 USGS topographic maps. This he translated into macrorelief classes of which six are described for the study area (Table 3-2). Appendix D provides a more detailed description of the macrorelief classes. All classes except "2.1: gently rolling, undissected" were present in large enough areal extent in the study area to allow representation by the image samples.

Justification for utilizing macrorelief classes as the basic stratification from which to select image samples rests with the observation that landform features, including macrorelief classes, are among the more salient resource features visible on space photography in arid regions (Morrison, 1969). Furthermore, single macro-

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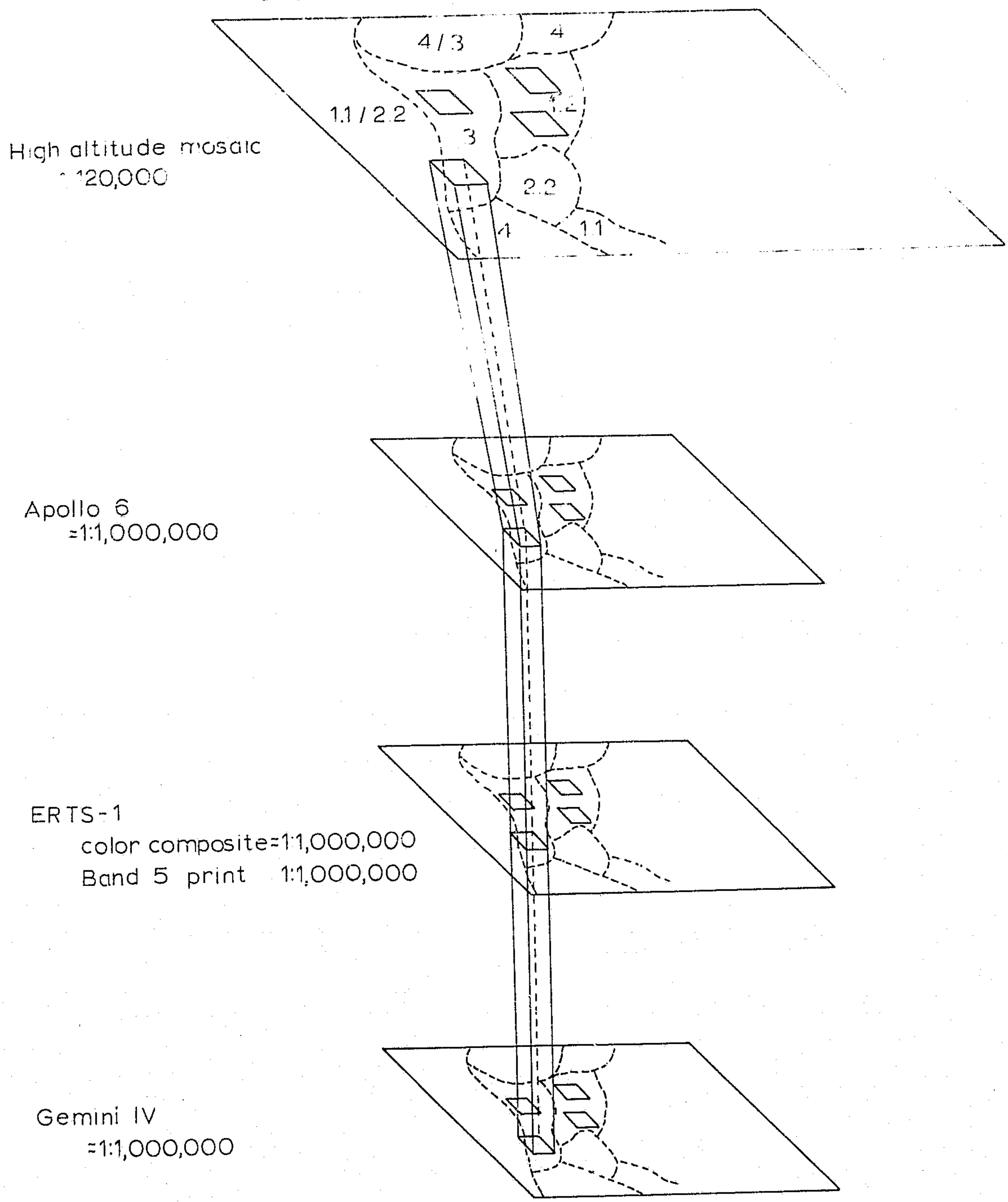
3-1/ The terminology "image groupability" is coined here to distinguish from "photo interpretation." In photo interpretation testing, the observers are required to predict the relationship between the photo image and ground subject and from such predictions (interpretations), image samples are grouped. In image groupability testing the observers need not know what subjects are represented in the images. Images are grouped based on inherent image characteristics rather than on an interpretation of what subjects are thought to be represented by the images.

Figure 3-2. Image selection scheme used in space photo comparison. Image samples were drawn based on macrorelief mapping of high altitude photography. All image samples from each space photo represent the same piece of land.

SOUTHERN ARIZONA TEST SITE



relief classes often occupy extensive areas, making it possible to select image samples from space photos of about 1:1,000,000 scale that primarily contain a single macrorelief class. In total, 45 image samples in addition to 13 image standards were drawn from each of the three space photo types (Table 3-2). This represented the maximum number of samples which could be drawn from the areas of uniform macrorelief while minimizing sample overlap to prevent neighboring sample recognition. The restricted number of image samples (45) also served in a desirable way by limiting the time required to take a test to usually less than 20 minutes. The highly variable number of image samples drawn from each macrorelief class served to minimize observer prediction of class size.

Image samples and standards were approximately 0.5 inch square, with some deviation due to variation in photo scales. Each was individually mounted on a 2x2 inch card and number coded. For ERTS, a pair of images of the same area was mounted on each card, one from the color composite and the other from Band 5. The small size of the images and their mounts was intended to facilitate sorting and thereby minimize observer fatigue.

Table 3-2. Image sample representation. Macrorelief provided the basic strata from which to draw space photo image samples.

Macrorelief Class[1/]		Number of Images Drawn	
Numerical Symbol	Technical Description	Sample	Standard
1.1	Flat, smooth topography	11	2
1.2	Flat, slightly dissected	4	2
2.1	Gently rolling, undissected	0	0
2.2	Moderately dissected	9	4
3	Hilly, 100' to 1000' relief	12	4
4	Mountains, > 1000' relief	9	1
Total		45	13

[1/] See Appendix D for more detailed macrorelief class descriptions.

Testing Procedure

A total of 13 observers were chosen for the testing. Selection was based on (1) the desire to have represented a cross-section of photo interpretation experiences; (2) an expressed interest by the observers to participate; and (3) the need to have a large number of observers such that differences detected in image groupability results could assuredly be ascribed to something other than a lack of adequate replication (observer variation).

Each observer took two tests for each of the three types of space photography, or a total of six tests apiece. The same set of image samples was used for the two tests in each space photo type.

The first test (unrestricted) was designed to determine to what extent observers could similarly group the images when there was no restriction on the number of groups allowed nor on the number of image samples within a group. The second test (restricted) required that observers place image samples into one of five groups by matching the samples to image standards (see Table 3-2). The groups represented the macrorelief classes from which the image samples and standards were originally drawn; however, this was not known by the observers, except that those who were experienced photo interpreters undoubtedly recognized a correlation between groups and some landform changes.

Test scheduling was designed to minimize the effect of learning or memory from one photo type to the next. Observers were divided into three nearly equal sized groups with each group having a cross section of experience levels. As originally envisioned, each group was to start testing on a different type of space photography, and there was to be a minimum of two weeks between each test. Observers were to complete both tests for a space photo type before proceeding to the next. Due to photo processing problems and observers' personal scheduling conflicts, test scheduling was altered but not in a detrimental way.

Analysis

Test 1 (unrestricted) was analyzed by analysis of variance (ANOVA), to examine the mean numbers of image groups established. This provided an estimate of image complexity. Apollo and ERTS were further analyzed by constructing a matrix of image sample pairs. For each observer, if two image samples were placed in the same group, the occurrence of the "pair" was recorded in the appropriate matrix cell. By tallying the pairs which occurred most regularly, nearly mutually exclusive image sample groups were established. These then provided an objective means of stratifying the Apollo and the ERTS space photographs. The stratification provided the first stage in the two stage sampling in Chapter 7.

Test 2 (restricted) was analyzed primarily in a 3x5x13 factorial ANOVA (photo types x macrorelief classes x observers). Ratios established from "correct responses:expected responses" provided the mean values from the ANOVA. Several non-orthogonal, single degree of freedom comparisons were drawn from the ANOVA. In addition to the tables and the charts derived following the ANOVA, tables of omission and commission were also developed to illustrate the nature of the errors made in Test 2.

Concept Development and Its Value

In the area of photo interpretation testing, two questions of major concern are (1) can photo interpreters do a comparable job in interpretation; and (2) can imagery of different types be visually compared to assess relative differences in information content? Solutions to these problems appear to be straightforward; however, there are logistic problems of considerable dimension.

Although the primary concern addressed here is one of imagery information content, the problem of photo interpreter capability differences can have a profound impact on imagery comparisons. In fact, in comparing imagery through photo interpretation, testing procedures can have so many unisolated extraneous variables that meaningful comparisons of the imagery itself may be impossible. As an example, the traditional approach to image comparison has been to assess human interpretation results of "ground subjects" as imaged in the photography of concern. This can be accomplished as long as the interpreters can bridge the gap between photo image and apparent ground subject. However, for some types of photo image comparisons it may not be necessary for the "interpreter" to infer ground subject. Another part of the same traditional approach often involves photo image delineation. The difficulty in comparisons involving delineations is obvious, i.e., interpreters do not delineate identically. In photo interpretations, or more generally, image comparisons, it would appear that a combination of area and boundary similarity determinations would be ideal. However, the difficulty of conducting meaningful qualitative, and more especially quantitative, analyses using a combination of the two calculations is difficult and of questionable value. Furthermore, testing procedures that rely on subject identifications cannot easily isolate interpreter experiences and subject familiarity factors. In the setting of image comparisons, these factors would seem to mask qualitative analyses and confound statistical analyses.

For these reasons a concept and procedure in photo image comparisons were developed and may constitute a worthwhile contribution in the field. The concept involves "image groupability" testing and was initiated to give a comparative evaluation of image variation among photographic images of Apollo 6, ERTS-1, and Gemini IV. An underlying contention is that there is a direct and positive correlation between the number of distinct images in a space (or aerial) photograph and the potential mapping detail of that photography. Therefore, in the approach no mapping exercises were conducted; rather, assessments were made as to the facility with which observers (not necessarily trained photo interpreters) could group photo images into similar classes and into classes which represented similar ground subjects. When done in this way, it was not necessary for observers to know what subjects were represented or for that matter that the photographs were even displaying earth resources.

The image groupability concept, especially when applied in the form of image sample grouping, serves several desirable purposes:

(1) It minimizes differences in interpreter experience and area familiarity by limiting, insofar as is practical, the use of associated evidence.[3-2/] Although the use of associated image evidence is an essential portion of operational photo interpretation and mapping, it can disguise differences in image comparisons.

3-2/ Associated evidence in photo interpretation is that knowledge which can be gained about a photo image of interest from an examination of neighboring images. With appropriate inferences drawn from the examination, the image of interest can be identified as to subject with a higher degree of certainty than it could if neighboring image inferences were not made.

(2) It enables the use of a large number of observers and does so without undue concern about differences in experience levels.

(3) It avoids the problem of area and boundary determinations common to some approaches in photo interpretation.

(4) It enables ready statistical comparisons by ANOVA and, depending on the nature of the test, it is also suited for entry into tables of commission-omission.

(5) It provides a means of directly comparing one type of imagery to another in terms of apparent interpretable subject content. This is accomplished for the imagery of interest by selecting image samples which represent the same ground area in each type of imagery being examined.

(6) It is suitable for photo image testing when the image groups developed are intended to represent ground subjects described in a hierarchical manner.

(7) It can be designed to test the image grouping capabilities of prospective interpreters. This might be suggestive of the native photo interpretation capabilities of observers.

(8) It does not depend on observer established subject-image relationships; therefore, image samples can be considered for grouping on the basis of image characteristics alone, and not on a consideration of interpreted subjects. For many types of image comparisons this is desirable.

The advantages listed above are not all necessarily limited to image groupability testing. That is, except as noted, established photo interpretation testing procedures can also list the same or similar desirable characteristics.

Macrorelief Class (Restricted) Testing and Commission-Omission Analysis

For each type of space photography, results of macrorelief class testing were expressed as count data. Table 3-3 compares Apollo, ERTS, and Gemini count data in an easy to read form. Perhaps the greatest value in commission-omission tables is that the nature of the errors which were made can be determined easily. The tables represent an application of the statistical sampling expression of errors in drawing conclusions about a stated hypothesis (H_0):

(a) Type I error (error of omission)-reject the H_0 when it is true.

(b) Type II error (error of commission)-accept the H_0 when it is false.

Table 3-3. Summary commission-omission tables of macrorelief class testing for Apollo, ERTS, and Gemini. Values represent sums for image sample placement by the 13 observers.

APOLLO

OBSERVER CREATED GROUPINGS	MACRORELIEF CLASS IDENTIFICATION 1.1	1.2	2.2	3	4	TOTAL # GROUPS	# TYPE II ERRORS	% TYPE II ERRORS
1.1	83	11	17	2		113	30	26.6
1.2	9	25	34	5		73	48	65.8
2.2	43	16	45	22		126	81	64.3
3	8		21	107	27	163	56	34.4
4				20	90	110	20	18.2
TOTAL # CLASSES	143	52	117	156	117	585		
# TYPE I ERRORS	60	27	72	49	27		235[1]	
% TYPE I ERRORS	42.0	51.9	61.5	31.4	23.1			40.2[2]

ERTS

OBSERVER CREATED GROUPINGS	MACRORELIEF CLASS IDENTIFICATION 1.1	1.2	2.2	3	4	TOTAL # GROUPS	# TYPE II ERRORS	% TYPE II ERRORS
1.1	31	20	13			64	33	51.6
1.2	37	18	32			87	69	79.3
2.2	73	14	64	13		164	100	61.0
3	2		8	132	18	160	28	17.5
4				11	99	110	11	10.0
TOTAL # CLASSES	143	52	117	156	117	585		
# TYPE I ERRORS	112	34	53	24	18		241	
% TYPE I ERRORS	78.3	65.4	45.3	15.4	15.4			41.2

GEMINI

OBSERVER CREATED GROUPINGS	MACRORELIEF CLASS IDENTIFICATION 1.1	1.2	2.2	3	4	TOTAL # GROUPS	# TYPE II ERRORS	% TYPE II ERRORS
1.1	54	11	12			77	23	29.9
1.2	33	24	41			98	74	75.5
2.2	53	16	45	21		135	90	66.7
3	3	1	19	130	26	179	49	27.4
4				5	91	96	5	5.2
TOTAL # CLASSES	143	52	117	156	117	585		
# TYPE I ERRORS	89	28	72	26	26		241	
% TYPE I ERRORS	62.2	53.8	61.5	16.7	22.2			41.2

1. Total number correct

2. Total % correct identification

In table 3-3, the columns headed by "macrorelief class identification" indicate those classes as determined from the 1:120,000 high altitude, macrorelief map. Each row headed by "observer created groupings" begins with a macrorelief class symbol, and the values along the row represent the placement of image samples. By way of an example, in the Apollo portion of the table the row headed by macrorelief class "1.1" show a total for all observers of 113 image samples in this group. Of these, 83 were correctly called "1.1" and the remaining 30 (11+17+2) actually belonged to other classes making them Type II errors (commission). In the column headed "1.1," the total number of image samples in this class is 143. Of these, observers collectively and correctly placed 83, but a total of 60 (9+43+8) which should have been called "1.1" were not. The 60 were erroneously omitted from the "1.1" class and are Type I errors (omission). Throughout the table, the values in the darkened diagonal boxes contain the correct responses.

In an inter-photo comparison of results, one of the striking features is that the total number of correct responses for each space photo is nearly the same with 235 for Apollo, and 241 each for ERTS and Gemini. However, distinct differences are apparent among the photos on a class by class comparison. This is particularly true for the flatter terrain types, 1.1, 1.2, and 2.2. The primary observer confusion among classes was centered around difficulty in properly grouping image samples of class 2.2. The tendency was to place incorrectly a large number of class 1.1 samples into the 2.2 class. Further, large numbers of samples from classes 1.1 and 2.2 were placed incorrectly in class 1.2.

At the other end of the scale, groupings into classes 3 and 4 were rather accurate among photo types. In general, the errors were less for these two classes as compared to errors in most other classes.

Macrorelief Class (Restricted) Testing and Analysis of Variance

Accounts of sample variability approach a highly meaningful level when variation is isolated and especially when it can be statistically tested. This was possible in the image groupability testing where observers were forced to group all images into one of five categories (which represented macrorelief classes) based on image standards. Every image sample was correctly or incorrectly placed making it possible to establish proportions of correct responses for each of the image sample groups created by the observers:

$$\frac{\text{Number of image samples correctly placed}}{\text{Number of image samples belonging to the group}}$$

The values thus established were utilized to generate means for a factorial analysis of variance (ANOVA) (Table 3-4).

Table 3-4. Analysis of variance showing sources of variation in image groupability testing of 45 image samples placed in five categories.

Source of Variation	DF	Mean Squares
Observers (R)	12	0.036 *
Photo type (P)	2	0.007 ns
R x P	24	0.018 ns
Macrorelief Class (M)	4	1.642 **
R x M	48	0.034 **
P x M	8	0.184 **
R x P x M	96	0.016
Total	194	

ns Not significantly different

* Significantly different (P<0.05)

** Significantly different (P<0.01)

One of the more obvious features of the ANOVA is that there was no difference (P>0.5) in groupability of image samples among the space photo types. This, or course, was expected from the "Total number correct" box tallies of Table 3-3. Virtually all of the variation (P<0.01) in groupability was due to macrorelief classes alone or to interactions involving macrorelief.

Early in the study, the realization was made that information as general as that derived from ANOVA in Table 3-4 would not shed sufficient light on the exact nature of variation in image groupability testing. For that reason, several single degree of freedom comparisons were planned, the results of which are shown in several tables which follow. In all of these tables, the single degree of freedom comparisons are essentially lsd comparisons and should be different at least at P<0.025 in order to place much reliance on having detected real differences.

From Table 3-4, it is apparent that most of the variation was associated with differences in macrorelief groupability. This is even more evident in the main effect single degree of freedom comparisons of Table 3-5. However, within the macrorelief classes category (M), the classes as grouped gave variable results. The grouping, "1.2 & 2.2 vs 1.1, 3 & 4" was an attempt to maximize the likelihood of

Table 3-5. Single degree of freedom comparisons for main effects derived form ANOVA for image groupability testing.

Source of Variation	DF	Mean Squares
Observers (R)	12	
Inexperienced vs. experienced[1/]	1	0.051 ns
Photo type (P)	2	
ERTS vs. Apollo	1	0.013 ns
ERTS vs. Gemini	1	0.001 ns
Apollo vs. Gemini	1	0.006 ns
Macrorelief class (M)	4	
1.2 & 2.2 vs. 1.1, 3 & 4	1	2.372 ***
1.1, 1.2, 2.2 vs. 3 & 4	1	7.134 ***
1.1 & 1.2 vs. 2.2	1	0.287 ns
3 vs. 4	1	0.002 ns
Two-way interactions	80	
RxPxM	96	0.016
Total	194	

ns Not significantly different (P>0.025)

*** Significantly different (P<0.005

[1/] Based on observers' statements (Appendix I). Observers listing "none" and "limited" experience were considered inexperienced. Those listing "moderate" and extensive" experience were considered experienced.

detecting differences among macrorelief classes. Although successful ($P<0.005$), a greater difference existed between the flatter vs. mountainous grouping (1.1, 1.2, 2.2 vs 3 & 4) as one looks at the corresponding mean squares, 2.372 and 7.134, respectively. Although it is academic for purposes of this test, the comparison shows that the success in grouping class 1.1 image samples was more nearly like the success for classes 1.2 & 2.2 than it was for classes 3 & 4. The point in creating the groupings, flatter vs. mountainous, flat vs. rolling (1.1 & 1.2 vs 2.2), and hills vs. mountains (3 vs 4) is that even the most general level of macrorelief discrimination (flatter vs mountainous) can be related to broad differences in the occurrence of natural vegetation and other resource features. This has implications when space imagery is used for sampling in earth resource related surveys.

Even though differences among macrorelief class grouping were evidenced in Table 3-5, the same table shows that each of the individual comparisons for photo type (P) was not significantly different ($P>0.025$). However, the photo type x macrorelief class interaction (P x M) of Table 3-4 was different ($P<0.01$) and these realizations led to another set of individual degree of freedom comparisons. The results of the detailed photo type x macrorelief class comparisons are in Table 3-6. The pattern of significant differences in Table 3-5 is strongly paralleled in the Table 3-6 pattern. The information content of the table at first may appear to be difficult to translate. By way of explanation, in the first comparison of the table, the groupability of image samples for 1.2 & 2.2 vs 1.1, 3 & 4 was different ($P<0.005$) between ERTS and Apollo.

Table 3-7 is presented as an example of a method for drawing together the information expressed in Tables 3-4, 3-5, and 3-6, that is the ANOVA. It's advantage over the other three tables is that the directionality of differences can also be shown. For example, in the ERTS vs. Apollo column, the predicted "easier" to group macrorelief classes were, in fact, easier or better grouped than the "harder" classes (symbolized as "Easier>Harder"). Further, directionality and reversal interaction inferences for comparisons not tested can be shown. For

Table 3-6. Single degree of freedom comparisons for photo type x macrorelief class effects derived from ANOVA for image groupability testing.

Source of variation	DF	Mean squares
1.2 & 2.2 vs. 1.1, 3 & 4:		
ERTS vs. Apollo	1	1.517 ***
ERTS vs. Gemini	1	1.461 ***
Apollo vs. Gemini	1	1.846 ***
1.1, 1.2, 2.2 vs. 3 & 4:		
ERTS vs. Apollo	1	4.491 ***
ERTS vs. Gemini	1	6.006 ***
Apollo vs. Gemini	1	3.414 ***
1.1 & 1.2 vs. 2.2:		
ERTS vs. Apollo	1	1.040 ns
ERTS vs. Gemini	1	0.650 ns
Apollo vs. Gemini	1	0.302 ns
3 vs. 4:		
ERTS vs. Apollo	1	0.228 ns
ERTS vs. Gemini	1	0.041 ns
Apollo vs. Gemini	1	0.144 ns
R x P x M	96	0.016
Total	194	

ns Not significantly different (P>0.025)

*** Significantly different (P<0.005)

Table 3-7. Summary and inferences from the ANOVA, Tables 3-4, 3-5, and 3-6.

	Photo Comparisons			
Tested components of ANOVA	ERTS vs. Apollo	ERTS vs. Gemini	Apollo vs. Gemini	ERTS vs. Apollo vs. Gemini
Over all macrorelief classes	ns	ns	ns	ERTS=Apollo=Gemini ns
1.2 & 2.2 vs. 1.1, 3 & 4 (harder to group vs. easier)[1]	Easier > harder (P > 0.01)	Easier > harder (P > 0.01)	Easier > harder (P > 0.01)	Easier > harder (P > 0.01)
For harder classes (1.2 & 2.2)	ERTS > Apollo nt	ERTS > Gemini nt	Apollo ≥ Gemini	ERTS > Apollo ≥ Gemini nt
For easier classes (1.1, 3 & 4)	Apollo > ERTS nt	Gemini > ERTS nt	Apollo > Gemini	Apollo > Gemini > ERTS nt
1.1, 1.2, 2.2 vs. 3 & 4 (flatter vs. mountainous)	Mountainous > flatter (P > 0.01)	Mountainous > flatter (P > 0.01)	Mountainous > flatter (P > 0.01)	Mountainous > flatter (P > 0.01)
For flatter classes (1.1, 1.2 & 2.2)	Apollo > ERTS nt	Gemini > ERTS nt	Apollo > Gemini nt	Apollo > Gemini > ERTS nt
For mountainous classes (3 & 4)	ERTS > Apollo nt	ERTS > Gemini nt	Gemini > Apollo nt	ERTS > Gemini > Apollo nt
1.1 & 1.2 vs. 2.2 (flat vs. rolling)	Flat > rolling (P > 0.05)	Flat > rolling (P > 0.05)	Flat > rolling ns	Flat > rolling ns
For flat classes (1.1 & 1.2)	Apollo > ERTS nt	Gemini > ERTS nt	Apollo > Gemini nt	Apollo > Gemini > ERTS nt
For rolling class (2.2)	ERTS > Apollo nt	ERTS > Gemini nt	Apollo > Gemini nt	ERTS > Gemini= Apollo nt
3 vs. 4 (hills vs. mountains)	Hills > mountains ns	Hills > mountains ns	Mountains > hills ns	Hills = mountains ns
For hill class (3)	ERTS > Apollo nt	ERTS > Gemini nt	Gemini > Apollo nt	ERTS > Gemini > Apollo nt
For mountain class (4)	ERTS > Apollo nt	ERTS > Gemini nt	Gemini > Apollo nt	ERTS > Gemini > Apollo nt

[1] Based on the author's experiences of interpreting macrorelief classes on several different types of space and aerial photography.

ns No significant difference at the 5% level of probability.

nt No statistical test was made for this comparison.

(P > ...) Significantly different (P > ...) at the indicated level of probability (0.01 or 0.05)

> or ≥ Can be translated to mean that for the components, one type of photography was better (>) or slightly better (≥) than another in terms of observers' ability to group together image samples of the components.

example, in the "ERTS vs. Apollo" column at the "harder class" row, the groupability of ERTS is greater than for Apollo. Just the opposite is true for the "easier class" in the next row down.

Information such as that in Table 3-7 can also be read to suggest which type of photography might be best for interpreting selected features, say macrorelief classes. By looking at the last column, "ERTS vs. Apollo vs. Gemini," one can see that given the image format constraints used in testing, ERTS and Apollo were generally the better imagery types. More specifically, Apollo was more successful on flat land subjects and ERTS was better in hilly and mountainous subjects. It should be remembered that these comparisons are based on inferences and not statistically tested. The differential success can be related to original imagery quality. In the mountains, Apollo was too dark to see much image detail; on the flat lands ERTS was "washed out" and lacking in detail.

The nature of these differences is illustrated in Figure 3-3. Relative differences are seen among imagery types for each macrorelief class. However, the greater differences would appear to be among macrorelief classes than among imagery types. Significant differences among macrorelief classes have previously been discussed. Following a cursory examination of imagery types within macrorelief class, additional single degree of freedom comparisons were extracted from the factorial ANOVA. These are shown in Table 3-8, and from these comparisons there is only one that approaches a statistically significant difference (ERTS vs. Apollo within class 1.1).

The final extraction which was made from the ANOVA was an image groupability comparison between the "inexperienced" and "experienced" observers for individual macrorelief classes (Table 3-9). No differences were detected in the comparison. Earlier, significant values were determined among macrorelief classes (Tables 3-4, 3-5, and 3-6). The suggestion from these results is that the testing procedure was successful in eliminating differences among observers while allowing expressions of differences in macrorelief. Thus, the image sample approach appears to have eliminated observer differences due to factors of experience and/or subject familiarity.

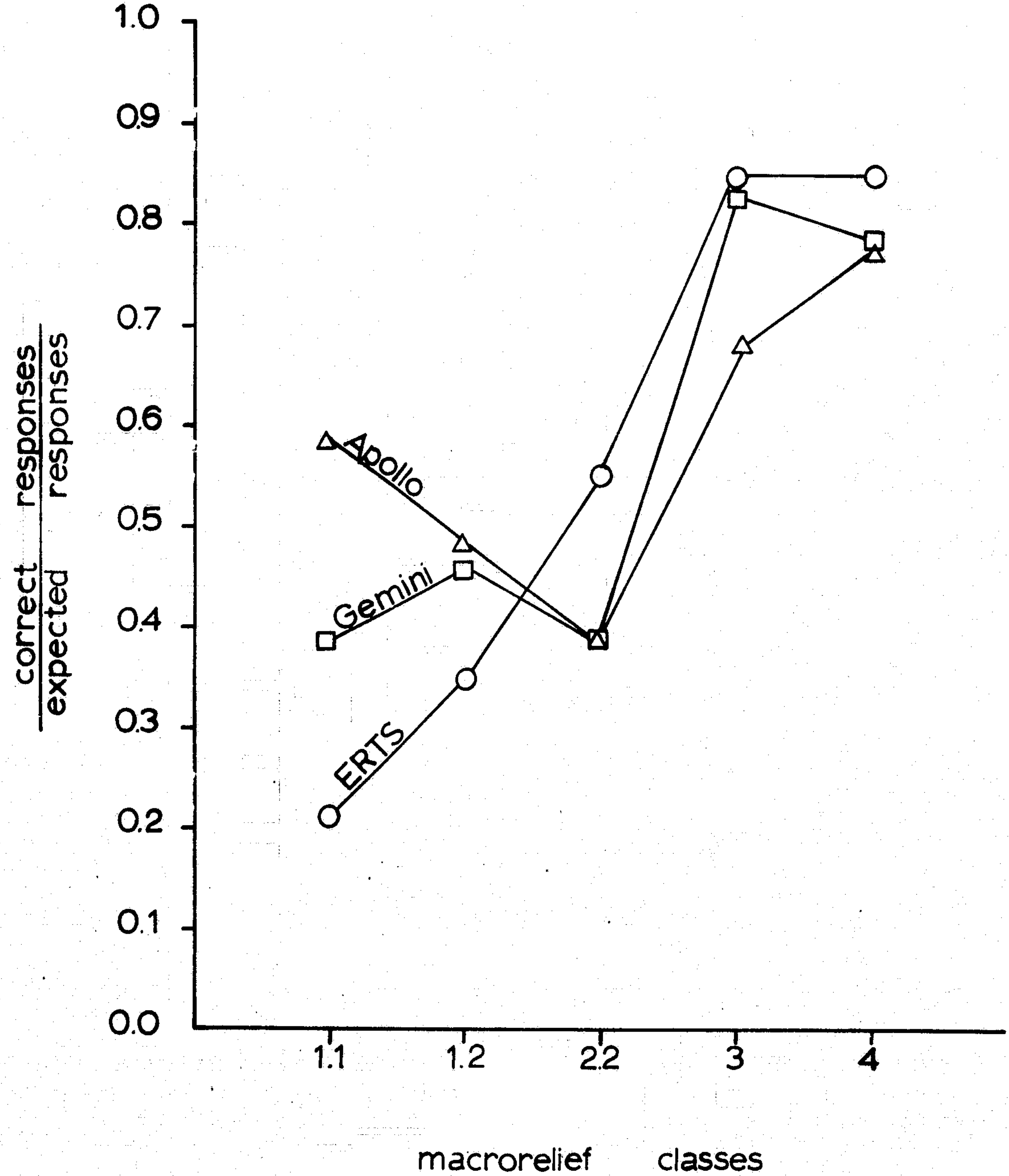


Figure 3-3. Image groupability testing of space photo images by macrorelief class.

Table 3-8. Single degree of freedom comparisons for photo type within macrorelief class effects derived from ANOVA for image groupability testing.

Source of variation	DF	Mean squares
Within class 1.1:		
ERTS vs. Apollo	1	0.860 ns
ERTS vs. Gemini	1	0.168 ns
Apollo vs. Gemini	1	0.267 ns
Within class 2.2:		
Apollo & Gemini vs. ERTS	1	0.229 ns
Within class 3:		
ERTS & Gemini vs. Apollo	1	0.205 ns
Within class 4:		
Apollo & Gemini vs. ERTS	1	0.046 ns
R x P x M	96	0.016
Total	194	

ns Not significantly different (P>0.025).

Table 3-9. Single degree of freedom comparisons for macrorelief classes between experience level effects derived from ANOVA for image groupability testing.

Source of variation	DF	Mean squares
Inexperienced vs. experienced:[1/]		
class 1.1	1	0.012 ns
class 1.2	1	0.004 ns
class 2.2	1	0.036 ns
class 3	1	0.019 ns
class 4	1	0.089 ns
R x P x M	96	0.016
Total	194	

1/ Based on observers' statements. Observers listing "none" and "limited" experience were considered inexperienced. Those listing "moderate" and "extensive" experience were considered experienced. Observer statements are summarized in Appendix I.

ns Not significantly different (P>0.025).

Imagery Complexity Testing and Analysis of Variance

A portion of the image groupability testing was designed to compare relative photo complexity among Apollo, ERTS, and Gemini imagery. As noted in the methods section, the same image samples for macrorelief class testing were used for testing image complexity. Observers were not restricted to a set number of groups. Testing was based on the contention that the relative number of groups established is an index of image complexity, which is directly and positively correlated with photo image information content. Photo information content can be expected to be related to potential for mapping detail.

In a testing scheme in which image samples are drawn from photographs in such a way that identical pieces of land are represented for each type of photography, direct comparisons of image complexity are possible (Table 3-10). From the table, it is apparent that the mean

Table 3-10. Analysis of variance and lsd comparisons showing sources of variation by photo type in image groupability testing. Test involved 13 observers, 45 image samples, and an unrestricted number of image groups.

Source of variation	DF	Mean squares
Photo type	2	24.95*
Error	36	5.88
Total	38	

* Significantly different ($P<0.05$).

Photo type lsd comparisons from above ANOVA

Apollo $\bar{X}$ >ERTS $\bar{X}$ ($P<0.05$)

Apollo $\bar{X}$ >Gemini $\bar{X}$ ($P<0.05$)

ERTS $\bar{X}$ =Gemini $\bar{X}$ ($P>0.10$)

number of groups established varied by photo type. The nature of the differences was detected by lsd comparisons (Steel and Torrie, 1960). The mean number of image groups established for the space photos is presented in Table 3-11. Modal and range statistics suggest that

Table 3-11. Results of image groupability testing with an unrestricted number of image groups.

Image group established	Apollo	>	ERTS	=	Gemini
Mean	10.0		7.8		7.5
Range	6-16		5-12		5-11
Mode	6,10,11,12		5,6,9		8

there was more variation among observers for Apollo and ERTS than there was for Gemini.

Proceeding with the caution that the image classes established might not be resource relevant, one can conclude that under the conditions of the test, Apollo had greater information content than either ERTS or Gemini which were not different from each other. Of greater importance is the possibility that the concept of image groupability may be of substantial benefit in comparatively judging imagery as to content for subject relevant information.

It would appear that for judging photography suitability, image complexity testing and image groupability by subject testing both have value. For example, from Table 3-12, Apollo is seen to have the greatest image diversity. Yet when image samples were related to a resource subject (in this case macrorelief), there was no clear advantage for either Apollo or ERTS, except that both were apparently superior to Gemini. This would suggest that image complexity evaluations alone may not yield the best index for selecting photography. Rather some evaluation which indicates the relative degree of image-subject relationship may be essential. Therefore, the selection of the most suitable photography may often be based on specific image-subject examinations.

Table 3-12. Ranking of space photo types as generalized from ANOVA.

Component 1/	Photo Type: Apollo	ERTS	Gemini
Image complexity	+	0	0
All macrorelief classes	0	0	0
Flat classes (1.1 & 1.2)	+	-	0
Flatter classes (1.1, 1.2 & 2.2)	+	-	0
Harder classes (1.2 & 2.2)	0	+	+
Rolling class (2.2)	0	+	0
Easier classes (1.1, 3 & 4)	+	-	0
Hill class (3)	-	+	0
Mountainous classes (3 & 4)	-	+	0
Mountain class (4)	-	+	0

1/ For any row, the best to worst discrimination is indicated respectively by "+, 0, -". With the exception of "Image complexity" statistical significance cannot be inferred directly.

Photo Stratification

In resource inventories, one of the primary values of having more than one scale of photography is realized in multistage sampling. In comparing the relative value of photography in sampling, it is necessary to stratify objectively the photography being compared if an unbiased estimate of the photography is to be realized.

Image complexity testing discussed above provided for an objective stratification of the Apollo and ERTS photographs. The 13 photo observers who sorted the 45 image samples, in effect, established photo image sample pairs, many pairs of which overlapped to create image groups. For both the Apollo and ERTS photos, a matrix of the 45 image samples was developed (Table 3-13). The number of image sample pairs created by the 13 observers was recorded in a dot-line tally. The table enabled ready recognition of image sample pairs. This led to the establishment of nearly mutually exclusive groups of image samples based on the collective image pairings. For both ERTS and Apollo, the image groups resulted from image sample pairs which seven or more observers had recognized.

Each image group basically represented a distinct type of image. Because there is a relationship between photo image and ground subject, each image group was considered as being composed of image samples drawn from a unique stratum. Thus each group could be considered a sample of a stratum. By plotting the image of a group (now identified as to stratum) on the space photos from which they were originally drawn, it was a relatively easy matter to objectively draw new strata boundaries which reflected not only the image groups but the image contrasts on the space photographs as well. The nature of the stratifications thus achieved can be seen in the values given (Table 3-14) and in Figure 3-4. Althought number of strata and number of mapping units are similar, major differences in the nature of the strata are apparent in the figure.

Table 3-13. Partial matrix of ERTS image samples. Dot-line tallies indicate image sample pairs created by 13 photo observers. A single dot or line segment represents one observer's pairing.

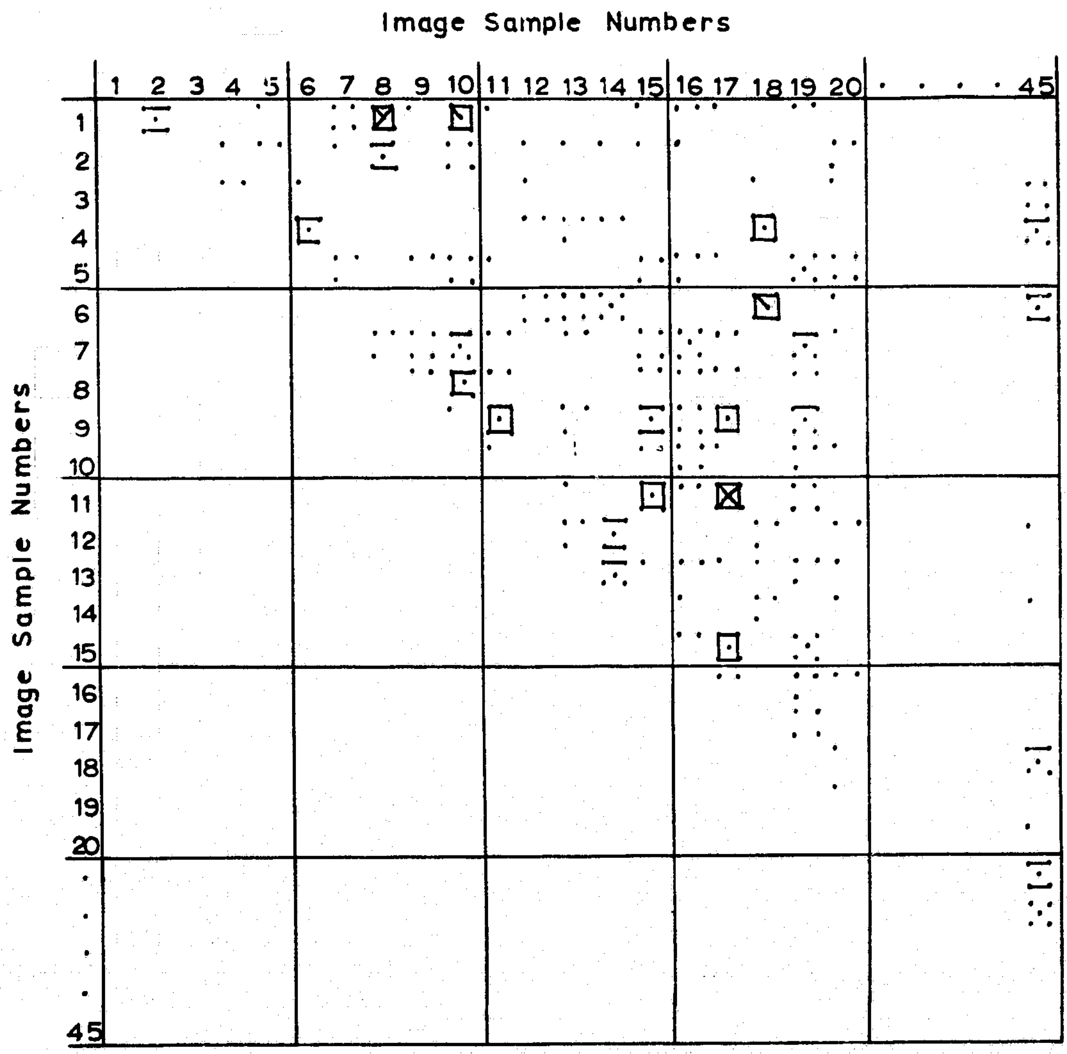


Figure 3-4. Objectively developed, space photo stratification from image groupability testing involving 13 photo observers. The top sketch illustrates the areas which were sampled in two stage sampling comparison of Apollo and ERTS. The middle (Apollo) and bottom (ERTS) sketches represent the entire study area stratifications. In these, the unshaded portions represent the areas involved in the two stage sampling.

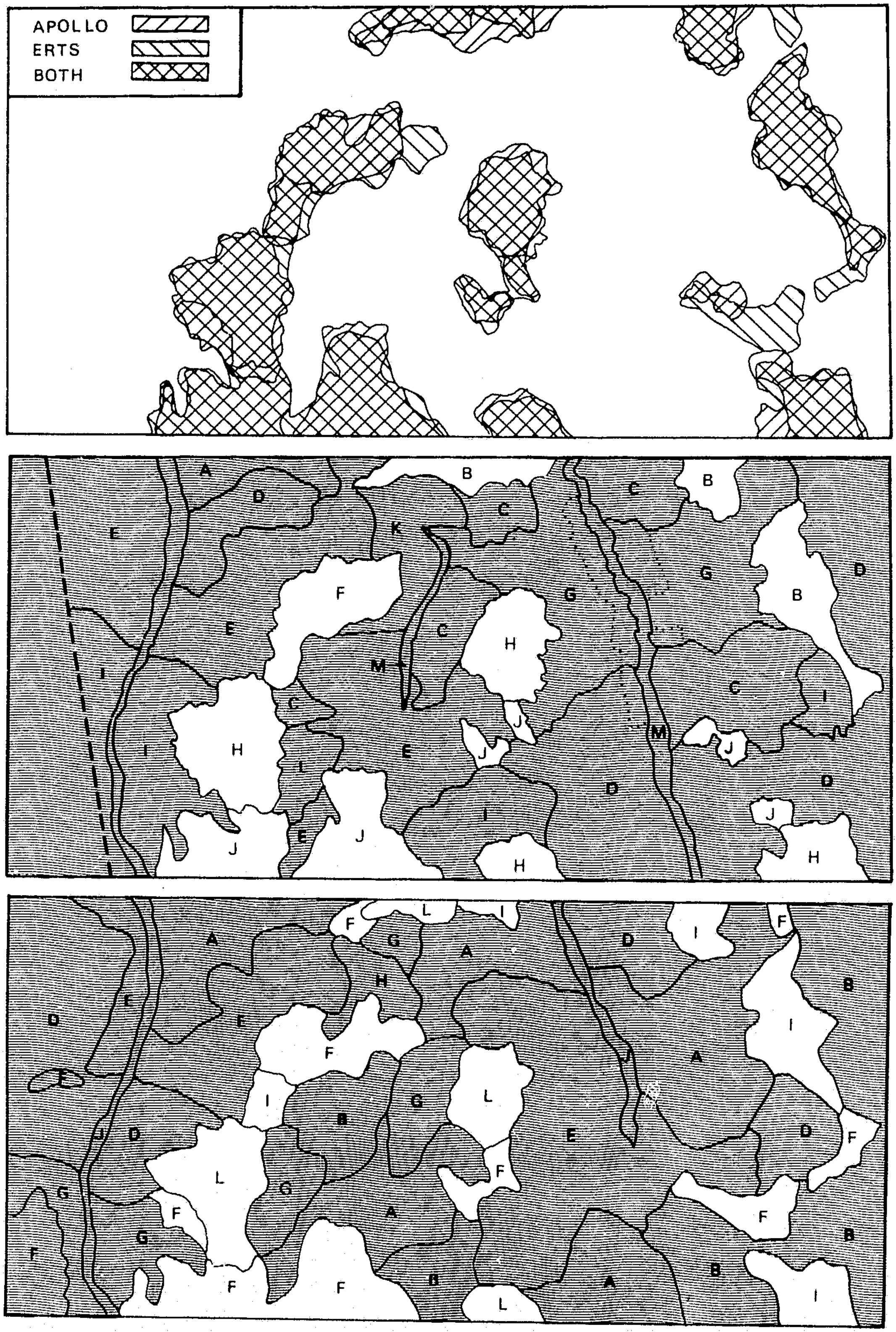

APOLLO
ERTS
BOTH

Table 3-14. A comparison of the number of new strata and mapping units created as a result of imagery complexity testing on space photography for the Southern Arizona Test Site.

	Apollo	ERTS
Number of new strata	13	10
Number of mapping units	38	40

INTERMEDIATE SCALE AERIAL PHOTO IMAGE COMPARISONS

Using the same concepts and similar techniques as reported above for space photo image comparisons, two types of aerial photography were tested to determine (1) the facility with which images could be similarily grouped, and (2) the accuracy with which images could be matched to standard images that represented known vegetation associations. An abbreviated report of that research (Ross, 1973) is given here.

Approach

Testing was restricted to the Tombstone portion of the Study Area. Vegetation for the 164,000 acre tract had been classified to a very detailed level (Garcia-Moya, 1972). This classification is not to be confused with the broader scale classification presented in Chapter 2 and which is applicable to the entire Study Area. The vegetation associations had been photo mapped for the Tombstone area. Ground records used for developing the vegetation classification were available.

A scale of photography was selected that was suitable for vegetation association interpretations. The panchromatic minus blue filtered photography was taken by conventional aircraft in September 1971, on 9" x 9" format and at a scale of 1:34,000. The available color infrared was from December,1972, as 9" x 9" transparencies, at 1:114,000. The panchromatic film was print copied at contact scale and the infrared was duplicated as prints at 1:32,000. Stereo models of known vegetation associations were prepared for both types of photography. Candidate stereogram locations were chosen based on several screening considerations: (1) Each was a reasonably typical example of one of Garcia-Moya's associations; (2) Each major photo image type corresponding to an association had to be represented in the samples; (3) The association example of interest in the image type had to be documented by ground samples and present in at least one-third of the area of the stereo pair; (4) Stereo pairs could not overlap other stereo pairs if they represented the same association. A total of 43 stereo pair samples were selected from 13 associations for both types of photography.

Testing was conducted with volunteer interpreters representing a wide range of experiences. One part of that test is of particular interest and is reported here. In it, interpreters were required to group the 43 samples according to the standards that represented the 13 associations.

Results and Discussion

Based on Student's t-test comparisons, interpreters more accurately grouped image samples by image standards for the panchromatic compared to the color infrared photography.

panchromatic, group 1 > color infrared, group 1 ($P<0.01$)
panchromatic, group 1 > color infrared, group 2 ($P<0.01$)
color infrared, group 1 = color infrared, group 2 ($P>0.05$)

Groups one and two represented different groups of interpreters. Interpreters from group one first interpreted the panchromatic stereo pairs and then most of them interpreted the color infrared pairs. There was some concern that a bias might be imposed in the color infrared interpretation because it was interpreted after the panchromatic. As a check, a second group of interpreters with similar backgrounds also interpreted the color infrared but without first having interpreted the panchromatic pairs. There was no significant difference between the two groups of color infrared interpretations; however, overall correct interpretation for group one was 52 percent as contrasted to 44 percent for group two (see Table 3-15) suggesting a learning influence.

The nature of the successful interpretations is shown in Table 3-15. Throughout the panchromatic and color infrared interpretations

Table 3-15. Comparative accuracy of aerial photography stereo pair sample placement based on vegetation association standards. Count values are test totals for interpreters.

Garcia-Moya Vegetation Class	Panchromatic Correct Sample Grouping Number	Panchromatic Correct Sample Grouping Percent	Color Infrared Interpretation Group One Correct Sample Grouping Number	Color Infrared Interpretation Group One Correct Sample Grouping Percent	Color Infrared Interpretation Group Two Correct Sample Grouping Number	Color Infrared Interpretation Group Two Correct Sample Grouping Percent
Alliance I	52	72	17	28	12	29
Association A	27	75	15	50	10	48
Association B	25	69	2	7	2	10
Alliance II	89	62	66	55	45	54
Association C	23	64	21	70	16	76
Association D	26	72	27	90	14	67
Association E	24	67	10	33	8	38
Association F	16	44	8	27	7	33
Alliance III	70	65	66	73	35	56
Association I	26	72	20	67	5	24
Association J	20	56	18	60	13	62
Association K	24	67	28	93	17	81
Individual Asso.						
Association G	44	92	30	75	14	50
Association H	6	13	14	35	11	39
Association L	12	25	3	8	4	14
Association M	37	77	26	65	11	39
No. Interpreters	12		10		7	
Total Count	310		222		132	
Total in Test	516		430		301	
Avg. % Correct		61		52		44

the accuracy with which the samples were matched to the vegetation standards is highly variable. Neither film type provided displays a consistent advantage for interpreting at either the association or alliance level. Given the specified test conditions, the vegetation association level of identification, the scale of the photography, and the generally sparse vegetation, interpreters were better able to detect similar patterns of vegetation arrangement with panchromatic photography than with the color infrared test prints.

For the panchromatic photography, the decisive features for the interpreters appeared to be the landforms on which the vegetation was located and the pattern of the vegetation which was strongly influenced by the amount of non-vegetated ground.

For the color infrared photography, landform again appeared to be the major influencing factor in the interpretation, particularly where vegetation was sparse. Pattern was again the major influencing factor where vegetation cover was dense. The influence of pattern was diminished somewhat due to inconsistency of color balance which may have introduced variability (color) that confounded real pattern variation and image contrasts. Soil differences were much more distinct in color than in panchromatic photography. This negatively influenced the interpretability of the two vegetation associations (B and L) which had among the least ground cover.

The tests in this study were designed to evaluate the interpretability for vegetation at the association level of vegetation classification. In many cases where vegetation test classes were not individually well separated from each other, the classes which were mixed were of the same physiognomic type. Therefore, the errors that were made most often were errors relating to level of classification. At a higher physiognomic level of classification the accuracy of the interpretation improved.

Beyond the specific results of the tests, the image g .upability concept appears to have demonstrated an objective approach to photo image comparison that is applicable with conventional scales of aerial photography.

SUMMARY

A procedure was developed and tested for objectively comparing photo images. The procedure consisted of two parts, image groupability testing and image complexity testing. The procedure was designed to eliminate the need for "interpreter" inferences of ground subject. The image groupability concept which was developed serves several desirable purposes:

(1) It minimizes differences in interpreter experience and area familiarity;

(2) It enables use of a large number of observers (interpreters) without major concern over differences in experience levels;

(3) It avoids the problem of area and boundary determinations;

(4) It enables statistical comparisons by analysis of variance, and is sometimes suited for commission-omission analysis;

(5) It provides a means of directly comparing one type of imagery to another in terms of apparent interpretable subject content;

(6) It is suitable for photo image testing when image groups are intended to represent ground subjects hierarchically developed;

(7) It can be designed to test the image grouping capabilities (and photo interpretation capabilities) of prospective interpreters;

(8) It does not depend on observer established subject-image relationships.

In comparing space photos of Apollo 6, ERTS-1, and Gemini IV, image complexity was greater for Apollo than for the other two. Image grouping for macrorelief class discrimination was variable among the three, with Gemini usually worse than Apollo or ERTS-1. Image complexity was used to demonstrate a method for objectively stratifying small scale photos. The Apollo and ERTS photos were stratified in this manner for a two stage sampling comparison. The use of image complexity was extended to a comparison of intermediate scale aerial photography, where image samples represented examples of a detailed vegetation classification.

CHAPTER 4

TERRAIN VARIABLE - VEGETATION RELATIONSHIPS

OBJECTIVE 2

The study of relationships among landforms and vegetation is of paramount importance in the understanding and classification of environmental systems. Such studies provide resource planners and managers with an ideal base for gathering information with which to conduct regional planning. Vegetation distribution frequently provides an excellent indicator of geologic variables which may serve as restrictions in land use as well as indications of agricultural potential. Landform variables provide restricted information on a host of other land use potentials. Together, physiographic variables including climate and soils information and vegetation present a precise environmental model. Equivalent environments can be determined and a subsequent land conversion potential scheme for a fairly large and diverse area can be adequately presented.

The principal theme of this objective is an assessment of the feasibility of utilizing small-scale aerial and satellite photography in the interpretation of vegetation. Easily recognized images on such photography are physiographic and pedologic variables. The interpretation of vegetation, therefore, can be accomplished only if convergent and associative evidence is directly employed in the interpretation process. In this, the interpreter usually makes his best estimate as to the type of vegetation he encounters. A thorough understanding of the relationships which exist between vegetation and physiographic variables would greatly facilitate the interpretive process. Objective 3 entails an attempt to arrive at the interpretability of some of those physiographic variables.

This study was undertaken to provide much-needed information on the relationships between terrain variables and vegetation. The objectives of this research allow for a greater understanding of those natural vegetation resources. They are:

(1) To supply background information for an ecologically based classification of natural resources in an arid and semiarid environment.

(2) To assess the correlation between individual plant species and various terrain variables including elevation, parent material, landform type, macrorelief, drainage density, slope angle, slope aspect, and solar radiation.

(3) To isolate those plant species which might be considered as reliable indicators of the above-mentioned terrain variables.

(4) To assess the relationships between the vegetation types determined from the classification and the terrain variables studied.

(5) To isolate specific vegetation types which might be considered as reliable indicators of the terrain variables.

Pertinent Literature Review

This literature review will cover only the aspects of terrain variable - vegetation relationships pertinent to this study. While it is recognized that other types of studies have been conducted in the general field of terrain variable - vegetation relationships, those studies seem largely, with one exception, irrelevant to this particular study.

An important study on terrain variables and vegetation was conducted by Kassas, *et al.*, in Egypt. That study has considerably influenced the thinking of this author. Kassas' major effort was on habitat and plant communities in the Egyptian desert (for example, Kassas, 1952 and 1961; Kassas and El-Abyad, 1962; Kassas and Girgis, 1964; and Kassas and Imam, 1959).

Kassas felt that each "community type" needs to be referred to a discrete habitat type as a prerequisite to its identity. The community type is a unit of an ecosystem--an "ecocoenosis" (see, for example, Kassas and Girgis, 1964). Kassas found that the vegetation of Egypt was affected by water availability which, in turn, is influenced by landforms. As a result, the vegetation follows rather discrete patterns of landforms and concomitant moisture availability. Kassas recognizes three basic geomorphic divisions in northeastern Egypt (his study area): drainageways (wadis), sand and gravel deserts, and hard-rock erosional surfaces (hamadas) generally comprised of limestone.

Each of those geomorphic divisions has an array of community types or ecogeomorphic systems dependent upon the degree of succession, frequently a function of soil development, and moisture availability.

In southeastern Arizona, terrain variable-vegetation studies can be considered in the context of the types of individual variables studied.

One of the most common terrain variable associates with vegetation has been elevation and exposure (slope aspect). Those two terrain characteristics are considered together as they have been studied in that manner by so many workers. The observation that vegetation changes with elevation has essentially resulted in the lifezone concept (Lowe, 1964). Shreve (1915) stated that the upper limits of species was considerably higher on north-facing slopes than on south-facing slopes. He showed that the influence of slope exposure was greater with increasing elevation. He felt that the effect of altitude on vegetation was through moisture factors, temperature factors, and light factors. Whittaker and Niering (1965, 1968a, and 1968b) arrived at similar conclusions. They showed that ravines depressed elevational ranges of species by a couple of thousand feet. Species tended to occur approximately one thousand feet lower on north-facing slopes than on south-facing slopes.

Cumming (1951), in a study on The Effect of Slope and Exposure on Range Vegetation in Desert Grassland and Oak Woodland Areas of Santa Cruz County, Arizona found that both perennial grass as well as shrub density was greater on north aspects than on south aspects. Annual grasses had low densities on all sites.

Several studies on relationships between vegetation and parent materials and/or landforms in southeastern Arizona have been conducted (for example, Bradbury, 1969; and Zimmermann, 1969).

Bradbury (1969), in a study on Vegetation as an Indicator of Rock Types in the Northern Swisshelm Mountains, Southeastern Arizona, concluded that eight species were not only reliable indicators of rock type but were also relatively common in his limited (approximately two square miles) study area. Those species were *Ceanothus greggii*, *Condalia spathulata*, *Cowania mexicana*, *Dalea formosa*, *Mortonia scabrella*, Parthenium incana, and Quercus pungens on limestone, and Quercus toumeyi on rhyolite.

Zimmermann (1969) undertook a study of Plant Ecology of an Arid Basin, Tres Alamos - Redington Area, Southeastern Arizona. Half of his 750 square mile study area lies within the north-central portion of the study area. Zimmermann found striking variations in the vegetation occurring at similar altitudes. He attributed those variations as being caused by differences in moisture regimens in different substrates. He noted that on undissected slopes, the soils supported small trees (mainly Prosopis juliflora and Acacia spp.) and a grass cover, while dissected slopes supported only stands of shrubs (mainly Larrea tridentata) without grasses. Zimmermann noted that drainage area, geology, and flow regimen are probably the three most important controls in the distribution of valley floor vegetation.

METHODS

Data Collection

Prior to the specific collection of data for the analysis of the relationships between terrain variables and vegetation, several reconnaissance transects of the study area were conducted. The purpose of these trips was to acquire general knowledge of possible vegetation types, to become familiar with the flora, and to consider the terrain variables.

In order for these relationships to be objectively studied, it was felt that data should be collected from samples drawn from a stratification of one or more of the variables to be examined. Those variables were chosen from the terrain features rather than from the vegetation. The reason for this sampling was because one of the ancillary purposes of this objective was to infer vegetation from the terrain variables.

It was decided that the most objective and readily mapped terrain variables were elevation and parent materials. Although elevation per se is objective and mappable, it also correlates well with precipitation and soil moisture, which in turn correlate well with vegetation.

Parent material information was obtained from geological maps available for the study area (Arizona Bureau of Mines; 1959, 1960, 1969). Five classes of parent materials were chosen and they were then mapped at a scale of 1:250,000.

The concept of macrorelief entails the general gross relief of a local area. Local relief, relative dissection, and slope angle comprise the concept. Generally speaking, regional slope combines with local relief in determining classes.

The descriptions for landforms were listed and classes developed to handle them. It is recognized that the landform classes were non-parametric and therefore it was not possible to use them in a meaningful way in analyses that considered data in a parametric fashion. Classes of landform type were selected on the basis of environmental significance, facility for remote sensing interpretation, and acceptance by other geomorphologists. The landform type classes describe either the morphologic character of a particular surface, a morphogenetic character of the surface, or a relative position of that surface with respect to other similar surfaces.

Drainage density is the ratio of total lengths of drainageways of a sampled site to the area of that sampled site. It is a measure of relative dissection of a landscape as well as a relative indicator of internal drainage characteristics. An area having a high drainage density tends to be better drained than an area with a low drainage density. Drainage density values in the study area ranged from 0 to 14.3 miles per square mile. Classes of drainage density values were established so as to assign interpretations of low, medium, and high values to the quantitative indicators of drainage density.

Slope angles measured in the field (with a Brunton compass) ranged in value from level to over 100 percent. As values of slope angle were not evenly distributed throughout the range, classes were devised in order to reflect basic geomorphic differences within the study area. The classes fell into an approximate geometric progression. Values of slope aspect were rounded to the nearest 1/8 compass point. Values were ordinated with respect to their relative moisture condition. The southwest class was considered to be the most xeric (Geiger, 1965; and Whittaker, 1965) and therefore was assigned a value of "1." The northeast class was considered to be the most mesic and therefore was assigned a value of "9." The level class was developed to include slopes of less than 3½ percent. It was considered intermediate in moisture condition and was placed in the middle.

Values of potential solar beam irradiation at the surface were assigned to each site (after Frank and Lee, 1966). These values are obtained from slope aspect and slope angle data. One of the chief influences of slope angle and slope aspect on vegetation is through its determination of solar radiation incident on the vegetation. An index of solar radiation indicates that combined effect. The solar radiation index, in this report expressed as a percent, is the ratio of the total annual potential insolation to the maximum potential insolation at the site. In the study area, the maximum value on steep south slopes is 60½, while the minimum value observed on steep north slopes was 24. The value on a level surface is 52.7 (Frank and Lee, 1966). Table 4-1 illustrates the classes of terrain variables in this research.

Field Data Collection Techniques

A sampling system was needed in order for field data collection to begin. Initially, the map showing elevation classes was superimposed with the map showing parent material types. The result was a combination of elevation and parent material units. A fine dot grid was placed over the resultant map for purposes of calculating the areas of elevation and parent material units. The area of each unit was then recorded and a percentage of total area attached to each unit. The total number of field samples chosen, 250, was arrived at on the basis of two primary considerations. The first was that there would be approximately 25 different vegetation types (that figure was determined from previous field reconnaissances, and advice from my colleagues). 250 field samples would allow for ten samples per type. The second consideration was that time and financial constraints limited field work to an interval in which some 200 to 300 field samples could physically be gathered. The 250 potential field samples were divided and assigned to elevation and parent material units on the basis of the area of each unit. The minimum number of potential field samples was three.

Potential field samples were selected on the basis of relative access by pick-up truck. They were plotted on 1:120,000 scale aerial

Table 4-1. Terrain Feature Classes.

Elevation Class and Range

Elevation Class	Range
1	2,600 feet to 2,999 feet
2	3,000 feet to 3,499 feet
3	3,500 feet to 3,999 feet
4	4,000 feet to 4,499 feet
5	4,500 feet to 4,999 feet
6	5,000 feet to 5,999 feet

Parent Materials and Classes

Class	Parent Material
1	Alluvium
2	Sedimentary (other than limestone)
3	Limestone
4	Intrusive igneous (and metamorphics)
5	Volcanics

Drainage Densities and Value

Drainage Density Class	Value
1 (low Dd)	<5.0 mi/mi^2
2 (medium Dd)	5.0 - 7.2 mi/mi^2
3 (high Dd)	>7.2 mi/mi^2

Slope Angle and Significance

Class	Slope Angle	Geomorphic Significance
1	0 - 1%	Level surfaces (playas, valley-fill)
2	1½ - 3%	Undissected bajada surfaces
3	3½ - 10%	Upper bajadas and pediment surfaces
4	11 - 25%	Gentle hills; some side slopes of dissected bajadas
5	26 - 50%	Hill slopes; typical side slopes of dissected bajadas
6	Over 50%	Steep hill slopes, talus, bare rock surfaces, cliffs, and some of the steeper side slopes of dissected bajadas

Table 4-1. Terrain Feature Classes, Continued.

Macrorelief Classes

Flat Lands - A generally flat landscape with prominent slopes <10%.

1 - Essentially smooth. Dissection is minimal. The regional slope is nearly always between 0 and 3%.

2 - Relatively flat. However, dissection has progressed to a noticeable point. Dissection is either widely spaced (in which case, side slopes may be over 10%) with sharp angles, or more closely spaced with a gently rolling topography. Where side slopes exceed 10%, local relief is generally less than ten feet.

Rolling and Moderately Dissected Lands - Prominent slopes 10 to 25% (side slopes may exceed that figure in the case of dissected planar surfaces).

3 - A moderately to strongly dissected planar surface (i.e., pediment, bajada, valley-fill, etc.). The regional slope is generally between 2 and 6%; side slopes must be steeper than 10%. If side slopes are steeper than 25% (which is relatively common in the study area), relief must be less than 100 feet. The drainage network is generally finer than that of class No. 2.

4 - Rolling or hilly. A regional slope is not readily apparent unless it is between 10 and 25%. Relief must be less than 100 feet.

Hilly Lands

5 - Hilly to submountainous. Slopes are moderate to steep, usually exceeding 25%. Relief is generally over 100 feet but less than 1,000 feet. Where relief approaches 1,000 feet, the topography appears fairly homogeneous.

Mountainous Lands

6 - Mountainous, having high relief, usually over 1,000 feet. Slopes are moderate to steep, frequently exceeding 50%. The landform system appears quite complex and heterogeneous. The drainage networks usually have base levels independent of one another.

Table 4-1. Terrain Feature Classes, Continued.

Landforms Developed Upon Non-Consolidated Materials

Class	Landform
01	swale
02	floodplain
03	narrow floodplain
04	alluvial terrace
05	valley-fill
06	dissected valley-fill
07	lacustrine plain
08	sand dunes
09	wash
10	undifferentiated bajada
11	upper bajada
12	lower bajada
13	undifferentiated dissected bajada
14	convex slope of dissected bajada
15	midslope of dissected bajada
16	interfluve (area between adjacent drainageways, not included in other classes)

Landforms Developed Upon Consolidated Materials

Class	Landform
21	upper convex hillslopes
22	upper-middle hillslopes
23	middle hillslopes
24	lower-middle hillslopes
25	lower concave hillslopes
26	interfluve
27	drainageway
28	pediment

Table 4-1. Terrain Feature Classes, Continued.

Slope Aspects

Aspect Class	Aspect
1	Southwest
2	South
3	West
4	Southeast
5	Level
6	Northwest
7	East
8	North
9	Northeast

Solar Radiation Index

Class	SR Index
1 (low SR)	< 51%
2 (medium SR)	51 - 54%
3 (high SR)	> 54%

photographs. Field sample points were transferred to topographic maps at a scale of 1:62,500. Final selection on the topographic maps took into account slope aspect.

Field data were collected on macrorelief, landform type, and soils. Slope aspect was measured with a Brunton compass and recorded to the nearest 1/8 compass point (i.e., north, northeast, east, etc.). Slope angle was also measured with a Brunton compass and recorded to the nearest 1 percent. Slopes gentler than 3½ percent were recorded to the nearest ½ percent. Elevation was estimated from topographic maps while in the field. Parent material was also determined in the field. Soil pits were dug at each site and soil samples were collected near the surface, at six inches depth, and at twelve inches depth. Surface soil color (primarily dry hue, value, and chroma) was recorded using a Munsell soil color chart.

Values of drainage density were determined and assigned to each field sample. The area chosen to compute the drainage density value was a circle with a one mile radius. Drainageways were photointerpreted at a scale of 1:120,000 with stereoscopic reinforcement. All interpretable drainageways were included in the compilation of the drainage density values. If the one mile radius circle included landform types different from the type at the field sample site, that portion of the circle would be deleted from the computation. Values of potential solar beam irradiation (after Frank and Lee, 1966) were assigned to each field sample site in the office.

Vegetation data included the recording of prominence and cover values for all species observed at the time of the field data collection.

The ground observations were taken from homogeneous units of vegetation in a plotless method. In terms of area, the "stand" sampled would be approximately 25 to 50 meters in diameter.

Included in the preparation of the data for analysis was the classification of the vegetation.

The Vegetation Classification

Two general analyses of vegetation and terrain variables were conducted in the report research. The first series of analyses involved the relationships between individual species and terrain variables. Numerical values for species in this series of analyses consisted of values for cover classes.

The second series of analyses involved the determination of relationships between vegetation types and terrain variables. This necessitated the prior development of a vegetation classification, as none was available and this research partially rests upon the use of that classification. That vegetation classification is located in another section of this final report.

Throughout the remainder of this objective the term "vegetation type" will be used to indicate the final set of vegetation units arrived at by the classification scheme.

Data Analysis

As was mentioned previously, two general analyses were conducted on vegetation and terrain variables. One of those involved the relationships between individual plant species and terrain variables. The other involved the relationships between vegetation types and terrain variables.

One of the methods used in both analyses involved the construction of graphs and tables showing the distribution of the values (which includes cover and presence) of the individual species with regard to the separate terrain variables. Other tables and graphs illustrated the manner in which vegetation types were arranged with respect to one another according to values of specified terrain variables. The interpretation and assessment of those charts and graphs constituted one method in the data analysis.

Another method of data analysis involved the use of stepwise discriminant analysis. Stepwise discriminant analysis was used because it could determine which terrain variables could best discriminate the vegetation types, the differences among vegetation types according to their terrain variables, the individual species which could best discriminate groups of individual terrain variables, and the differences among groups of individual terrain variables in terms of species observed as occurring with them.

Stepwise discriminant analysis is a program (BMD07M; Sampson, 1968) which performs a multiple-discriminant analysis in a stepwise manner. At each step in the program, a variable is entered into the set of discriminating variables (for example, terrain variables). The variable entered is selected if it has the largest F value. This is the same as the variable which gives the greatest decrease in the ratio of within to total generalized variances. A variable is deleted if its F value becomes too low. This never happened in the analyses conducted. The program also computes canonical correlations and coefficients for canonical correlations. This is important as the program includes the plotting of the first two canonical variables to give an optimal two-dimensional picture of the dispersion among observations (this is referred to as a "scatter diagram" in the Results and Discussion section). Each canonical variate is a function of all the original variables. In this study, the only use of the canonical variables produced by the program was the production of the above-mentioned two-dimensional picture of the dispersion of observations on the basis of the variables employed.

The program also produces a classification matrix of the groups. Observations are placed into a particular program-derived group on the basis of the values of the set of variables noted for the observation (field sample site). Illustrating with an example considering vegetation types as groups and terrain variables as "variables," the classification matrix considers floristically-defined vegetation types (groups) and terrain variable-defined vegetation types (groups) to define the matrix. A field site (or observation) identified as a certain floristically-defined vegetation type is then placed in a terrain variable-defined vegetation type. Often the selected terrain variable-defined vegetation type is different from the floristically-defined vegetation type to which the observation had originally been assigned. A schematic Venn diagram shown on Figure 4-1 can be used to aid the reader in understanding how sets of terrain variables are better correlated with one vegetation type than with another. Two hypothetical vegetation types, A and B, are used in the illustration. An accurate illustration depicting the interaction of all twenty-five vegetation types would require a graphic portrayal of twenty-five dimensions. The scatter

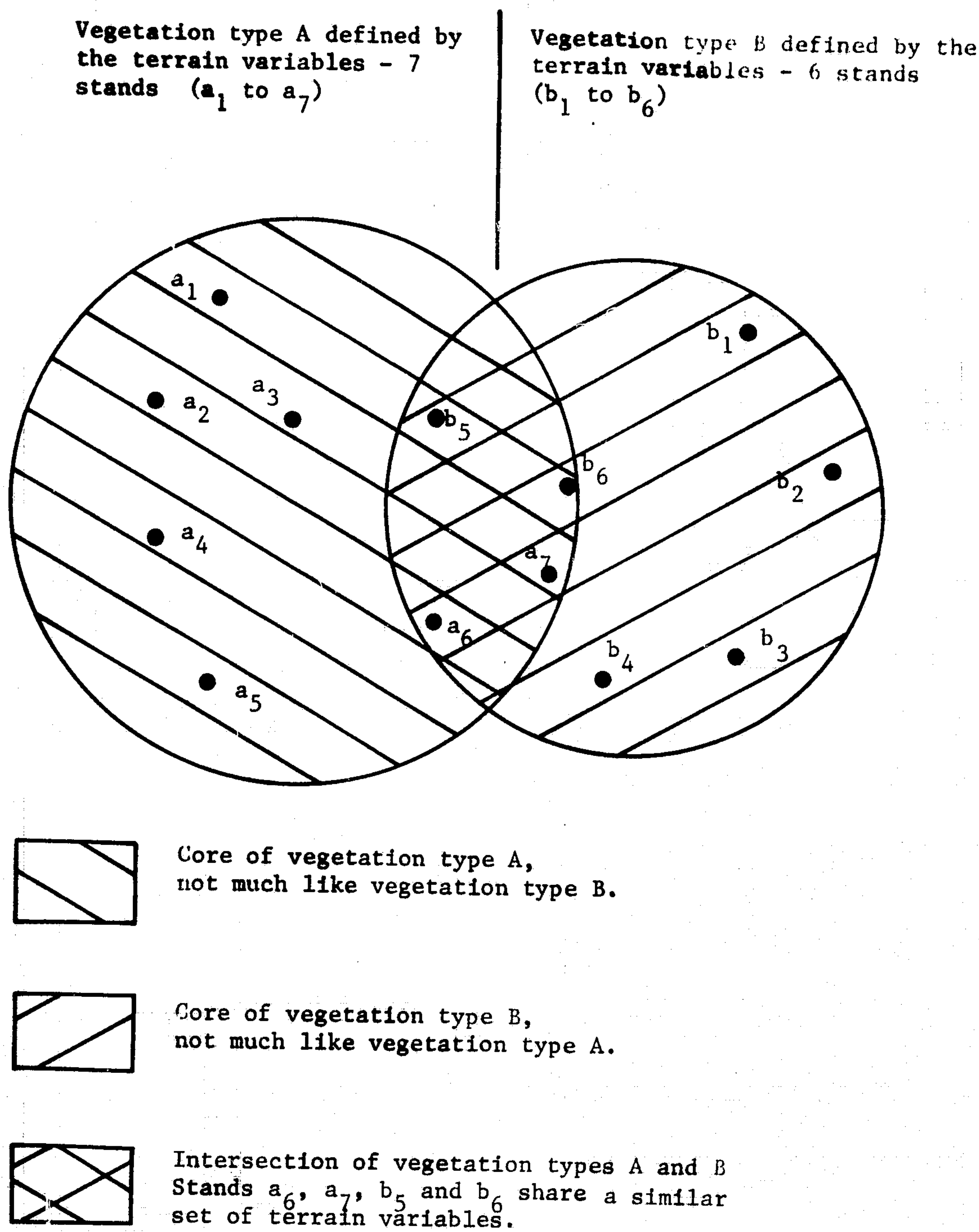


Figure 4-1. A schematic Venn diagram of two hypothetical vegetation types according to their sets of terrain variables.

diagram produced by the program is essentially a projection of that twenty-five dimensional diagram onto a two-dimensional surface (see Figure 4-21). In the Venn Diagram (Figure 4-1) are two vegetation types, A and B, which have been restructured into program-derived terrain variable-defined vegetation classes. The set of terrain variables, A, includes all possible combinations of terrain variables which could theoretically exist for the hypothetical vegetation type A. The set of terrain variables, B, includes all possible combinations of terrain variables which could theoretically exist for the hypothetical vegetation type B. The overlap between the two sets means that for that particular subset of terrain variables, two vegetation types can theoretically exist. In Figure 4-1, vegetation type A is considered to have seven stands, while type B has six stands. Stand A_1 has a set of terrain variables that is most like the typical set of A terrain variables. It is not very much like type B. Stand A_3 is on the very fringe of terrain variables that can have a vegetation type A. Its set of terrain variables is actually more like the "typical" B set.

Stepwise discriminant analyses discussed in this research which used individual plant species and individual terrain variables can be understood in a similar context, with respect to their classification matrices, as the above example.

RESULTS AND DISCUSSION

As was indicated previously, the research involved two fundamental types of relationships between vegetation and terrain variables: relationships between individual species and terrain variables, and relationships between vegetation types and terrain variables. Toward achieving an understanding of those relationships, solutions and partial solutions were obtained of ancillary objectives. Those objectives included supplying background information for an ecologically based classification of natural resources in an arid and semiarid environment and in assessing the accuracy of photo-interpretation in recognizing the vegetational pattern within my study area.

Another ancillary objective involved in studying relationships between individual species and terrain variables included isolating indicator species. These species would indicate not only specific parent materials, but also other terrain variables.

Relationships Between Individual Species and Terrain Variables

Results of analyses performed indicated two basic sets of information. One was the determination of the amplitude or range of physiographic conditions over which each species was found. The other involved the degree to which particular species discriminated groups or classes of terrain variables.

Of the 160 species in the sample sites, 106 had frequencies of five or more. Those 106 species were then used in the computer analyses described earlier. They were subsequently reduced to 41 on the basis of frequency and on preliminary results obtained for the 106 species. These 41 species will be discussed in this chapter (Table 4-2).

Elevation

Elevational amplitudes for the species revealed that some species occurred over a wide range of elevational values. Other species appeared to be narrowly restricted. Most, however, are limited or restricted to moderate ranges of elevation. Figure 4-2 illustrates the distribution of species by elevation.

The elevational ranges of the species may be considered to fall into approximately seven groups or categories. Table 4-3 illustrates the distribution tendencies of species among elevation groups.

Parent Materials

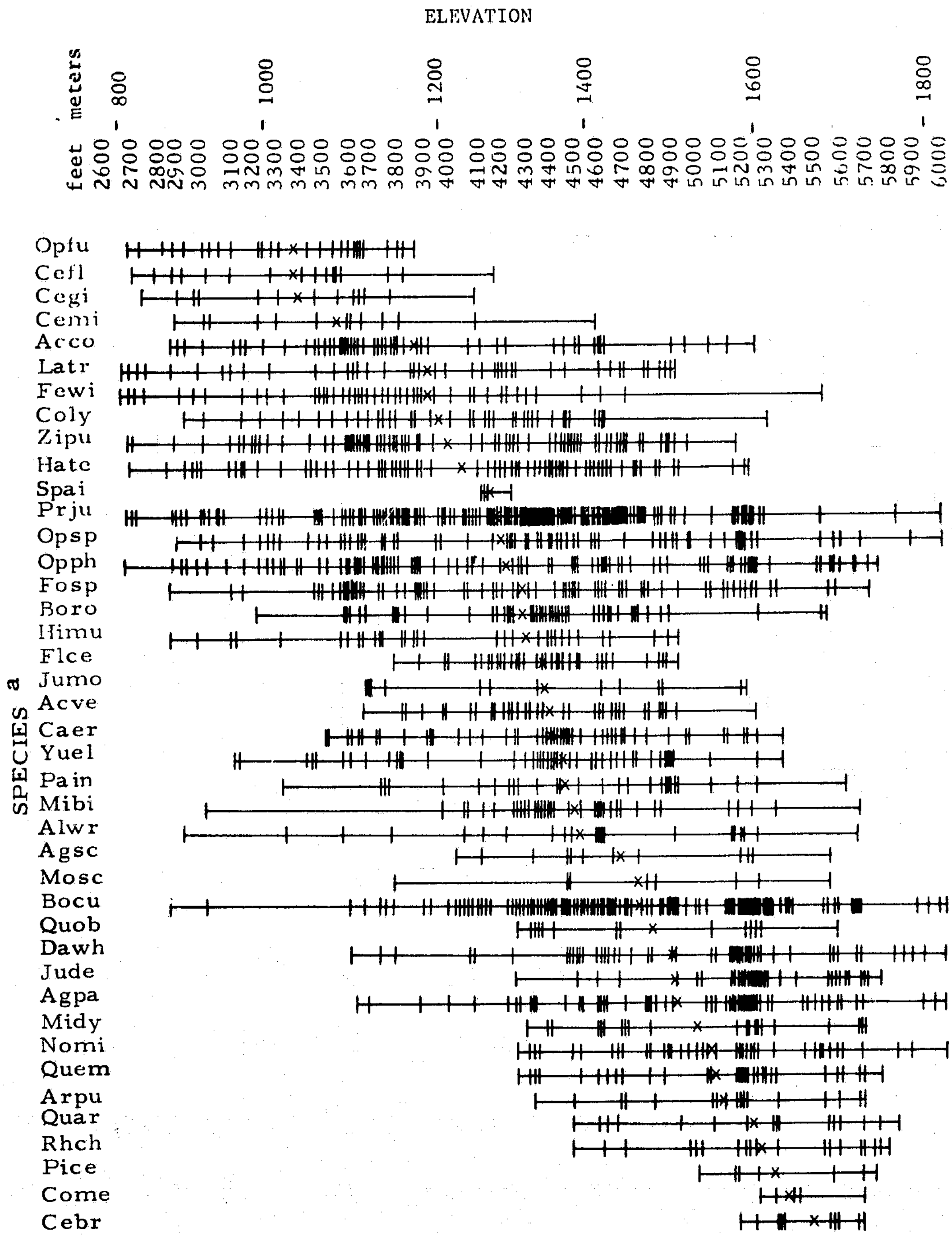
Species exhibited a wide range of occurrences on parent materials. Five basic sets of observations can be drawn from the observed frequencies of species on each of the parent materials. Some species are virtually restricted to alluvial parent materials, while others are virtually restricted to non-alluvial parent materials. Some species occur on all parent materials but are noticeably absent from one. Some species favor neither alluvial nor non-alluvial parent materials. Finally, some species occur on all parent materials but are limited by one. Figure 4-3 illustrates the range in disbribution of species according to the types of parent material they were associated with. Species in that figure are listed in the same sequence as they were listed in Figure 4-2, the illustration of elevational ranges for species.

Table 4-2. Plant species used in the data analyses (for complete list of plant species see Appendix C). Scientific names are from Kearney and Peebles (1964) and Benson (1969). Common names are from Benson (1969), Benson and Darrow (1954), and Kearney and Peebles (1964)

	Alpha title	Scientific name	Common name
Trees	Jude	*Juniperus deppeana*	Alligator juniper
	Jumo	*J. monosperma*	One-seed juniper
	Pice	*Pinus cembroides*	Mexican pinyon
	Quar	*Quercus arizonica*	Arizona oak
	Quem	*Q. emoryi*	Emory oak
	Quob	*Q. oblongifolia*	Mexican blue oak
Shrubs	Acco	*Acacia constricta*	Whitethorn
	Acve	*A. vernicosa*	Mescat acacia
	Alwr	*Aloysia wrightii*	Wright's lippia
	Arpu	*Arctostaphylos pungens*	Manzanita
	Caer	*Calliandra eriophylla*	Fairy duster
	Cefl	*Cercidium floridum*	Blue palo verde
	Cemi	*C. microphyllum*	Foothill palo verde
	Cebr	*Cercocarpus breviflorus*	Mountain mahogany
	Coly	*Condalia lycioides*	Gray-thorn
	Come	*Cowania mexicana*	Cliffrose, Quinine-bush
	Flce	*Flourensia cernua*	Tarbush
	Fosp	*Fouquieria splendens*	Ocotillo
	Hate	*Haplopappus tenuisectus*	Burroweed
	Latr	*Larrea tridentata*	Creosotebush
	Mibi	*Mimosa biuncifera*	Wait-a-minute bush
	Midy	*M. dysocarpa*	Velvet-pod mimosa
	Mosc	*Mortonia scabrella*	Sandpaper bush
	Pain	*Parthenium incanum*	Mariola
	Prju	*Prosopis juliflora*	Mesquite
	Rhch	*Rhus choriophylla*	Woodland sumac
	Zipu	*Zinnia pumila*	Desert zinnia
Leaf Succulents	Agpa	*Agave parryi*	Mescal
		A. palmeri	Mescal

Table 4-2, Continued.

	Alpha title	Scientific name	Common name
Leaf Succulents	Agsc	A. schottii	Amole
	Dawh	Dasylirion wheeleri	Sotol
	Nomi	Nolina microcarpa	Beargrass (Sacahuista)
	Yuel	Yucca elata	Soaptree yucca
Stem Succulents	Cegi	Cereus giganteus	Suguaro
	Fewi	Ferocactus wislizenii	Barrel cactus
	Opfu	Opuntia fulgida	Jumping Cholla
	Opph	O. phaeacantha	Prickly pear
	Opsp	O. spinosior	Cane cholla
Grasses	Bocu	Bouteloua curtipendula	Sideoats grama
	Boro	B. rothrockii	Rothrock grama
	Himu	Hilaria mutica	Tobosa
	Spai	Sporobolus airoides	Alkali sacaton



x = mean value

Each vertical bar = one observation

[a]Alphametric correspondence given in Table 4-2.

Figure 4-2. Distribution of species by elevation.

Table 4-3. Distribution tendencies of species among elevation groups.

Low Elevation

mean: 3,300 to 3,500'
range: primarily 2,700' to 3,800'
Species: Opfu, Cefl, Cemi, Cegi

Low & Middle Elevation

mean: 3,800' to 4,000'
range: primarily 2,700' to 4,900'
Species: Acco, Coly, Fewi, Hate, Latr, Zipu

Middle Elevation

mean: 4,100' to 4,500'
range: primarily 3,500' to 4,900'
Species: Acve, Caer, Flce, Jumo, Mibi, Pain, Yuel, Boro, Himu, Spai

Upper Middle Elevation

mean: 4,600' to 5,000'
range: primarily 4,300' to 5,300'
Species: Agsc, Arpu, Jude, Midy, Mosc, Quem, Quob

Middle & Upper Elevation

mean: 4,700' to 4,900'
range: primarily 4,000' to 5,950'
Species: Agpa, Dawh, Bocu

High Elevation

mean: 5,000' to 5,400'
range: primarily 4,500' to 5,750'
Species: Cebr, Come, Nomi, Pice, Quar, Rhch

Wide Range in Elevation

Species: Alwr, Fosp, Opph, Opsp, Prju

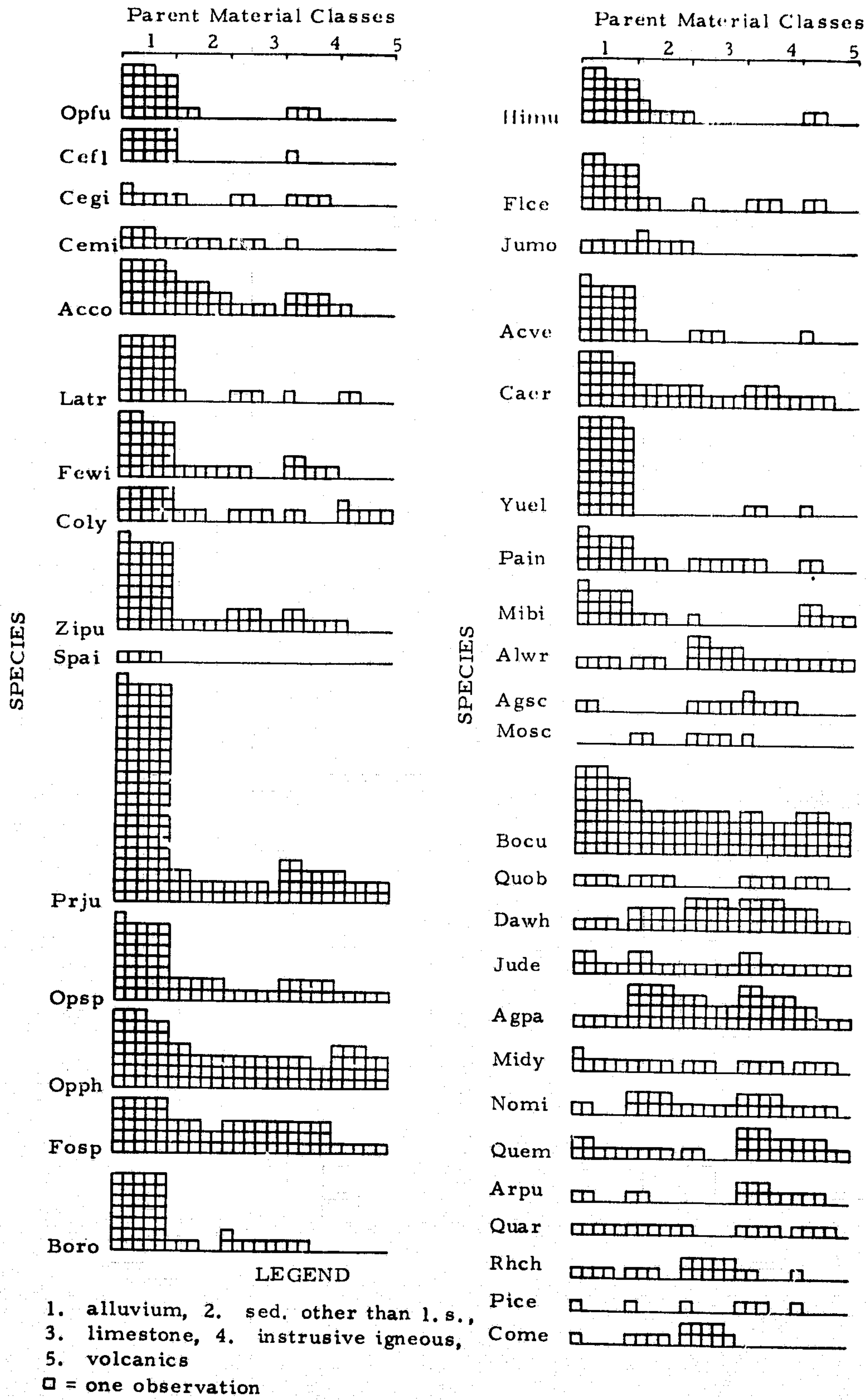


Figure 4-3. Distribution of species by parent materials.

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Parent material is not uniformly distributed with elevation. At the lowest elevations within the study area, below 3000 feet, alluvial parent materials comprise nearly all of the area. Above 5000 feet, however, alluvial parent materials comprise only a small percentage of the area. Thus, it is not a simple task to discern whether or not species are limited to alluvial or non-alluvial parent materials, for example, or to high or low elevations. Table 4-4 illustrates the distribution tendencies of species among parent materials.

Two sets of stepwise discriminant analyses were performed at this point: species and parent materials; and species and elevation-parent material units. Elevation-parent material units were chosen for two reasons. First was the difficulty of ordinating parent materials on a continuum or meaningful numeric gradient and the subsequent problem of not being able to average values for parent materials. Secondly was the importance of elevation to plant growth (through moisture and temperature) and the distribution of parent materials with elevation. To explain the function of the analyses, species and parent materials will be considered. In this analysis, the stepwise discriminant program considers species as variables and parent materials as groups. The species were considered together to discriminate the groups (analogous to classes) of parent materials. An identification of species observations (an observation that a particular species occurred on a parent material at a given field sample site) with those parent material groups (= classes) that the set of species is most closely aligned with is the result of the stepwise discriminant analysis. Stepwise discriminant analysis identifies with each group of parent materials an array of the species that best correlates as a set with the particular class of parent materials. The program analyzes the species of an observation (species in a field sample site) and then classifies that observation into the parent material group with which it best correlates. If the observation is placed into the parent material group which was identified as such in the field, then a correct match was made. An overall evaluation can be made of the ability of the parent material classes to be discriminated by the plant species. The uniqueness of each parent material can be judged in this manner. Stepwise discriminant

Table 4-4. Distribution tendencies of species among parent materials.

Species occurring primarily on alluvium:

Acve, Boro, Cefl, Flce, Hate, Himu, Latr, Opfu, Spai, Yuel

Species occurring primarily on non-alluvial parent materials:

Primarily limestone: Alwr, Cebr, Come, Mosc, Rhch

Primarily igneous: Arpu, Pice

Undifferentiated: Agpa, Dawh, Nomi, Opph

Primarily on limestone and igneous parent materials: Agsc

Species occurring on all parent materials but absent from one:

Absent from volcanics: Cegi, Cemi, Fosp

Absent from limestone: Arpu, Quob

Species not favoring either alluvial or non-alluvial parent materials:

No preference: Bocu, Caer, Coly, Jude, Midy, Opsp, Pain, Prju

Species limited by volcanics:

Acco, Fewi, Zipu

Species limited by limestone:

Mibi, Quar, Quem

Primarily on alluvium and sandstone: Jumo analysis also groups the variables, in this case the species, into the order in which they aid in the discriminating process: that is, the best discriminants of the parent materials.

Results of the two sets of stepwise discriminant analysis were similar. Cercocarpus breviflorus, Rhus choriophylla, Agave spp., Acacia constricta, Opuntia phaeacantha, Agave schottii, Aloysia wrightii, and Mortonia scabrella were among the best discriminants of groups of elevational-parent material units. Likewise, Agave spp. (not including A. schottii), Cercocarpus breviflorus, Aloysia wrightii, Mortonia scabrella, Agave schottii, Bouteloua curtipendula, Acacia constricta, and Quercus emoryi were the top discriminants of parent materials. Among the poorest discriminants of elevational-parent material units were Pinus cembroides, Dasylirion wheeleri, Bouteloua rothrockii, and Acacia vernicosa. A. vernicosa was the only species which was also a poor discriminant of parent material classes as well as of elevational-parent material units. Other species poor for discriminating parent materials were Prosopis juliflora, Quercus arizonica, Zinnia pumila, Opuntia spinosior, Mimosa biuncifera, Haplopappus tenuisectus, and Flourensia cernua. Figure 4-4 bears out these relationships, indicating that those species are, indeed, distributed over a wide range of parent materials. It is to be remembered that the stepwise discriminant analysis programs take into account not only the presence of the species, but also the cover values as well.

An interesting observation drawn from these results indicates that grass species were either very good discriminants of parent material classes and elevational-parent material units, or else they were very poor discriminants. Few were intermediate.

Species appeared to separate parent material classes more effectively than classes of elevational-parent material units. However, on further examination and consideration this is probably due, at least in part, to the fact that there were five classes of parent materials as opposed to twelve classes of elevational-parent material units. In parent material analyses, four runs were performed. The final run included those species which were the best discriminants among the first three. In the final run (using 41 species), 214 of the 250

Symbol	Parent Material
A	Alluvium
S	Sedimentary other than limestone
L	Limestone
I	Igneous
V	Volcanics
⊛	Group mean values (e.g., A)
○	Overlap of values

[a]A linear transformation of the original variate which maximizes the discrimination among the groups.

Figure 4-4. A scatter diagram of the first two canonical variates[a] where groups are from parent materials and variables are individual plant species.

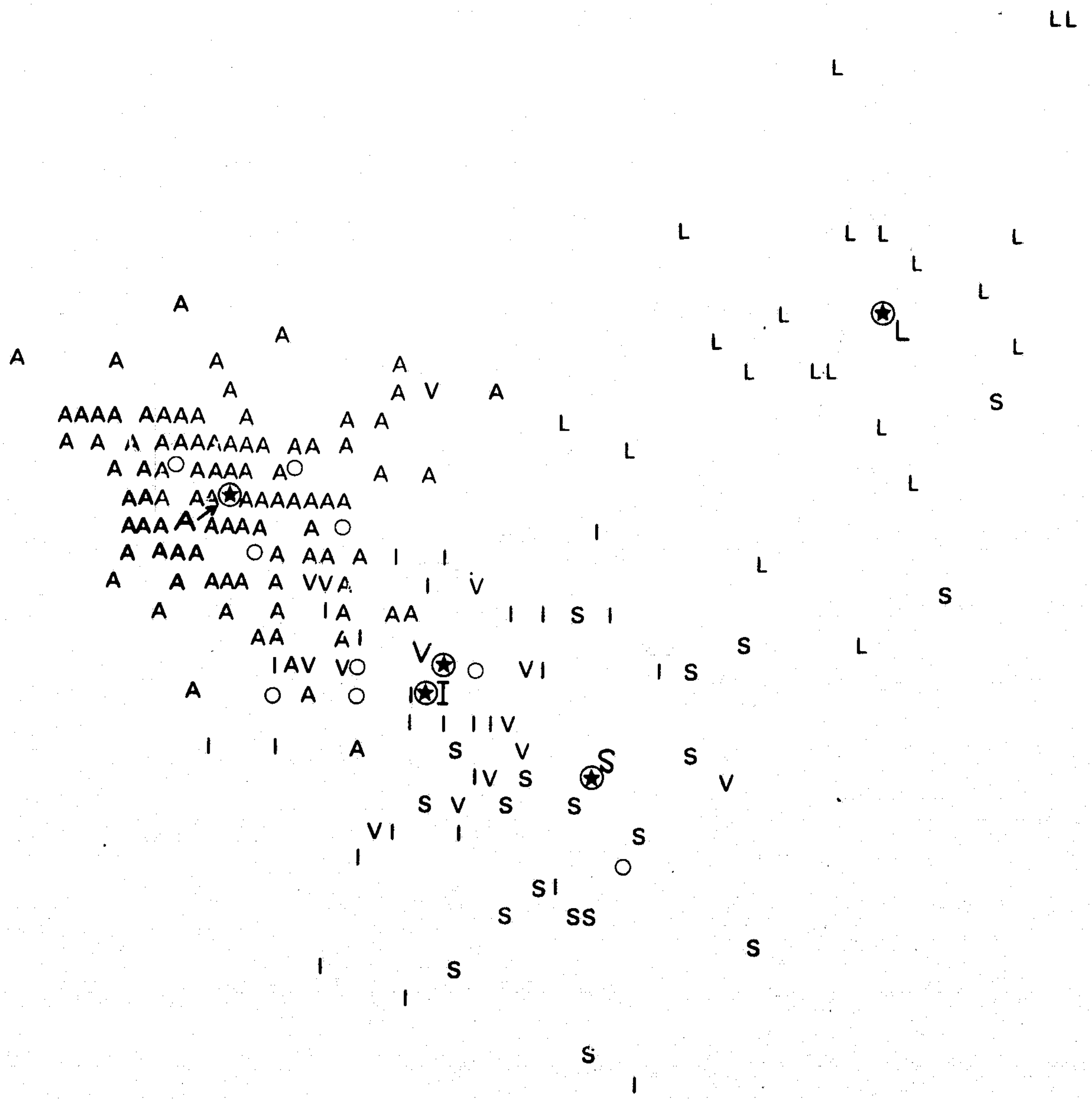


Figure 4-4. Continued.

observations (field sample sites) were placed in the correct parent material class on the basis of the species information. The alluvial group was especially well identified with 139 of 152 observations (or field sample sites) placed correctly. Among the non-alluvial parent materials, the igneous parent material class was the poorest discriminant with 23 of 32 observations placed correctly.

The twelve classes chosen for the classes of elevational-parent material units included four elevational classes of alluvial parent materials and two elevational classes for each of the non-alluvial parent materials. Results of the two stepwise discriminant analysis runs (41 species in each run) indicated a correct placement of 165 and 175, respectively, of the 250 observations (field sample sites) for each run. The four alluvial groups did not appear to be well classified; 65 percent were accurately placed, in comparison to the other parent materials (73 percent for limestone, 72 percent for sandstone, 67 percent for igneous, and 80 percent for volcanics). However, the figure is raised to 90 percent when results of all alluvial classes are combined regardless of elevation.

The above discussion suggests the relative indicator value of species with respect to parent materials as well as for the classes of elevational-parent material units. Figures 4-4 and 4-5 represent a graphic protrayal by the stepwise discriminant analysis of the separation of classes of parent materials and of elevational-parent material units by species. They summarize what was discussed above.

Macrorelief

Plant species had a fairly widespread distribution on different types of macrorelief. Figure 4-6 illustrates this distribution. Some species appeared to occur only on specific macrorelief types while others appeared to be uncontrolled or unaffected by it. Upon examination of Figure 4-6, categories of relationships become apparent. Table 4-5 illustrates the distribution tendencies of species among macrorelief classes. In it, five categories of distribution tendencies are given.

Symbol	Elevation-Parent Material Unit
A	Low elevation alluvium
B	Lower middle elevation alluvium
C	Upper middle elevation alluvium
D	Upper elevation alluvium
S	Lower elevation sedimentary other than limestone
Z	Upper elevation sedimentary other than limestone
L	Lower elevation limestone
M	Upper elevation limestone
I	Lower elevation igneous
G	Upper elevation igneous
V	Lower elevation volcanics
U	Upper elevation volcanics
⊛	Group mean values (e.g., A)
○	Overlap of values

Figure 4-5. A scatter diagram of the first two canonical variates where groups are from twelve elevation-parent material units and variables are individual plant species.

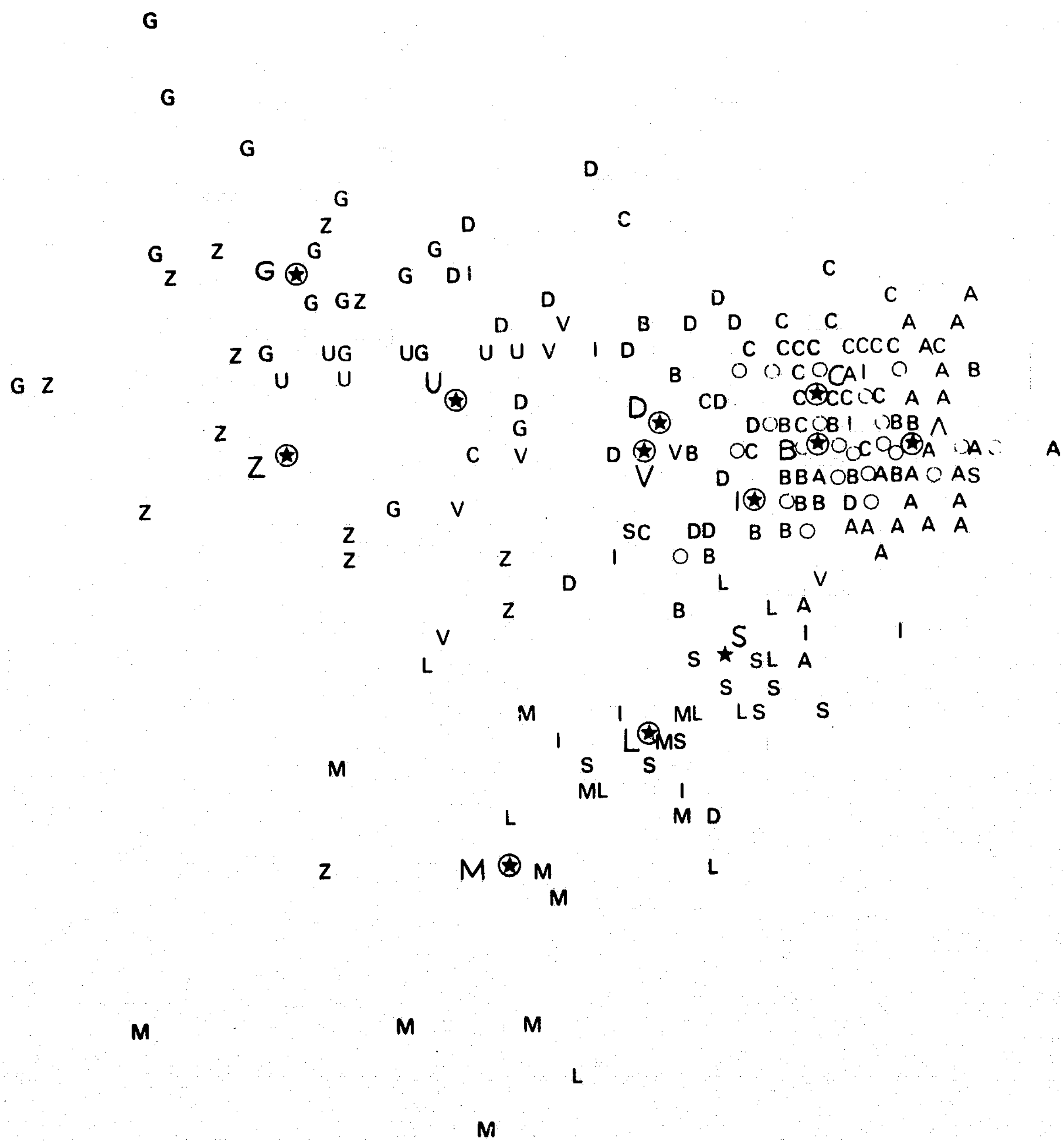
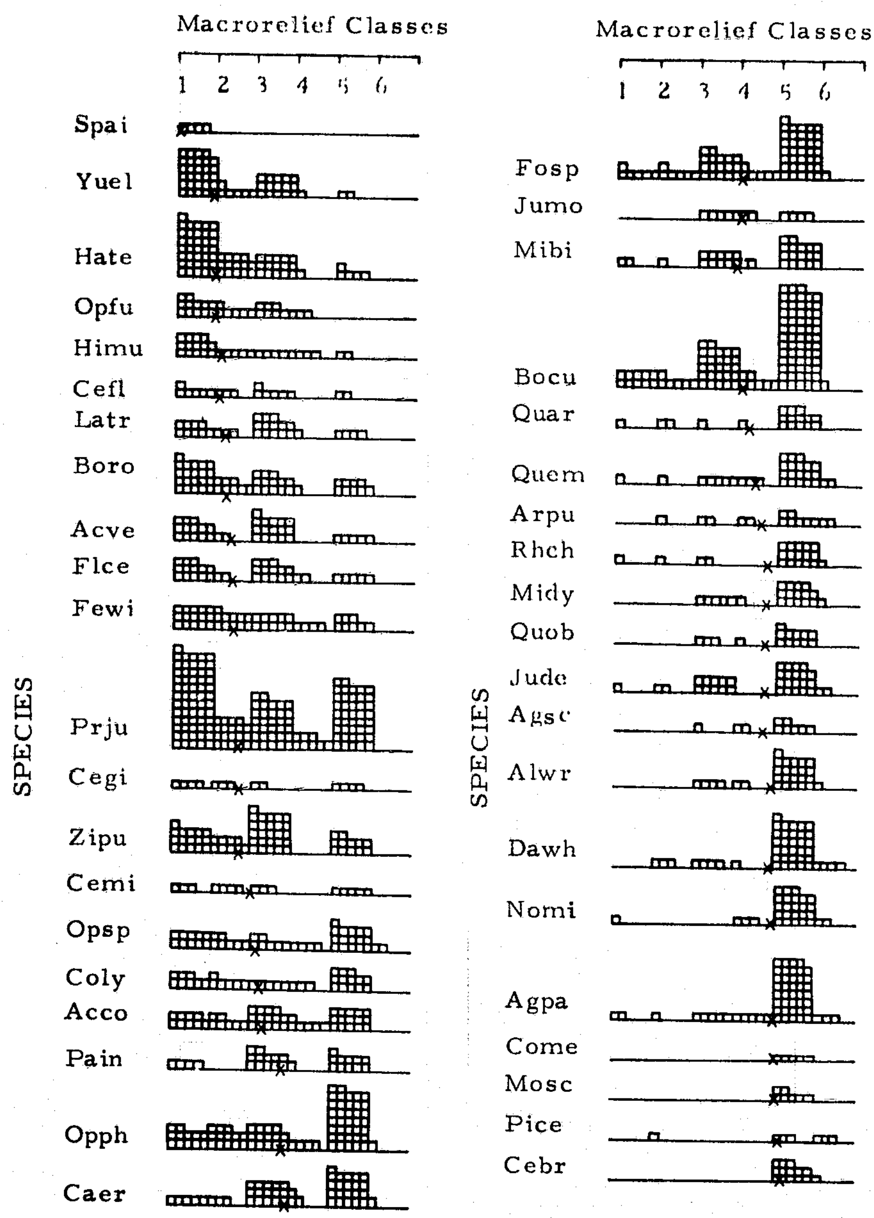


Figure 4-5. Continued.



LEGEND

Flat lands (regional slope < 10%)
- 1 - nondissected
- 2 - dissected (local relief < 10%)

Rolling slopes (10-25%) and moderately dissected lands
- 3 - dissected (local relief 3' to 30' regional slope apparent)
- 4 - rolling (regional slope not apparent)

Hilly and mountainous lands
- 5 - hilly lands (local relief > 350m slopes > 25%)
- 6 - mountainous lands (local relief > 305m slopes > 25%)

x = mean value

□ = one observation

Figure 4-6. Distribution of species by macrorelief classes.

Table 4-5. Distribution tendencies of species among macrorelief classes.

Macrorelief Class 1 (primarily flat)

Species: Himu, Spai

Macrorelief Classes 1, 2, & 3 (flat and dissected)

Species: Yuel, Hate, Opfu, Cefl, Latr, Boro, Acve, Flce, Fewi

Macrorelief Classes 3, 4, 5 & 6 (dissected and hilly)

Species: Cemi, Caer, Pain, Fosp, Mibi, Quar, Quem, Quob, Jude, Jumo, Midy

Macrorelief Classes 4, 5, & 6 (hilly and mountainous)

Species: Arpu, Rhch, Agsc, Agpa, Alwr, Dawh, Nomi, Come, Cebr, Mosc, Pice

Wide range of Macrorelief Classes

Species: Prju, Cegi, Zipu, Opsp, Coly, Acco, Opph, Bocu

Drainage Density

The distribution of plant species according to drainage density is graphed in Figure 4-7. While at first glance results appear to be vague, when groups of values are considered, results are more apparent. Table 4-6 illustrates the distribution tendencies of species among drainage densities.

Drainage density values ranged from zero to 14.3 mi/mi^2 with most values occurring between 4.0 and 8.0 mi/mi^2. Three classes of drainage density were developed. Those observations which were considered to have low drainage densities had values ranging from zero to 4.9 mi/mi^2. Medium drainage densities ranged from 5.0 to 7.2 mi/mi^2. The high drainage density category consisted of those values over 7.2 mi/mi^2. Drainage density tended to vary directly with elevation. Low elevation observations had low drainage densities on both alluvial and non-alluvial parent materials. High elevation observations had relatively high drainage densities. Of the non-alluvial parent materials, limestone had the lowest values. The highest drainage densities occurred on alluvial parent materials in high elevations.

Landform

The associations of landforms and species indicates a range from species occurring on one specific landform type to species occurring on a wide variety of landform types. In the preliminary data analysis, landform types occurring with each species (according to species) were noted. As the list of landform types associated with each species was quite long and certainly tedious to examine, the list was reduced to include only the principal landform types associated with each species. That list has been transformed into Table 4-7 which shows the distribution tendencies of species among landform types. Only those species which would most likely be associated with the landform types have been listed.

Slope Angle

It would be expected that relationships between slope angles and plant species would be somewhat similar to the relationships between macrorelief and plant species. Species that occur predominantly on

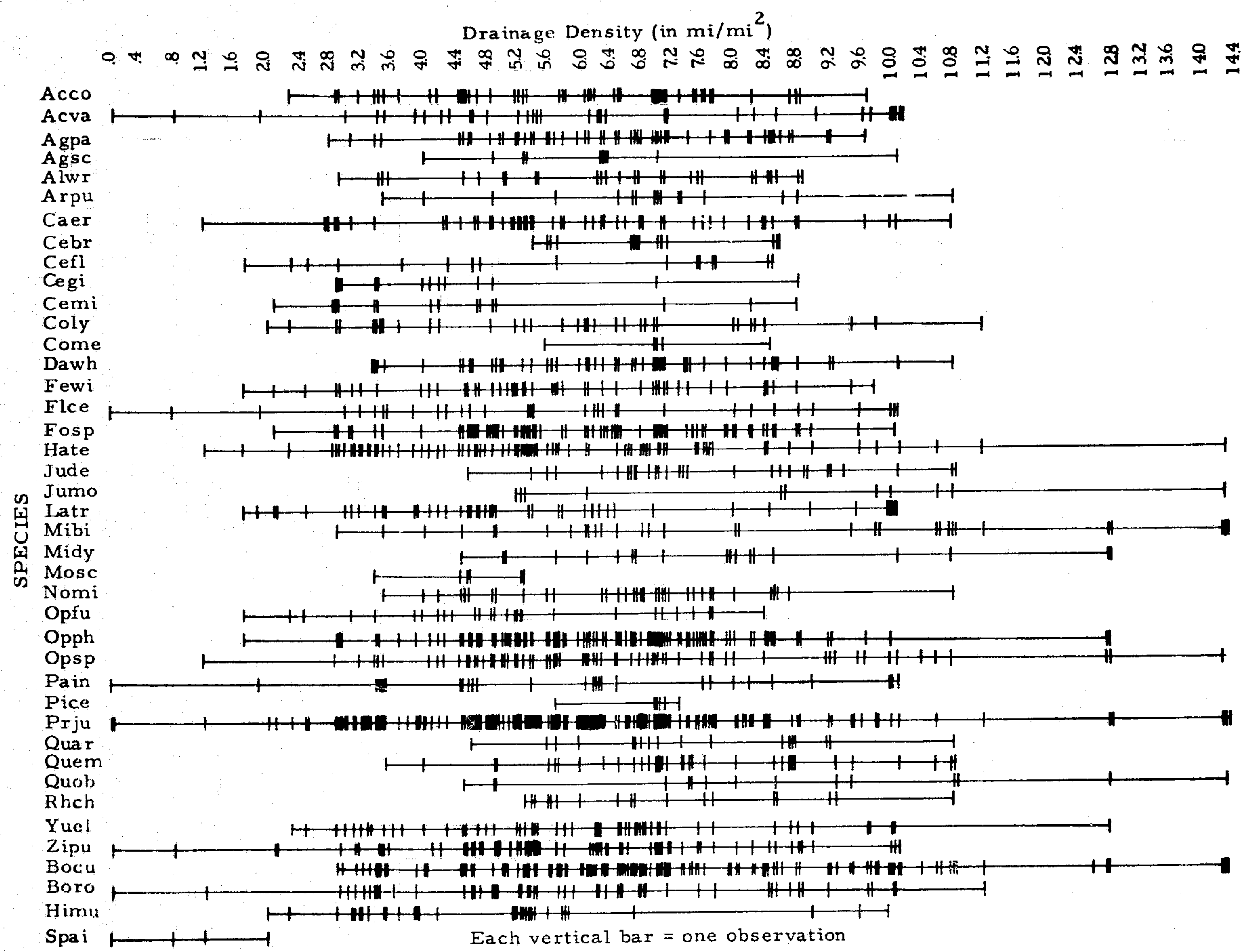


Figure 4-7. Distribution of species by drainage density.

Table 4-6. Distribution tendencies of species among drainage densities.

Low Drainage Density (Dd generally < 6.0 mi/mi^2)

Species: Flce, Latr, Opfu, Hate, Spai, Cegi, Cemi, Himu, Mosc

Wide Range of Drainage Density but with Concentration on Low Values (Dd generally < 7.0 mi/mi^2)

Species: Acco, Prju, Yuel

Wide Range of Drainage Density but with Concentration on Middle Values (Dd generally 4.5 to 8.0 mi/mi^2)

Species: Agpa, Agsc, Caer, Dawh, Fewi, Fosp, Opsp, Opph, Zipu

Wide Range of Drainage Density

Species: Acve, Cefl, Coly, Pain, Boro

Wide Range of Drainage Density but with Concentration on High Values (Dd generally > 5.0 mi/mi^2)

Species: Alwr, Arpu, Bocu

High Drainage Density (Dd generally > 6.0 mi/mi^2)

Species: Jude, Cebr, Come, Rhch, Pice, Quob, Quem, Quar, Jumo, Midy, Mibi, Nomi

Table 4-7. Distribution tendencies of species among landform types.

	Species
Alluvial Landforms	
Floodplains & terraces	Acco, Cefl, Coly, Hate, Himu, Opfu
Smooth alluvial surfaces (other than floodplains & terraces)	Acco, Acve, Cegi, Fewi, Flce, Hate, Himu, Latr, Nomi, Opfu, Opph
Alluvial interfluves	Acco, Acve, Bocu, Cemi, Fewi, Flce, Fosp, Hate, Himu, Jumo, Latr, Opfu, Opph, Pain
Side slopes of dissected bajadas	Acve, Bocu, Cemi, Jumo, Latr, Pain, Zipu
Alluvial in general	Boro, Cefl, Fosp, Mibi, Opsp, Prju
Non-Alluvial Landforms	
Upper convex slopes	Agsc, Come, Dawh, Opph
Middle or undifferentiated slopes	Acco, Acve, Agpa, Agsc, Alwr, Arpu, Bocu, Boro, Caer, Cebr, Cemi, Coly, Come, Dawh, Fosp, Jude, Mibi, Midy, Mosc, Nomi, Opph, Opsp, Pain, Prju, Quar, Quem, Quob, Zipu
Lower concave slopes	Fewi, Flce, Pice
Pediments	Cegi, Opfu

flat topography would also tend to occur on slopes of low angle, while species occurring on hilly and mountainous topography would also tend to occur on slopes of high angle. Figure 4-8 illustrates the distribution of species according to slope angle class. The array of species according to slope angle class was grouped into five classes or categories of relationships of species among slope angle classes. Table 4-8 represents the distribution tendencies of the species among slope angles.

Table 4-8. Distribution tendencies of species among slope angles.

<u>Low Slope Angles</u> (averaging < 5%)

Species: Cefl, Hate, Himu, Opfu, Spai, Yuel

<u>Wide Range of Slope Angles</u> (primarily lower slope angles averaging 8-25%)

Species: Acco, Acve, Boro, Cegi, Cemi, Fewi, Flce, Latr, Prju, Zipu

<u>Wide Range of Slope Angles</u> (primarily higher slope angles averaging 20-40%)

Species: Arpu, Bocu, Caer, Coly, Fosp, Jude, Mibi, Opph, Opsp, Pain, Quar

<u>Moderately High Slope Angles</u> (averaging 37-50%)

Species: Agsc, Come, Jumo, Pice, Rhch

<u>High Slope Angles</u> (averaging > 45%)

Species: Agpa, Alwr, Cebr, Dawh, Midy, Mosc, Nomi, Quob

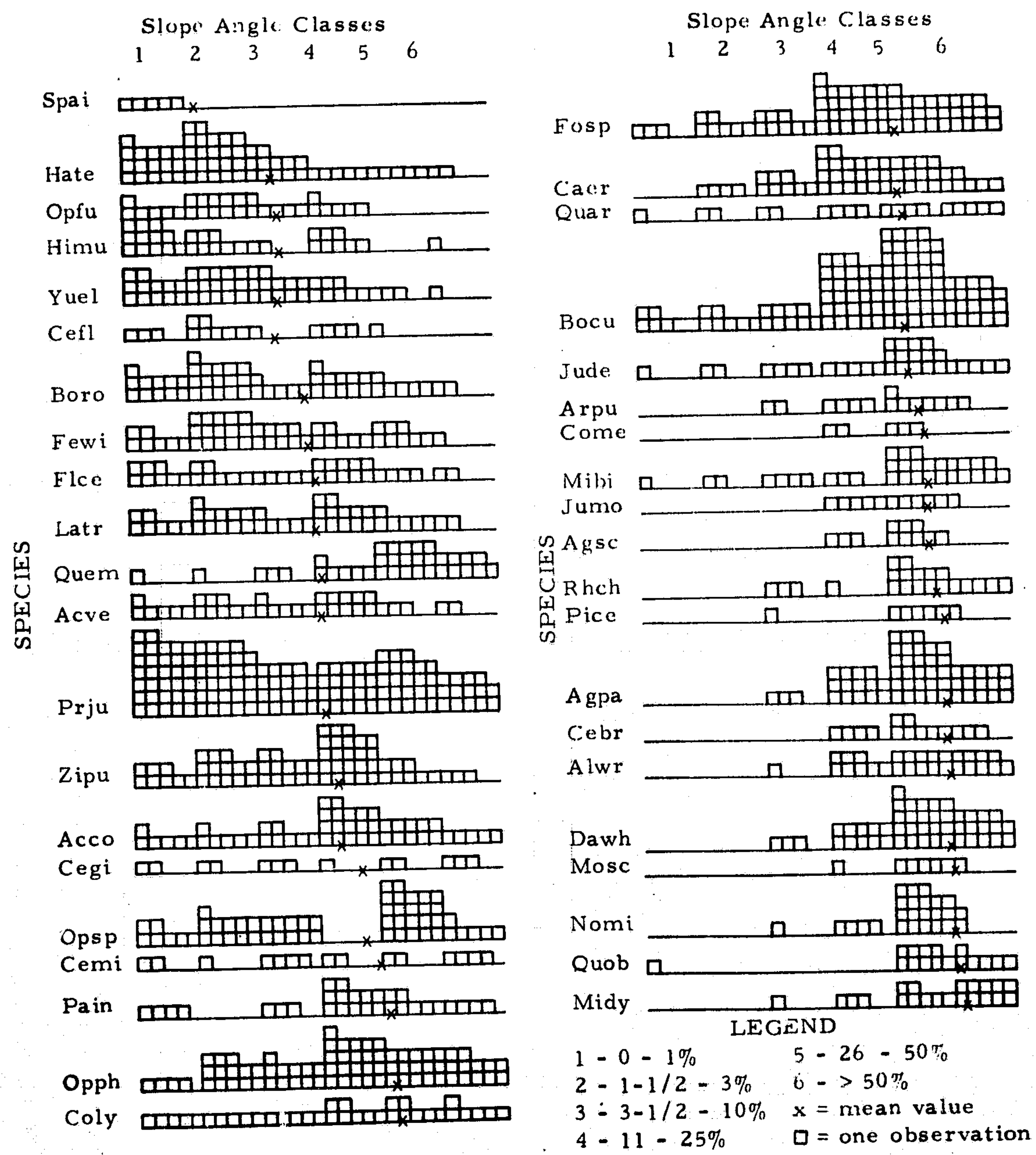


Figure 4-8. Distribution of species by slope angle classes.

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Slope Aspect

The association of slope aspect with species proved to be rather disappointing (see Figure 4-9). Although only higher slope angle observations were placed in an aspect class other than level, species still tended to occur over a wide range of slope aspects. Most species which occurred most often on high average aspect values (indicating a tendency toward northeasterly aspects) or low average aspect values (indicating a tendency toward southwesterly aspects) had a number of observations on the opposite aspect classes. In considering the distribution tendencies of species among the aspect classes, the species were grouped into only three categories of slope aspect: southerly aspects, northerly aspects, and little aspect preference or primarily level, see Table 4-9.

Table 4-9. Distribution tendencies of species among aspect classes.

Southerly Aspects	
Species:	Agsc, Caer, Cegi, Cemi, Come, Fewi, Midy, Pain
Little Aspect Preference or Primarily Level	
Species:	Acco, Acve, Agpa, Alwr, Arpu, Bocu, Boro, Cefl, Coly, Dawh, Flce, Fosp, Hate, Himu, Jumo, Latr, Mibi, Opfu, Opph, Opsp, Prju, Spai, Yuel, Zipu
Northerly Aspect	
Species:	Cebr, Jude, Jumo, Mosc, Nomi, Pice, Quar, Quem, Quob, Rhch

Solar Radiation

Since the solar radiation index (described at greater length in "Methods") is a function of slope aspect and slope angle, one would

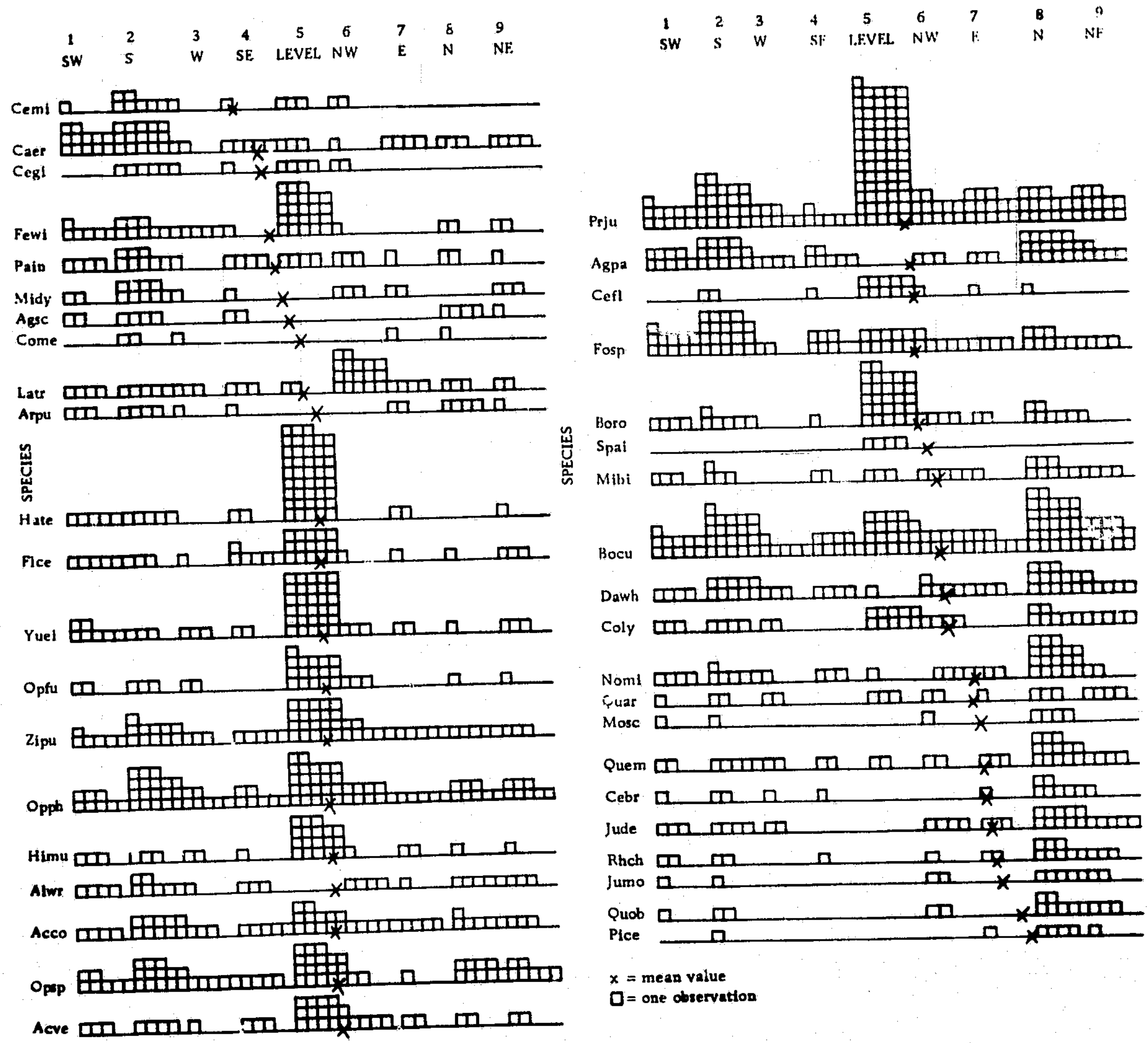


Figure 4-9. Distribution of species by aspect.

expect low values for observations occurring on steep northerly slopes and high values for observations (field sample sites) occurring on steep southerly slopes. The species occurring at each field sample site are attributed the value of the solar radiation index for that site. Relative indices of solar radiation were grouped into three categories: low, average, and high. The distribution of the species according to those classes is illustrated in Figure 4-10. The distribution tendencies of the species among the solar radiation classes are given in Table 4-10.

Table 4-10. Distribution tendencies of species among solar radiation index values.

Low Solar Radiation Index

Species: Cebr, Jude, Jumo, Mosc, Nomi, Pice, Quar, Quem, Quob, Rhch

Average Solar Radiation Index

Species: Acco, Acve, Agpa, Alwr, Arpu, Bocu, Boro, Cefl, Coly, Dawh, Fice, Hate, Himu, Latr, Mibi, Opfu, Opph, Opsp, Prju, Spai, Yuel, Zipu

High Solar Radiation Index

Species: Agsc, Caer, Cegi, Cemi, Come, Fewi, Fosp, Midy, Pain

---

The final stepwise discriminant analysis involving plant species was an analysis which included slope angle and slope aspect classes. Observations were separated as to parent material: alluvial versus non-alluvial parent materials. The categories were as follows:

Low slope angle (classes 1 and 2) on alluvium
High slope angles (classes 3, 4, 5, and 6), on alluvium, and on northerly aspects
High slope angles (classes 3, 4, 5, and 6) on alluvium, and on southerly aspects
High slope angles (classes 3, 4, 5, and 6), on non-alluvial parent materials, and on northerly aspects
High slope angles (classes 3, 4, 5, and 6), on non-alluvial parent materials, and on southerly aspects

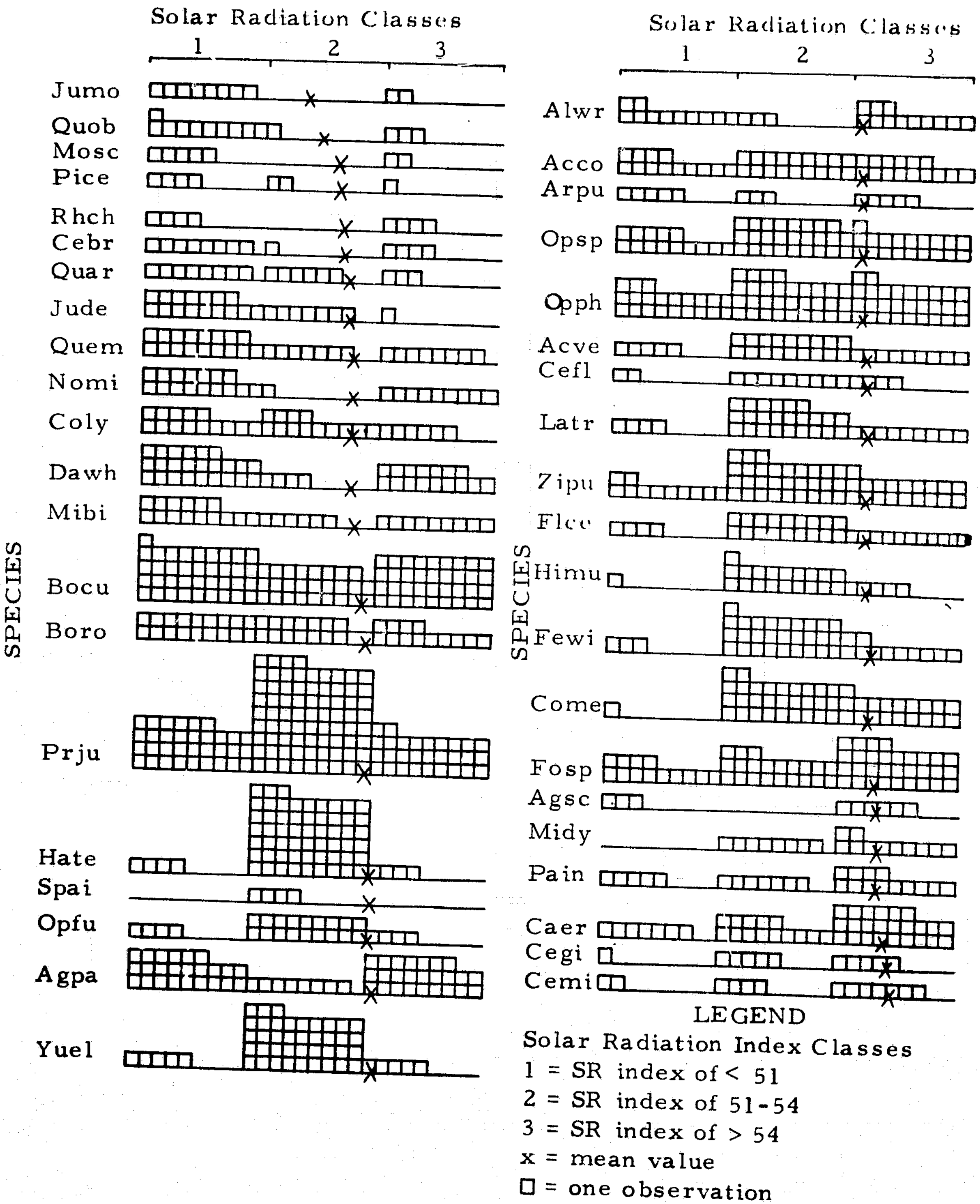


Figure 4-10. Distribution of species by solar radiation index classes.

A low angle, non-alluvial class was not included because of the limited observations in this class.

Stepwise discriminant analysis resulted in an excellent separation of alluvial and non-alluvial parent materials, as Figure 4-11 illustrates (observations classed into groups L, S, and N from X and M). It also produced a good separation of the three categories of alluvial parent material observations (that is, groups L, S, and N). Considerable mixing of observations within the two classes of non-alluvial parent materials is illustrated in the scatter diagram.

The species which were determined to be the best discriminants of the categories of parent material, slope aspect, and slope angle included Agave spp. not including A. schottii, Bouteloua curtipendula, Fouquieria splendens, Prosopis juliflora, Nolina microcarpa, Opuntia phaeacantha, and Juniperus monosperma. The poorest discriminants included Opuntia fulgida, Juniperus deppeana, Ferocactus wislizenii, Dasylirion wheeleri, Hilaria mutica, and Yucca elata.

Relationships Between Vegetation Types and Terrain Variables

The relationships of vegetation types with terrain variables will be considered in a similar fashion to the relationships of the individual plant species with the terrain variables. The ecological amplitudes of the vegetation types for the terrain variables are included in this section. In addition, the ability of terrain variables to discriminate vegetation types will also be discussed.

The range of vegetation types across the individual terrain variables is narrower in most instances than are the ranges of individual plant species. A probable explanation for this observation is that the community or vegetation type, being a socially compatible group of species, presents an integration of the ecological amplitudes of all its component species. Many of those species are members of other vegetation types. Thus, each vegetation type reflects a narrower ecological amplitude by truncating that part of the species amplitude that represents its occurrence in other vegetation types.

In the following discussion, each vegetation type is identified by a number, a description, and an abbreviated name (see Table 4-11). The numbers are used in tables and figures and the abbreviated names in the text.

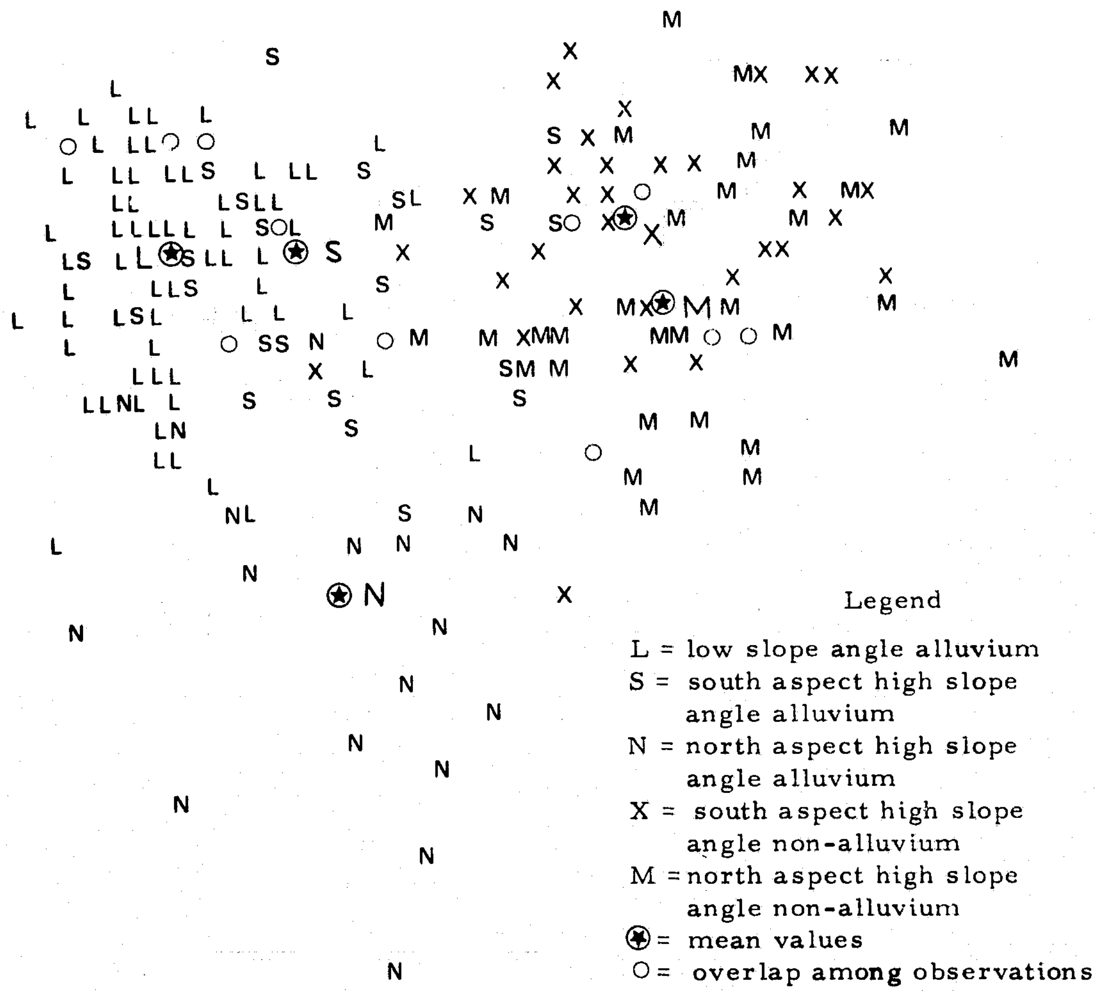


Figure 4-11. A scatter diagram of the first two canonical variates where groups are from parent materials, aspect, and slope angle, and variables are individual plant species.

Table 4-11. Vegetation types used in the analysis of relationships between vegetation types and terrain variables.

Identifier Number	Descriptive Name and Short Title	Abbreviated Alpha Title
2	Larrea tridentata with Prosopis juliflora and/or Opuntia (cholla). = Larrea tridentata with Prosopis juliflora	Latr-Prju
4	Cercidium microphyllum and Cereus giganteus often with Encelia farinosa and Opuntia, (without Franseria deltoidea). = Cercidium microphyllum	Cegi-Enfa
6	Acacia vernicosa, Flourensia cernua, and Larrea tridentata (without Rhus microphylla and Dalea formosa). = Acacia vernicosa (without Rhus microphylla)	Acve-Latr
7	Acacia vernicosa, Flourensia cernua, Larrea tridentata, and Rhus microphylla. = Acacia vernicosa with Rhus microphylla	Acve-Latr-Rhmi
8	Aloysia wrightii usually with Fouquieria splendens, Acacia constricta, and Opuntia (prickly pear). = Aloysia wrightii	Alwr-Fosp-Acco
9	Mortonia scabrella (without Rhus choriophylla). = Mortonia scabrella	Mosc
11	Prosopis juliflora and Haplopappus tenuisectus with Opuntia (cholla), (without Acacia constricta and Calliandra eriophylla). = Prosopis juliflora with Opuntia spp. (cholla)	Prju-Hate-Cholla
12	Prosopis juliflora and Haplopappus tenuisectus, (without Acacia constricta, Opuntia (cholla), and Calliandra eriophylla). = Prosopis juliflora (without Opuntia spp. - cholla)	Prju-Hate
13	Acacia constricta and Prosopis juliflora usually with Opuntia, (without Calliandra eriophylla). = Acacia constricta (without Calliandra eriophylla)	Acco-Prju
14	Calliandra eriophylla usually with Acacia constricta, Fouquieria splendens, and Prosopis juliflora, (without Coldenia canescens). = Acacia constricta with Calliandra eriophylla	Caer-Acco-Prju
15	Calliandra eriophylla and Bouteloua usually with any or all of Fouquieria splendens, Acacia greggii, Mimosa biuncifera, M. dysocarpa, and Ferocactus wislizenii, (without Acacia constricta). = Bouteloua spp./Fouquieria splendens	Caer-Prju-Mimosa
16	Calliandra eriophylla and Bouteloua with any or all of Ephedra trifurca, Yucca baccata, Y. elata, and Prosopis juliflora, (without Acacia constricta). = Bouteloua spp./Yucca elata	Caer-Eptr-Yucca

Table 4-11. Continued

Identifier Number		Abbreviated Alpha Title
17	Bouteloua and Aristida (without large shrubs, Nolina microcarpa, Yucca, and Calliandra eriophylla). = Bouteloua spp. (without Nolina microcarpa)	Bout-Arist
18	Prosopis juliflora and Bouteloua, (without Nolina microcarpa, Quercus, and Juniperus). = Prosopis juliflora/Bouteloua spp.	Prju-Bout
19	Bouteloua, Aristida, and Nolina microcarpa, (without Calliandra eriophylla). = Bouteloua spp./Nolina microcarpa	Bout-Arist-Nomi
21	Hilaria mutica and Prosopis juliflora. = Hilaria mutica	Himu-Prju
22	Sporobolus wrightii often with Prosopis juliflora. = Sporobolus wrightii	Spwr-Prju
23	Prosopis juliflora and Bouteloua with Quercus (usually Q. oblongifolia) and/or Juniperus deppeana. = Prosopis juliflora/Bouteloua spp. with Quercus spp.	Prju-Quercus-Jude
24	Cowania mexicana usually with Juniperus. = Cowania mexicana	Come
25	Quercus and Nolina microcarpa (without Cercocarpus breviflorus, Arctostaphylos pungens, and Mimosa biuncifera. = Quercus spp./Nolina microcarpa	Quercus-Nomi
26	Quercus and Mimosa (without Arctostaphylos pungens and Cercocarpus breviflorus). = Quercus spp./Mimosa biuncifera	Quercus-Mimosa
27	Quercus and Arctostaphylos pungens usually with Mimosa biuncifera, (without Pinus cembroides). = Quercus spp./Arctostaphylos pungens with Mimosa biuncifera	Quercus-Arpu-Mibi
28	Quercus, Arctostaphylos pungens, Pinus cembroides, and Juniperus deppeana, (without Mimosa biuncifera). = Quercus spp./Arctostaphylos pungens (without Mimosa biuncifera)	Quercus-Arpu-Pice
29	Cercocarpus breviflorus with Juniperus deppeana and/or Pinus cembroides and usually with Quercus. = Cercocarpus breviflorus	Cebr
30	Populus fremontii, Fraxinus velutina, Platanus wrightii, and/or Chilopsis linearis. = riparian	Pofr, Plwr, Chli

Elevation

The distribution of vegetation types on an elevational gradient is shown in Figure 4-12. Mean elevational figures in addition to the elevational location of individual sites are included in the figure and show that some vegetation types have broad ranges while others are narrowly defined. In Table 4-12, the elevational distribution of the vegetation types have been grouped into four elevation classes.

Parent Materials

Unlike the relationships between the individual species and terrain variables, vegetation types appeared to have quite definitive associations with parent materials. Most vegetation types had a strong association with just one or two parent materials. Figure 4-13 illustrates the relation of vegetation types with respect to parent materials. Table 4-13 illustrates the distribution tendencies of vegetation types among parent materials.

Twelve vegetation types occurred primarily on alluvial parent materials. Two vegetation types occurred primarily on sandstone parent materials, and three vegetation types occurred primarily on limestone parent materials. Limestone was observed to be the most restrictive parent material of vegetation types in the study area. Two vegetation types occurred primarily on igneous parent materials. No vegetation types were observed as occurring primarily on volcanic parent materials.

The six remaining vegetation types, those which did not occur primarily on a single parent material, had a rather diverse range of tolerances and intolerances of various parent materials.

Macrorelief

Although an examination of macrorelief data indicates fairly wide ranges of distributions of vegetation types with respect to macrorelief (see Figure 4-14), it does indicate better relationships than those that exist between the individual species and macrorelief. The best relationships were for the vegetation types occurring on flat topography (macrorelief class 1) and for vegetation types occurring on hilly and mountainous topography (macrorelief classes 4, 5, and 6). Table 4-14 illustrates the distribution tendencies of vegetation types among macrorelief classes and vegetation types.

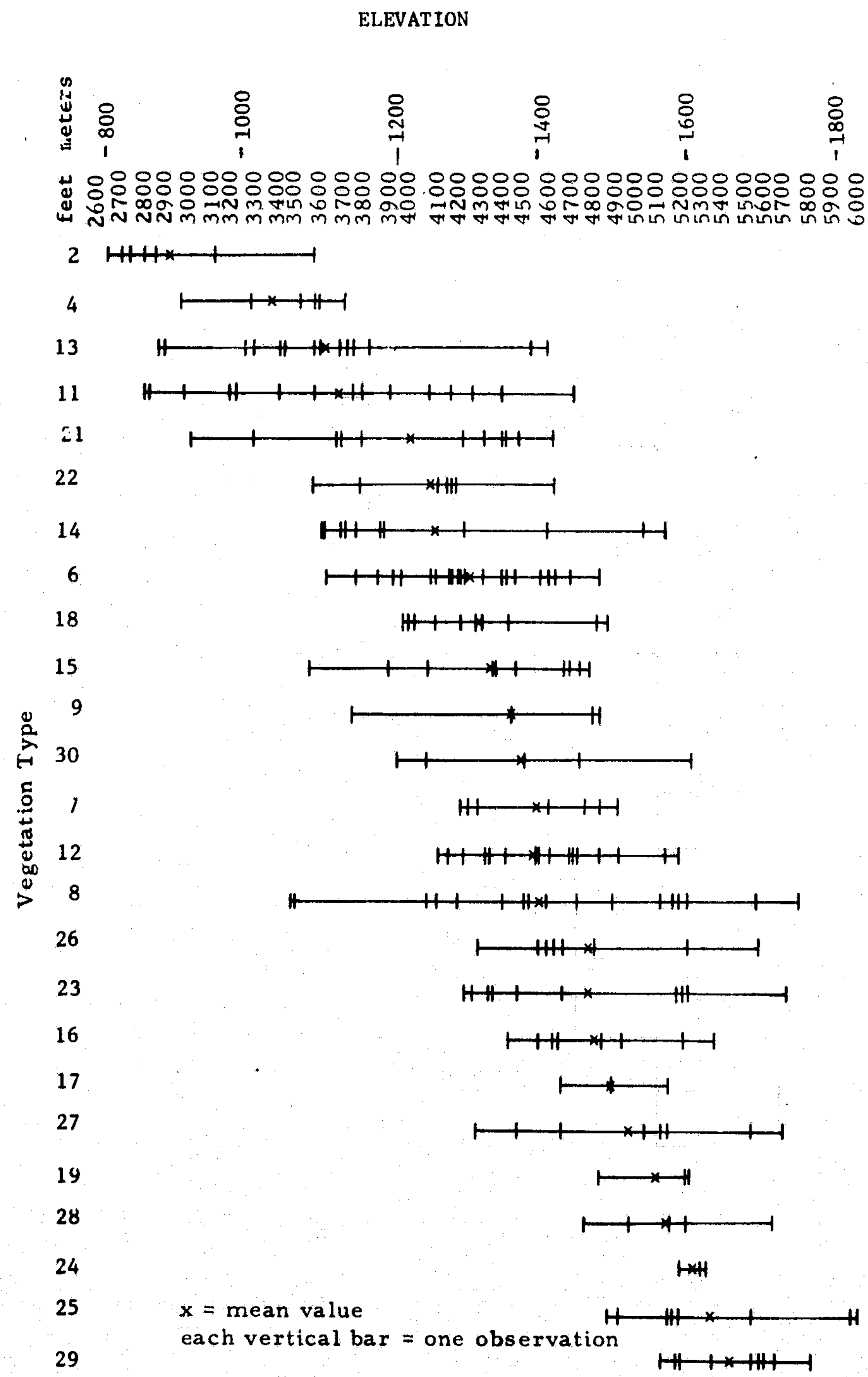


Figure 4-12. Distribution of vegetation types by elevation.

Table 4-12. Distribution tendencies of vegetation types among elevation groups.

<u>Low Elevation</u>

mean: 2,900' to 3,400'
range: primarily 2,700' to 3,600'
vegetation types: 2, 4 (very low)

mean: 3,600' to 4,000'
range: primarily 3,000' to 4,500'
vegetation types: 13, 11, 21

<u>Lower Middle Elevation</u>

mean: 4,100' to 4,500'
range: primarily 3,700' to 5,200'
vegetation types: 22, 14, 6, 18, 15, 9, 30, 7, 12, 8

<u>Upper Middle Elevation</u>

mean: 4,750' to 4,900'
range: primarily 4,200' to 5,500'
vegetation types: 26, 23, 16, 17, 27

<u>High Elevation</u>

mean: 5,050' to 5,350'
range: primarily 4,750' to 5,750'
vegetation types: 19, 28, 24, 25, 29, 30, 23

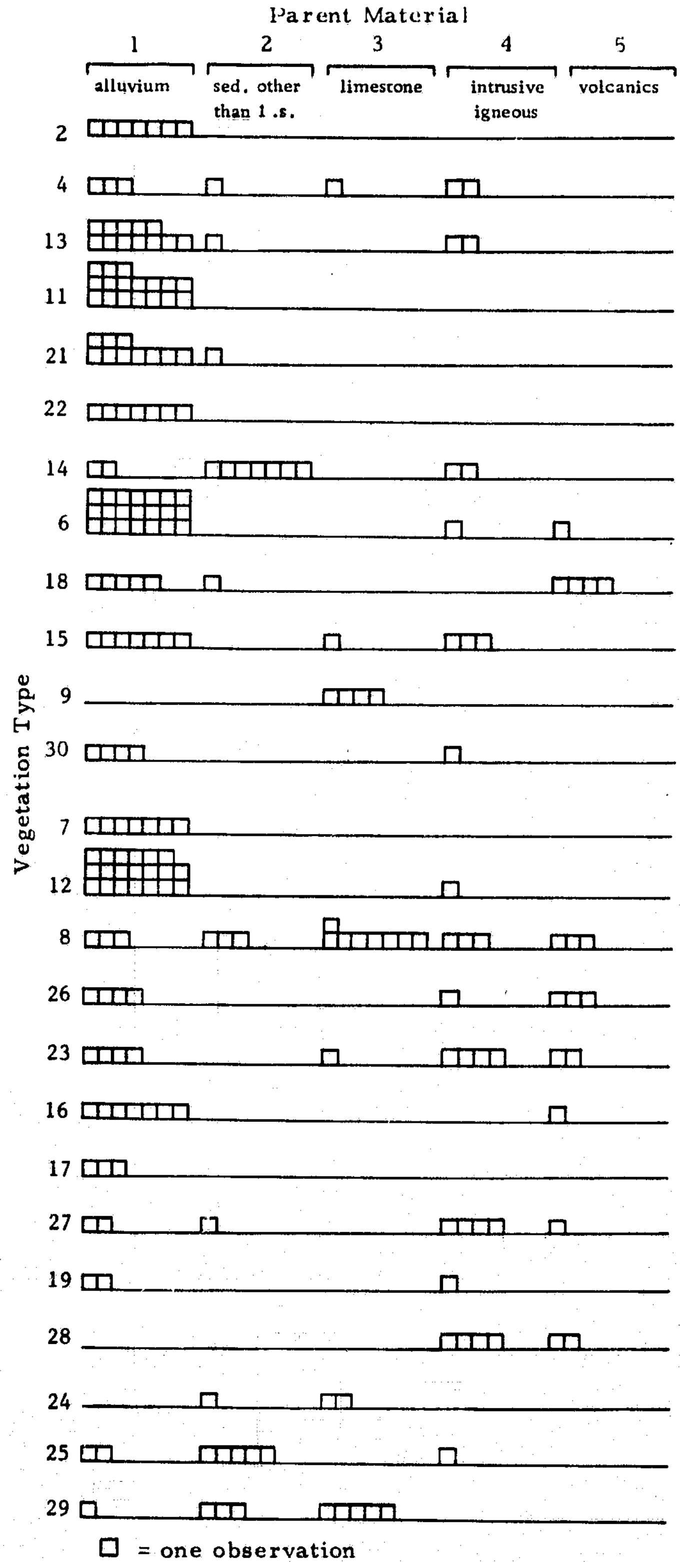


Figure 4-13. Distribution of vegetation types by parent materials.

Table 4-13. Distribution tendencies of vegetation types among parent materials.

Vegetation Types	Parent Material: Alluvium	Sandstone	Limestone	Igneous	Volcanics
Occurring two or more times on:	2,4,6,7,8,11,12,13,14,15,16,17,18,19,21,22,23,25,26,27,30 (21 types)	8,13,25,29 (4 types)	8,9,24,29 (4 types)	4,8,13,14,15,23,27,28 (8 types)	8,18,23,26,28 (5 types)
Occurring primarily on:	2,6,7,11,12,13,16,17,19,21,22,30 (12 types)	14,25 (2 types)	9,24,29 (3 types)	27,28 (2 types)	none
Absent or nearly absent on:	8,9,14,24,25,28,29 (7 types)	2,6,7,9,11,12,15,16,17,19,22,23,26,28,30 (15 types)	2,6,7,11,12,13,14,16,17,18,19,21,22,25,26,27,28,30 (18 types)	2,7,9,11,16,17,18,21,22,24,29 (11 types)	2,4,7,9,11,12,13,14,15,17,19,21,22,24,25,29,30 (17 types)

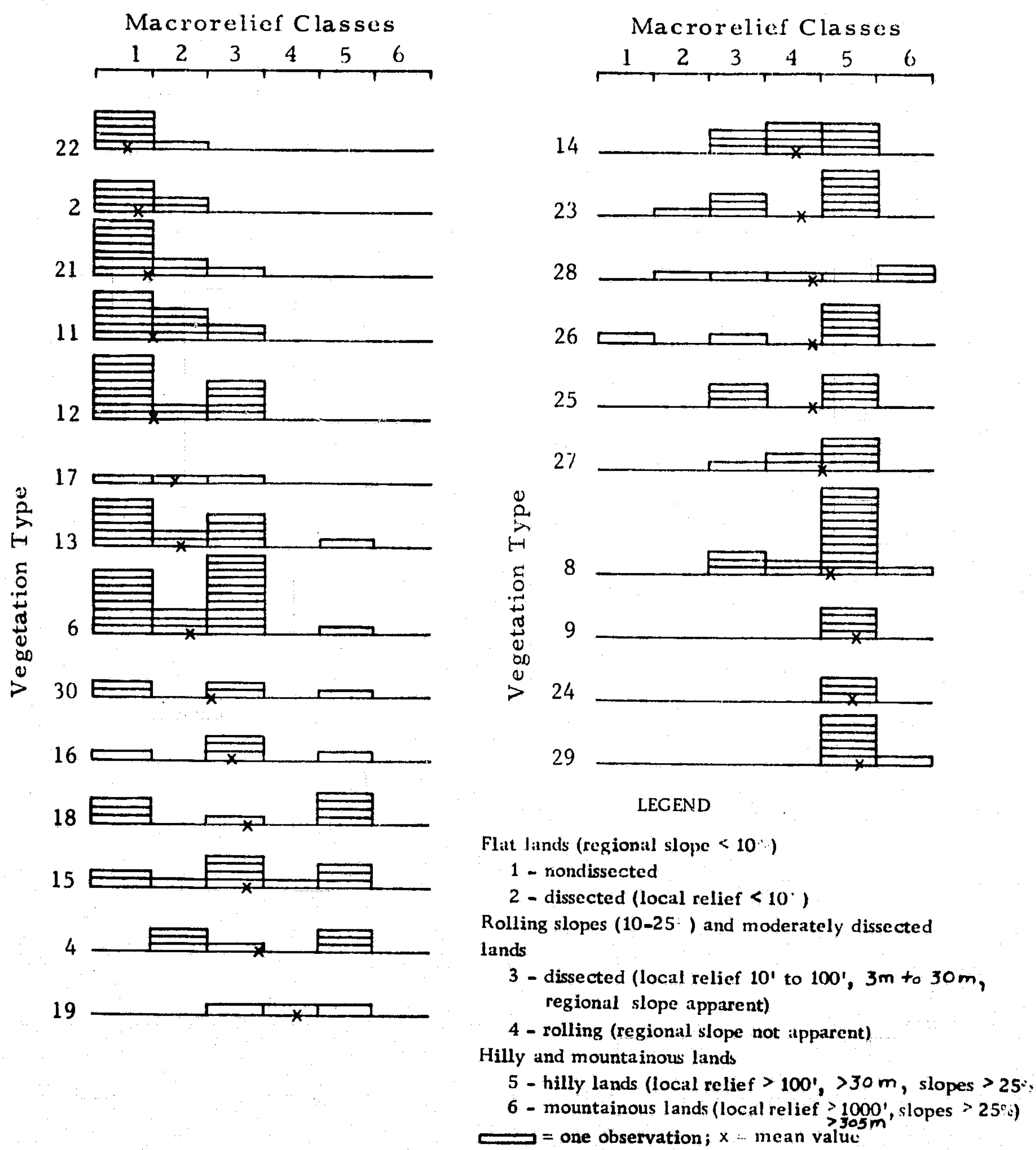


Figure 4-14. Distribution of vegetation types by macrorelief classes.

Table 4-14. Distribution tendencies of vegetation types among macrorelief classes.

Macrorelief Class 1 (primarily flat)

Vegetation Types: 22, 2, 21, 11, 12

Macrorelief Classes 1, 2, & 3 (flat and dissected)

Vegetation Types: 13, 17, 6, 30, 16

Macrorelief Classes 1, 4, & 5 (flat and hilly)

Vegetation Type: 18

Wide Range of Macrorelief Classes

Vegetation Type: 15

Macrorelief Classes 2, 3, & 5 (dissected and hilly)

Vegetation Types: 4, 23, 25

Macrorelief Classes 4, 5, & 6 (primarily hilly or mountainous)

Vegetation Types: 14, 8, 19, 28, 27, 26

Macrorelief Classes 4, 5, & 6 (exclusively hilly or mountainous)

Vegetation Types: 9, 24, 29

Drainage Density

Observations of vegetation types according to drainage density values indicate wide ranges for most vegetation types (see Figure 4-15). When the vegetation types are reordinated into low, medium, and high drainage densities (less than 5.0, 5.0 to 7.2, and over 7.2 mi/mi^2, respectively), results appear to be more understandable (see Figure 4-16). Vegetation type distributions according to drainage density fall into seven basic groups of observations (see Table 4-15).

Table 4-15. Distribution tendencies of vegetation types among drainage densities.[1]

Low Drainage Density (Dd generally < 5.0 mi/mi^2)

Vegetation Types: 2, 4, 9, 22

Low & Middle Drainage Density (Dd generally 2.5-7.0 mi/mi^2)

Vegetation Types: 21, 11

Wide Range of Drainage Density

Vegetation Types: 12, 6, 7, 27, 30

Very Wide Range of Drainage Density

Vegetation Types: 23, 15

Middle Drainage Density (Dd generally 4.5-8.0 mi/mi^2)

Vegetation Types: 14, 13, 29

Middle & High Drainage Density (Dd generally 5.0-10.0 mi/mi^2)

Vegetation Types: 8, 18, 16, 28, 24, 26

High Drainage Density (Dd generally > 7.0 mi/mi2)

Vegetation Types: 19, 25, 17

[1] Drainage density is the ratio of the length of streams in a given area to the area (miles/square miles).

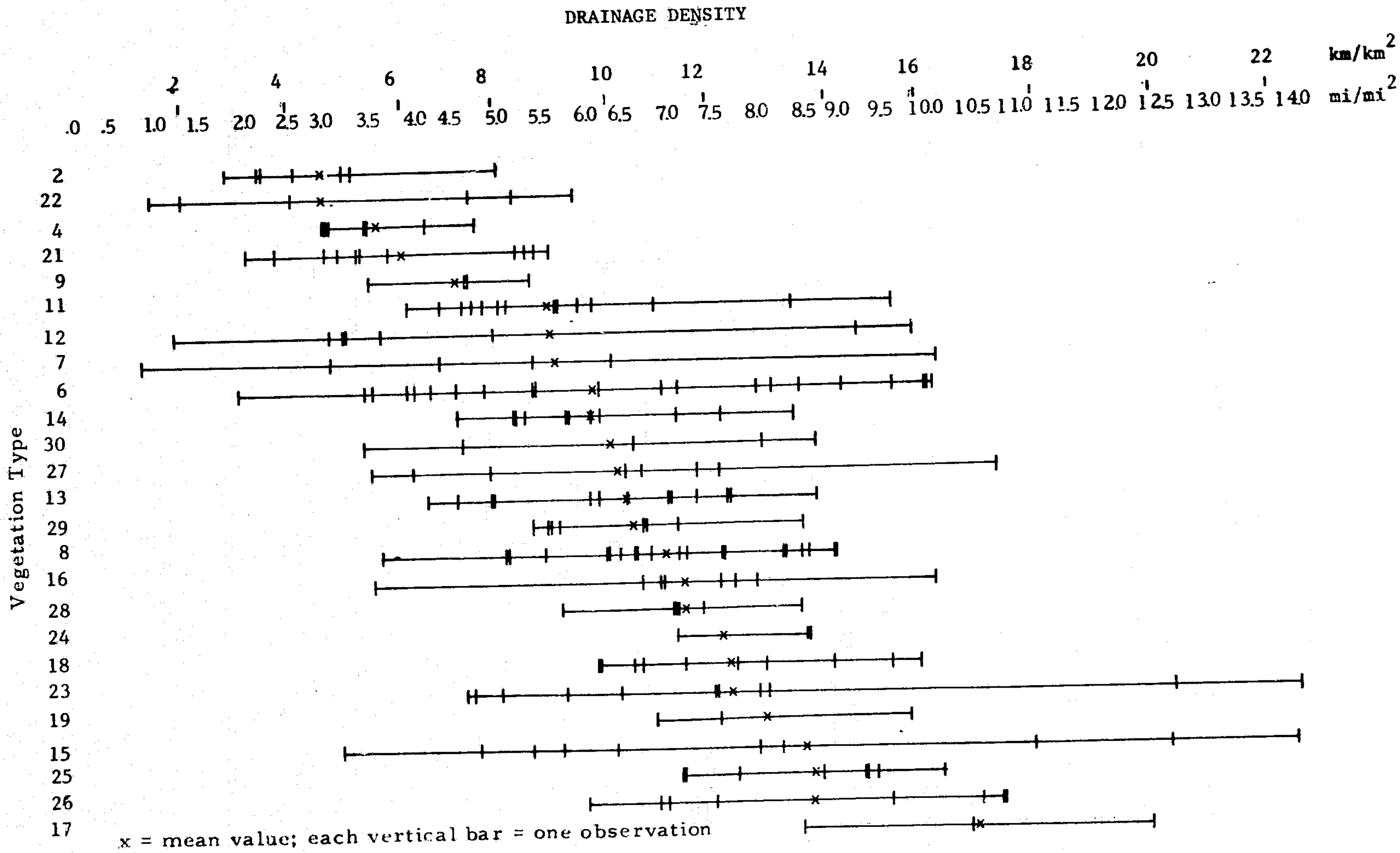


Figure 4-15. Distribution of vegetation types by drainage density.

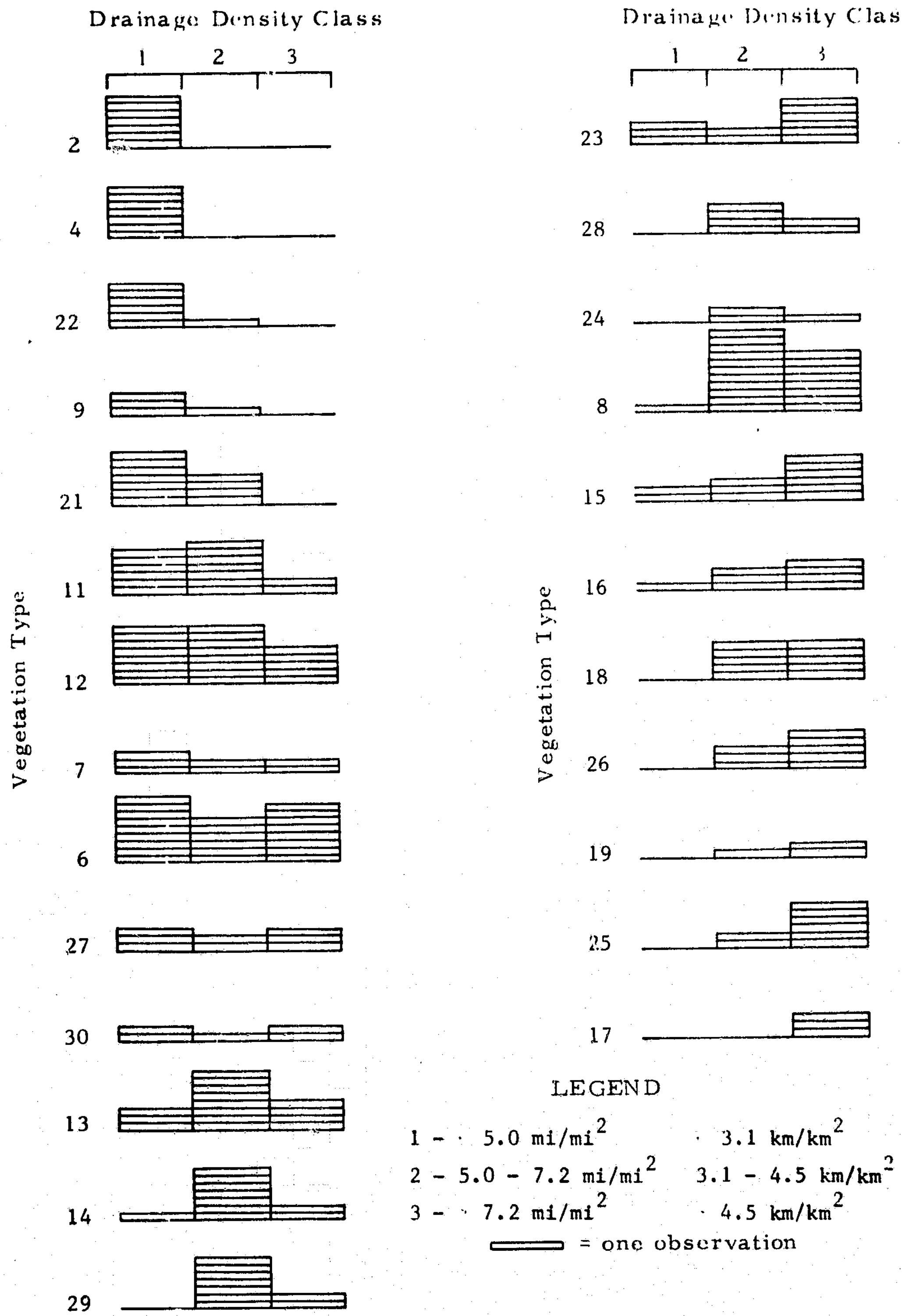


Figure 4-16. Distribution of vegetation types by drainage density classes.

Landform

Vegetation types exhibited a wide range of occurrences on different landform types, although they were more narrowly restricted to a given landform than were the individual species. Table 4-16 illustrates the distribution tendencies of the vegetation types among the landform types. Only the stronger associations between the vegetation types and the landform types are listed in that table.

Table 4-16. Distribution tendencies of vegetation types among landform types.

Alluvial Landforms	
Floodplains	21, 22, 26, 30
Terraces	21, 30
Valley Fill	2, 12, 21, 22
Smooth Bajadas	7, 11, 12, 13, 18, 21, 22
Side Slopes of Dissected Bajadas	2, 6, 16, 19, 23, 26
Interfluves	2, 4, 11, 13, 14, 16, 17
Non-Alluvial Landforms	
Upper Convex Slopes	9, 14, 16, 24, 27
Middle of Undifferentiated Slopes	4, 8, 9, 14, 18, 23, 25, 26, 27, 30
Lower Concave Slopes	4, 19, 28

Slope Angle

The degree of the relationships between slope angle classes and vegetation types was about the same as between slope angle classes and individual plant species. Figure 4-17 illustrates the distribution of vegetation types with respect to the slope angle classes. Observations on that figure were later reordinated into low, medium, and high slope angle categories (less than 10%, 10% to 25%, and over 25%, on the average, respectively). Table 4-17 illustrates the distribution tendencies of the vegetation types among slope angles.

Table 4-17. Distribution tendencies of vegetation types among slope angles.

Low Slope Angles (averaging less than 10%)

Vegetation Types: 22, 17, 21 (very low slope angles)
Vegetation Types: 2, 11, 12, 30, 13

Middle Slope Angles (averaging 10-25%)

Vegetation Types: 7, 6, 16, 15
18, 28, 19, 24, 4

High Slope Angles (averaging over 25%)

Vegetation Types: 26, 14, 25, 8, 27, 23, 9, 29

Slope Aspect

Better relationships existed between vegetation types and slope aspect than between individual plant species and slope aspect. Figure 4-18 illustrates the distribution of vegetation types according to slope aspect. Those observations were later reordinated into three general aspect classes: southerly; little aspect preference or primarily level; and northerly. See Table 4-18.

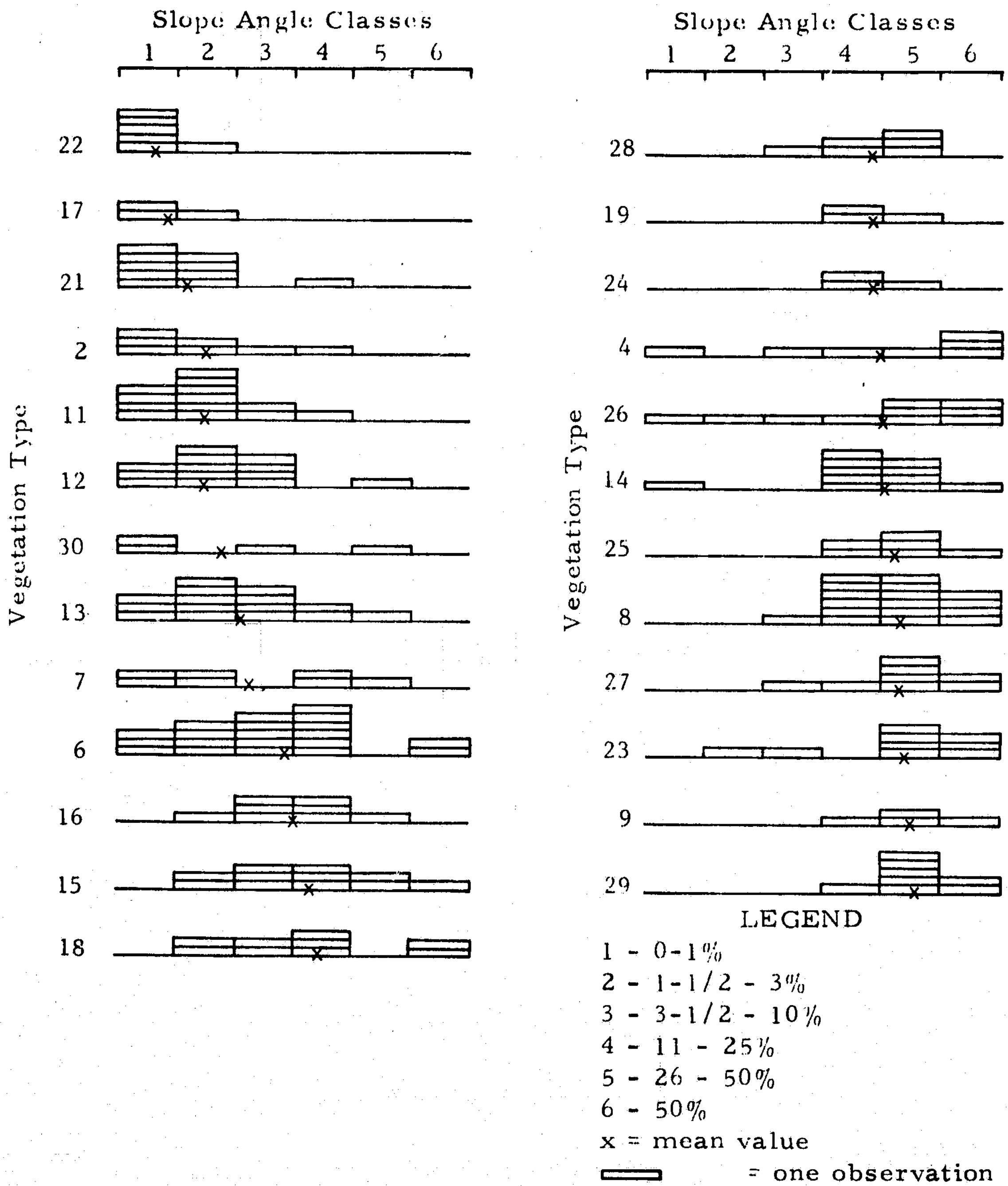


Figure 4-17. Distribution of vegetation types by slope angle classes.

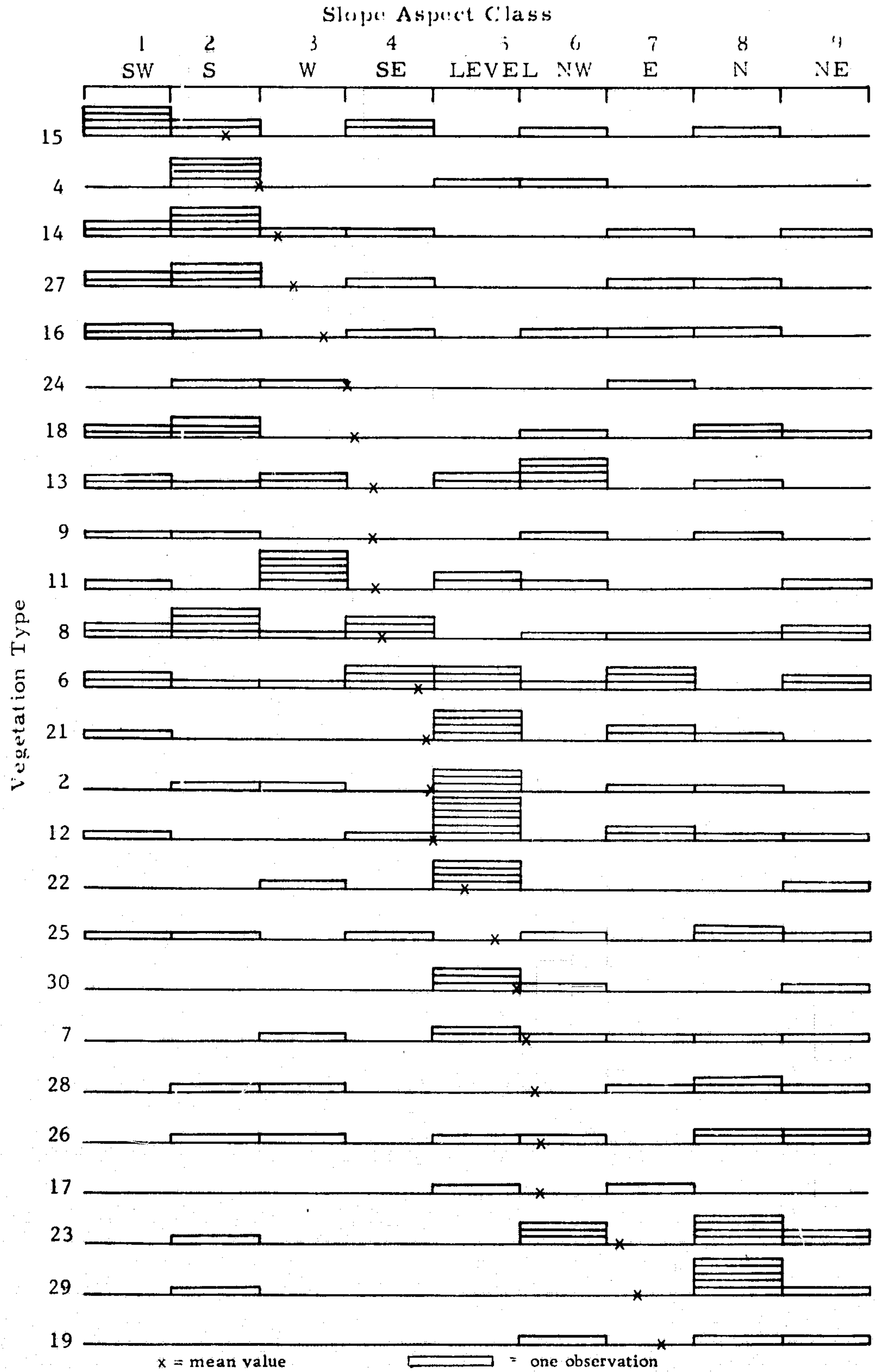


Figure 4-18. Distribution of vegetation types by slope aspect.

Table 4-18. Distribution tendencies of vegetation types among slope aspect classes.

<u>Southerly Aspects</u>	
Vegetation Types:	15, 4, 14, 27, 16, 24
<u>Little Aspect Preference or Primarily Level</u>	
Vegetation Types:	18, 13, 9, 11, 8, 6, 21, 2, 12, 22, 25
<u>Northerly Aspects</u>	
Vegetation Types:	30, 7, 28, 26, 17, 23, 29, 19

Solar Radiation Index

The final terrain or environmental variable to be discussed in relation to vegetation types is solar radiation index. This, together with elevation is a good moisture correlate. Figure 4-19 illustrates the range of occurrences of the vegetation types according to classes of the solar radiation index. That distribution was reordinated into groups of low, average, and high distribution tendencies (see Table 4-19).

Table 4-19. Distribution tendencies of vegetation types among solar radiation index values.

<u>Low Solar Radiation Index</u>	
Vegetation Types:	19, 29, 23 (very low solar radiation index)
Vegetation Types:	26, 7, 28
<u>Average Solar Radiation Index</u>	
Vegetation Types:	25, 30, 2, 13, 21, 11, 9, 18, 17, 16, 22, 24
<u>High Solar Radiation Index</u>	
Vegetation Types:	12, 8, 6, 15
Vegetation Types:	4, 27, 14 (very high solar radiation index)

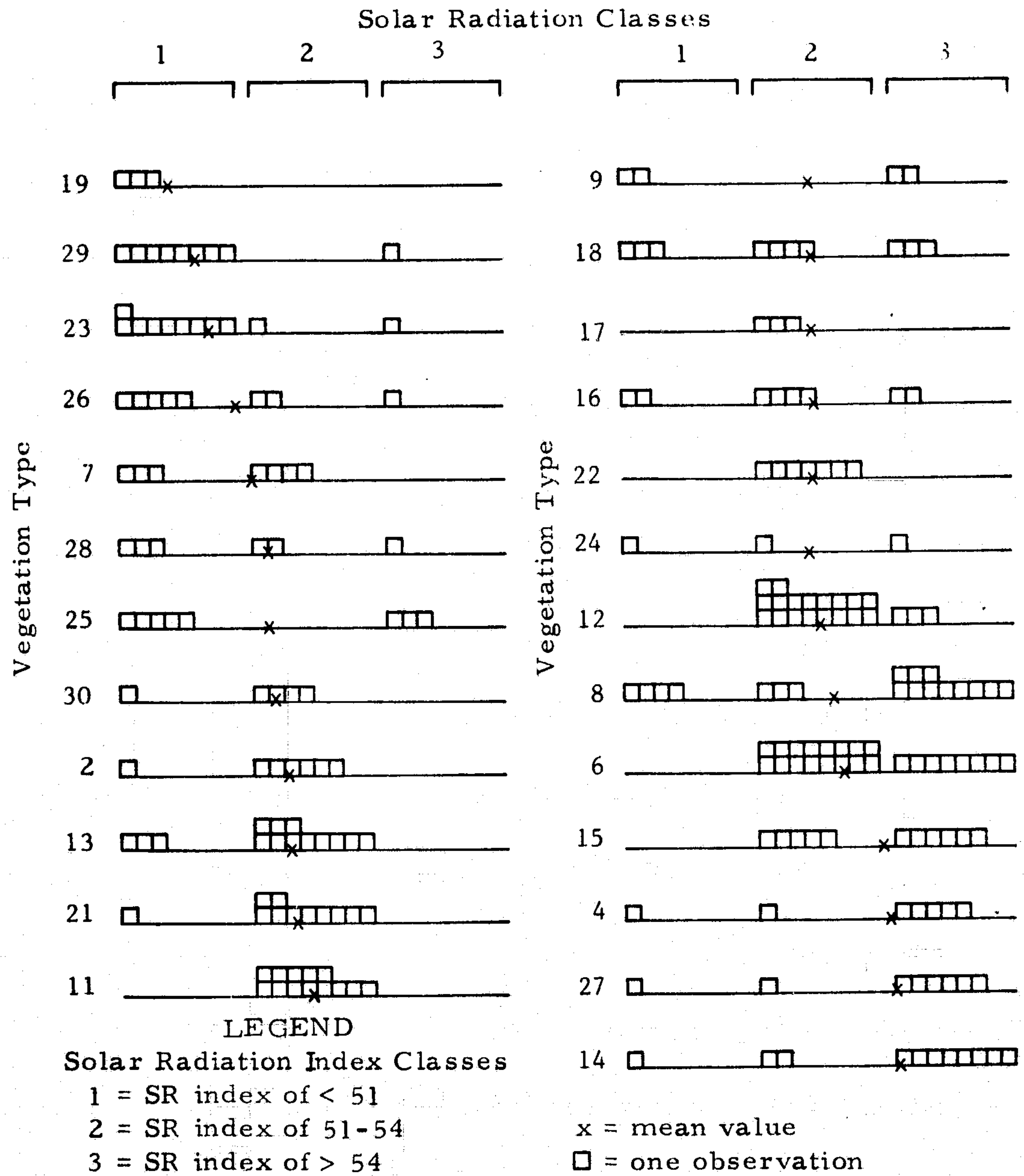


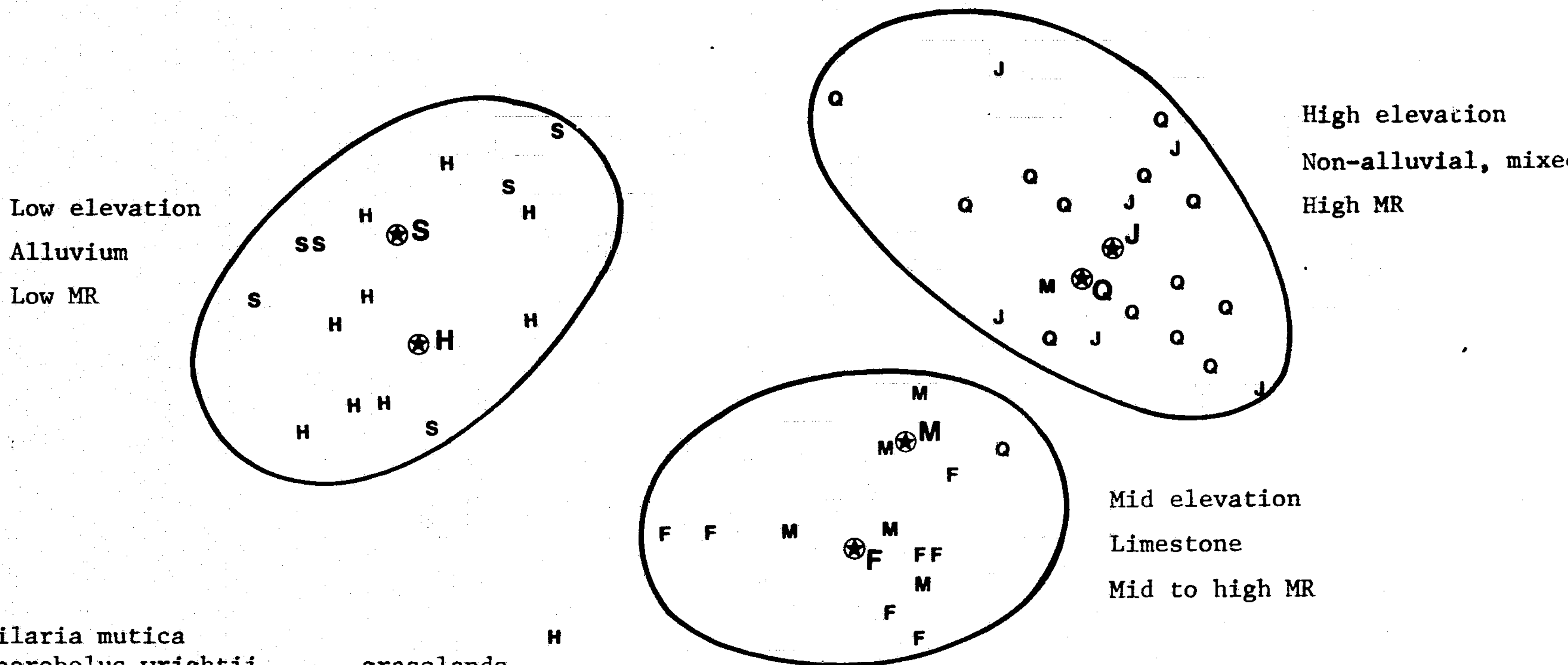
Figure 4-19. Distribution of vegetation types by solar radiation index classes.

Analysis of the Relationships Between Vegetation Types and Terrain Variables Using Stepwise Discriminant Analysis

In the stepwise discriminant analysis programs that analyzed the relationships between vegetation types and terrain variables, the vegetation types were considered as groups and the terrain variables as "variables." All terrain variables were considered together and analyzed to assess the vegetation types. The stepwise discriminant analysis program determined the order in which the terrain variables could discriminate or differentiate the group of vegetation types. The vegetation types, themselves, are then classified or plotted in a two-way table to show the relative separation among types. It is to be remembered that the program analyzes only numerical values of the variables. Hence, if a particular variable is relatively non-parametric (for example, parent material), it's association with vegetation types will not be as accurately determined as would the association between more highly parametric variables (such as elevation).

The first program employing stepwise discriminant analysis to examine relationships between terrain variables and vegetation types was a run which employed only six vegetation types. Those vegetation types were determined prior to the vegetation classification which resulted in thirty-one vegetation types being identified in the study area. It was decided that the six types would be chosen from among the three widely separate physiognomic types in the study area region: grassland, shrubland, and woodland. Within each of these three physiognomic types, two vegetation units were chosen. The six vegetation types were: from the grassland, a Sporobolus wrightii type and a Hilaria mutica type; from the shrubland, a Fouquieria splendens type and a Mortonia scabrella type; and from the woodland type, a Quercus emoryi type and a Juniperus deppeana type. Those six vegetation types do not coincide with any of the thirty-one vegetation types determined by our vegetation classification.

The results of the run indicated a nearly perfect separation of the three physiognomic types on the basis of the terrain variables employed. Figure 4-20 illustrates the scatter diagram produced by the program and indicates the separation of the physiognomic types.



H = Hilaria mutica
S = Sporobolus wrightii — grasslands
F = Fouquieria splendens
M = Mortonia scabrella — shrublands
Q = Quercus emoryi
J = Juniperus deppeana — woodland

⊛ = Group means

Figure 4-20. A scatter diagram of the first two canonical variates where groups are from six vegetation units and variables are terrain variables.

The terrain variables listed in order of declining ability to discriminate the six vegetation types were macrorelief, drainage density, elevation, solar radiation index, slope angle, parent material, landform type, and slope aspect. In general, the Sporobolus wrightii type and the Hilaria mutica type occurred on sites having low elevation, low drainage density, and low macrorelief (therefore, a tendency toward flat topography). The Fouquieria splendens type and the Mortonia scabrella type tended to occur at middle elevations, medium drainage densities, and medium to high macrorelief (a tendency toward dissected and hilly topography). The Quercus emoryi type and the Juniperus deppeana type had a tendency to occur on sites with high elevations, high drainage densities, and high macrorelief (a tendency toward hilly to mountainous topography).

In this particular analysis, stepwise discriminant analysis identifies for each vegetation type an array of values of the terrain variables that best correlates as a set with that particular vegetation type. The program then analyzes the terrain variables of a given observation (or field sample site; there were 51 in this run) and then classifies or identifies that observation into the vegetation type with which it best correlates on the basis of the values of terrain variables at that site. If the observation is placed into the vegetation type which was identified as such by field observation (and then subsequent classification), then a correct match was made. An observation can, however, be placed into a vegetation type other than the one identified by the field observation. The program perfectly discriminated the grassland types from the other two physiognomic types (as Figure 4-20 illustrates). In fact, of the six Sporobolus wrightii type occurrences, only one was considered to be more like the Hilaria mutica type than the Sporobolus wrightii type in terms of its terrain variables. Based on distance measures, of the ten Hilaria mutica type occurrences, two were considered to be more like the Sporobolus wrightii type than the Hilaria mutica type.

Of the fourteen shrubland occurrences, one was more like a woodland type than a shrubland type; while of the twenty-one woodland occurrences, two were more like a shrubland type than a woodland type in terms of their respective terrain variables. Of the seven Fouquieria splendens type occurrences, one was more like a Mortonia scabrella type than a Fouquieria splendens type. Of the seven observations placed into the Mortonia scabrella type, two were more like a Fouquieria splendens type, and one was more like a Juniperus deppeana type than a Mortonia scabrella type in terms of the terrain variables observed for the type. Of the fifteen Quercus emoryi type occurrences, one was more like a Fouquieria splendens type than a Quercus emoryi type, one was more like a Mortonia scabrella type than a Quercus emoryi type, and two were more like the Juniperus deppeana type than the Quercus emoryi type in terms of observed terrain variables. Finally, among the six Juniperus deppeana type occurrences, only one was more like another type (the Quercus emoryi type) than like the Juniperus deppeana type.

This preliminary analysis indicated the efficacy of the method (Mouat, 1972). The vegetation types reported were not the same as the types arrived at by our more extensive vegetation classification, but they nevertheless illustrated the use of the program.

The real test in using stepwise discriminant analysis in the study of the relationships between terrain variables and vegetation types came when all vegetation types and all observations were included. In those analyses, elevation and macrorelief were the best discriminants of the vegetation types. Elevation had nearly twice the F statistic value that macrorelief had, indicating the discriminating ability of that variable. The next best discriminant was the incident solar radiation index. That was followed closely by drainage density and then parent material. The poorest discriminants were landform type, slope angle, and slope aspect. On another run using all vegetation types, it was decided to delete the landform types because of their being non-parametric. Figure 4-21 illustrates the scatter diagram produced by the program and indicates the separation of the 25 vegetation types by the terrain variables.

Results of the stepwise discriminant analysis show that of the 242 observations included in an analysis of twenty-five vegetation types, 120 were placed by the program into the correct vegetation type from the standpoint of the terrain variables. The program neither "agrees" nor "disagrees" with the vegetation classification. It does, however, state

Symbol	Vegetation Types Names	Identifier Number
A	*Larrea tridentata* with *Prosopis juliflora*	(2)
B	*Cercidium microphyllum*	(4)
C	*Prosopis juliflora* with *Opuntia* spp. (cholla)	(11)
D	*Prosopis juliflora* (without *Opuntia* spp. - cholla)	(12)
E	*Acacia constricta* with *Calliandra eriophylla*	(14)
F	*Acacia constricta* (without *Calliandra eriophylla*)	(13)
G	*Acacia vernicosa* (without *Rhus microphylla*)	(6)
H	*Acacia vernicosa* with *Rhus microphylla*	(7)
I	*Aloysia wrightii*	(8)
J	*Mortonia scabrella*	(9)
K	*Prosopis juliflora*/*Bouteloua* spp.	(18)
L	*Prosopis juliflora*/*Bouteloua* spp. with *Quercus* spp.	(23)
M	*Bouteloua* spp./*Nolina microcarpa*	(19)
N	*Bouteloua* spp. (without *Nolina microcarpa*)	(17)
O	*Bouteloua* spp./*Yucca elata*	(16)
P	*Sporobolus wrightii*	(22)
Q	*Hilaria mutica*	(21)
R	*Cercocarpus breviflorus*	(29)
S	*Quercus* spp./*Arctostaphylos pungens* (without *Mimosa biuncifera*)	(28)
T	*Quercus* spp./*Arctostaphylos pungens* with *Mimosa biuncifera*	(27)
U	*Cowania mexicana*	(24)
V	*Quercus* spp./*Mimosa biuncifera*	(26)
W	riparian	(30)
X	*Quercus* spp./*Nolina microcarpa*	(25)
Y	*Bouteloua* spp./*Fouquieria splendens*	(15)

⊛ Mean values (e.g., A)

○ Overlap of values

Figure 4-21. A scatter diagram of the first two canonical variates where groups are from twenty-five vegetation types and variables are terrain variables.

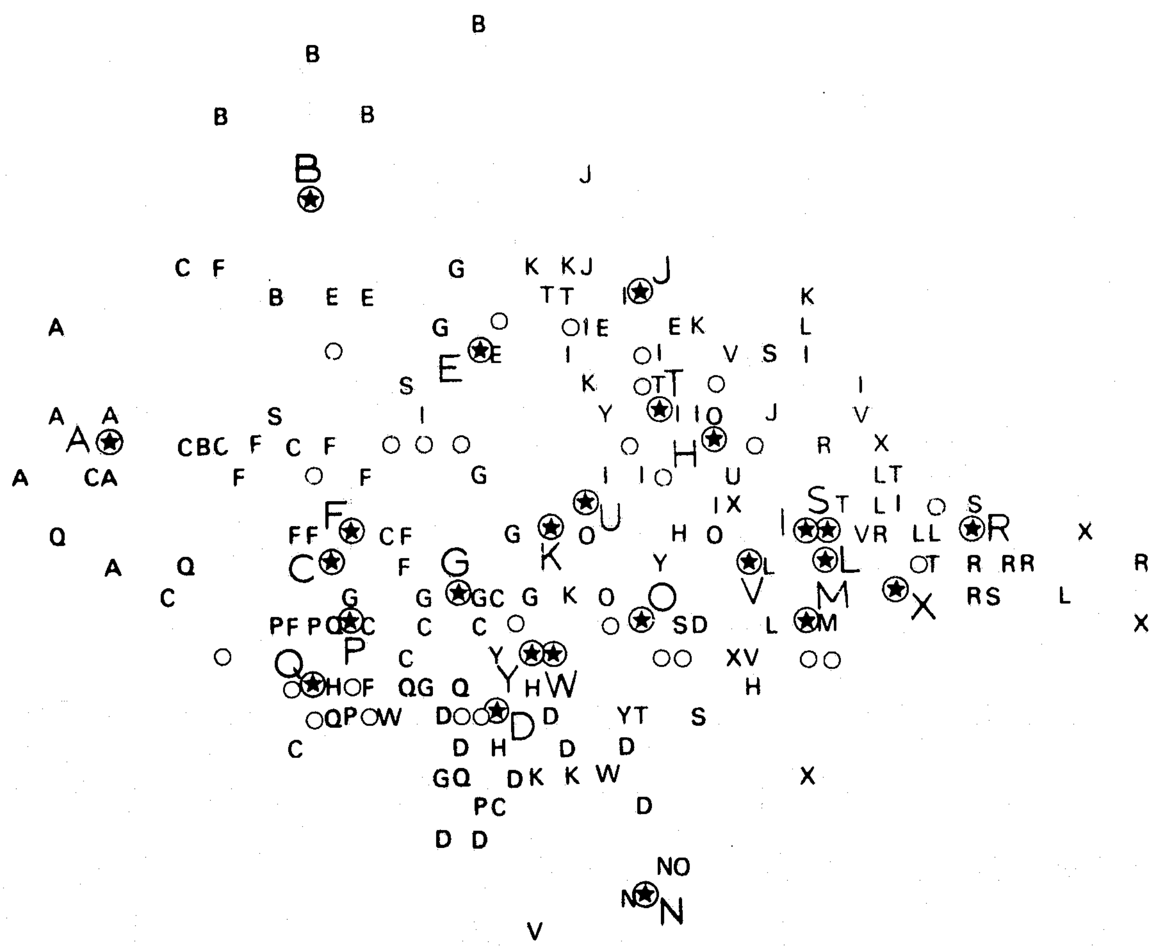


Figure 4-21. Continued.

the degree of cohesion within and among groups from the standpoint of terrain variable interaction.

The classification can be considered in its two-way format as follows: it determines which observations placed by the vegetation classification into a particular vegetation type have terrain variables most like that vegetation type or most like some other type.

Figure 4-22 summarizes the classification (or identification) performed by the program; it is a two-way matrix. On the left side of the matrix is the floristically-defined vegetation type. Along the top of the matrix are listed the analogous vegetation type classes. However, instead of their being floristically defined, they are defined by the set of terrain variables which were observed to occur for those sites that comprise the type. The "program-derived terrain variable-defined vegetation types" represent an ordination of the vegetation types based upon the set of terrain variables which are identified with each vegetation type. Thus, field sites (or observations) listed below each of the program-derived terrain variable-defined vegetation types indicate that a site (or observation) has terrain variable associations more closely aligned with a given floristically-defined vegetation type than with any other vegetation type. The chief criterion for "closeness" is a measure of Mahalanobis distance as defined and determined by the stepwise discriminant analysis. The number of field sites placed in the boxes along the diagonal of the matrix indicate observations that have been classified the same way by the two different methods. Field sites which are not listed on the diagonal indicate that a program-derived terrain variable-defined vegetation type is more like some other floristically-defined vegetation type than like a vegetation type derived by the program from terrain variable classes. Field sites (or observations) placed on the same horizontal line as a floristically-defined vegetation type belong to that vegetation type, thus there are seven sites belonging to vegetation type 2 = Latr-Prju. The floristic classification indicates that seven stands (similar to observations) were placed in that type (that is, 2 = Latr-Prju). The classification indicates that all seven stands are most like the program-derived terrain variable-defined vegetation type 2' with which it is analogous. However, when the vegetation

Program-Derived Terrain Variable-Defined Vegetation Types

Floristically-Defined Vegetation Types	2'	4'	11'	12'	14'	13'	6'	7'	8'	9'	18'	23'	19'	17'	16'	22'	21'	29'	28'	27'	24'	26'	30'	25'	15'	(total number of floristically-defined type stands)
2	7																									7
4		5	1		1																					7
11	2	1	6	2											1	2	1									15
12			1	11											2	2	1		1						3	21
14					8		2													1						11
13		1	2	1		10																1				15
6		1		4		1	8				1			1	2	2	1			1					2	24
7				3				1					1				1								1	7
8					1	2	1		5	1								1		3	1	4		1		20
9										4																4
18				2	1						1	2			2							1			1	10
23							1					7			1							1		1		11
19												1	1						1							3
17														3												3
16				1				1				1	1		2						1				1	8
22							1									5							1			7
21			1	1		2										1	6									11
29									1			1						7								9
28												1	1						2	1	1					6
27								1	1			1								4				1		8
24																					3					3
26														1						1	1	5				8
30										1						1			1				2			5
25												1	2						1	1				3		8
15				1	2	1			1		1				1										4	11
(total number of program-derived terrain variable-defined type stands)	9	8	11	26	13	16	13	3	8	6	3	15	6	5	11	13	10	8	6	12	7	12	3	6	12	

Figure 4-22. A two-way classification matrix of floristically-defined vegetation types and terrain variable-defined vegetation types.

types are considered from the standpoint of the terrain variables, two stands are classified which were floristically defined as in vegetation type 11 = Prju-Hate-Cholla, and seven stands were correctly placed into the type 2 = Latr-Prju. Using floristically-defined vegetation types to determine terrain variable classes or associations of stands, results using the Larrea tridentata with Prosopis juliflora and/or Opuntia (cholla) (2 = Latr-Prju) as an example would be most favorable.

As a second example, consider the Aloysia wrightii type (8 = Alwr-Fosp-Acco). Twenty stands were floristically identified as belonging to the type. The program-derived terrain variable-defined classification indicates that only five stands are most like the terrain variable-defined type 8'. Fifteen other stands are more like other terrain variable-defined vegetation types. From the standpoint of floristics, five stands were most like the floristically defined vegetation type 8 = Alwr-Fosp-Acco, while three other stands were more like some other floristically-defined vegetation type. Those eight stands had a terrain variable association that coincided with the terrain variable-defined vegetation type 8'.

SUMMARY AND CONCLUSIONS

A study to determine the relationships between plant species and eight terrain variables and between thirty-one vegetation types and the terrain variables was conducted in a 4,000 square mile area south and east of Tucson, Arizona. The eight terrain variables included elevation, parent material, macrorelief, landform type, drainage density, slope angle, slope aspect, and solar radiation index, a derivative of slope angle and slope aspect. The term "terrain variable" was chosen to describe several easily measured and identified properties of the landscape.

Data were collected from 250 field sample sites which were selected on the basis of parent material and elevation from within the study area. Floristic data collected consisted of a listing of species at the sampled site and estimates of species cover and prominence. Elevation, parent material, macrorelief, landform type, slope angle, and slope aspect were also determined at each field sample site. Drainage density and solar radiation index were determined in the laboratory.

The data were analyzed qualitatively using graphs and tables in order to determine general associations between the species and terrain variables, and between vegetation types and the terrain variables.

Stepwise discriminant analysis (BMD07M) was also used to quantitatively analyze the data. Computer runs employing stepwise discriminant analysis used individual species to discriminate groups of terrain variables and terrain variables to discriminate vegetation types.

Conclusions Regarding Plant Species

Plant species that appeared to be closely correlated with elevation include, 1) Opuntia fulgida, Cercidium floridum, C. microphyllum, and Cereus giganteus, all of which occurred primarily in the lower elevations (that is, below 3,800 feet); 2) Sporobolus airoides and Flourensia cernua, which occurred primarily in the middle elevations, 4,000 feet to 4,800 feet; and 3) Pinus cembroides, Cowania mexicana, and Cercocarpus breviflorus, which occurred primarily only at higher elevations, above 5,100 feet. Several species, notably Prosopis juliflora, Opuntia spinosior, Opuntia phaeacantha, and Fouquieria splendens, occurred throughout a wide range of elevations, primarily between 3,000 feet and 5,500 feet. Plant species are found to be closely associated with parent materials.

Cercocarpus breviflorus, Aloysia wrightii, and Mortonia scabrella are clearly defined by floristic analysis as well as by results of the stepwise discriminant analysis as being closely associated with limestone parent materials. Aloysia wrightii, while observed to occur over a wide variety of parent materials, is included as an indicator of limestone on account of its much higher cover values on limestone than on the other parent materials. Agave schottii is considered to be a good indicator of limestone and of igneous parent materials. Yucca elata and Cercidium microphyllum are nearly limited in their occurrence to alluvial parent materials and can be considered as good indicators of alluvium.

Two species, Sporobolus airoides and Hilaria mutica, are closely associated with flat topography (macrorelief class 1). Several species, including Arctostaphylos pungens, Agave schottii, Aloysia wrightii, Mortonia scabrella, and Cercocarpus breviflorus, are closely associated with hilly and mountainous topography (macrorelief classes 4, 5, and 6). Most species, however, are not closely associated with macrorelief.

Species relationships with drainage density, likewise, are not particularly close. Most species had fairly wide ranges of drainage density distributions. Drainage density was felt to represent a close correlation with elevation since low drainage densities were strongly related to low elevations, and high drainage densities were strongly related to high elevations.

Species tend to occur over a fairly wide variety of landform types. Aloysia wrightii, Cercocarpus breviflorus, and Mortonia scabrella, are generally restricted to non-alluvial hillslopes. Pinus cembroides occurs predominantly on the lower concave hillslopes on non-alluvial parent materials. Acacia vernicosa, Haplopappus tenuisectus, and Yucca elata tend to occur only on smooth alluvial surfaces. Most other species occur over a fairly wide range of alluvial surfaces.

Sporobolus airoides, Haplopappus tenuisectus, Cercidium floridum, Hilaria mutica, and Yucca elata can be considered as good indicators of low slope angles. Cowania mexicana, Juniperus monosperma, Agave schottii, Pinus cembroides, Rhus choriophylla, Mortonia scabrella, and Cercocarpus breviflorus occur primarily on moderate slope angles. Aloysia wrightii, Dasylirion wheeleri, Nolina microcarpa, Quercus emoryi, Q. oblongifolia, and Mimosa dysocarpa, occur predominantly on the steepest slopes. The remaining species occur over a fairly wide range of slope angles.

Species do not relate as well to slope aspect as was expected. The best species for discriminating slope aspect classes were Cercidium microphyllum, Calliandra eriophylla, and Cereus giganteus, for southerly aspects, and Quercus oblongifolia, Pinus cembroides, and Juniperus monosperma for northerly aspects. Those species which related well to slope aspect also related well to incident solar radiation index.

Table 4-20 illustrates the relationships of the forty-one more important species to terrain variables. The Table represents a subjective summary of the relationships. Excellent relationships are indicated by a "5" and the poorest ones are indicated by a "1". Numbers in between represent relationships ranging from good to fair. While many species exhibit little or no relationship to many of the terrain variables studies, most bear a strong relationship to at least one or two.

Table 4-20. Degree of relationships between species and terrain variables based upon subjective evaluation of the data available.

Numerical entries 1 through 5 correspond respectively to values of poor, fair, moderate, good, and excellent relationships.

Species	Elevation	Parent Material	Slope Aspect	Slope Angle	Solar Radiation	Landform	Macrorelief	Drainage Density
Acacia constricta	2	2	1	3	1	3	1	2
Acacia vernicosa	3	5	2	2	1	2	3	1
Agave palmeri and/or parryi	4	3	2	4	1	4	5	2
Agave schottii	4	4	3	4	2	5	5	1
Aloysia wrightii	2	4	1	4	1	4	5	3
Arctostaphylos pungens	4	4	2	4	1	3	4	2
Bouteloua curtipendula	3	2	2	3	1	3	3	3
Bouteloua rothrockii	3	3	2	2	1	1	2	1
Calliandra eriophylla	3	1	3	3	3	2	3	2
Cercidium floridum	4	5	2	3	1	3	3	3
Cercidium microphyllum	4	2	5	2	3	3	1	4
Cercocarpus breviflorus	5	5	4	4	3	5	5	4
Cereus giganteus	4	3	3	1	3	3	2	4
Condalia lycioides	2	2	3	3	2	2	2	2
Cowania mexicana	5	5	2	4	4	5	5	4
Dasylirion wheeleri	3	4	3	4	2	4	5	3
Ferocactus wislizenii	3	2	4	3	3	2	2	2
Flourensia cernua	4	4	1	2	2	4	2	1
Fouquieria splendens	2	2	1	2	3	2	2	2
Haplopappus tenuisectus	2	2	1	4	3	3	3	1
Hilaria mutica	3	4	1	4	3	4	4	3
Juniperus deppeana	3	2	4	3	4	3	3	3
Juniperus monosperma	3	4	4	4	5	3	4	3
Larrea tridentata	2	4	1	1	2	2	2	2
Mimosa biuncifera	3	3	3	3	2	2	3	1
Mimosa dysocarpa	4	1	3	5	4	4	4	3

Table 4-20. (Continued).

Species	Elevation	Parent Material	Slope Aspect	Slope Angle	Solar Radiation	Landform	Macrorelief	Drainage Density
Mortonia scabrella	4	5	3	5	4	5	5	5
Nolina microcarpa	4	3	3	4	3	2	5	3
Opuntia fulgida	1	4	1	3	1	1	2	2
Opuntia phaeacantha	1	1	1	3	1	1	1	2
Opuntia spinosior	1	1	1	2	1	2	1	1
Parthenium incanum	4	2	3	3	3	2	4	1
Pinus cembroides	5	2	5	4	4	5	4	5
Prosopis juliflora	2	1	1	3	1	2	1	1
Quercus arizonica	4	2	3	2	3	3	4	3
Quercus emoryi	4	4	4	4	3	3	4	4
Quercus oblongifolia	4	2	5	5	5	3	4	2
Rhus choriophylla	4	4	4	4	2	4	5	4
Sporobolus airoides	5	5	5	5	5	5	5	5
Yucca elata	3	5	1	4	2	3	4	2

Conclusions Regarding Vegetation Types

Vegetation types were determined from data collected from several hundred observations of floristic characteristics within the study area. Twenty-five vegetation types of the thirty-one identified have frequencies of three or more among the 250 sample sites considered in this report.

Vegetation type amplitudes of terrain variables are found to be narrower in most instances than the amplitudes for individual species. With a couple of exceptions (for example, the *Aloysia wrightii* type - 8) vegetation types display neatly defined elevational ranges. Examples of vegetation types with restricted elevation ranges include the *Larrea tridentata* type (2), the *Cercidium microphyllum* type (4), the *Prosopis juliflora*/*Bouteloua* spp. type (18), the *Acacia vernicosa* with *Rhus microphyllum* type (7), the *Bouteloua* spp./*Nolina microcarpa* type (19), the *Bouteloua* spp. (without *Nolina microcarpa*) type (17), the *Cowania mexicana* type (24), and the *Cercocarpus breviflorus* type (29).

Vegetation types are found to have quite close associations with parent materials. Nineteen vegetation types occur primarily on one parent material. Twelve vegetation types occur predominantly on alluvial parent materials of which five occur exclusively on it. Two vegetation types occur primarily on sandstone parent materials, three types occur primarily on limestone, and two types occur primarily on igneous and metamorphic parent materials. No vegetation types occur predominantly on volcanic parent materials.

The most positive relationships between vegetation types and macrorelief are for those types which occur on flat topography and for those types which occur primarily on hilly and mountainous topography (macrorelief classes 4, 5, and 6). The *Sporobolus wrightii* type (22) and the *Larrea tridentata* type (2) are examples of vegetation types which occur predominantly on flat topography (macrorelief class 1). Examples of the vegetation types which occur extensively on hilly and mountainous topography include the *Mortonia scabrella* type (9), the *Cowania mexicana* type (24), and the *Cercocarpus breviflorus* type (29).

Vegetation types do not appear to have particularly strong relationships with drainage density. Four vegetation types: the *Larrea* *tridentata* type (2), the *Cercidium microphyllum* type (4), the *Mortonia scabrella* type (9), and the *Sporobolus wrightii* type (22), occurred mainly on low drainage densities. Three vegetation types: the *Bouteloua* spp./*Nolina microcarpa* type (19), the *Quercus* spp./*Nolina microcarpa* type (25), and the *Bouteloua* spp. (without *Nolina microcarpa*) type (17), occurred primarily on the high drainage densities. The remaining eighteen vegetation types have scattered relationships with drainage density.

The vegetation types exhibit a wide range of occurrences on landform types, although they have closer relationships with landform types than do the individual species.

The vegetation types have a fair association with slope angles. Eight vegetation types occur predominantly on low slope angles (less than 10%), eight vegetation types occur predominantly on middle slope angles (11-25%), and nine vegetation types occur predominantly on the higher slope angles (greater than 25%).

Closer associations were discovered between vegetation types and slope aspect than between species and slope aspect. Six vegetation types occur primarily on southerly aspects while eight vegetation types occur primarily on northerly aspects.

Six vegetation types have good relationships with low solar radiation index values while seven vegetation types have good relationships with high solar radiation index values.

Table 4-21 lists the degree and type of relationships existing between each vegetation type and each terrain variable in much the same manner as the table illustrating the relationships between individual plant species and terrain variables (see Table 4-20). A highly generalized cross-section of terrain utilizing the terrain variables employed is presented in Figure 4-23 to summarize relationships between terrain variables and vegetation types.

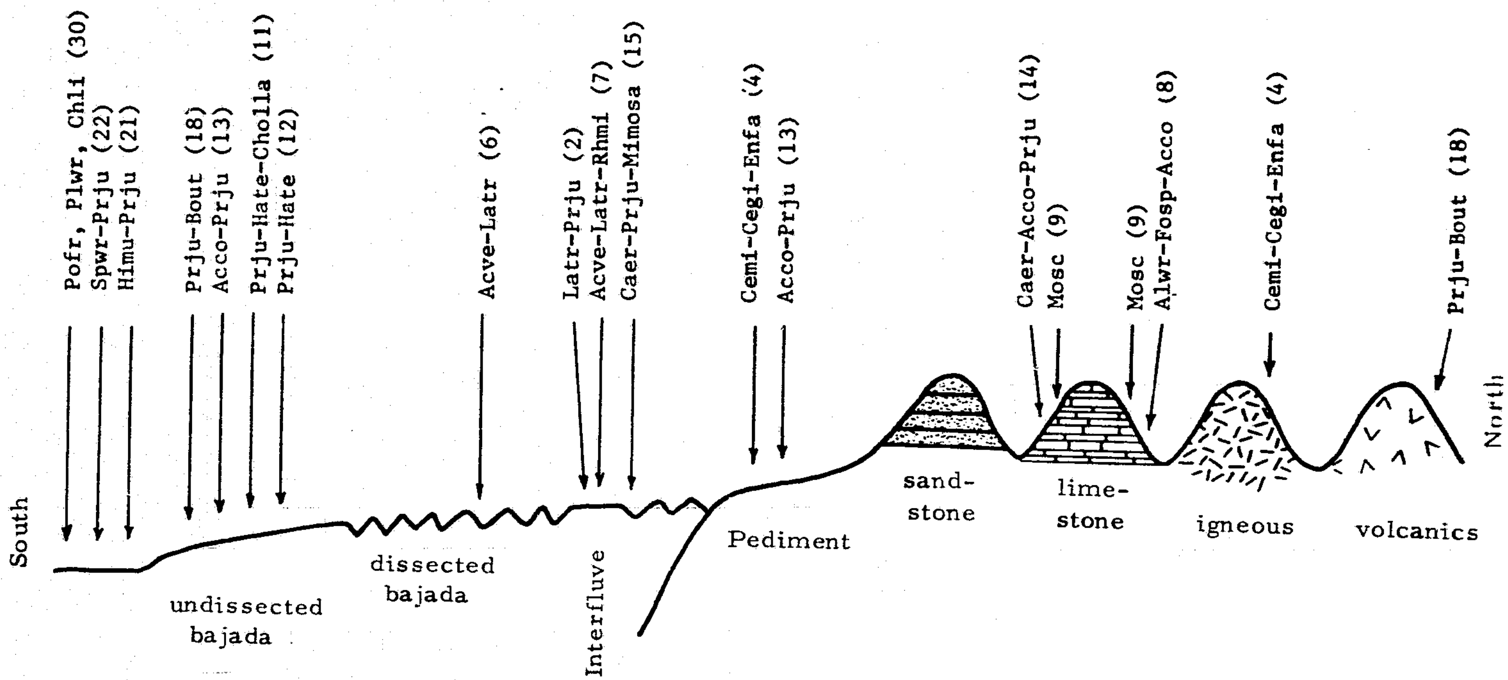
The use of stepwise discriminant analysis to analyze relationships between terrain variables and vegetation types was most illuminating and accomplished two things. It determined which terrain variables were the best discriminants of vegetation types. It also determined which field sample sites (or observations), placed by the vegetation

Table 4-21. Degree of relationships between vegetation types and terrain variables based upon subjective evaluation of the data available.

Numerical entries 1 through 5 correspond respectively to values of poor, fair, moderate, good, and excellent relationships.

Vegetation Type	Elevation	Parent Material	Slope Aspect	Slope Angle	Solar Radiation	Landform	Macrorelief	Drainage Density
2 = Latr-Prju	5	5	1	4	3	4	4	4
4 = Cemi-Cegi-Enfa	5	3	4	3	4	3	3	4
6 = Acve-Latr	3	5	1	2	3	3	3	1
7 = Acve-Latr-Rhmi	4	5	4	2	4	4	3	1
8 = Alwr-Fosp-Acco	2	3	2	4	2	4	4	3
9 = Mosc	3	5	2	4	2	5	5	4
11 = Prju-Hate-Cholla	2	5	2	4	4	4	4	3
12 = Prju-Hate	4	5	2	4	3	4	4	1
13 = Acco-Prju	3	4	3	3	3	3	3	3
14 = Caer-Acco-Prju	3	4	4	3	4	2	3	3
15 = Caer-Prju-Mimosa	3	4	5	2	3	2	1	1
16 = Caer-Epti-Yucca	4	4	4	3	1	4	2	2
17 = Bout-Arist	4	5	4	4	3	3	3	3
18 = Prju-Bout	4	4	3	2	1	2	2	3
19 = Bout-Arist-Nomi	5	3	5	4	5	2	3	4
21 = Himu-Prju	3	5	2	4	4	4	4	3
22 = Spwr-Prju	4	5	2	5	4	4	5	3
23 = Prju-Quercus-Jude	3	3	4	4	4	2	3	2
24 = Come	5	4	3	4	1	5	5	4
25 = Quercus-Nomi	3	4	1	4	3	4	3	3
26 = Quercus-Mimosa	3	3	3	3	4	2	4	2
27 = Quercus-Arpu-Mibi	3	3	4	4	4	4	4	2
28 = Quercus-Arpu-Pice	4	4	3	4	3	4	3	4
29 = Cebr	5	4	5	5	5	4	5	4
30 = Pofr-Plwr-Chli	3	4	3	3	3	4	2	2

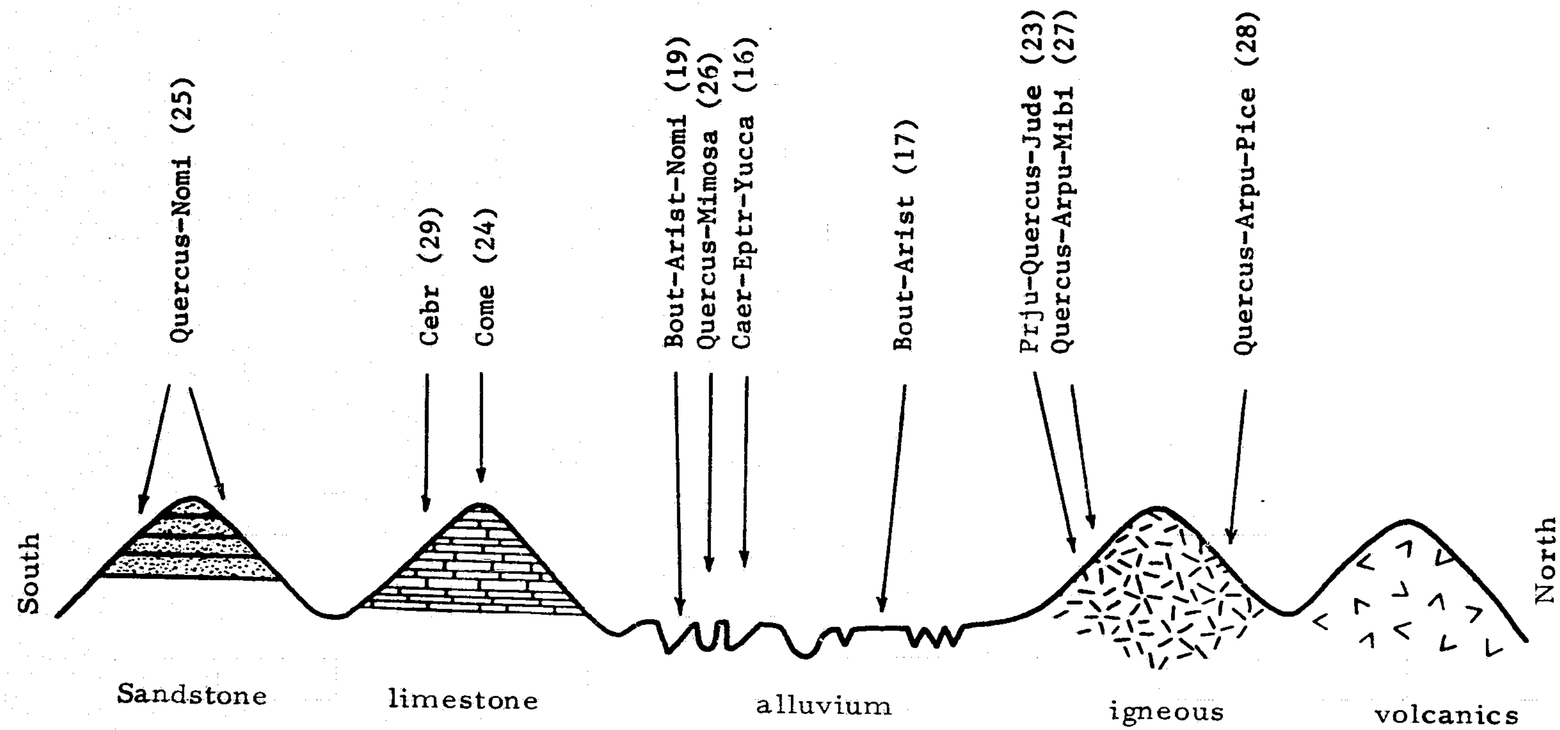
*The symbology for the vegetation type is an abbreviation of the principal species characterizing the vegetation type. A full list of the vegetation types is given in Chapter 2.



Low elevation < 4600'

< 1402 m

Figure 4-23. Highly generalized cross section of terrain indicating typical vegetation type occurrences.



High elevation > 4600'

> 1402 m

Figure 4-23. Continued

classification into a particular vegetation type, have terrain variables most like that vegetation type, and which field sample sites belonging to that particular vegetation type have terrain variables more like other types.

The terrain variables which were found to best discriminate vegetation types were, in order: elevation, macrorelief, solar radiation, drainage density, and parent material.

What is ultimately hoped for in this type of study is a set of terrain variables that are sufficient in themselves to enable accurate inferential identification of vegetation types. One of the methods for enabling inferential identification of vegetation types is through the use of stepwise discriminant analysis. It is theoretically possible that one terrain variable would perfectly discriminate the vegetation types. However, in this study, that was not the case. In fact, all eight terrain variables interacting together did not perfectly discriminate the twenty-five vegetation types. Part of the reason for the "failure" was the similarity among vegetation types. Different vegetation types might represent different successional stages of similar habitat types, for example, and thus result in sets of terrain variables being nearly identical for two different seral types. Another reason for the failure of the eight terrain variables to perfectly discriminate the twenty-five vegetation types is that those terrain variables did not include all of the important environmental variables which result in differences in vegetation distribution.

Thus, while relationships have been shown to exist between plant species and terrain variables, and between vegetation types and terrain variables, they are not perfect relationships. Perfect relationships probably do not exist. A better understanding, however, of other vegetation considerations (such as succession) and of other environmental variables might result in an apparent increase in observed relationships.

CHAPTER 5

TERRAIN VARIABLES INTERPRETATION TESTING

OBJECTIVE 3

The purpose of Objective 3 was to show the facility with which interpreters could interpret terrain variables. The idea behind this is consistent with our goals: if positive relationships exist between terrain variables and vegetation, how accurately and consistently can those terrain variables be identified and interpreted on various types of imagery? Concomitantly, with what facility can ERTS be employed to interpret those variables vis-à-vis other small-scale photographic products?

To help solve that problem we decided to interpret two of the best terrain variable discriminants: elevation and macrorelief.

INTERPRETATION OF ELEVATION

An ERTS black and white print and a high altitude photograph mosaic, both at a scale of 1:250,000, were employed in the task of interpreting elevation. Three skilled photo interpreters were asked to draw 500 foot contours for the entire study area. They delineated the ERTS photo first and then a month later delineated the high altitude photo mosaic. Transects were placed on the ground truth map and contours were marked on those transects. Contours delineated by the interpreters were superimposed over the ground truth. Errors by elevation category were tabulated according to image type and interpreter. A two-way analysis of variance was employed to analyze the data. Table 5-1 illustrates the raw data and the results of the analysis of variance. Interpretation of elevation on ERTS resulted in less error than on high altitude imagery (image type = "A"). However, the results indicate that the difference is insignificant. That is, image type does not significantly affect the ability to delineate elevation. The most consistent aspect of the test lay in the interpreters themselves. Interpreters tended to judge each image in a similar fashion.

Table 5-1. Elevation interpretation errors according to photo type and interpreter.

Raw Data

Photo type	Interpreter	A	B	C	D	E	F	G	H	I	J	Total Errors
		Transects										
	1	12	24	10	11	0	2	15	3	1	21	99
Hi-flite	2	88	37	14	0	0	10	19	85	8	7	268
	3	21	33	6	0	1	4	0	0	7	8	80
												447
	1	36	6	5	0	0	3	5	48	3	7	112
ERTS	2	17	18	3	80	4	34	11	16	11	22	216
	3	18	2	3	0	8	3	0	1	17	0	52
												380

Analysis of Variance

Source of variation	DF	Mean squares
Photo type (A)	1	74.8 ns
Interpreters (B)	2	1705.6 **
Transects (C)	9	520.1 nt
AB	2	53.6 ns
Error	45	318
Total	59	

ns Not significantly different

nt No test

** Significantly different (P<0.01)

C-3

Figures 5-1 and 5-2 illustrate how the interpreters delineated each image type. Three of the ten transects have been reproduced to indicate how the interpreters perceived the terrain.

Results

According to data taken from the transects, the interpreters were 88.3 percent accurate in delineating elevation on the high altitude photo mosaic and 89.7 percent accurate in delineating elevation on the ERTS imagery. Individual interpretive accuracies ranged from 82.3 to 95.8 percent for the ERTS interpretations to 79.5 to 93.9 percent for the high altitude photo mosaic interpretations. Thus the interpretive accuracy for elevation for either image type is quite high.

INTERPRETATION OF MACRORELIEF

One of the principal terrain feature variables, the interpretation of which was studied, was macrorelief. Macrorelief is a gross measure of local elevational differences and slope angle. Appendix D describes the macrorelief classes. Macrorelief is one of the more salient features on space photography, consequently, it has been the subject of numerous interpretation tests (Poulton, Johnson, and Mouat, 1970). The interpretability of macrorelief on ERTS imagery forms the basis of this section.

High Sun Angle Stereoscopic vs. Low Sun Angle Monoscopic Interpretation

An assumption is made that there is an angle of illumination which affords the greatest contrast among different relief types in arid areas. This angle of illumination might produce shadows on the steepest slopes and grazing light (relatively dark tones) on moderate slopes of the study area. Higher angles of illumination would lessen the contrast while lower angles would obscure the terrain with excessive shadowing. It was assumed, therefore, for the slope angles of the study area that an angle of illumination of 30^{o} might prove to be ideal. Another assumption is made on the method of viewing this imagery. That is, stereoscopic interpretation of relief affords more accurate identification and delineation of subject types than monoscopic interpretation. Accordingly, it was decided that a test would be devised, the purpose of which was to compare low sun angle monoscopic interpretation and

ERTS INTERPRETATIONS

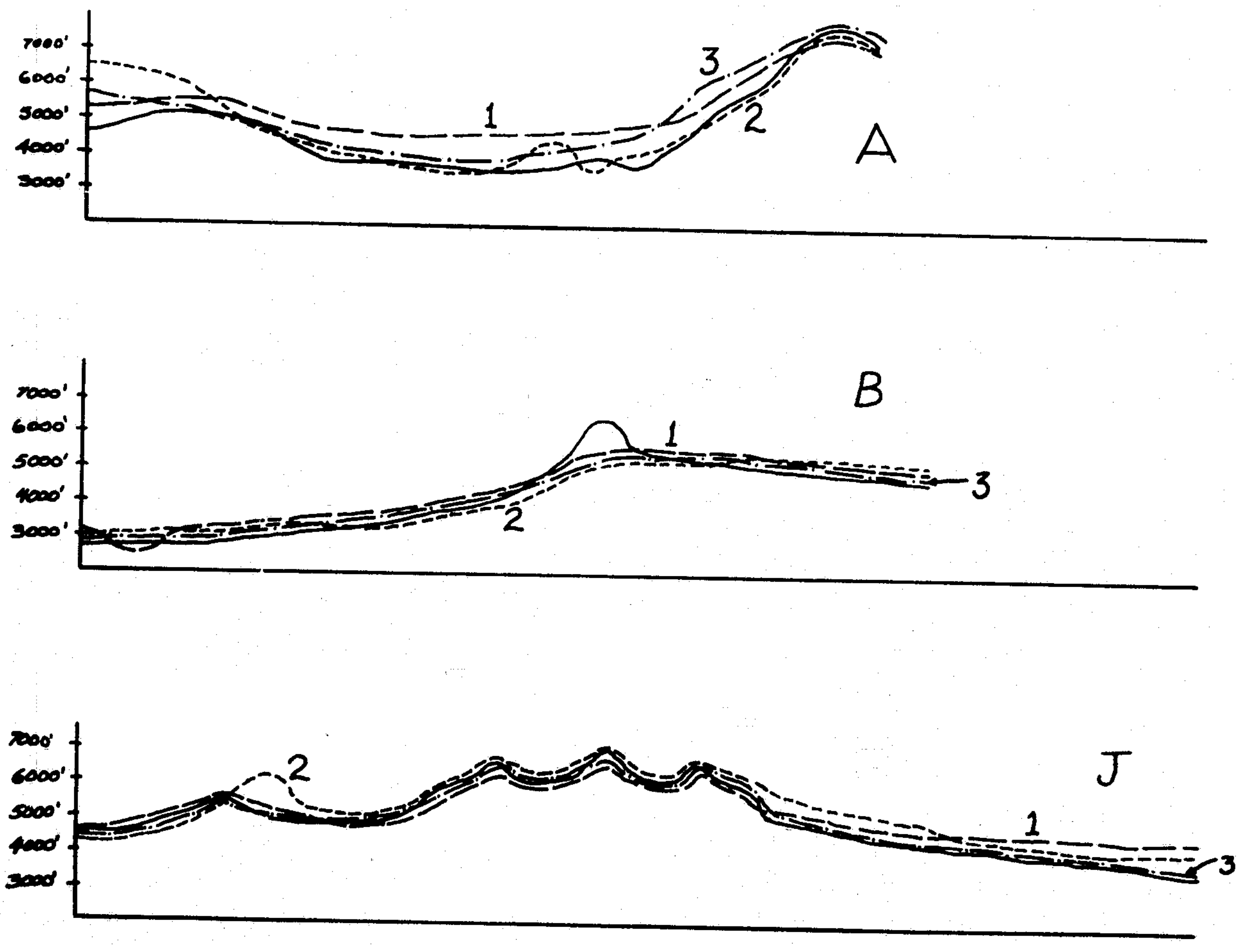


Figure 5-1. Interpretation of elevation along transects on ERTS-1 imagery. Results from interpreters 1, 2, and 3 are plotted in conjunction with the plot (solid line) which shows the true elevational transect. (On inch along the horizontal axis equals four miles on the ground.)

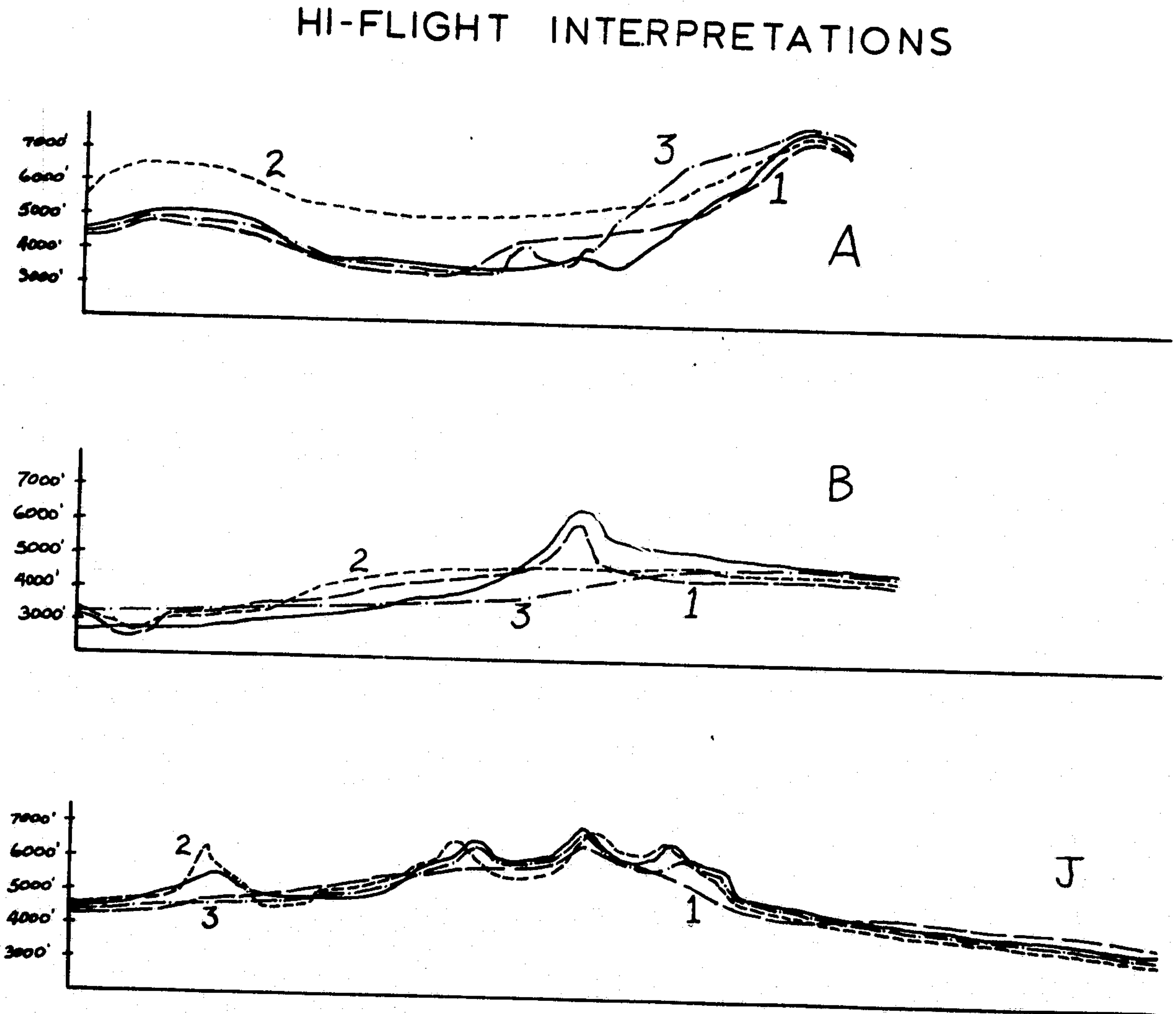


Figure 5-2. Interpretation of elevation along transects on high altitude aerial photography (flight altitude ca. 65,000' msl). Results from interpreters 1, 2, and 3 are plotted in conjunction with the plot (solid line) which shows the true elevational transect. (One inch along the horizontal axis equals four miles on the ground.)

high sun angle stereoscopic interpretation of ERTS imagery. This would determine if the relief accentuation afforded by low sun angle overcomes the disadvantage of not having stereo viewing.

Accordingly, an interpretation test was set up for an area for which ground truth was not known by the interpreter. The area chosen is situated in southern Maricopa County, Arizona, east of Gila Bend and containing Rainbow Valley. ERTS imagery used for the high sun angle stereoscopic interpretation test was the Mesa frame of 23 August 1972 (NASA ERTS 1031-17325) and the Gila Bend frame of 24 August 1972 (NASA ERTS 1032-17382). The elevation angle of the sun over the test area on those dates of imagery was 56^{o}. The ERTS imagery used for the low sun angle monoscopic interpretation test was the Mesa frame of 21 November 1972 (NASA ERTS 1121-17333) on which date the elevation angle of the sun was 31^{o}. A 25^{o} difference in sun elevation angle was noted between the two dates of imagery. Those ERTS frames were chosen on account of their availability, clear coverage, selection of relief forms, and relative lack of knowledge of the ground truth by the interpreter. MSS Band 5 was used for the tests. Interpretation materials were prepared at an approximate scale of 1:500,000. A study area was chosen consisting of most of the overlap area between the Mesa and Gila Bend frames. This study area covered an area having dimensions of approximately 35 by 50 miles (56 by 80 km).

The low sun angle imagery of 21 November 1972 was interpreted first, monoscopically. An attempt was made to map the macrorelief solely on the basis of the appearance of the terrain as it was imaged on the print. The test area was mapped as accurately as practicable. The high sun angle imagery of 23 and 24 August was interpreted, stereoscopically, one month later. The reasoning behind the time delay was to allow the interpreter time to forget the identification of the delineations. After the stereoscopic interpretations, a "ground truth" map was compiled from 1:62,500 USGS topographic maps. Results of each of the interpretation tests were compared to the ground truth map using a geometric dot grid as a sampling scheme. Ninety samples were used.

Results of the interpretation test comparisons are shown on Table 5-2. The percent accurate interpretations are shown along the bottom and right

Table 5-2. Macrorelief interpretation with high sun angle stereoscopic and low sun angle monoscopic viewing.

High Sun Angle Stereoscopic Interpretation Results

		Identifications from topographic maps						Total interpreted	# Type II errors	% Correct
		1.1	1.2	2.1	2.2	3	4			
Interpretations from ERTS-1 imagery	1.1	33	8	0	2	0	0	43	10	77
	1.2	12	4	0	2	0	0	18	14	22
	2.1	0	0	0	0	1	0	1	1	0
	2.2	0	1	0	1	0	0	2	1	50
	3	0	0	0	0	23	0	23	0	100
	4	0	0	0	0	0	3	3	0	100
Total in sample		45	13	0	5	24	3	90	26	71
# Type I errors		12	9	0	4	1	0	26		
% Correct		73	31	-	20	96	100	71		

Low Sun Angle Monoscopic Interpretation Results

		Identifications from topographic maps						Total interpreted	# Type II errors	% Correct
		1.1	1.2	2.1	2.2	3	4			
Interpretations from ERTS-1 imagery	1.1	14	4	0	0	0	0	18	4	78
	1.2	20	3	0	4	0	0	27	24	11
	2.1	0	0	0	0	0	0	0	0	--
	2.2	11	6	0	1	0	0	18	17	6
	3	0	0	0	0	24	0	24	0	100
	4	0	0	0	0	0	3	3	0	100
Total in sample		45	13	0	5	24	3	90	45	50
# Type I errors		31	10	0	4	0	0	45		
% Correct		31	23	-	20	100	100	50		

hand edges. Numbers of Type I and Type II errors are given in the next row up or next column over. Type I errors are considered to be errors of omission. They are errors caused when a given sample point should have been classified one way but was not. Type II errors are considered to be errors of commission resulting from classifying a sample point one way when it should not have been.

It can quickly be noted that high sun angle stereoscopic interpretation of ERTS imagery is more accurate in identifying macrorelief than low sun angle monoscopic interpretation - 71 percent and 50 percent accuracy, respectively. It must be remembered, though, that "accuracy" in these cases refers to the ground truth map as delineated and identified from topographic maps.

The table indicates the relative accuracy of identifying individual macrorelief types. The ground truth macrorelief classes 1.1, 1.2, and 2.2, were poorly interpreted on the low sun angle imagery (less than 1/3 of the identifications were correct). The ground truth classes 1.2 and 2.2 were poorly identified on the high sun angle interpretation test (also less than 1/3 accurate identifications). Images that were identified as 1.1, 3, and 4 on the low sun angle imagery were accurately identified (78, 100, and 100 percent, respectively). Concomitantly, the same interpretations on the high sun angle interpretations were accurately made (77, 96, and 100 percent, respectively). The high sun angle interpretation identified more images in class 1.1 than did the low sun angle interpretation. Both modes of interpretation were, therefore, highly successful in accurately identifying hilly and mountainous terrain. This accuracy might be a reflection of the sharp transition between hilly or mountainous terrain and flat planar surfaces. That feature of terrain diversification is characteristic of most arid regions.

It appears, therefore, that from the basis of this preliminary interpretation comparison test, that low sun angle monoscopic interpretation of macrorelief is not as accurate as high sun angle stereoscopic interpretation for relatively flat topography.

Interpretation of Macrorelief on Apollo 6 Photography

During the summer of 1970, field work was conducted by the investigator in the study area. Among the results of that field work was the compilation of a ground-truth map delineating the study area according to macrorelief classes. This map was constructed at a scale of 1:250,000 using U.S. Geological Survey topographic sheets as a base. This ground truth map was next generalized and plotted on the Apollo 6 frame AS-6-1442.

The macrorelief legend was adapted for use as an interpretation key so that the classes might be accurately delineated on the Apollo 6 frame. This adaptation was intended to enable experimental interpreters to understand the legend system and hopefully to reach the right interpretive decision. Six people, all having had experience with photo interpretation but having varying degrees of acquaintance with the study area, with space photography, and with the macrorelief legend system, were selected to delineate the classes. The interpreters were given the same written instructions for making the delineations. In addition, an area identified by the investigator as being representative of each of the classes was circled outside the study area on frame AS-6-1443 and given to the interpreters.

The interpreters used frames AS-6-1441, AS-6-1442, and AS-6-1443 to insure full stereo coverage. They all used magnifying binocular stereoscopes. Care was taken to insure that there was no discussion among interpreters and that no extra information was given to any parricular interpreter. In this way, it was hoped that results would be independent. The length of time required for each interpreter to complete his task was recorded to give us an idea of the time required for such tasks. One of the purposes was to evaluate interpretation accuracy when working without group training and to discover the kinds of interpretation problems that would need emphasis in subsequent training sessions.

Results

Data on the completed maps were compiled by determining the areas of each delineation with an electric area calculator. The delineations were summed and the percent area of each class charted. The results of the six interpretation maps are illustrated and compared with the ground truth data on Table 5-3. Also included in that table are the raw summed results of the relatively flat land categories (1a, 1b, 2a, and 2b) and

Table 5-3. Interpretation results.

Percent total area in following classes:

		Relatively flat topography				Hilly-mountainous	
		1a	1b	2a	2b	3	4
Interpreters	1	35	3	20	17	14	11
	2	30	17	10	16	22	5
	3	9	24	0	41	10	16
	4	20	42	2	17	15	4
	5	5	38	0	31	15	11
	6	9	29	7	29	12	14
Ground truth		25	13	<1	28	26	7

				Alteration on account of principal obviated error (see text)	
		Relatively flat topography	Hilly or mountainous	Relatively flat topography	Hilly or mountainous
Interpreters	1	75	25	68	32
	2	73	27	66	34
	3	74	26	67	33
	4	81	19	74	26
	5	74	26	67	33
	6	74	26	67	33
Ground truth		67	33	67	33

the hilly and mountainous categories (3 and 4). In addition, an obviated error has been compensated for by adding or subtracting, as the case may be, 7 percent from the results.

Summarizing the actual macrorelief of the study area, it can be seen that about 25 percent is essentially smooth (Willcox Playa falls into that category) and 41 percent of the area belongs to the remainder of the relatively flat land categories (1b, 2a, and 2b). Most of that land represents dissected planar surfaces. It is interesting to note that less than 1 percent of the area is rolling topography not developed from a planar surface. Just over 25 percent of the study area is strongly hilly while the remainder, approximately 7 percent of the study area, can be considered mountainous land.

The interpreters varied quite widely amongst themselves in delineating the macrorelief and, at first glance, the results seem quite unsatisfactory. Principal errors occurred where very shallow drainage systems have a strongly contrasting vegetation associated with them than as found on the interfluves. This pattern suggests much rougher topography. Many interpreters had difficulty differentiating classes within the two principal categories. If the data of the individual classes are compiled in the two categories, the deviation among interpreters is not great (see Table 5-3). In one large area just west of the Whetstone Mountains, in the center of the study area, a bajada is dissected to such a degree that it falls into the "3" class. That area plus one other similar situation comprises 7 percent of the study area. Those dissected bajadas appeared on the imagery to belong to the "2b" class. If that obviated error is accounted for, the results among interpreters compared to the ground truth data are remarkably similar. From the results, it can clearly be seen that the interpretations of the macrorelief of the study area differed quite widely in terms of areal percentage of the classes. However, the results are quite similar when only the two major categories of relatively flat lands and hilly/mountainous terrain are compared. When the individual classes are compared, it must be remembered that errors of commission and omission appear to be twice as great. Macrorelief interpretation on space photography is a relatively subjective process. It is therefore essential, in lieu of the research reported in this section, to make the instructions given to the photo interpreters more clear.

In summary, we accomplished four things in this study:

(1) We adapted the resource analysis symbolic mapping legend to geomorphic considerations inherent in southern Arizona.

(2) We constructed an accurate macrorelief map for the study area on AS-6-1442.

(3) We discovered that photo interpreters exhibited a moderate variance in mapping the macrorelief from a written set of instructions.

(4) We identified training problems in the interpretation process.

CHAPTER 6

SEASONAL VEGETATION CHANGE DETECTION
OBJECTIVES 4 AND 5

INTRODUCTION

A plant's growth and development involve periodic biological changes which in a year's time constitute its phenology. Phenological phenomena may include foliation, stem elongation, blossoming, fruiting, and leaf senescence. The order in which these developments occur may be characteristic of a species or a group of species. The timing of developments may vary from year to year due to annual climatic variations. Thus, the sequence of change may differ among plant species, as well as the time of year when an analogous change occurs. However, for any one species, the sequence may remain fairly constant with timing subject to local climatic conditions.

Foliation, dropping of leaves, and retention of green leaves or needles through a year are some of the more visible phenological phenomena in plants. Plants in leaf are usually predominately green, and those without leaves are the color of their stems and branches. These colors are manifestations of the various spectral reflectivities plants may exhibit. They can be observed and are usually easily recorded with a camera and film, which provides the opportunity to monitor some changes of plant spectral reflectivity.

The following thoughts are pertinent to a study of plant phenological phenomena in relation to remote sensing with synoptic imagery: 1. Natural vegetation types are usually a mixture of plant species, rather than monospecific; 2. Plant cover of the ground varies within and among vegetation types and can, therefore, vary from one location to another; 3. Individual plants are not usually discernable in the imagery; 4. The smallest portion of the landscape that can be resolved in the imagery could include plants, soil, gravel, stones, rocks, litter, animals, water, and man-made objects; 5. Spectral signatures (reflected and emitted electromagnetic energy) can be an integration of energy from some or all of the landscape components; 6. At some locations, the spectral signature is primarily from plants, and may provide an indication of the phenological status of those plants; 7. Each stage of annual development (phenological status) may have a unique spectral signature; 8. The integrated radiant energy from a vegetation type observed at specific stages of annual development may or may not show a definite pattern of change which can be found repeated annually and spatially wherever that type occurs; 9. The degree to which a definite pattern can exist may depend on such parameters as the heterogeniety of the species mixture which constitutes the vegetation type, the growth form, and ground cover exhibited by those species, and the phenology of each.

Consideration of the foregoing discussions of multispectral, synoptic, and repetitive remote sensing, plant phenology, and the inherent variation in natural vegetation raised the following two questions: 1. Can vegetation types be characterized in terms of phenological patterns of change detected with multidate remote sensing? and 2. Can apparent phenological patterns be utilized for stratifying synoptic, multidate remotely sensed imagery? This investigation explored the answers to those questions, and included the following: 1. Observation of selected plant species to determine patterns of phenological changes, particularly those changes associated with leaf development and senescence; and 2. Analysis of ERTS-1 imagery for phenological pattern recognition and image stratification technique.

If both of these questions can be answered in the affirmative, then the opportunity may exist to monitor variations in spectral reflectivity, distinguish patterns of change that can be related to plant phenology, and to utilize this capability in natural vegetation inventory. If vegetation stands of the same type are found to exhibit similarly appearing phenological patterns on multidate imagery, then the detection of patterns could be used to delimit areas of the imagery which represent unique groups of vegetation types. The optimum stratification would occur if (a) the multidate images of stands of one vegetation type were quite similar and therefore tended to fall into a few or a single image class; (b) if the images of closely related vegetation types were similar; and (c) if the images of distantly related or unrelated vegetation types were quite dissimilar.

METHODS

Field Data Collection for Plant Phenology

Phenological data were collected on 14 dates between April, 1969, and March, 1971. Nine people contributed to the effort at various times. Usually, a ground photograph was obtained, accompanied by a plant species list and notes pertaining to the state of development of leaves and flowers when present. Those notes were recorded with the symbols present in Figure 6-1.

On some of the dates, only a photograph was acquired. Each was interpreted for the required phenological information. Only the more prominent species at each location were considered. Initially, 27 locations were visited. Seventeen were repeatedly visited in dates in 1969; of those, nine were continued through the 1970 and 1971 sampling periods. Locations that were eliminated were either essentially duplicatory of others or were agricultural fields. From various combinations of 17 naturally vegetated locations and 14 dates, 152 ground checks were made (Tables 6-1 and 6-2). Phenolgoical notes were gathered for 47 species.

The field data were tabulated in chronological order to determine temporal patterns of phenological development for species.

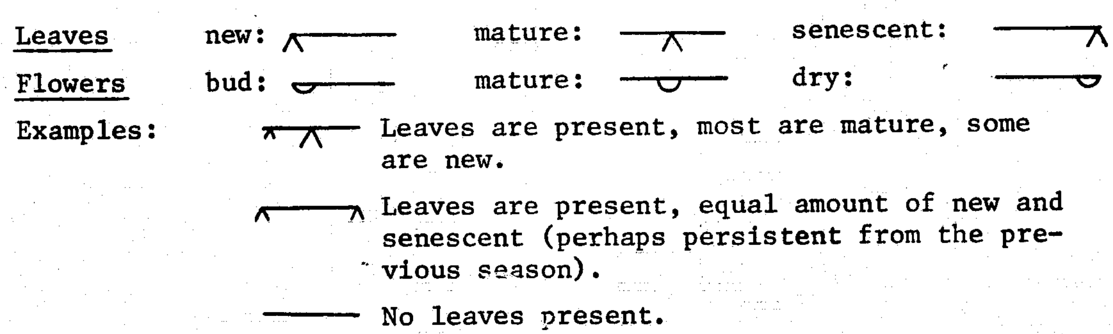


Figure 6-1. Symbols for recording simple observations of plant phenological development

Table 6-1. Township and Range grid locations and elevation for plant phenology field checks.

Stop No.		Elevation Meters	Feet
1.	T.16 S., R.16 E., Sec 21 NW¼ SW¼	998	3275
2.	T.16 S., R.16 E., Sec 27 SE¼ SE¼	1050	3445
3.	T.17 S., R.17 E., Sec 1 NE¼ SW¼	1097	3600
4.	T.17 S., R.19 E., Sec 18 NE¼ NE¼	1280	4200
5.	T.17 S., R.21 E., Sec 5 SW¼ SW¼	1152	3780
6.	T.16 S., R.22 E., Sec 15 SW¼ SW¼	1425	4675
7.	T.16 S., R.22 E., Sec 14 SE¼ SE¼	1440	4725
8.	T.16 S., R.22 E., Sec 24 NW¼ NE¼	1425	4675
9.	T.16 S., R.22 E., Sec 12 NE¼ SE¼	1433	4700
10.	T.15 S., R.23 E., Sec 30 SW¼ SE¼	1433	4700
11.	T.15 S., R.23 E., Sec 9 SE¼ NE¼	1349	4425
12.	T.21 S., R.21 E., Sec 11 SW¼ SE¼	1232	4040
13.	T.21 S., R.21 E., Sec 28 NE¼ SW¼	1311	4300
14.	T.21 S., R.20 E., Sec 21 SE¼ SW¼	1387	4550
15.	T.20 S., R.19 E., Sec 17 NE¼ NE¼	1433	4700
16.	T.20 S., R.18 E., Sec 4 SE¼ NE¼	1501	4925
17.	T.19 S., R.16 E., Sec 26 SE¼ NE¼	1463	4800

Table 6-2. Dates of field data collection for plant phenological development.

<u>Months: January - November</u>

	J	F	M	A	M	J	J	A	S	O	N
1969				23	21		1	30	30	30	
1970				23	21	10	24				14
1971	22	12	4								

Catalog of ERTS-1 Imagery of the Study Area

The first date of ERTS-1 imagery acquired of the study area was on 22 Aug 1972. Eighteen additional dates of imagery were available for this study.

Information for the 19 dates of imagery is given in Table 6-3. Snow cover was quite noticeably present on the areas of interest on 26 March 1973.

Table 6-3. ERTS-1 imagery acquired of the study area from 22 August 1972 to 12 July 1973.

Scene ID Number	Date	Sun Elev.	Sun Azimuth 1/	Clouds over areas of interest
1030-17271	22 Aug 72	56°	120°	no
1048-17272	9 Sep	52	129	yes
1066-17272	27 Sep	48	138	yes
1084-17274	15 Oct	43	145	yes
1102-17280	2 Nov	37	149	no
1120-17281	20 Nov	33	151	yes
1138-17281	8 Dec	29	151	yes
1156-17280	26 Dec	28	149	no
1174-17275	13 Jan 73	29	146	no
1192-17281	31 Jan	32	143	yes
1210-17282	18 Feb	36	139	no
1228-17283	8 Mar	42	135	yes
1246-17283	26 Mar	49	130	no 2/
1264-17283	13 Apr	55	124	no
1282-17283	1 May	59	116	yes
1300-17281	19 May	62	109	no
1318-17280	6 Jun	63	102	yes
1336-17275	24 Jun	62	100	yes
1354-17274	12 Jul	61	102	yes

1/ Measured eastward from north.

2/ Snow cover on the areas of interest precluded the use of this date of imagery for the desired purposes in much the same way that cloud cover did on several other dates.

Multidate Radiance Determinations for Plant Phenological Classes

Of the nineteen dates of imagery listed in Table 6-3, seven could be considered for this study. Other dates were rejected due to cloud or snow cover over areas of interest. Three dates were selected for analysis: 22 August and 2 November, 1972; and 13 April 1973. This selection was based on an evaluation of the photographic formats of ERTS data. Known examples of the three phenological classes - evergreen (EVGN), winter dormant (WIND), and winter-spring dormant (WISP) - were evidently in leaf at the time of the 22 August 1972 imagery (see "Results and Discussion, Plant Phenology" in this chapter for explanation of phenological classes). Only EVGN showed any evidence of having green foliage on 2 November 1973. On 13 April 1973, both the EVGN and WIND vegetation examples showed evidence of green foliage, however, the latter was probably in an early stage of foliar development. Thus, these three dates of imagery depicted the vegetation of the three phenological classes in the three possible combinations of being in leaf or not in leaf.

Computer compatible tapes (CCT's) of ERTS-1 MSS data for the three dates selected for phenological pattern analysis, plus one additional tape for 15 October 1972 were obtained. Facilities at the Center for Remote Sensing Research (CRSR), University of California, Berkeley, were used for extracting selected portions of the data from the tapes and for portions of the analyses.

A color television console accompanied by appropriate hardware and computer software permitted rapid display of the ERTS-1 data for visual assessment. By displaying three of the four MSS bands with different colors it was possible to recognize on the screen patterns of color representing drainageways, mountainous terrain, shaded and insolated slopes, and associated vegetation. Some cultural features as city streets, airport runways, railroad lines, highways, and mine tailings were also discernable. By displaying bands from different dates, it was possible to superimpose those patterns representing landscape features and in that manner identify resolution elements from different dates of data that very closely represented the same area of ground. The three dates of data selected for phenological pattern analysis were overlaid using that technique, thus producing a three date multidate tape. Each area was then represented by 12 channels of data: four bands from each of three dates.

By associating the color patterns on the television screen with the photographic images of 1:120,000 color infrared aerial photography, blocks of resolution elements were specified which represented known portions of the landscape. A computer program was them employed to extract the radiance data for those blocks. In this way, the spectral radiance was determined for vegetation stands progressing through the annual sequences of phenological change typical of each of the three recognized phenological pattern classes. The vegetation stands selected were considered to exhibit the ultimate expression of phenological change representative of the three pattern classes. The chosen stands satisfied the following criteria: 1. vegetation ground cover was close to 100 percent - high enough to minimize the spectral signal from subjects other than plants; 2. simple and homogeneous with regard to species composition; and 3. homogeneous with regard to phenological development of the species. The stands that were finally selected were inspected by at least two of the following methods: (a) from a helicopter; (b) on the ground; and (c) on aerial photography.

The selected stands were:

(a) Near the tops of the highest peaks in the Santa Rita Mountains, representing the evergreen phenological pattern class (EVGN) and belonging to the vegetation type Pinus, with or without P. cembroides, often with Pseudotsuga menziesii, Quercus hypoleucoides, and Q. gambelii.

(b) On the flood plain of the San Pedro River between the towns of St. David and Benson, Arizona, representing the winter dormant phenological pattern class (WIND) and belonging to the type Prosopis juliflora bosque.

(c) In the drainage bottom of Government Draw (near Tombstone, Arizona), representing the winter-spring dormant phenological pattern class (WISP), and belonging to the type Hilaria mutica and Prosopis juliflora.

In addition, a fourth subject class named TAIL was also represented. This class was established to represent a "no change" subject, and was constituted by three piles of copper mine tailings. Radiance data were extracted for the three piles of tailings, however, data for only one were used for most of the analyses. A study of aerial photography acquired over the mining area on 1 August 1972, 5 September 1972, 12 December 1972, 20 March 1973, and 19 April 1973[6-1/] revealed that only one of the three piles remained unchanged and of stable appearance throughout the sampling period. The images in the 1:120,000 color infrared photography showed that one "pile" was actually two completely enclosed settling ponds. Compared to the other two piles, the settling pond's bottoms were extremely highly reflective in late summer and the following spring, but the December photography showed a darkened surface presumably due to moisture accumulation. The other two "piles" were, in fact, tailing piles with very broad, horizontal tops. They supported little, if any, vegetation and were, therefore, not subject to changes of appearance due to foliar developments. However, during the fall of 1972, a substantial amount of new material was added to the east and north sides of one pile; the new material appeared more highly reflective than the old as represented on the photography. Consequently, only one of the three provided a suitable surface to represent "no change." It evidently retained highly consistent spectral reflectance over the dates of concern.

Details pertaining to the location, slope, aspect, etc., of the ground areas chosen to represent the phenological and "no change" classes are available in Appendix E. The EVGN class was represented by four ground areas represented by 361, 16, 135, and 35 ERTS resolution elements. The EVGN class was, therefore, represented by 547 samples. Similar specifics for the other three classes were:

WIND: Five ground areas of 9, 6, 14, 24, and 12 resolution elements for 65 samples.

WISP: Five ground areas of 30, 28, 16, 56, and 40 resolution elements for 170 samples.

TAIL: Three ground areas of 85, 56, and 12 resolution elements for 153 samples. The ground area giving 56 samples was used to represent the class for most analyses except those accomplished with the CALSCAN/CLASSIFY subprogram. Data from all three areas were used with that subprogram. This variation in procedure probably had no effect on results because in either case the TAIL class was quite unlike any of the other three classes.

6-1/ NASA Ames Research Center aircraft mission numbers: 72-129, 72-154, 72-180, 72-213, 73-049, and 73-059, respectively.

The radiance data extracted for these blocks of resolution elements defined the spectral signature for the ground subjects represented by the blocks of data. A signature based on ERTS-1 data consisted of the four radiance levels by the MSS detectors. This concept was expanded to include radiance data gathered on several dates. The multidate spectral signature characterized a subject in terms of radiance levels in specific bands of wavelengths on specific dates (or at a specific stage of development or condition of the subject).

MSS Data Classification Schemes

The schemes utilized to classify the MSS data were of two types. One group of schemes was based on the classification of values at given points in time. The values were MSS CCT counts, and ratios of those values (e.g., MSS 5 values ÷ MSS 7 values). The points in time were the moments of ERTS-1 overpass on the consecutive dates sampled in August, November, and April. The other group of schemes based classification on the manner in which those values (counts or ratios of counts) varied among the points in time.

Radiance Classification: MSS CCT counts selected from the three dates of ERTS-1 data were classified by using the CALSCAN automatic image analysis computer program which was available at the Center for Remote Sensing Research, University of California, Berkeley (Center for Remote Sensing Research, 1973). That program was a version of the discriminant analysis program developed at the Laboratory for Applications of Remote Sensing (LARS), Purdue University, West Lafayette, Indiana. Description of the program and the theory associated with it were provided in the Laboratory for Applications of Remote Sensing (1970), Landgrebe (1973), and Swain (1972). A pattern (response values constituting the spectral signature of an area of the earth's surface) was assigned to a class according to which pattern class Gausian density function had the largest value (or maximum likelihood) for that set of response values. EVGN, WIND, WISP, and TAIL were, for example, pattern classes. The density functions for each of these classes were developed from the response values from the resolution elements in the ground areas sampled to represent those phenological and "no change" classes. Density functions can be calculated with data from all MSS spectral bands on all dates. In practice, the number of bands used is usually less than the total available, and limited to those bands which appear to be most useful for making the desired class discriminations. The selection of bands was accomplished with the SELECT subprogram of CALSCAN which utilized a measure known as divergence to provide an indication of separability of classes within each band.

Ratios of response values were also used for classifying spectral data from the given points in time. Two types of ratios were utilized: (1) MSS 5 values ÷ MSS 7 values, the 5/7 or red/IR ratio; and (2) (7-5) ÷ (7+5), sometimes called the "vegetation index." These bands were chosen for ratioing because of the high absorption and reflection in wavelengths in Bands 5 and 7, respectively, by green vegetation, and the documented sensitivity of wavelengths in these bands to changes in ground cover, biomass, and plant maturity in specific cases (Colwell, 1973; Knipling, 1970). Tucker, Miller, and Pearson (1973) achieved good correlation between the ratio of reflectance of 0.68μ and 0.8μ and the green fraction of dry biomass in prairie grassland, and Rouse _et_ _al_. (1973) found a good relationship between green biomass and a square root transformation of the vegetation index for data for a relatively uniform grassland site. Also, ratio transformations of multispectral scanner data have proven useful for reducing variations in levels of irradiance, although ratios involving adjacent spectral bands were used (Kriegler, _et_ _al_., 1969; Smedes, Spencer, and Thomson, 1971).

Ratioed data were classified using the Euclidean distance measure (Sokal and Sneath, 1963):

$$\Delta_{jk} = \left[\sum_{i=1}^{n} (X_{ij} - X_{ik})^2 \right]^{1/2}$$

where: Δ_{jk} = distance between two points in n-dimensional space,

X_{ij} = is the X_i standard for class j,

X_{ik} = is the X_i value for observation k, and

n = the number of comparisons made between an observation and a class.

If 5/7 ratios were being classified, then each class had three standards: a 5/7 value for August, November, and April, calculated from class means. The comparable values were calculated for each observation; an observation was an ERTS-1 MSS resolution element or small field of elements with associated radiance data in four spectral bands from three dates. A distance value was calculated between each observation and the classes EVGN, WIND, WISP, and TAIL; the observation was assigned to that class from which the distance was the least.

Classification of (7-5) ÷ (7+5) was handled in a like manner.

Change Evaluation: Given three dates of data, three changes may be considered: between the first and second dates, between the second and third dates, and between the first and third dates. The actual changes may be an increase, decrease, or no change in the values being compared. An idealization of the possible combinations of changes between the first and second, and second and third dates are shown in Figure 6-2.

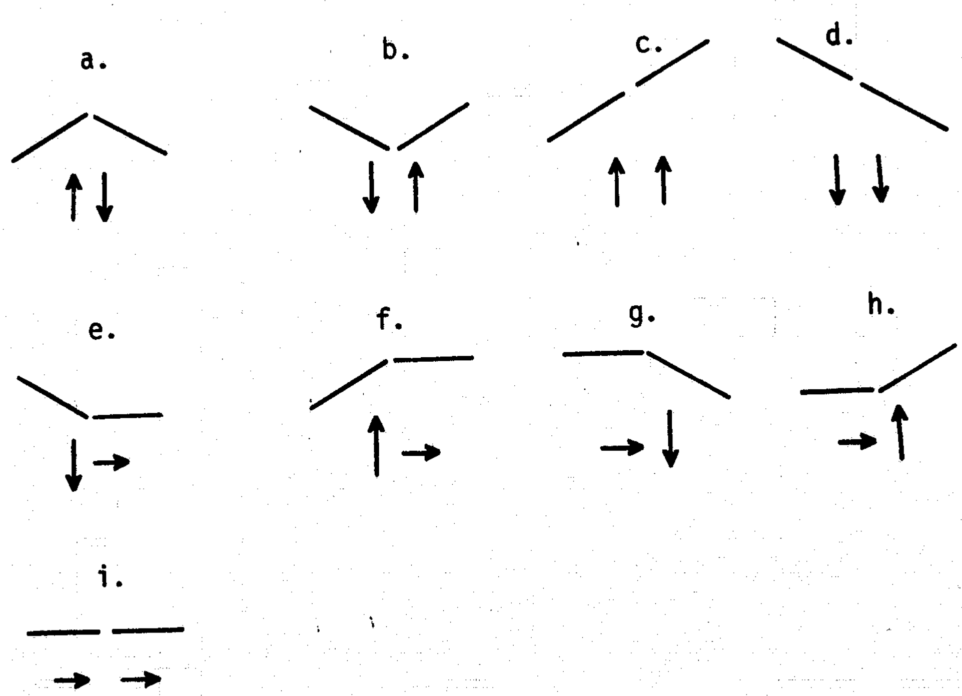


Figure 6-2. Patterns of radiance variation among three dates. These idealized patterns show increase (arrow up), decrease (arrow down), and no change (arrow across) of radiation between the first and second, and the second and third dates. A third change, between the first and third dates, is achieved by connecting the end points. Values of band ratios may follow these same patterns of change.

The patterns suggest one method of change evaluation, a qualitative method that considers only the direction of change.

A second approach utilized a quantitative measure. Possibilities included (a) actual difference, plus or minus; (b) percent change, plus or minus; and (c) change factor. The last was used in this study for quantitative change evaluations. The change factor for a feature (band or band ratio) incidates its change in value from one date to the next. It is merely the ratio of the value on the second date over the value on the first. Classifications were based on two change factors (August to November, and November to April) and three change factors (the preceeding plus August to April).

Classification of Training Field Elements

The blocks of resolution elements chosen to represent the phenological and "no change" classes may be called training fields. This terminology results from their use for "training" the maximum likelihood classifier (CALSCAN discriminant analysis computer program). The several classification schemes discussed in the previous section were used for classifying the data from the training fields. This was done to provide an evaluation of the merits of the various schemes in producing correct classifications.

The three phenological classes and the "no change" class were represented by 17 blocks of resolution elements; 12 radiance variables, called features (MSS 4, 5, 6, and 7 counts from the three dates), were associated with each resolution element. The CALSCAN program was utilized to classify each element of each field. This classification utilized the "best six" features, as determined by the SELECT subroutine of CALSCAN, for discriminating the four classes. All other schemes (ratios of radiance values, change factors, direction of change) were used to classify the mean radiance (feature) values for each training field. The fields were characterized by the average values of their component parts, the resolution elements.

Stratification of an ERTS-1 Scene

The word "stratification" was used in this study to imply the process of partitioning the array of resolution elements into units that represented distinct subject classes. In this case, the classes were EVGN, WIND, WISP, and TAIL. Thus, a successful stratification would result in recognition of those portions of the landscape supporting evergreen, winter dormant, and winter-spring dormant vegetation, plus a fourth type of landscape supporting little or no vegetation.

Two areas of the region to the south and east of Tucson, Arizona, were chosen for the evaluation of stratification techniques. Those areas are outlined on an ERTS-1 scene in Figure 6-3. They were designated as the Canelo and Rincon grid areas and were known to contain extensive areas which supported vegetation representing the three phenological classes. The Canelo grid primarily contained WISP and EVGN; the Rincon grid, WIND and EVGN. These identifications were verified in the field, from aircraft, and through the interpretation of aerial and ERTS photography.

Several stratification strategies were investigated which utilized the classification schemes discussed earlier, two sets of class standards derived from different origins, and two methods of sampling the ERTS data. The classification schemes employed were: CALSCAN, MSS 5 ÷ MSS 7, Three 5/7 Change Factor, Direction of 5/7 Change, and Vegetation Index.

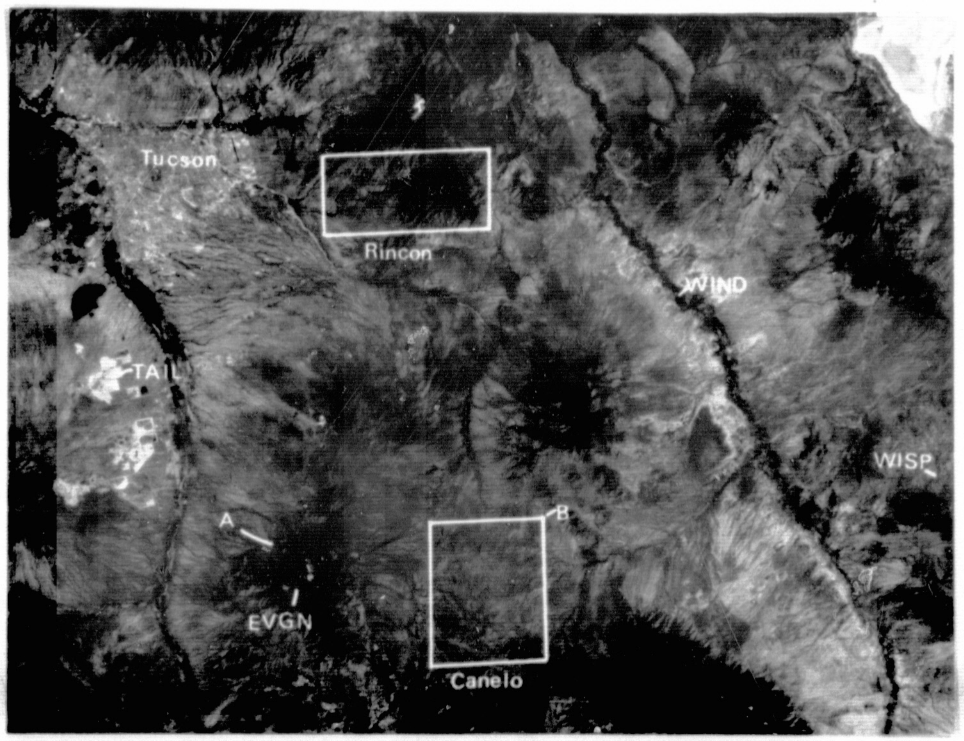


Figure 6-3. Portions of the ERTS-1 MSS scene 1264-17283 used for stratification testing.

One set of class standards was derived from the radiance values for the EVGN, WIND, WISP, and TAIL training classes (Table 6-4). These were the primary standards because they were based on the radiance from vegetation types which provided the best examples of the phenological classes. However, those vegetation types were relatively unique in that most of the vegetation in the study area was more heterogeneous and had considerably lower total vegetative ground cover. For this reason, an alternate set of class standards was derived from the evergreen and winter-spring dormant vegetation types of the Canelo grid, and from the winter dormant vegetation of the Rincon Grid (Table 6-5).

The Canelo area was represented by a grid of ERTS data consisting of 206 scan lines, each with 229 resolution elements. The Rincon grid was 131 lines by 382 elements. The total number of elements in the two grids was 47,174 and 50,042, respectively. Rather than to classify every element in achieving a stratification, a systematic sample was extracted from each grid. One sample consisted of four by four element fields (called grid fields) spaced at regular intervals throughout the grids.

Table 4. Radiance data for Primary standards.

	August		November		April	
Class	MSS 5	MSS 7	MSS 5	MSS 7	MSS 5	MSS 7
EVGN	15.96	17.64	10.55	13.16	15.42	15.06
WIND	22.42	24.29	15.88	8.89	31.14	18.89
WISP	24.20	27.38	24.08	13.84	46.57	21.32
TAIL	93.58	34.93	67.76	25.97	96.99	37.55

Table 5. Radiance data for Alternate standards.

	August		November		April	
Class	MSS 5	MSS 7	MSS 5	MSS 7	MSS 5	MSS 7
EVGN	31.67	21.32	20.93	13.43	40.25	20.79
WIND	45.16	24.27	31.45	16.80	45.19	24.77
WISP	36.47	22.34	26.28	13.63	44.17	21.37

Twenty-one lines and 21 elements separated each grid field; each field contained 16 elements and represented a ground area of approximately 6.4 ha. The Canelo grid was represented by an array of 90 fields; Rincon by 96 grid fields.

A second systematic subsample was extracted from the grids by taking every 25th element along every 25th line beginning with line one, element one, at the northwest corner of both grids. The elements thus defined were the northwest element of each of the 16 element blocks. This provided the same number fo fields per grid as before (90 and 96), except each grid field was only one element in size rather than 16 and represented 0.4 ha. of ground area (1.1 acres).

The 16-element grid fields provided a three percent sample of each of the grids. The single element grid fields provided a 0.2 percent sample of all the elements in each grid.

An acceptable stratification was judged primarily by whether each grid was partitioned into two major areas, and whether the major areas of each grid were correctly identified. This simply involved a visual assessment of each classification output. This procedure was chosen because the concept of "acceptability" was related to (1) the usefulness of the output for quickly producing a "map" on which the landscape was partitioned into phenologically distinct areas; and (2) similar areas were identified as being the same. Some amount of misclassification was acceptable if the output appeared to have utility. The percent correct and incorrect classifications were not as important as a successful blocking of grid fields in a pattern which approximated the known distribution of ground areas belonging to the EVGN, WIND, WISP, and TAIL classes.

Classification obtained with the use of the Primary standards could be interpreted in relation to temporal radiance patterns. These, in turn, were attributable to plant phenological changes occurring in dense, relavively homogeneous stands. The Alternate standards were derived from areas where the vegetation may have been heterogeneous and the percent of bare ground was high. There was a high percent of bare ground in the Rincon grid fields that were used for the WIND standards. There was usually a well developed herbaceous understory in those fields of the Canelo grid that were chosen to serve for the EVGN standards. The date to date variations in spectral signatures for those grid fields, therefore, could have been representing mixtures of phenological patterns and changes in the soil surface.

Vegetation Stand Classifications

Converting Density Measurements to MSS Counts: Computing time availability and the wide geographic distribution of the vegetation stands to be classified necessitated the use of a different method of data extraction than was used for the grid field classifications. The second method involved the determination of radiance values from densitometric measurement of the ERTS-1 MSS photographic reconstitutions. Those photographs were in positive transparency form with a scale of 1:1,000,000. The procedure was modified from instructions given in the ERTS-1 Data Users Handbook, Appendix F (National Aeronautics and Space Administration, 1972). A density measurement of a portion of the transparency was made with a Welch Densichron-One. This instrument measured the diffuse density to white light. A one-millimeter lucite aperture was used which meant that each measurement represented approximately 75 hectares of 185 acres on the ground. Each measurement was corrected by means of a calibrated step wedge, converted to a transmission value, and then converted to a scaled MSS sensor count by using a table such as the one given in Table 6-6.

The gray scale provided with each ERTS-1 MSS transparency is composed of 15 steps of progressively decreasing transmission. A "rise" was taken to be the change in transmission from one step to another. Rise values varied among pairs of steps, but their corresponding MSS count differences were constant. That count difference between steps was 4.5 counts. There were 15 steps, 14 rises between steps, and therefore 15 x 4.5 counts = 63 counts represented by the density range of the gray scale. To calculate the MSS count value which corresponded to a measured transmission value, the rise number and fractional rise corresponding to the transmission value were determined from the table and multiplied by 4.5 counts/rise. In practice, it was easier to expand the table to include an MSS count value for each consecutive transmission value calculated to the nearest tenth of a percent. A table was constructed for each date of ERTS-1 data being analyzed. Gray scale

Table 6-6. Percent transmission and corresponding MSS counts for 22 August 72, MSS 5 and 7.

Gray Scale Step	Corresponding MSS Count	Rise No.	% Transmission and rise values Band 5	rise	Band 7	rise
1	63.0		42.7		45.7	
2	58.5		43.2		47.3	
3	54.0		46.8		47.9	
4	49.5		45.7		49.0	
5	45.0		45.7		49.6	
6	40.5		43.2		47.9	
7	36.0		39.4		43.6	
8	31.5	8	36.3	3.1	38.9	4.7
9	27.0	7	32.7	3.6	35.5	3.4
10	22.5	6	29.5	3.2	31.3	4.2
11	18.0	5	23.4	6.1	25.7	5.6
12	13.5	4	17.8	5.6	18.2	7.5
13	9.0	3	10.4	7.4	10.4	7.8
14	4.5	2	2.8	7.6	2.7	7.7
15	0.0	1	0.7	2.1	0.6	2.1

steps one through six in Table 6-6 gave ambiguous transmission values. Had transmission values in the scene been encountered which exceeded 39.4 percent for Band 5 or 43.6 percent for Band 7, they would have been ignored because they would have been in the range of the ambiguous first six steps. This situation was not encountered. This reversal was only found associated with gray scales on the earlier dates of ERTS-1 imagery.

Densitometric Sampling of Vegetation Types: Eleven vegetation types were chosen for evaluating the tendencies among stands of the same type to exhibit similar multidate signatures. Two of the 11 were grouped and considered as one type; they were the two types characterized by *Mortonia scabrella*. The vegetation types were chosen to represent the three phenological classes and the variety of vegetation occurring within the study area. Stands from each type that were sampled with the densitometer were chosen by random number selection from the association tables that were constructed during the vegetation classification procedure. If the image containing a stand fell in an area of the photograph having a highly complex array of very small images, then that stand was rejected and the selection process went on to the next randomly selected stand. Only a few were rejected in this manner; this was done to minimize the possibility of partially including an incorrect image in the field of view of the densitometer. Ten stands for each vegetation type were sampled. That involved six measurements for each stand (MSS 5 and 7 from three dates). During the sampling process, it became evident that some of the stands could not be sampled on all three dates. This was due to snow cover and a shift in ground coverage by the successive ERTS scenes. Consequently, three of the vegetation types were represented by nine, rather than ten, stands.

Classification of Density Measurements: An MSS 5 ÷ MSS 7 ratio was calculated for each vegetation stand for each of the three dates. These were classified by using the 5/7 classification scheme with standard ratios derived from the Alternate standards. In order to utilize the 5/7 values based on digital data for classifying 5/7 values based on density measurements, it was necessary to determine the correlation between the digitally derived values and their corresponding densitometrically derived values.

From various portions of the study, there were available pairs of radiance measurements derived from the computer compatible tapes and the reconstituted photographs which represented, to greater and lesser degrees, the same ground area. The area sampled from the tape fell within that sampled on the on the photograph, the size of the former varied, the latter was fixed. There were 12, 12, and 10 pairs respectively for August, November, and April data. Two 5/7 ratios were calculated for each pair and linear regression analysis was used to determine the relation between the digital and density data. In this manner, a regression equation was established for data from each month. The equations were:

22 Aug 72: $y = .922x + .043$

2 Nov 72: $y = .855x + .154$

13 Apr 73: $y = .868x + .099$

The correlation coefficients were .99, .99, and .94, respectively. The standards used for classifying the densitometrically derived 5/7 values were converted from the Alternate standards for EVGN, WIND, and WISP, and the Primary standards for TAIL through the use of the regression equations. For example, the 5/7 Alternate standards for EVGN were substituted for "x" in the equations, and the equations were solved for "y" to provide the EVGN class standards for this classification.

RESULTS AND DISCUSSION

Plant Phenology

Temporal Patterns of Change: The 47 species or genera for which phenological information was gathered included five tree, 19 shrub, eight leaf or stem succulent, and 15 grass species. Of these, *Prosopis juliflora*, a deciduous, leguminous shrub commonly known as mesquite, was most ubiquitous. Data for this species are used in Figure 6-4 to demonstrate the temporal nature of a plant species' annual development, variations among sites within a year, and variations among years. *Prosopis juliflora* is not portrayed as typical of other species. However, other species displayed similar temporal patterns of development; most also underwent year to year variations in the timing of their development. During the first quarter of the year, mesquite may have a few dried leaves persisting from the previous year. New leaves may begin to develop early in the second quarter and individuals can have combinations of new and mature leaves during April-June. Mature foliage is retained through the third quarter, although leaves may begin to dry and turn light brown in early and mid summer due to drought, and again in September. Combinations of mature and senescent leaves may be present from September into November. Plant phenology check locations one, two, and three were the lowest in elevation. Leaf development had usually progressed further at these sites during early spring than at the other more elevated sites. Notes from one field check indicated the presence of new leaves in late July following the onset of summer rains. The frequency of occurrence of new leaves at that time of year needs corroboration.

Analysis of the phenology data indicated three classes to which species in the area could be assigned according to the presence of foliage at certain times of the year. The classes were: 1. those plants retaining green leaves or maintaining a relatively stable green appearance throughout the year - evergreen (EVGN); 2. those in which foliage growth occurs primarily in the spring - winter dormant (WIND); and

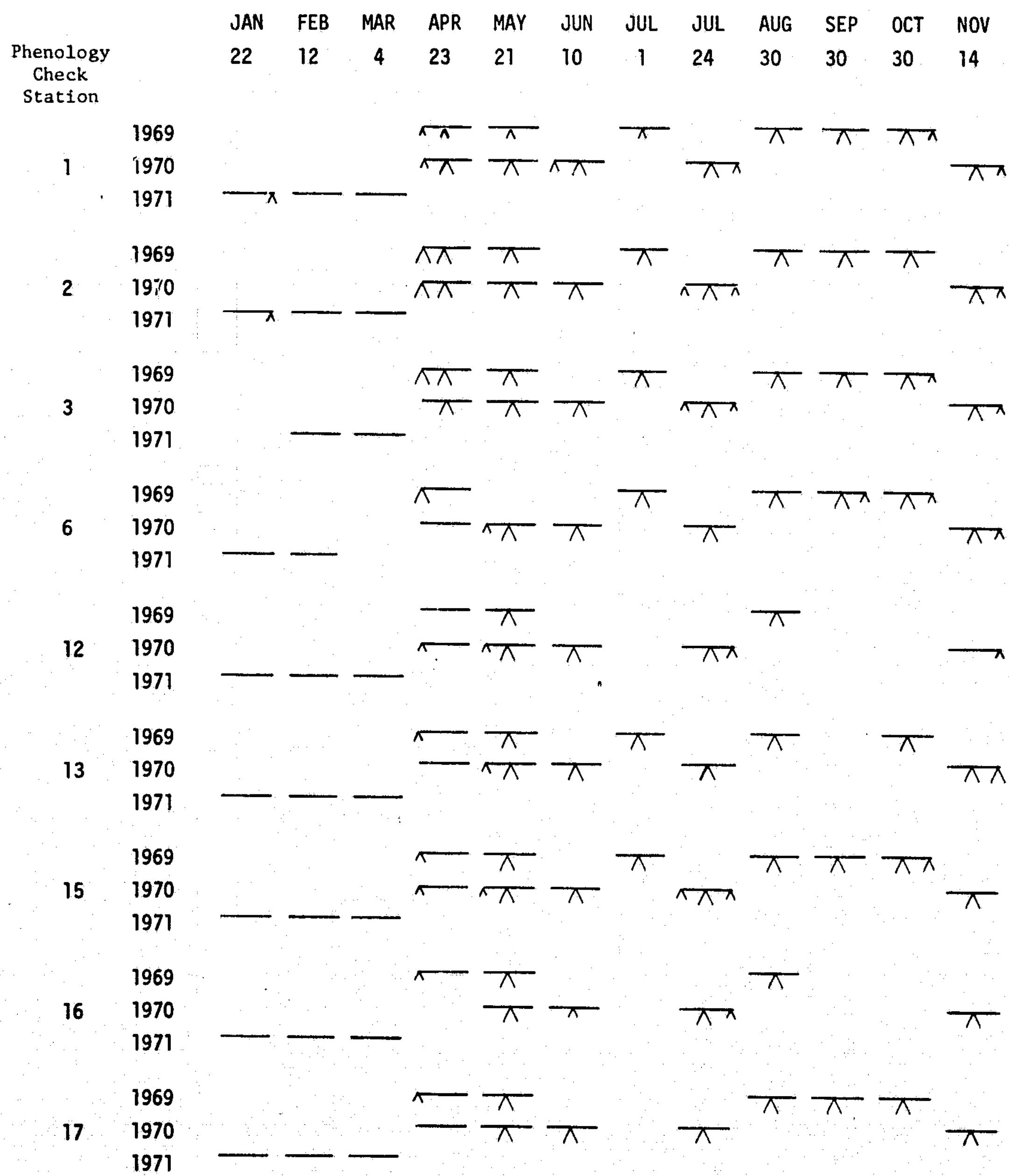


Figure 6-4. Foliage development and senescence for <u>Prosopis juliflora</u>.

3. those in which foliage growth occurs primarily in the summer - winter-spring dormant (WISP). Species and two genera representing each class are included in Figure 6-5 which summarized the data collected for each species or genus at all locations where it occurred, and for the portions of three years that field notes on phenology were taken.

Classification of Species by Phenological Criteria

The evergreen class includes conifers, several chaparral shrub species, and most of the oaks occurring in the study area. In the spring, both old and new leaves may be present, the old giving the plant a dull reddish or yellow-brown appearance. *Quercus oblongifolia* is a good example. *Larrea tridentata* (creosote bush), a desert shrub, has persistant leaves and is also included in this class. Plants of this species may undergo changes of leaf color from green to a yellow; the changes are apparently associated with drought. Leaf succulents (*Agave*, *Dasylirion*, *Nolina*, and *Yucca* species) are evergreens. The cacti are also placed in this class by virtue of the photosynthetic tissue present in their succulent stems.

The winter dormant species includes plants that are in leaf during the spring, summer, and early fall. The principle time for leaf development and growth is during the spring. This class includes some desert shrub species which leaf out in the spring, but may drop their leaves during a summer drought. They may leaf out again when moisture becomes available from the summer rains (e.g., *Cercidium microphyllum*). Species of *Sporobolus* occurring in drainages may put forth luxuriant growth in the spring.

The winter-spring dormant species may not actually be dormant in the spring. They are considered in this group because their dramatic change in appearance due to foliage development comes in mid- to late summer following the onset of the summer rains. Species of *Bouteloua*, *Aristida*, and *Hilaria* comprise the bulk of this group. One desert shrub, *Acacia vernicosa*, also fits this phenological pattern.

Year to year fluctuations of climatic factors, particularly precipitation, apparently can impose considerable variation in the timing of phenological events and the color of leaf material. Given the availability of sufficient moisture and appropriate temperatures, perennial grass species which usually grow in the summer, may put forth considerable

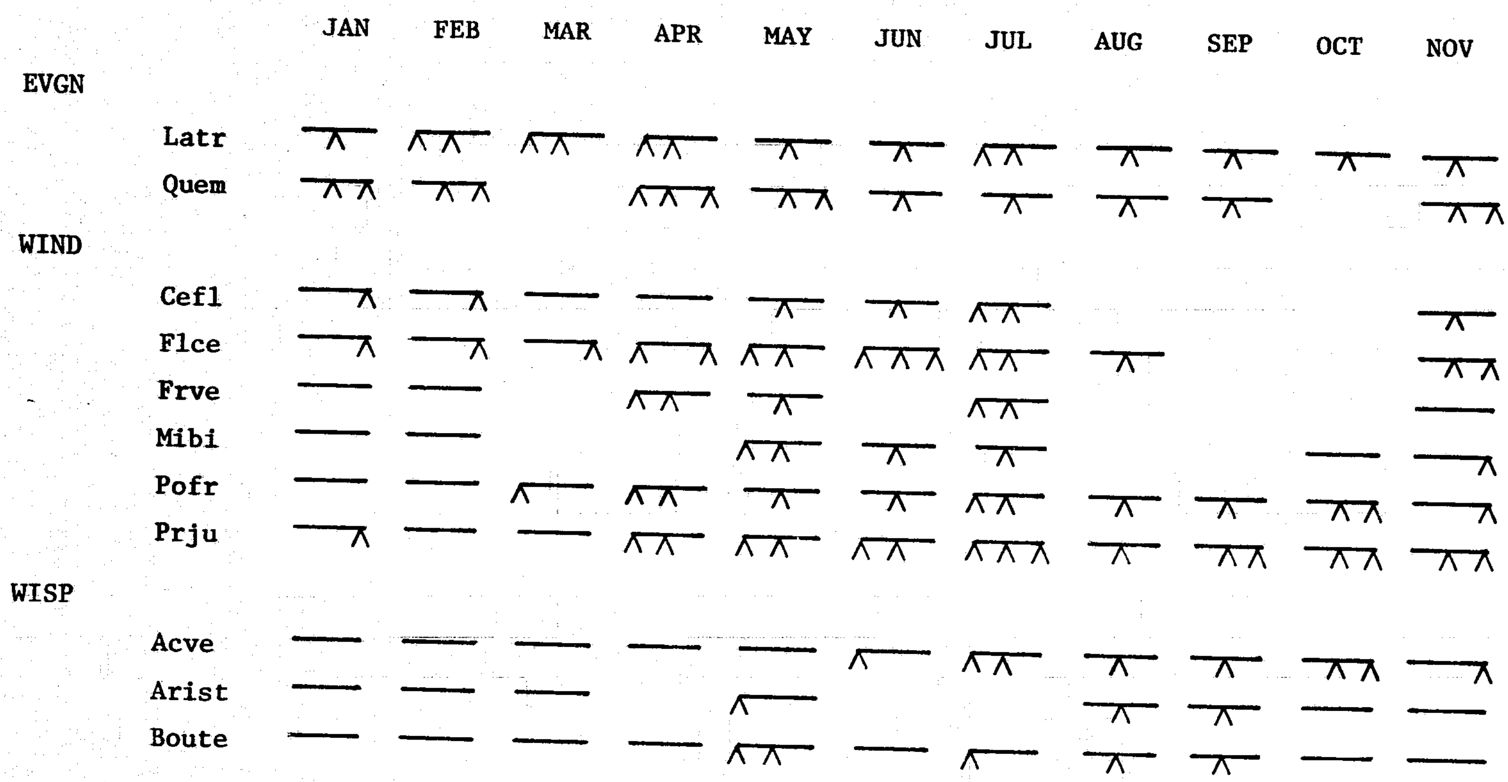


Figure 6-5. Summary of phenological data for nine species and two genera representing evergreen (EVGN), winter dormant (WIND), and winter-spring dormant (WISP). The species are Larrea tridentata (Latr), Quercus emoryi (Quem), Cercidium floridum (Cefl), Flourensia cernua (Flce), Fraxinus velutina (Frve), Mimosa biuncifera (Mibi), Populus fremontii (Pofr), Prosopis juliflora (Prju), and Acacia vernicosa (Acve). The genera are Aristida (Arist) and Bouteloua (Bout); only perennial species were considered. Each symbol indicates that leaves at a specific state of development were present; no attempt is made in this figure to indicate relative proportions of leaves in different stages of development. Because cured leaves from the previous year were usually present on perennial grass plants the symbol indicating the presence of senescent leaves is omitted in this summary.

spring growth. Conversely, summer drought may severely hamper the growth of these same species during their usual active growth period.

Figure 6-6 diagramatically depicts the time of year when plants are either dormant or have green leaves, and the timing of the two rainy seasons. The start and end of those seasons vary, as do the amounts of precipitation, in both space and time. There may be accompanying variations in the development and growth of many plants. Some of the variations and uncertainties are depicted by the figure: annuals may or may not be present; there is variability in the timing of leaf growth and scenescence, and summer drought may cause some warm season deciduous species to drop their leaves. Evergreens usually have a period when both new and old green leaves are present on the plant.

The species listed in Tables 6-7, 6-8, and 6-9 are those which received a prominence rating of three or higher (see Appendix A for explanation of prominence) at least once in the sampling accomplished for the vegetation classification. They are assigned to one of the three phenology categories according to results of field observations supplemented by the literature (Humphrey, 1960a, 1960b; Kearney and Peebles, 1964). Some species display phenological development characteristic of only one class. Other species might qualify for more than one class, but are placed in the one where they appear to best fit. Ephedra trifurca and the cacti are placed with the evergreens. They maintain a relatively stable green color throughout the year which is little influenced by their development of reduced and modified leaves. The Cercidium species also have photosynthetic material in their bark, and therefore remain green or blue-green appearing through the year. However, they are placed in the winter dormant class because they do undergo a pronounced change in appearance when their leaves develop and expand. This change was noted from direct visual observation and a review of color infrared ground photographs.

Multidate Radiance Standards for Phenological Classes

ERTS-1 MSS CCT counts for the three plant phenological classes plus the "no change" class are given in Table 6-10. Those data were considered to represent the ultimate expression of phenological change and of "no change." Comparisons of the data contained in Table 6-10 can be conviently

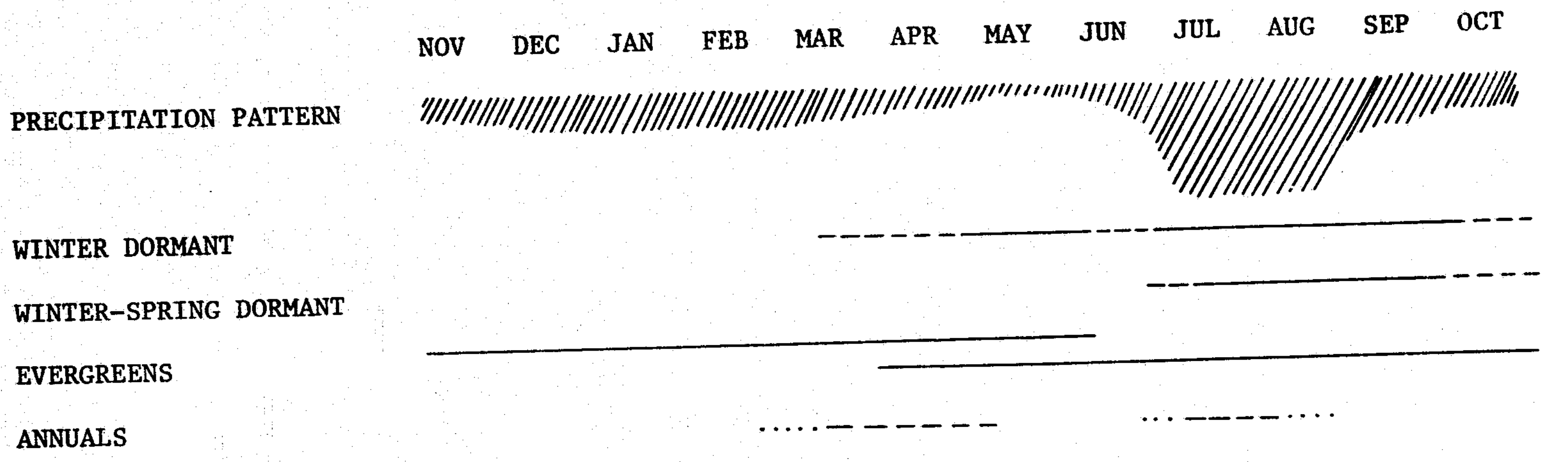


Figure 6-6. Seasonal occurrence of precipitation and foliage development. Solid horizontal lines indicate periods when green vegetative material was most likely to be present; the associated dashes indicate that the onset of leaf initiation and senescence was variable. Annual species were sometimes present. The overlapping lines for evergreens indicate the time period when old and new green leaves were present. (Evergreen oaks are the principal group represented.)

Table 6-7. Evergreen plant species commonly occurring in the study area.

Trees	Leaf succulents
Juniperus deppeana	Agave palmeri
J. monosperma	A. parryi
Pinus cembroides	A. schottii
P. engelmannii	Dasylirion wheeleri
P. ponderosa	Nolina microcarpa
Pseudotsuga menziesii	Yucca baccata
Quercus arizonica	Y. elata
Q. emoryi	Y. schottii
Q. hypoleucoides	
Q. oblongifolia	
Q. rugosa	
Shrubs	**Stem succulents (cacti)**
Arctostaphylos pungens	Cereus giganteus
Ceanothus greggii	Ferocactus wislizenii
Cercocarpus breviflorus	Opuntia sp. (cholla)
Coldenia canescens	Opuntia sp. (prickly pear)
Cowania mexicana	
Ephedra trifurca	
Garrya wrightii	
Haplopappus laricifolius	
Larrea tridentata	
Mortonia scabrella	
Quercus pungens	
Rhus choriophylla	

Table 6-8. Winter dormant species commonly occurring in the study area.

Trees	Grasses
Celtis reticulata	Heteropogon contortus
Chilopsis linearis	Muhlenbergia montanus
Fraxinus velutina	Scleropogon breviflorus
Platanus wrightii	Sporobolus airoides
Populus fremontii	S. wrightii
Quercus gambellii	Tridens pulchellus

Shrubs

Acacia constructa
A. greggii
Aloysia wrightii
Atriplex canescens
Calliandra eriophylla
Cercidium floridum
C. microphyllum
Encelia farinosa
Flourensia cernua
Fouquieria splendens
Gutierrezia lucida
G. sarothrae
Haplopappus tenuisectus
Mimosa biuncifera
M. dysocarpa
Parthenium incanum
Prosopis juliflora
Psilostrophe cooperi
Rhus microphyllum
Zinnia pumila

Table 6-9. Winter-spring dormant species commonly occurring in the study area.

Shrubs	Grasses
Acacia vernicosa*[a/]	Andropogon barbinodis
	A. scoparius
	Bouteloua curtipendula*
	B. eriopoda
	B. gracilis
	B. hirsuta
	B. rothrockii
	Eragrostis lehmannii*
	Hilaria belangeri
	H. mutica*
	Leptochloa dubia
	Lycurus phleoides
	Muhlenbergia porteri
	Setaria macrostachya*
	Aristida divaricata*
	A. glabrata*
	A. hamulosa*
	A. longiseta*
	A. purpurea*
	A. ternipes*

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a/ Those species marked with an asterisk (*) may show varying amounts of new leaf growth in the spring if favorable growing conditions (e.g., moisture and temperature) prevail.

Table 6-10. Average ERTS-1 MSS computer compatible tape counts for plant phenological and "no change" classes. The STATS subprogram of CALSCAN provides the class mean calculated to the hundredths position.

		CCT Counts			
Class	Month	MSS 4	MSS 5	MSS 6	MSS 7
EVGN	Aug	20.89	15.96	30.13	17.64
	Nov	17.50	10.55	23.44	13.16
	Apr	20.89	15.42	26.93	15.06
WIND	Aug	26.91	22.42	43.11	24.29
	Nov	21.22	15.88	18.80	8.89
	Apr	32.74	31.14	37.26	18.89
WISP	Aug	28.99	24.20	48.01	27.38
	Nov	25.82	24.08	27.59	13.84
	Apr	42.66	46.57	45.42	21.32
TAIL	Aug	76.99	93.58	85.50	34.93
	Nov	60.64	67.76	62.35	25.97
	Apr	79.63	96.99	87.12	37.55

made only among classes within a single band and date. For example, among the four classes, EVGN had the lowest MSS 4 value in August. The second lowest was WIND, then WISP; TAIL had the highest value. The same relationship held true for the MSS 5, 6, and 7 values. Also, the vegetated surfaces had much lower radiance values in the MSS 4, 5, and 6 bands than did the bare mineral surface, TAIL.

However, a straightforward comparison among bands and dates is difficult because real radiance differences are modified by temporal variations in angle of incidence by solar radiation and by atmospheric attenuation. Real differences are also obscured by differences among the response characteristics of the MSS detectors and the scales on which the values are portrayed. In order to inspect the character of the multiseasonal spectral signatures, the data were adjusted for the variables just noted, plus an anomaly in the November data, which gave radiance values believed to be too high. Analysis of ERTS data, such as a classification of radiance values with CALSCAN, or a classification of ratios of radiance values with a distance measure, can commence without regard for the variables noted above. Adjustments of the data usually retain the same relative differences among those features which are used for classification. For this consideration of adjusted data, it was necessary to substitute the radiance values for two training fields in place of means for EVGN and TAIL classes. The two substitutions were made for different reasons. Of the three phenological classes, EVGN was the only one represented by ground areas having significant slopes and aspects (see Appendix E). The angle of incidence of solar radiation on a surface is a function of both the sun's position above the horizon (elevation and azimuth) and the slope and aspect of the surface (see calculations for surface two in Appendix F). It was, therefore, necessary to select one of the EVGN training fields to represent the class because each of the fields in that class had different slope and aspect components. The training field selected to represent the TAIL class was that pile of mine tailings which remained unchanged and retained the same appearance throughout the sampling period (see discussion on pages 192 and 193).

The values in Table 6-11 can be compared among subjects, bands, and dates. Differences among the values are due primarily to the reflectance characteristics of the subjects. The standard deviations associated with the mean radiance values in this table are contained in Appendix G. The adjusted radiance values were used for constructing the three dimensional block diagrams in Figures 6-7 and 6-8. These figures enable a visual assessment of the patterns of change within and among dates and spectral bands associated with the multidate, multiband radiance values for the phenological and "no change" classes.

The spectral radiance of EVGN-4 on the three dates and that of WIND and WISP in August showed the multiband pattern of radiance typical of green foliage. Theoretically, the WIND April radiance should have exhibited a similar pattern, apparently the foliar development had not proceeded sufficiently to achieve the expected spectral radiance levels. The green foliage spectral radiance pattern consistently had the highest adjusted count in MSS Band 7, second highest in Band 6, third in Band 4,

Table 6-11. ERTS-1 MSS computer compatible tape counts adjusted for angle of incidence, atmospheric attenuation, an anomaly in the November data, detector response, and data scale.

		Adjusted CCT Counts			
Subject	Month	MSS 4	MSS 5	MSS 6	MSS 7
EVGN-4	Aug	49	34	52	151
	Nov	39	32	60	192
	Apr	34	18	35	104
WIND	Aug	56	37	63	187
	Nov	46	33	33	90
	Apr	66	51	54	142
WISP	Aug	60	40	71	211
	Nov	61	64	52	146
	Apr	86	76	65	160
TAIL-3	Aug	157	157	127	272
	Nov	166	166	132	292
	Apr	160	159	125	284

and the lowest adjusted count in Band 5. The impact of chlorophyll absorption on the red wavelengths (MSS 5) is evident. The high MSS 7 radiance values were characteristic of all the phenological classes, regardless of whether they had green leaves. The "no change" class also had a high MSS 7 radiance. If the radiance values from all detectors were expressed on a "per 0.1μ" basis, then Band 7 values would be reduced by two-thirds (see the one-third levels indicated in Figure 6-7). This would occur because the MSS 7 sensor detects over a 0.3μ bandwidth. In the green foliage radiance pattern, this would put the Band 7 level approximately even with that of Band 6 and, therefore, only slightly higher than Band 4. This adjustment does not clarify the issue however, because there was a substantial drop off of Band 7 detector sensitivity in the longer wavelengths of the 0.8 to 1.1μ spectral range. The spectral radiance pattern for TAIL-3, in strong contrast to the pattern for green

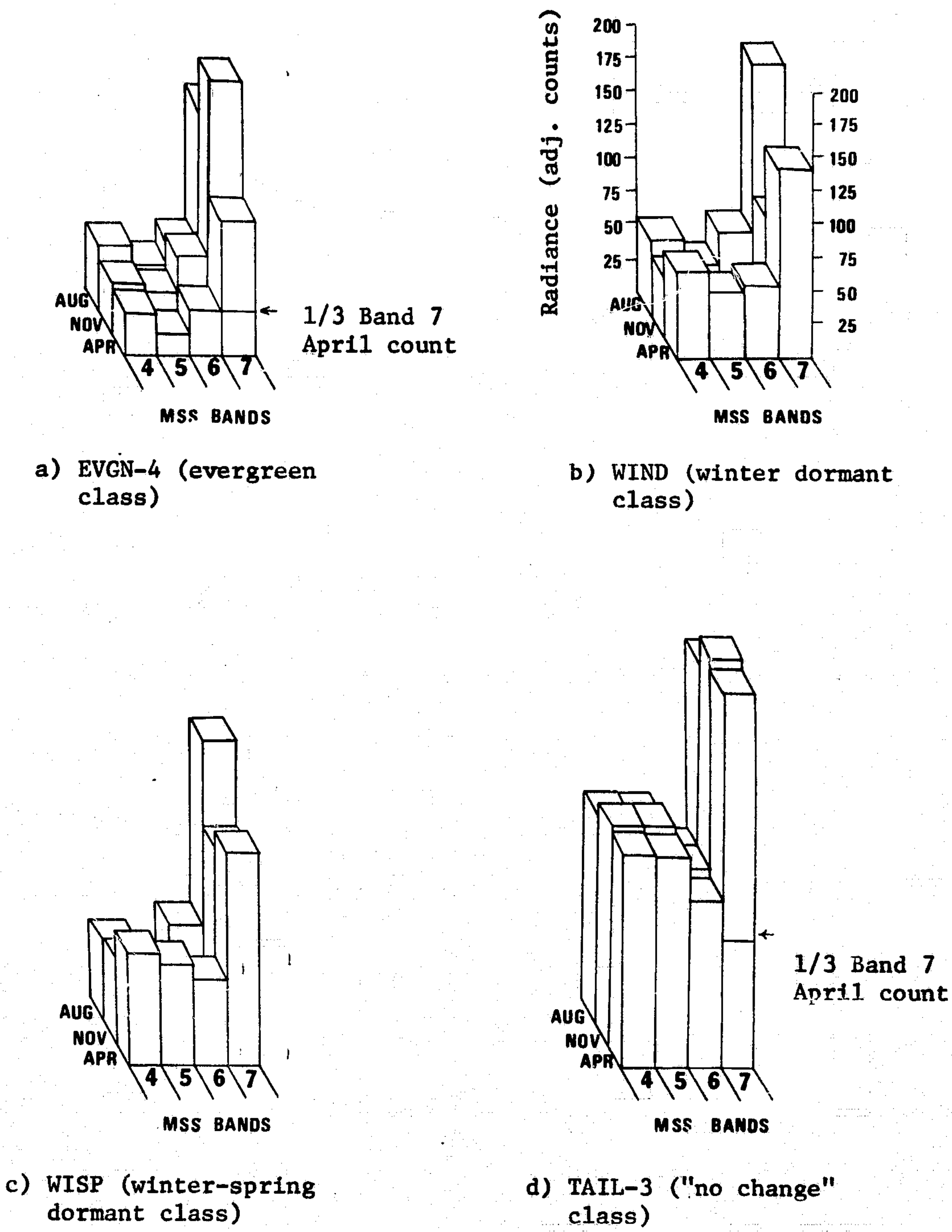
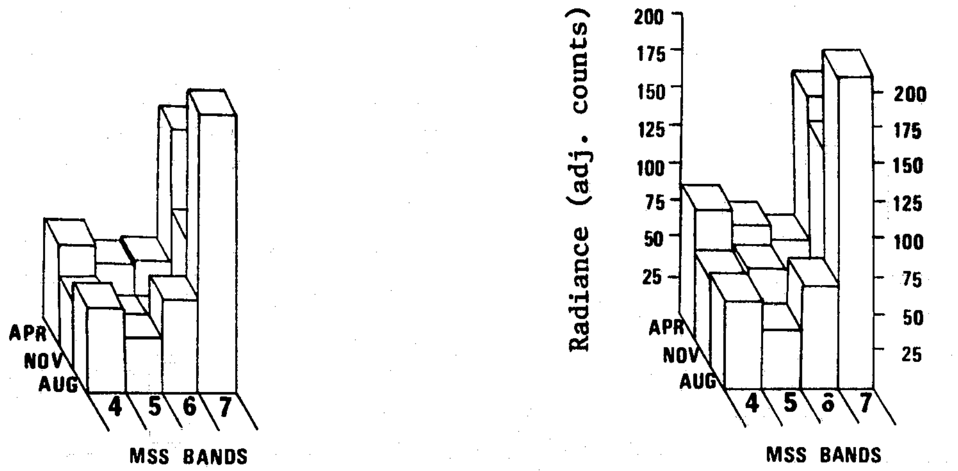


Figure 6-7. Adjusted counts (see Table 6-11) for phenological and "no change" classes. The tops of some columns are not visible. Radiance scale is the same for all graphs.



a) WIND (winter dormant class)

b) WISP (winter-spring dormant class)

Figure 6-8. Adjusted counts for WIND and WISP phenological classes. The data in these graphs are the same as presented in Figure 6-7b and 6-7c, only the arrangement has been altered. August radiance levels are displayed by the front row of columns; April by the back. This arrangement for these subjects made visible the tops of two columns that were hidden in Figure 6-7b, and two of three columns that were hidden in Figure 6-7c. Radiance is the same for both graphs.

foliage, showed high radiance values in the visible wavelengths. This pattern bore semblance to the spectral distribution of global radiation as presented by Robinson (1966).

The spectral radiance pattern described above for green foliage followed two different types of change as leaves were dropped, as was the case with WIND (principally a deciduous shrub, Prosopis juliflora), and as leaves and culms dried as occurred in WISP (principally grasses). The radiance levels decreased in all four bands in WIND, and especially in Bands 6 and 7, between August and November. In the absence of leaves, the radiance from the WIND subjects represented the dark, bare branches of Prosopis juliflora, shadows, the soil background, and litter. The radiance levels representing the WISP subject decreased in Bands 6 and

7, increased in Band 5 (visible red radiation) and remained virtually unchanged in Band 4, between August and November. From November to April, the radiance levels for this subject increased in all the spectral bands detected by the MSS system.

The decrease of radiance levels in all bands for EVGN-4 between November and April remained a puzzle. This temporal pattern of change was displayed by two of the ground areas chosen to represent the EVGN class (areas Three and Four). Areas One and Two displayed the opposite trend. There was also no answer evident for the increased Band 6 and 7 radiance between August and November as exhibited by EVGN-4.

Changes in radiance, as presented in Figures 6-7, 6-8, and Table 6-11, were taken as indirect evidence of changes in spectral reflectance. Each phenological and "no change" class appeared to have a unique multi-date spectral signature as indicated by the adjusted radiance values.

Classification of Elements Representing Class Standards

Classifications of multispectral data are seldom conducted which utilize all available channels of data. It is usually necessary to identify the subset of features (the four bands of MSS data from the three dates equal 12 features) which provides the optimal trade-off between classification costs and classification accuracy. One method for identifying an appropriate subset is through the use of divergence measurements (Swain, 1972).

Divergence is a measure of the dissimilarity of two data distributions. The dissimilarity depends upon the distance between the means of the two distributions and their variances. The divergence for two non-identical distributions is greater than zero, and the addition of more features never decreased the divergence. The measurements therefore, provide a means for assessing the ability of the "maximum likelihood" classifier (CALSCAN) to discriminate between classes (data distributions).

Because divergence is defined for two classes, it was necessary to evaluate the merits of feature combinations for separating the classes in a pairwise fashion (i.e., EVGN-WIND, EVGN-WISP, EVGN-TAIL, WIND-WISP, WIND-TAIL, and WISP-TAIL). One possible strategy was to consider the average divergence value. This procedure was followed in selecting the best six of 12 features for discriminating the four training classes. The six features selected in this manner were: MSS Bands 5 and 7 from August; Bands 4, 5, and 7 from November; and Band 4 from April data.

All the ERTS resolution elements which constituted the training classes were classified with CALSCAN using the training class statistics for those six features. The resultant classification had an overall performance of 99.8 percent correct. In the EVGN class, one of 546 resolution elements was misclassified as WISP. Of the 64 elements in the WIND class, one was also misclassified as WISP. All elements in the WISP and TAIL classes were correctly classified. This merely served to indicate that the four classes, as represented by the ERTS-1 MSS data, were distinct, and that the resolution elements were good representatives of their respective classes.

The six features selected on the basis of average divergence probably were not, in fact, the best combination. The reason for this could be seen in Figure 6-9, a spectral plot showing the count intervals (mean $\pm$ one standard deviation) for each feature in each class. Within each feature, the TAIL class was distinct from the other three, with the one exception of WISP in the August Band 7 data. The best six features should have been selected on the basis of the separability of the three phenological classes without regard for the "no change" class. When the selection of bands was conducted in this manner, there were nine combinations of the twelve features that were better, in terms of average divergence, than the "best six" given above. Those combinations of features are given in Table 6-12. The values in the bottom row of Table 6-12 were the "best six" features when TAIL data were considered in the divergence calculations.

The selection of the best feature combination may be additionally modified by a strategy for maximizing the minimum divergence. From Table 6-12, it was evident that there was least dissimilarity between the WIND and WISP class regardless of the feature combination being considered, and that the divergence values for those two classes were considerably lower in every instance than the values for any other pair of classes. Table 6-13 contains several combinations of features which, if used for classification, would have provided a greater likelihood of discriminating the WIND and WISP classes. All of the combinations in this table provided a better divergence of the WIND-WISP pair than did any of the combinations of the previous table.

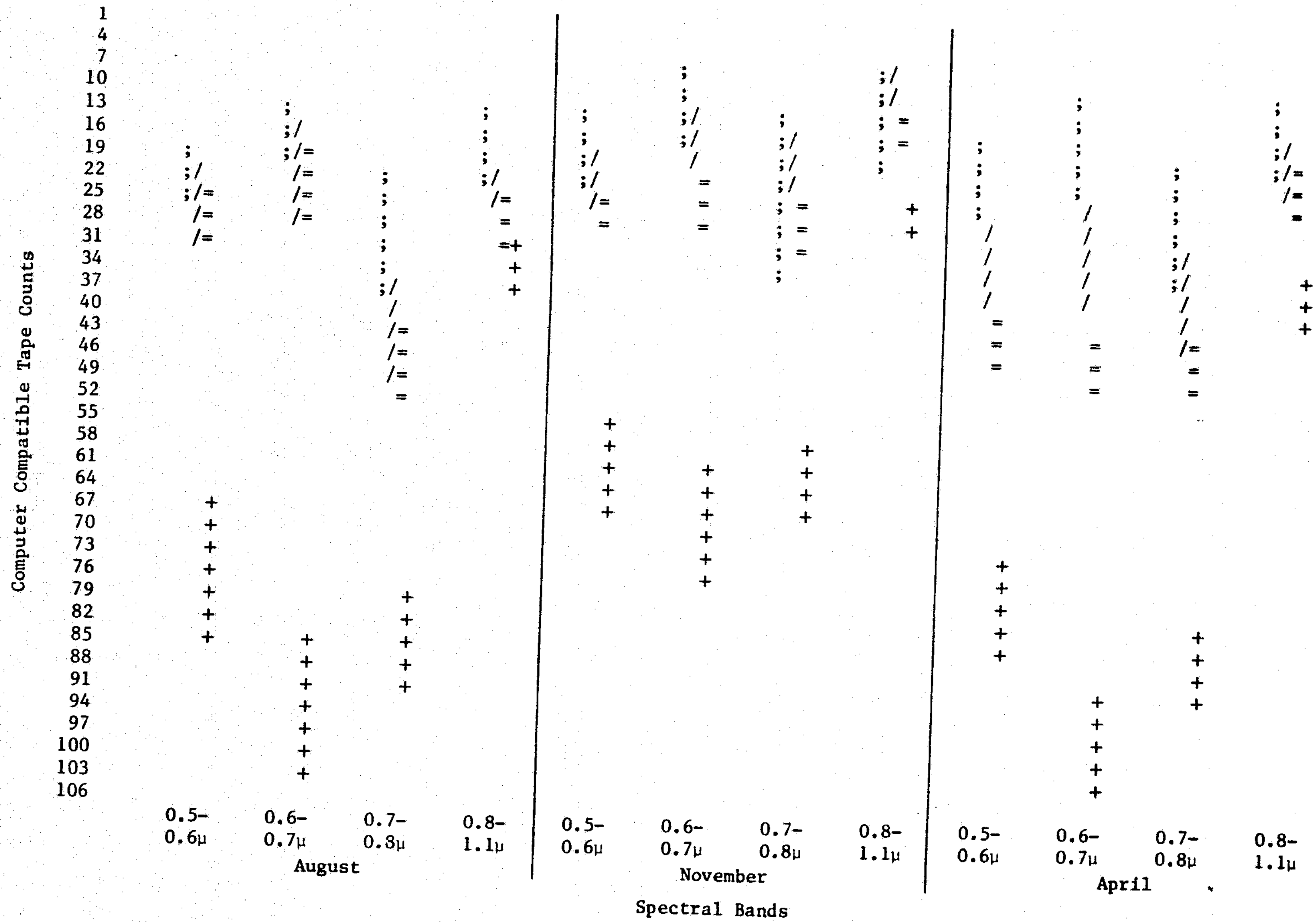


Figure 6-9. Spectral plots for EVGN (;), WIND (/), WISP (=), and Tail (+). Each plot indicates the mean count ± one standard deviation for data from the ERTS-1 MSS system on 22 Aug 72, 2 Nov 72, and 13 Apr 73.

Table 6-12. Divergence between phenological classes with selected feature combinations.

	August				November				April			
MSS Bands	4	5	6	7	4	5	6	7	4	5	6	7
Feature No.	1	2	3	4	5	6	7	8	9	10	11	12

Feature Combination	DIVERGENCE			
	EVGN/WIND	EVGN/WISP	WIND/WISP	Average
4,5,6,8,10,12	224	363	66	218
3,6,8,9,10,11	174	408	69	217
4,5,6,8,9,12	227	359	62	216
4,5,6,7,8,9	235	354	60	216
4,5,6,8,10,11	217	357	67	214
3,5,6,8,10,12	214	360	64	213
3,5,6,7,8,9	227	352	57	212
4,5,6,8,9,11	220	354	63	212
3,5,6,8,9,12	215	358	59	211
2,4,5,6,8,9	217	344	66	209

Table 6-13. Combinations of features which maximize the minimum pairwise divergence of WIND and WISP

	August				November				April			
MSS Bands	4	5	6	7	4	5	6	7	4	5	6	7
Feature No.	1	2	3	4	5	6	7	8	9	10	11	12

Feature Combination	DIVERGENCE			
	EVGN/WIND	EVGN/WISP	WIND/WISP	Average
2,4,6,8,10,11	182	356	72	203
2,4,5,8,10,11	171	341	72	195
2,4,8,9,10,11	110	289	72	157
2,4,6,8,10,12	186	362	71	206
2,4,5,8,10,12	176	353	71	200
2,6,8,9,10,11	158	364	70	197
2,4,6,7,10,11	124	329	70	174
2,4,5,7,10,11	125	307	70	167

There are eight combinations of six features listed in Table 6-13. Seventy-three percent of the features selected for these eight combinations were either Bands 5 or 7 from the three dates; the other 27 percent were either Bands 4 or 6. Bands 5 and 7 are, perhaps, the most useful of the four bands for detecting changes in the development and cover of vegetative material. The energy in Band 5, the red wavelengths, is absorbed by chlorophyll; the near infrared radiation of Band 7 is strongly reflected by green foliage. In contrast, the green wavelengths of Band 4 are reflected by green leaves, but not nearly as strongly as are the near infrared wavelengths. And Band 6 includes a range of wavelengths, some of which are strongly absorbed by green leaves, others are strongly reflected. It would seem, therefore, that those bands containing wavelengths which were critically interacting with green foliage were the most appropriate bands for use in discriminating among the three vegetation types considered here. Each of those types presented a nearly continuous cover of green foliage to the satellite's detectors on one or more of the three dates from which imagery was acquired for analysis. Upon considering the tradeoffs between minimum and average divergences in Table 6-13, it would seem that the combinations of features 2, 4, 6, 8, 10, and 11, and features 2, 4, 6, 8, 10, and 12 are the best two combinations of six features.

The divergence measurements provided further insights into the radiance data for the phenological types. For example (Table 6-14), the single feature which provided the best average divergence among the classes was the MSS Band 5 acquired in April. The April Band 4 provided the best (largest) minimum divergence with a single band. In contrast to those two features, the August Band 5 provided no separability of the WIND and WISP classes (divergence = 0). The mean radiance count for WIND in Band 5 for August was 22.42; that for WISP was 24.20.

The best average and minimum divergence measurements with a pair of features were provided respectively by features eight and ten, and eight and nine. When the best pair was selected from one date, April data provided the best separability among classes. The best four features are similarly reviewed in Table 6-14. Also, as the number of features increased from one to four without regard to date, both the average

Table 6-14. Divergence values for various feature combinations. These combinations provide the best average or minimum divergences for classes EVGN, WIND, and WISP.

	August	November	April
MSS Bands	4 5 6 7	4 5 6 7	4 5 6 7
Feature No.	1 2 3 4	5 6 7 8	9 10 11 12

Feature Combination		Divergence EVGN/WIND	EVGN/WISP	WIND/WISP	AVERAGE
Best ave. w/single	: 10	16	146	36	66
Best min. w/single	: 9	19	143	31	64
Best ave. w/pair	: 8, 10	38	183	44	88
Best min. w/pair	: 8, 9	40	180	41	87
Best ave. w/pair from one date	: 10, 12	21	171	43	78
Best min. w/pair from one date	: 9, 12	23	147	32	67
Best ave. w/four features	: 5, 6, 8, 9	185	305	50	180
Best min. w/four features	: 2, 4, 8, 10	96	199	59	118
Best ave. w/one date (November)	: 5, 6, 7, 8	187	111	24	107
Best min. w/one date (April)	: 9, 10, 11, 12	27	187	47	87
Poorest date (Aug)	: 1 2, 3, 4	27	39	11	26

divergence and the minimum divergence values increased. However, when the best two or four features were restricted to one date rather than being selected from all the features from three dates, there was a definite decrease in the divergence values. This was particularly noticeable in the comparison of the average divergence (180) by four features selected from three dates with the average divergence (107) by the four features of one date (Table 6-14).

The August data was the poorest for discriminating among the three phenological types. This was reasonable because August was the season when the most prominent species of the three types had green foliage. There was, therefore, much greater similarity in the appearance of the three types in August than on either of the other two dates. The April data provided the best possibility for distinguishing WISP from EVGN and WIND when two or four features were considered. The November data provided the best discrimination of EVGN and WIND.

In summary, where more than one feature was to be used for performing a classification of these EVGN, WIND, and WISP vegetation types, there was a definite advantage to be realized from utilizing radiance data from more than one date. A consideration of phenological change will definitely enhance the discrimination of some vegetation types.

Classification of Training Fields

Radiance data from the training fields representing the three phenological classes and the "no change" class were classified using the schemes involving ratios of radiance values, change factors, and direction of change. The radiance data in Bands 5 and 7 for training fields and classes are given in Appendix H. The performance of the various classification schemes was apparent from the results contained in Table 6-15. CALSCAN classification results were included to complete the comparisons among schemes. In addition to CALSCAN, perfect classifications were also achieved with the MSS 5 ÷ MSS 7 and the Vegetation Index (V.I.) schemes.

MSS 5 Count ÷ MSS 7 Count: A 5/7 ratio was calculated from each mean training field response in Bands 5 and 7 for each of the three dates. In that manner, each training field was characterized by a triad of 5/7 ratios: one each for 22 Aug 72, 2 Nov 72, and 13 Apr 73. Each ratio in

Table 6-15. Performance of classification schemes applied to training fields. The EVGN class included four training fields; WIND, five; WISP, five; and TAIL, three. A field classified as EVGN was assigned the symbol (;). Symbols for the other classes were: WIND (/), WISP (=), and TAIL(+).

	Training Fields			
Classification Scheme	EVGN(;) 1 2 3 4	WIND(/) 2 3 4 5 6	WISP(=) 1 2 3 4 5	TAIL(+) 2 3 4
CALSCAN (best six features)	; ; ; ;	/ / / / /	= = = = =	+ + +
MSS 5 ÷ MSS 7	; ; ; ;	/ / / / /	= = = = =	+ + +
Two 5/7 Change	; ; ; ;	+ + + + +	+ + + + +	; ; ;
Three 5/7 Change	; ; + +	/ / / / /	= = = = =	+ + ;
Direction of 5/7 Change	; ;	/ / /	= = = = =	+ +
Vegetation Index	; ; ; ;	/ / / / /	= = = = =	+ + +
Two V.I. Change	; ; ; ;	; ; ; ; ;	+ + + + +	; ; ;
Three V.I. Change	; ; ; +	/ / / / /	= = = = =	+ + /
Direction of V.I. Change	; ;	/ / / /	= = = = =	+

the triad had a corresponding ratio in the triads for the four classes: EVGN, WIND, WISP, and TAIL. A training field was assigned to a class by comparing the field's triad to those of the four classes and assigning it to the class to which it was most similar. Similarity was determined by the Euclidean distance measure.

Vegetation Index (7-5) ÷ (7+5): As was the case with the 5/7 ratio, the Vegetation Index (V.I.) indicates the "greenness" of a scene in relation to the amount of green vegetative material that is present. "Greener" scenes are associated with smaller 5/7 values and larger V.I. values than all scenes depicting less green vegetation. Extremes which demonstrate this can be calculated from the August MSS Band 5 and 7 data for EVGN, WIND, and WISP compared to the data for TAIL:

	$\frac{MSS\ 5}{MSS\ 7}$	$\frac{MSS\ 7 - MSS\ 5}{MSS\ 7 + MSS\ 5}$
EVGN	.905	.050
WIND	.923	.040
WISP	.884	.062
TAIL	2.679	-.456

Change Factor Classifications: Change factors indicate the manner in which characteristics vary from date to date.

Two-5/7 Change Factor

Each training field and class was characterized by a pair of change factors calculated as follows: November 5/7 ratio ÷ August 5/7 ratio, and April 5/7 ratio ÷ November 5/7 ratio. Each field and class, therefore, had a pair of change factors for the same time intervals. A training field's change factors were compared to those of each class by the Euclidean distance measure, and assigned to the class for which it had the smallest distance value.

Three-5/7 Change Factor

This classification scheme was performed in exactly the same manner as the two change factor scheme, but with the additional consideration of the August to April change factor (April 5/7 ratio ÷ August 5/7 ratio).

Vegetation Index Change Factors

Calculation and classification of two- and three-V.I. change factors paralleled the treatment of the 5/7 change factors.

The misclassifications by the several change factor schemes were evident from the results entered in Table 6-15. The three-change factor schemes far out-performed the two-change factor schemes. The former correctly classified WIND and WISP training fields and missed some EVGN and TAIL fields. The latter nearly failed completely.

Direction of Change Classifications:

Direction of 5/7 Change

Classification of training fields by this scheme considered whether the 5/7 ratio increased, decreased, or remained the same during the time intervals August to November, November to April, and August to April. This was a qualitative evaluation; no regard was given to the magnitude of change. The possible patterns of two-interval changes were displayed in Figure 6-2; three-interval changes would add the consideration diagrammed by connecting the end points of each plot. One type of pattern was identified for each class based on the manner in which the class 5/7 ratios varied. The standards were: EVGN (decrease, increase, increase), WIND (increase, decrease, increase), WISP (increase, increase, increase), and TAIL (no change, no change, no change). If, for example, an August 5/7 ratio equalled the corresponding November 5/7 ratio, then their ratio would equal unity. In the purest sense, no change would be unity. This seemed unlikely to occur, and in fact, did not even for the TAIL ("no change") class. No change was, therefore, defined as a range: 0.97 - 1.01; this was based on the actual performance of the TAIL class standards identified above in "MSS 5 count + MSS 7 count."

Direction of V.I. Change

Treatment of this scheme was the same as that for "direction of 5/7 change." As could be expected from the relationship of the two types of ratios to the "greenness" of a scene, the standards for this classification were just the opposite of those given above for the 5/7 change. That is, EVGN (increase, decrease, decrease), WIND (decrease, increase, increase), and WISP (decrease, decrease, decrease). The TAIL V.I. values showed greater variation than the TAIL 5/7 values. The "no change" range based on the performance of the TAIL class standards was: 0.89 - 0.98. Appropriate ratios of V.I.'s which fell in this range were taken to mean "no change:" the TAIL standards were, therefore: no change, no change, no change.

The classification results of the direction of change schemes were nearly identical (Table 6-15). Where training fields could be classified, their classifications were correct. However, some fields could not be classified because they presented patterns of change that were different from any of the class standards. For example, it a training field had an increase-increase-increase or an increase-decrease-increase pattern of change for its Vegetation Index, then the field could not have been matched to any of the class standards specified in the preceeding paragraph. This failure of some fields to classify accounts for the blanks in Table 6-15.

Classification of Grid Fields: The Canelo grid contained vegetation types having highly prominent evergreen or winter-spring dormant species. The grid included one section of grid fields belonging to the EVGN class and a second section of fields belonging to the WISP class. The evergreen species were primarily those of the juniper-oak woodland and chaparral vegetation types; the winter-spring dormant species were primarily perennial grasses. The northern and eastern portions of the grid were perennial grasslands, and the southern and western portions were woodland and chaparral shrub types of the Canelo Hills.

The Rincon grid also primarily represented two of the phenological classes: EVGN and WIND. The evergreen species included Pinus ponderosa, Pseudotsuga menziesii, and other pine species in addition to those of the juniper-oak woodland and the chaparral shrub vegetation types. The evergreens were located on the mid to upper elevations of the Rincon and Tanque Verde Mountains. These mountains also had large areas of rock outcroppings. The WIND species were those of the desert shrub and desert grassland vegetation types. Some of the species were Cercidium microphyllum, Prosopis juliflora, Acacia constricta, and Fouquieria splendens. Some perennial grass species were present in mid-prominence on the lower slopes of the mountains. This was also the location of extensive patches of Agave schottii, a low growing leaf succulent which forms extensive dense mats. Given sufficient prominence, the grass species could cause a grid field to be classified as WISP; on the other hand, the presence of the <u>Agave</u> could cause a classification of EVGN if it were sufficiently dense and extensive.

A fairly thorough familiarity with the Canelo and Rincon grid areas provided the basis for assigning a classification to each 16-element grid field of the two grids. Each grid field was identified as EVGN, WIND, or WISP according to the best approximation of each field's location. That approximation was achieved with an overlay of the systematic sampling plots on a 1:250,000 color enlargement of an ERTS scene. This provided a "ground truth map" of both grids (Figure 6-10). Some grid fields fell

Canelo Grid

	0	1	2	3	4	5	6	7	8	9
1	=	=	=	=	=	=	=	=	=	=
2	=	=	=	=	=	=	=	=	=	=
3	=	=	=	=	=	=	=	=	=	=
4	=	;	=	=;	=	=;	=;	=	=	=
5	=;	;	;	;	;	;	=;	=	=	=
6	;	;	;	;	;	;	=;	=	=;	=
7	;	;	;	;	;	;	;	=;	=;	=
8	;	;	;	;	;	;	;	;	;	=
9	;	=;	=;	;	;	;	;	;	;	;

Rincon Grid

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	/	;	;	;	;	;	;	;	;	;	;	;	;	;	;	/
2	/	;	/	;	;	;	/;	/;	/;	;	;	;	;	/;	/;	/
3	/	/	/	/	/	/	/	/	/	;	;	;	;	;	/;	/
4	/	/	/	/	/	/	/	/	/	;	;	;	;	/;	/	/
5	/	/	/	/	/	/	/	/	/	/	/;	;	/	/;	;	/
6	/	/	/	/	/	/	/	/	/	/	/	/	/	/;	/;	/

Figure 6-10. Identification of the 16-element grid fields in the Canelo and Rincon Grids. EVGN (;), WIND (/), and WISP (=). Some grid fields were suspected of containing two subjects, and were therefore identified with two symbols. A grid field was referenced by its column number first, then its row number. For example, Canelo grid field 5-4 was "=;". Rincon grid field 14-4 was "/".

in the area of transition from one phenological type to another. In these cases, the fields were identified as representing both types. If either of the two types were identified in a subsequent stratification analysis, then the classification was considered correct.

The following evaluation of the several stratification strategies does not include the results of every classification attempt. The results of those strategies which were more successful are shown, accompanied by some of the unsuccessful results for the purposes of comparison.

The blocking pattern achieved with the MSS 5 ÷ MSS 7 classification scheme serves to illustrate the success achieved with the use of 1) the Primary versus Alternate standards; 2) 16-element versus single-element grid fields; and 3) a reclassification procedure known as "nearest neighbor weighting."

When used in conjunction with the Primary standards, the MSS 5 ÷ MSS 7 scheme produced an inadequate classification of the Canelo grid fields and a less than marginally acceptable classification of the Rincon grid fields (Figure 6-11). A partitioning of the Rincon grid in accordance with these results would provide a very conservative estimate of the portion of the grid area which supported evergreens. In contrast, this same classification scheme when used with the Alternate standards, produced quite acceptable classifications of the grid fields (Figure 6-12). The results obtained with both types of standards can be compared with the the "ground truth map" in Figure 6-10. The Alternate standards give a slightly generous estimate of EVGN in the Rincon grid and a slight underestimate of EVGN in the Canelo grid. This was reasonable because of the manner in which the Alternate standards were constituted. The Alternate EVGN standards were based on the mean radiance of most of the Canelo EVGN fields in the "ground truth map" (a few grid fields were deleted due to high standard deviations associated with the mean radiance value of the 16 elements/field). The EVGN vegetation of the Canelo grid was not as distinct as that of the Rincon grid. Juniper-oak woodland, for example, frequently had a well developed herbaceous understory, whereas the mixed pine and fir coniferous forest of the Rincon grid did not. Consequently, the Alternate standard based on the Canelo evergreens permitted more grid fields in the Rincon grid to be classed as EVGN than

Canelo Grid

	0	1	2	3	4	5	6	7	8	9
1	=	/	=	=	=	/	=	=	=	=
2	=	/	/	=	=	/	=	=	/	=
3	=	=	=	=	=	=	=	=	=	/
4	=	=	=	=	/	=	=	=	=	/
5	=	=	=	=	/	=	=	=	=	=
6	=	/	=	=	=	/	=	=	=	=
7	/	=	/	/	/	=	=	=	=	/
8	/	;	;	;	;	;	/	/	/	/
9	=	/	;	/	/	/	/	/	=	/

Rincon Grid

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	/	/	/	/	;	/	/	/	/	;	;	/	/	/	/	/
2	/	/	/	/	/	/	/	/	/	/	/	;	/	/	/	/
3	/	/	/	/	/	/	/	/	/	/	/	/	;	/	/	/
4	/	/	/	/	/	/	/	/	/	/	/	/	;	/	/	/
5	/	/	/	/	/	/	/	/	/	/	/	;	;	;	/	/
6	/	/	/	/	/	/	/	/	/	/	/	/	/	/	;	/

Figure 6-11. MSS 5 ÷ MSS 7 classification of 16-element grid fields with Primary standards. EVGN (;), WIND (/), WISP (=).

the "ground truth map" incidates. In effect, the Alternate standard provided a broader interpretation of what constituted evergreen vegetation. The results of a classification obviously depend in great measure on the manner in which class standards are selected.

The results from classification of 16-element grid fields and single-element fields were quite similar. The MSS 5 ÷ MSS 7 scheme with Alternate standards was used to classify the smaller fields in both grids (Figure 6-13). These results are comparable with those in the immediately preceeding figure. A very similar blocking was achieved by both techniques.

Canelo Grid

	0	1	2	3	4	5	6	7	8	9
1	=	/	=	=	=	/	=	=	=	=
2	=	=	=	=	=	=	=	=	/	=
3	;	;	;	=	;	=	=	;	;	/
4	=	=	=	=	/	=	=	=	=	/
5	=	/	=	=	;	=	=	=	=	=
6	;	;	=	;	;	;	=	=	=	=
7	;	;	;	;	;	;	;	=	=	/
8	;	;	;	;	;	;	;	/	/	/
9	;	;	;	;	;	;	;	;	;	;

Rincon Grid

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	=	=	;	;	;	;	/	;	;	;	;	;	;	;	/	/
2	/	;	;	;	;	;	;	/	/	;	;	;	;	;	/	/
3	=	/	/	/	/	/	;	;	;	/	/	;	;	;	;	;
4	/	/	/	/	/	/	/	/	/	/	;	;	;	;	;	/
5	/	/	/	/	/	/	/	/	/	/	;	;	;	;	;	;
6	/	/	;	/	/	/	/	/	/	;	;	;	;	;	;	;

Figure 6-12. MSS 5 ÷ MSS 7 classification of 16-element grid fields with Alternate standards. EVGN (;), WIND (/), WISP (=).

Recall that the results of these two approaches were achieved by using samples of three percent and 0.2 percent, respectively, of all the resolution elements in the two grids.

Depending on the complexity desired from the partitioning procedure, the classification output may be simplified by a reclassification utilizing "nearest neighbor weighting." Care must be taken when using this approach because increasing the homogeneity of the output is only gained by eliminating detail.

The rules that were followed to achieve the reclassification were:

Canelo Grid

	0	1	2	3	4	5	6	7	8	9
1	=	/	=	=	=	/	=	=	=	=
2	=	=	=	=	=	=	=	=	/	=
3	=	=	;	=	=	=	=	=	=	=
4	;	;	=	=	/	=	=	=	=	=
5	;	/	/	=	;	=	=	=	/	=
6	;	=	;	=	;	;	;	=	=	=
7	;	;	;	;	;	;	;	;	/	=
8	;	;	;	;	;	;	;	;	;	/
9	/	;	;	;	;	;	;	=	=	=

Rincon Grid

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	=	=	;	;	;	/	;	;	;	;	;	;	;	;	/	/
2	/	;	;	;	;	;	;	;	;	;	;	;	;	;	/	/
3	=	/	=	/	/	/	;	;	/	=	/	;	;	;	;	/
4	/	/	/	/	/	/	/	/	/	/	;	;	;	;	;	/
5	/	/	/	/	/	/	/	/	/	/	;	;	;	;	;	/
6	/	/	/	/	/	/	/	/	/	/	;	;	;	;	;	;

Figure 6-13. MSS 5 ÷ MSS 7 classification of single-element grid fields with Alternate standards. EVGN (;), WIND (/), WISP (=).

1) Tabulate the original classification of the nine fields immediately surrounding the field in question.

2) Assign the field in question to the class to which most of the surrounding nine fields were classified.

3) In the case of a tie (no class included the majority of fields surrounding the field in question), leave the field as it was classified, assuming that its original classification was into a class which participated in the tie. If this assumption is incorrect, then proceed with the reclassification of all surrounding fields, and then return to the field in question and consider its reclassification in light of the reclassified identities of the surrounding nine fields.

This reclassification procedure was used to simplify the stratification that was achieved with classifying the single-element grid fields. The output from the reclassification is portrayed in Figure 6-14 to depict the partitioning effect achieved through the blocking of grid fields according to phenological class.

The Vegetation Index, when used with the Alternate standards, produced a nearly identical blocking pattern as did the MSS 5 ÷ MSS 7 scheme. For that reason, those results are not presented.

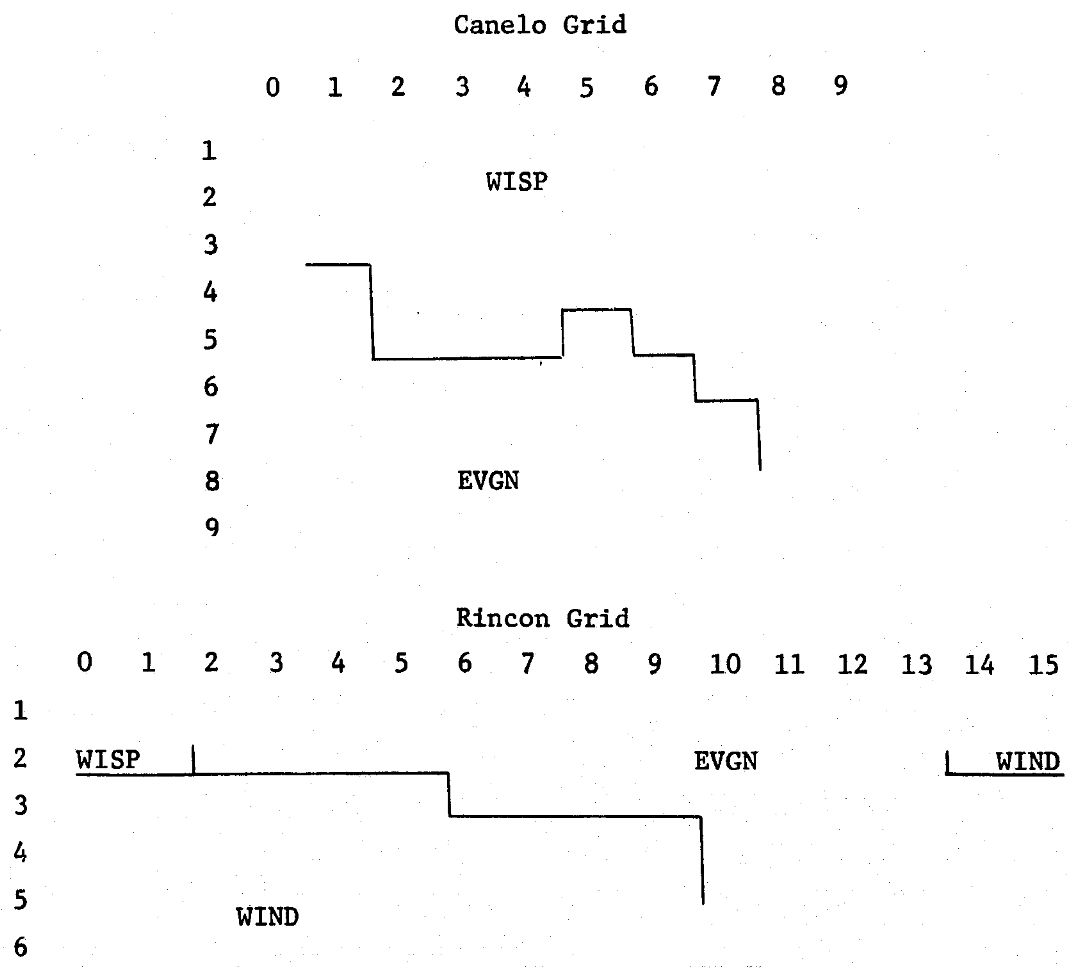


Figure 6-14. Stratification of the Canelo and Rincon grids. This partitioning effect was achieved with a strategy which employed: 1) Alternate standards; 2) MSS 5 ÷ MSS 7 classification scheme; 3) single-element grid fields; and 4) reclassification with nearest neighbor weighting.

An acceptable blocking of the Rincon grid fields was achieved with a CALSCAN classification utilizing the Primary standards (Figure 6-15). This classification was performed with the maximum likelihood classifier "trained" on the radiance of the training classes in MSS Bands 5 and 7 from August, November, and April. This combination of features was one of the best for discriminating the phenological training classes (see Table 6-13 and attendant discussions). Unlike the MSS 5 ÷ MSS 7 and the V.I. schemes which treated each grid field as a unit and based the classification on the mean radiance of the 16 elements which constituted the unit, CALSCAN classified each resolution element of a grid field. The grid field classification was then determined as being that class to which the majority of the 16 elements were assigned. There was the possibility

	6	7	8	9	10	11	12	13
1	/=	;	;	;	;	;	/	/
2	/=	=	=	/	;	;	/	/
3	/	/	=	=	=	;	;	/=
4	/	/	/	/	/	;	;	/
5	=	=	/	/	/	;	;	;
6	/=	=	/	/	=	=	;	/

1						
2	=	=	;	;	;	;
3	/	/	/	;	;	;
4	/	/	/	/	;	;
5	/	/	/	/	;	;
6						

Figure 6-15. Classification of Rincon grid fields using a "maximum likelihood classifier" trained on data in MSS Bands 5 and 7 from August, November, and April. The upper plot shows the results prior to reclassification of each field using a "nearest neighbor" weighting. The reclassified fields are shown in the lower plot. The partitioning effect is emphasized with lines. EVGN (;), WIND (/), WISP (=).

of having an even number assigned to two classes. Classification ties did occur as evidenced by the double symbols for a few grids. The problem of ties could have been reduced if the grid field size had been chosen as as odd number of elements not evenly divisible by the number of classes. Ties were resolved in an expedient manner; if one symbol of the pair was the correct classification, then it was chosen to represent the field. The results were then reclassified to simplify the stratification (Figure 6-15). Only the data in Rincon grid columns six through 13 were classified. This reduction in number of grid fields was done to reduce computing costs.

The "red" and "IR" from three dates classification could not be considered successful however because of the performance on the Canelo grid fields. A definite partitioning of the field was not achieved. Ninety-two percent of the WISP grid rields were correctly identified, the remaining were misclassified as WIND. Actually, WIND classifications in some locations in the WISP portion of the Canelo grid could have been quite acceptable. There were drainageways located in this area which supported the winter dormant tree Juglans major (Arizona walnut) and perennial grass species which characteristically "green up" in the spring. Only 33 percent of the EVGN grid fields were correctly identified; 19 percent were identified as WIND, and 48 percent at WISP.

The Canelo grid was partitioned into two distinct areas by the CALSCAN classifier trained on data from the MSS Band 5 from April. One area was correctly identified as WISP, however, fields in the other area were incorrectly identified as WIND rather than EVGN. Band 5 frcm April was the band which provided the best average divergence among phenological classes.

The other stratification strategies, i.e., change factors and direction of change with Primary or Alternate standards, did not produce acceptable results. Classification of the Rincon grid fields with the three 5/7 change factor scheme produced the results in Figure 6-16. A stratification of the grid was not achieved. The change factors calculated from the Alternate radiance standards for EVGN, WIND, and WISP were:

	Nov/Aug	Apr/Nov	Apr/Aug
EVGN	1.05	1.24	1.30
WIND	1.01	.97	.98
WISP	1.18	1.07	1.27
TAIL	.97	99	.96

Whenever Alternate standards were used for classifications, the Primary standards for TAIL were used.

The 5/7 change factors indicate that WIND and TAIL were similar in that there was little date-to-date variation in the 5/7 ratios for those subjects. The classification results indicated that the 5/7 ratios for 77 percent of the grid fields underwent little date-to-date variation. This included EVGN grid fields of dense conifers and WIND fields of sparsely scattered desert shrubs. In this case, extremely different subjects were recognized as similar by virtue of their similar patterns of change.

The Vegetation Index change factor proved unsatisfactory as a basis for classification for at least two reasons: 1. The index can equal zero if the radiance count in Bands 5 and 7 are equal. This potential never materialized, however, several indices had values close to zero. Such a value when either in the numerator or the dominator of a change

Rincon Grid

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	=	=	=	=	/	;	/	/	=	/	;	/	/	+	+	+
2	/	;	/	/	/	=	=	/	/	/	/	/	=	/	+	/
3	=	/	/	/	/	/	=	/	/	/	/	/	+	/	/	/
4	/	/	/	/	/	/	+	+	/	/	/	/	;	/	=	/
5	+	+	+	+	/	/	/	+	+	/	=	+	=	=	/	/
6	+	+	/	+	+	+	+	+	+	+	;	;	;	/	/	;

Figure 6-16. Three 5/7 Change Factor classification with Alternate standards. The grid fields contained 16 elements. The three change factors were for the time periods August to November, November to April, and August to April Grid fields which were classified as TAIL are indicated with a (+); EVGN (;), WIND (/), and WISP (=).

factor calculation can result in an extremely small or large quotient. Either case was very unlike the Primary or Alternate standards for change factors; 2. The Vegetation Index gave an indication of the "greenness" of a scene. Larger values indicated a greener scene, and vice versa. Some V.I. values were negative. If the values were negative on two successive dates with the second being a smaller negative number than the first, then that would indicate that the scene was less green on the second date than it was on the first. The value of the change factor ratio, however, would be positive and greater than one. Another location could have positive V.I. values on two dates with the second date greener (larger V.I.) than the first, Here again, the value of the V.I change factor ratio would be positive and greater than one. Thus Vegetation Index change factors can be ambiguous.

The direction of change classification scheme failed largely because the grid fields showed a greater variety on patterns of change than did the class standards. There were, therefore, several grid fields that remained unclassified.

Stratification of Santa Rita-Sonoita Transect

The most successful stratification strategy for stratifying grid fields was the MSS 5 ÷ MSS 7 scheme used with Alternate standards. This strategy was used to classify every 25th resolution element on three adjacent scan lines of ERTS data. The three lines extended from points A to B in the previous Figure 6-3. They represented a transect of approximately 40 km (25 mi) which began at the west (point A) in desert grassland and near a drainage with *Prosopis juliflora*, crossed over the Santa Rita Mountains and extended eastward into the Sonoita grassland. The classification results are given in Figure 6-17. The eastward extension of the EVGN type was entirely possible due primarily to the evergreen oaks which occupy the northerly aspects along the larger drainages. This provides a satisfactory discrimination among the major EVGN and WISP components of the landscape along the transect.

Classification of Vegetation Stands

The vegetation types of the study area selected for this analysis are listed in Table 6-16 and organized according to phenological class. That assignment to class was based upon the phenological character of the more prominent species of the vegetation type. Six EVGN types were

	1	26	51	76	101	126	151	176	201	226	251	276	301	326	351	376	401	426	451	476	501	526	551	576	601
1	=	/	;	;	;	;	;	;	;	;	=	=	=	/	;	=	/	=	=	=	/	=	=	=	=
2	/	;	;	;	;	;	;	;	;	=	;	=	=	=	=	;	=	=	=	=	/	=	=	=	=
3	;	;	;	;	;	;	;	;	;	;	;	/	;	;	;	;	=	=	=	=	/	=	=	=	=

Figure 6-17. Stratification of the Santa Rita-Sonoita transect. Every 25th resolution element in three adjacent scan lines of ERTS data were classified with the MSS 5 ÷ MSS 7 scheme used with Alternate standards. The transect was approximately 40 km (25 mi) in length. The major vegetational components along the transect were EVGN (conifer forest and juniper/oak woodland) and WISP (perennial grassland).

Table 6-16. Vegetation types selected for phenological classification with ERTS multiseasonal radiance data. The types are organized by phenological class (EVGN, WIND, and WISP) according to the phenological character of their more prominent species.

EVGN

Larrea tridentata with Prosopis juliflora and/or Opuntia (cholla).
Abbreviation: Latr-Prju

Mortonia scabrella without Rhus choriophylla; Mortonia scabrella with Rhus choriophylla.
Abbreviation: Mosc; Mosc-Rhch

Quercus and Nolina microcarpa; without Cercocarpus breviflorus, Arctostaphylos pungens, and Mimosa biuncifera.
Abbreviation: Quercus-Nomi

Quercus, Arctostaphylos pungens, Pinus cembroides, Juniperus deppeana, without Mimosa biuncifera.
Abbreviation: Quercus-Arpu-Pice

Cercocarpus breviflorus with Juniperus deppeana and/or Pinus cembroides and usually with Quercus.
Abbreviation: Cebr

WIND

Cercidium microphyllum and Cereus giganteus often with Encelia farinosa and Opuntia spp., and without Franseria deltoidea.
Abbreviation: Cemi-Cegi-Enfa

Prosopis juliflora and Haplopappus tenuisectus with Opuntia (cholla) and without Acacia constricta and Calliandra.
Abbreviation: Prju-Hate-Cholla

Acacia vernicosa, Flourensia cernua, Larrea tridentata, and Rhus microphylla.
Abbreviation: Acve-Latr-Rhmi

WISP

Calliandra eriophylla and Bouteloua with any or all of Ephedra trifurca, Yucca baccata, Y. elata, Prosopis juliflora, and without Acacia constricta.
Abbreviation: Caer-Eptr-Yucca

Bouteloua and Aristida without large shrubs, Nolina microcarpa, Yucca, and Calliandra eriophylla.
Abbreviation: Bout-Arist

considered; the stands from two of the types characterized by Mortonia scabrella were goruped together. Three WIND and two WISP vegetation types were also considered. More EVGN types were included than for WIND and WISP because of the great diversity that existed between desert shrub and forested evergreens. The stands were classified with the MSS 5 ÷ MSS 7 scheme with Alternate standards. The MSS 5 and 7 values were derived from density measurements. The 5/7 scheme was the stratification strategy which produced the most acceptable results in the classification of grid fields. The phenological classification (Table 6-17) based on ERTS multiseasonal radiance from specific vegetation stands produced four strata of vegetation types:

1) All stands classified as WIND:

   Latr-Prju
   Cemi-Cegi-Enfa
   Prju-Hate-Cholla

2) Stands classified as WIND and WISP:

   Acve-Latr-Rhmi
   Mosc; Mosc-Rhch
   Caer-Eptr-Yucca

3) Stands classified primarily as WISP:

   Bout-Arist

4) Stands classified primarily as EVGN:

   Quercus-Nomi
   Quercus-Arpu-Pice
   Cebr

The first five types listed in Table 6-17 had a shrub-scrub physiognomy. The three that classified exclusively as WIND were "microphyllous, non-thorny scrub, generally with succulents." Grasses generally had low prominence ratings in stands of these types. Even though Larrea tridentata is an evergreen the stands of the Latr-Prju group classified as WIND. Most likely, this was due to the low percent of vegetative cover which would have made the Latr-Prju stands "look like" WIND. The WIND grid fields of the Rincon grid, on which the classification standards were based, also had sparse vegetative ground cover. Cemi-Cegi-Enfa and Prju-Hate-Cholla both occur in that portion of the Rincon grid from which the Alternate WIND standards were derived. Radiance from these vegetation stands was, therefore, quite similar to the Alternate standards.

Table 6-17. Phenological classification of specific vegetation stands, EVGN (;), WIND (/), WISP (=), and TAIL(+). These results were achieved with the MSS 5 ÷ MSS 7 classification scheme utilizing Alternate standards adjusted for use with densitometrically derived 5/7 ratios. Two vegetation types were represented by nine rather than ten stands. This accounts for the two blanks present in the table.

Vegetation Type	Phenological classification by most prominent species	Phenological classification by ERTS multiseasonal, multispectral radiance — Stands									
		a	b	c	d	e	f	g	h	i	j
Latr-Prju	EVGN	/	/	/	/	/	/	/	/	/	/
Cemi-Cegi-Enfa	WIND	/	/	/	/	/	/	/	/	/	/
Prju-Hate-Cholla	WIND	/	/	/	/	/	/	/	/	/	/
Acve-Latr-Rhmi	WIND	/	/	/	/	=	=	=	=	=	=
Mosc; Mosc-Rhch	EVGN	/	/	/	/	/	=	=	=	=	
Caer-Eptr-Yucca	WISP	/	/	/	=	=	=	=	=	=	=
Bout-Arist	WISP	;	;	=	=	=	=	=	=	=	=
Quercus-Nomi	EVGN	;	;	;	;	;	;	/	/	=	+
Quercus-Arpu-Pice	EVGN	;	;	;	;	;	;	;	;	;	
Cebr	EVGN	;	;	;	;	;	;	;	;	;	/

It was evident from the field data that perennial grasses frequently attained mid- to high prominence in the stands of Acve-Latr-Rhmi, Mosc, and Mosc-Rhch. Thus, WISP could be an acceptable classification for stands of these types. A review of the field descriptions for these specific stands, however, did not indicate any noteable contrasts between those stands of the two groups which classified as WIND and those which classified as WISP. Although Mortonia scabrella is an evergreen, none of the Mosc or Mosc-Rhch stands were classified as EVGN. There was no apparent relationship between the classification of each Mortonia stand and either the type it belonged to, the prominence of Mortonia in the stand, or the prominence of the grasses.

The physiognomy of Caer-Eptr-Yucca stands was either "herbaceous" or "scattered tall shrubs over herbs." The prominent herbaceous component both of this type and the Bout-Arist type apparently influenced the classification of several stands. The stands which were classified as WISP contained grasses which were given a prominence rating of five. Those which classified as WIND had grasses at lower prominence.

The field data provided no indication of why the two Bout-Arist stands classified as EVGN.

The last three vegetation types in Table 6-17 contained several evergreen species. The physiognomy of each type could vary, as was indicated in their descriptions (preceeding Figures 2-25, 2-28, and 2-29). The classifications of Quercus-Nomi stands were quite varied. Of the last three groups, this group was the one which usually had a well developed herbaceous layer. Also, the stand which was classified as TAIL was the only stand not having oaks and/or junipers at a prominence of four or five. The Quercus-Nomi type appears to have been the most varied of the eleven types that were sampled.

The physiognomy of the Quercus-Arpu-Pice and Cebr vegetation types varied between a forest or wood aspect to that of a shrub aspect. Evergreen species were prominent in both physiognomic forms, and there was, consequently, less variation in the classification results. Cebr stands usually were found to have evergreen oaks, junipers, and/or Pinus cembroides in mid- to high prominence. The stand which classified as WIND did not have this well developed evergreen tree layer.

CONCLUDING STATEMENTS

This study was designed to investigate data analysis techniques which would achieve an initial approximation of a vegetation classification and a vegetation map for a specified region. The investigative course capitalized on the expression of plant phenological development that could be documented in multiseasonal, multispectral radiance data acquired by an orbital satellite.

Two questions were initially posed: 1. Can vegetation types be characterized in terms of phenological patterns of change detected with multidate remote sensing? and 2. Can apparent phenological patterns be used for stratifying synoptic, multidate remotely sensed imagery?

The following were determined in relation to the first question:

1) Variations in phenological development among plant species was noted as well as the tendency for the seasonal appearance of some vegetation types to be dominated by the appearance of one or a few similarly developing species.

2) As evidenced from the ground, most of the common plants in the study area could be characterized by the temporal aspects of their phenological development. On that basis, they could be assigned to one of three classes: evergreen (EVGN); winter dormant (WIND); or winter-spring dormant (WISP). Generally speaking, plants belonging to EVGN had green foliage throughout the year (e.g., conifers, oaks, leaf succulents). Those belonging to WIND had green foliage in spring, summer, and early fall (e.g., many desert shrubs). WISP plants greened up in the summer and dried up or lost their leaves in early fall (e.g., many perennial grasses).

3) There was a strong similarity among the spectral signatures of vegetation types in which the spectral return was dominated by green plant material. This was true for vegetation types of entirely different physiognomic character, but having nearly closed vegetative canopy. Radiant energy from EVGN, WIND, and WISP showed a similar pattern of spectral distribution among the ERTS MSS bands. This spectral signature pattern was also evident in the radiance from EVGN during three seasons - summer, winter, and spring.

4) When the soil background substantially contributed to the spectral return from a vegetation stand (vegetation with open canopies

and bare ground), then the spectral radiance and the vegetation physiognomy were apparently related. A vegetation type having a uniform physiognomy also tended to have one phenological spectral signature (e.g., *Larrea tridentata* with *Prosopis juliflora* and/or *Opuntia* (cholla). In contrast, vegetation types which could be represented by a variety of physiognomic forms also tended to have a variety of phenological spectral signatures (e.g., *Quercus* and *Nolina microcarpa*; without *Cercocarpus breviflorus*, *Arctostaphylos pungens*, and *Mimosa biuncifera*).

5) When the deciduous shrubs (e.g., *Prosopis juliflora*) of the WIND group lost their leaves, their spectral signature altered with a slight decrease of radiance in the visible wavelengths and a strong decrease in the near infrared.

6) As the foliage of perennial grasses (primarily *Hilaria mutica*) cured from August to November, its apparent green radiance remained unchanged, red radiance increased over 50 percent, and near infrared radiance decreased approximately 30 percent. Radiance in all MSS bands increased between November and April, presumably with additional curing of the grass foliage.

7) A highly reflective mineral surface exhibited high radiance levels in all four bands, thus providing a marked contrast to the absorption characteristics of vegetation canopies. The contrast was especially dramatic in data of the green and red bands of the ERTS-1 MSS system.

8) The maximum dissimilarity among the phenological classes EVGN, WIND, and WISP was achieved with radiance in spectral bands $0.6-0.7\mu$ (red) and $0.8-1.1\mu$ (near infrared) from summer, winter, and spring.

9) More than one date of radiance data is necessary to achieve the best discrimination among phenological types.

10) Classification schemes which successfully distinguished the phenological classes were:

a. A maximimum likelihood, discriminant analysis classifier (CALSCAN);

b. MSS 5 ÷ MSS 7;

c. August to November, November to April, and August to April MSS 5 ÷ MSS 7 change factors; and

d. (MSS 7 - MSS 5) ÷ (MSS 7 + MSS 5), the Vegetation Index.

11) Classification of training field elements representing EVGN, WIND, and WISP had an overall performance of 99.8 percent correct. In the EVGN class, one of the 546 resolution elements was misclassified as WISP. Of the 64 elements in the WIND class, one was also misclassified as WISP. All elements in the WISP and TAIL classes were correctly classified. This merely served to indicate that the four classes, as represented by the ERTS-1 MSS data, were distinct, and that the resolution elements were good representatives of their respective classes.

12) Classifications of training fields with MSS 5 ÷ MSS 7 and the Vegetation Index achieved 100 percent accuracy.

13) Change factor classifications achieved 82 percent accuracy.

The following were determined in relation to question 2:

1) Phenological patterns of change may not be useful for classifying vegetation having a high percentage of bare ground.

2) Multiseasonal spectral signatures for vegetation types having high percentages of bare ground could be successfully used to distinguish vegetation types which belonged to the three phenological classes.

3) A stratification of an ERTS scene could be achieved which distinguished phenologically dissimilar areas.

4) The stratification provided a fairly good approximation of "ground truth."

5) The stratification was accomplished by analyzing only 0.2 percent of the available ERTS data points.

6) A constant "no change" reference surface occurring within the scene was used to correct radiance data for subjects which were subject to temporal variation.

Several areas of interest for further investigation were recognized from these results. Of particular interest would be:

1) Further clarification of the relationships of the MSS 5 ÷ MSS 7 and Vegetation Index to such characteristics of natural vegetation as stand structure, floral composition, ground cover, and plant phenology.

2) The determination of detection thresholds pertaining to phenological change.

3) Further experimentation with the classification of vegetation with multiseasonal spectral radiance in comparison to single date classification.

4) Further theoretical development of the concept of subject recognition through the identification of unique and repeated patterns of temporal variation.

CHAPTER 7

TWO STAGE SAMPLING OF VEGETATION SUBJECTS

OBJECTIVE 6

INTRODUCTION

The use of conventional aerial photography in sampling schemes probably is more highly developed for forest sampling than in any other application. Evidence of this is seen in the Elementary Forestry Sampling handbook (Freese, 1962) and extensive recent bibliographies on forest sampling (Bonner, 1972; Murtha, 1969; and Nielson, 1971). In the natural vegetation resources area, beyond forestry, little application is made of small scale photography and refined sampling techniques. With the exception of timber volume estimate work (Langley, Aldrich, and Heller, 1969) little attention has been given to the possibility of coupling space and high altitude imagery to increase efficiency and accuracy of estimating a natural vegetation parameter. The potential exists for using multistage sampling to better estimate the areal extent of vegetation-soil systems.

Based on the arguments presented by Hansen, Hurwitz, and Madow (1953, p. 40-51), the sampling which was conducted as a part of this research would be described as stratified, two stage, clustered sampling. The concepts and constraints of the components of such sampling were described by Kelly (1970, p. 329-333) and are briefly summarized here. Stratified sampling allows a partitioning of sampling units in the universe; a population can be partitioned into strata which concentrates similar sampling units by strata. The intent is to reduce variance by gaining homogeneity, but this cannot be accomplished unless the strata are developed from criteria that are population related. Each stratum is treated as a separate subuniverse in which means and variances are separately calculated before weighting together. For subsampling (or two stage sampling) sampling does not have to be conducted in all strata. The universe is partitioned, and clusters of sampling units called primary sampling units (PSU's) are drawn which represent the universe. Each PSU is sampled as a subuniverse, and if extended to more than one level, the design is called multistage sampling. If stratification and subsampling are combined (as they were in my sampling approach), then the strata are the subuniverses and within strata estimates are calculated as is done for stratified sampling.

Colwell (1971, p. 152) discussed space photography and high altitude photography in the setting of their value in "multistage" sampling approaches whereby

> . . . resource inventory would be performed using three data collection systems: satellites, aircraft, and ground observers, in that sequence. Each of these in turn would provide progressively closer looks at progressively smaller areas, and would provide progressively more detailed information about these areas. Then, the more detailed information would, in each instance, be applied to a much larger area for which the limited sample appeared to be representative, is evidenced by the similarity of that area to certain surrounding areas, as seen on aerial and space photographs.

This is the concept which was operative in a much publicized and conceptually fruitful timber volume inventory in the Southeast (Langley, 1969; Langley, Aldrich, and Heller, 1969; Aldrich, 1971; Langley, 1971a; and Langley, 1971b). Their research provided the impetus and much of the procedural direction for the two stage sampling research reported in this dissertation.

The main question which Langley, Aldrich, and Heller (1969) wanted to answer was, "What contribution can the information obtainable from the space photos make toward reducing the sampling error of a timber inventory?" Their study area totaled 10 million acres in two 5 million acre blocks of land. In the Mississippi Valley survey, they stratified the space photo (Apollo 9) into an upland pine stratum and a bottomland and upland hardwood stratum. Primary sample units (PSU's) were drawn from a 4 x 4 mile grid. The smallest scale aircraft photography, 1:60,000, was used to predict timber volume, so that larger scale photography could be selected with probability proportional to predicted volume. For the third stage in the design, photography (1:2,000) was obtained along strips in the selected PSU's. The plots on this photography were partitioned into four squares (.6 to .8 acres each) and timber volume was predicted from height and crown cover estimates for both pine and hardwood. Of these plots, one per strip was selected for ground measurement based on the 1:2,000 scale estimate of probability proportional to predicted timber volume. In the field, tree measurements were made, again to estimate wood volume. The timber volume estimates for the entire area were then made by expanding back through the sampling formula. The sampling error for the Mississippi Valley survey was 13 percent. If stratification (due to space photography) had not been present, it would have been 30.7 percent. In the Georgia survey, the research was unable to show a sampling error advantage due to space photo stratification. The reason given was the low correlation between predicted timber volumes on the primary units and the estimated volumes in the subunits (Langley, 1971a; p. 135). However, ". . . the space photos did provide an operationally efficient frame with which to conduct the aerial survey" (Langley, 1971b, p. 125).

On stratification, Avery (1964) in a hypothetical example, showed that for estimating timber volume, efficiency and accuracy were improved as compared to results with no stratification. In testing stratification efficiency, two reports showed modest improvements in efficiency when estimating timber type and volume respectively (Kendall and Sayn-Wittgenstein, 1961; and Macpherson, 1962). Accuracy comparisons, on the other hand, require that the sampling scheme be compared against some standard. Perhaps the most comprehensive comparison was that of Kulow (1966) where 144 sampling designs of forest sampling techniques were accuracy tested. The very fact that 144 designs were tested is a testimonial to the vast number of sampling technique combinations that are available and are used. The choice of which technique to apply would undoubtedly depend upon the experiences of others who have previously conducted similar sampling. This, in a large measure, is why considerable direction was provided by the work done by Aldrich, Heller, and Langley. Even though they were estimating a single parameter (timber volume) as compared to the multiparameter issue of estimating areas for several vegetation types, they were applying small scale, low resolution imagery to an areal related resource problem.

METHODS

Based on the "Space Photo Image Content Comparison" research of Chapter 3, the Apollo-6-1442 photo had greater information content than did the Gemini IV (S-65-34681) photo. For this reason, Apollo was considered potentially better for sampling than Gemini and was chosen for a two stage sampling comparison with ERTS-1 photography. For the Southern Arizona Test Site, this meant that the best non-ERTS space photography was compared with ERTS photography. Figure 7-1 summarizes the sampling process.

Selection of a Resource Area for Sampling

Several considerations were made in selecting the resource area to be sampled. First and of greatest importance was the need to develop a sampling approach which would be compatible with and would take advantage of the vegetation classification developed for the test site. A second constraint was that a funding ceiling existed for the sampling phase of the research. The third consideration was the need to explore further the feasibility of using a helicopter for obtaining ground information. This had been accomplished for photo interpretation accuracy checking with a more simple vegetation-landform subject (Poulton, et al., 1971).

The decision was made to restrict the sample area to that portion of the test site which is generally the most hilly and mountainous. Not only did such a decision simplify the sample comparison by reduction of the area, but by having the sample area in rough terrain, ground examination by helicopter became an attractive alternative. Surface transportation would not have enabled examination of a sufficient number of ground sites owing to excessive time requirements. Access by fixed wing aircraft would have been feasible, but less desirable than by helicopter because of (1) faster air speeds; (2) longer turning radius; and (3) greater aircraft to ground distance when operating in turbulent conditions. These factors can greatly decrease the confidence level for identification of plant species from the air.

The area selected for sampling was based on an objective stratification of Apollo and ERTS (see Figure 3-4). From the stratification

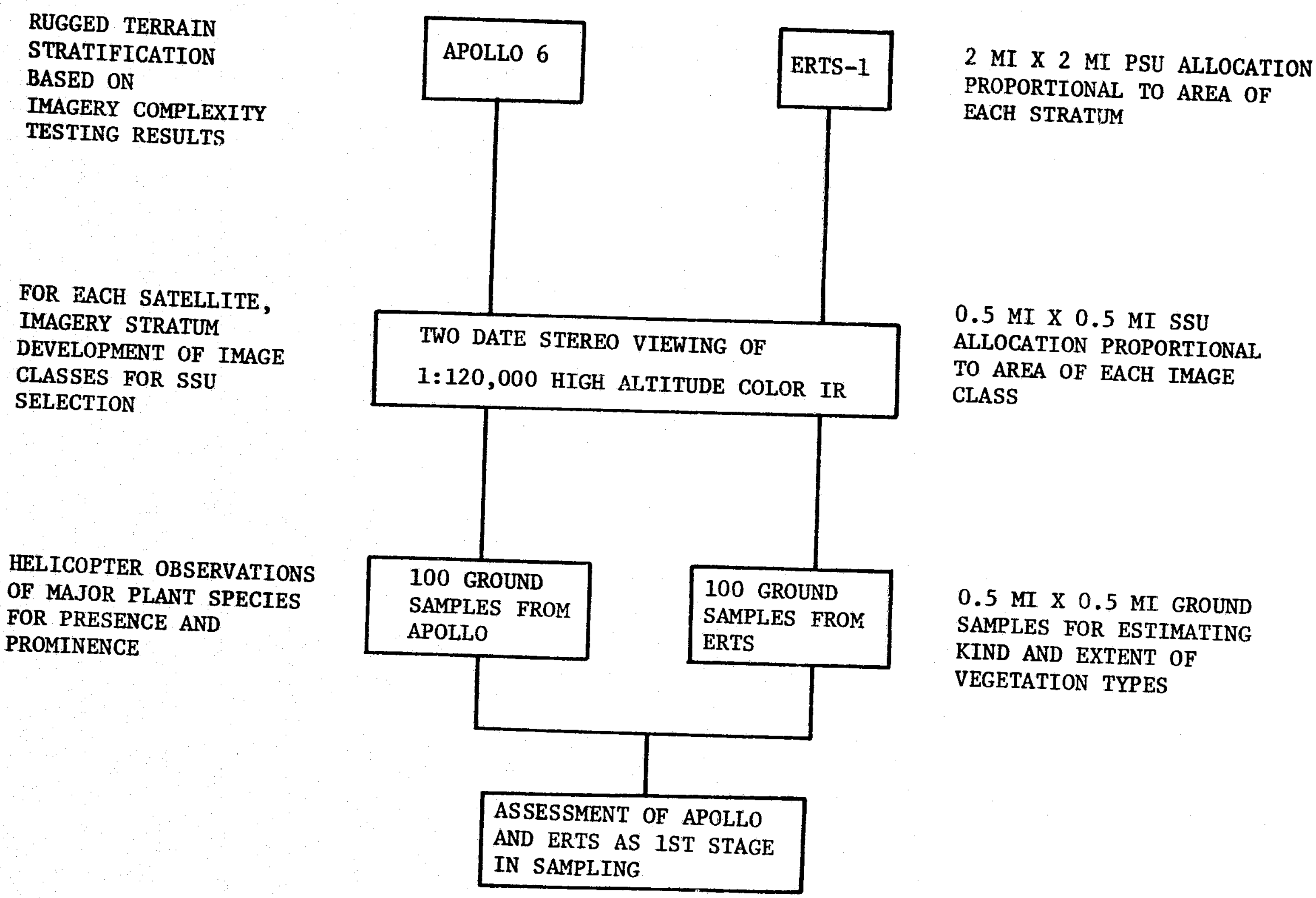


Figure 7-1. Comparative two stage sampling conducted for estimating the extent of vegetation types.

figure it is apparent that the areas sampled for the two space photo types are not identical even though primary areas are concurrent. This is a reflection of image differences on the intact space photographs which affected strata boundary placement, and differences in the way observers grouped image samples for the two space photos. Justification for comparing areas on photography which do not have identical external boundaries rests, in this case, in the way the strata were established and the boundaries drawn; that is, with a minimum of bias. An alternative would have been to restrict comparative sampling to those areas of the strata common to both space photo types. Such an approach would have prevented an objective assessment of stratification effectiveness for the two space photo types.

Space Photo Interpretations and Primary Sample Unit Selection

Working first with Apollo-6-1442 and then the 26 December 72 ERTS-1 photography, the entire sample area was photo interpreted by one person using a 1/8 x 1/8 inch grid which represented cells four miles square. The imagery used for both was 9 x 9 inch transparencies. Interpretations (predictions) were "wooded" versus "not wooded," generally to the nearest 10 percent of a cell area but in some cases to the five percent level. These predictions, within strata (Figure 3-4), were the basis for primary sample unit (PSU) allocation proportional to predicted area.

The choice of "wooded" and "not wooded" categories for prediction was based on our experiences that for the photography of interest, this split was the vegetational differentiation that could be made with the highest degree of certainty. Further, although the vegetation classification is not rigidly structured on physiognomic criteria, most examples of a particular vegetation type in the mountainous areas fall within one class that is "wooded" or "not wooded." Therefore, this dichotomy was a meaningful split at the first stage in the sampling scheme.

Distinctions between "wooded" and "not wooded" subjects were suspected of being more easily and accurately made on ERTS than on Apollo photography. To minimize the possibility of having learning experiences interfere with an objective prediction of the dichotomy, the Apollo photo was interpreted first. A single 9 x 9 transparency was viewed monocularly through an Old Delft stereoscope using 1.5X and 4.5X magnifications. Darker areas were, in general, interpreted as wooded and conversely.

The ERTS photography was predicted in a similar manner. Four color composites (Table 7-1) were chosen to help make the predictions.

Table 7-1. Reconstituted color infrared 9 x 9 ERTS frames used in "woods" versus "not woods" interpretations.

Date	Image I.D.	Bands	Method of Production
22 AUG 72	1030-17271	4,5,7	Photographic
2 NOV 72	1102-17280	4,5,7	Photographic
26 DEC 72	1156-17280	4,5,7	Diazo
19 MAY 73	1300-17281	4,5,7	Diazo

The 2 November 72 transparency appeared to be the sharpest, and was chosen as the primary photo for making predictions by viewing through the stereoscope. It had the strata overlay and the 2 x 2 mile square sampling grid. The other three transparencies were placed on nearby viewing tables and consulted frequently as predictions were made. A reading hand lens was used as necessary for viewing these three frames. The multiple date ERTS photography was valuable in determining whether green foliage (red coloration) was present from date to date as would be expected with trees or chaparral species, as opposed to herbaceous seasonal flushes. Primarily as a result of seasonal photography, the dichotomous decisions were made with more confidence on ERTS than on Apollo.

Following the predictions on the space photos, PSU's for further subsampling were drawn proportional to within stratum cumulative totals of predicted "wooded" and "not wooded" vegetation (Table 7-2). As shown in the mock-up, if integer 47 were selected, Cell C-11 would be chosen for further sampling because 47 is greater than 30 but less than or equal to 80. Other selected PSU's are C-12, D-13, E-14, E-9, E-11, and H-2. This selection process enabled subsampling allocations to be based on the proportion of the predicted resource present (Langley, 1971a). In the mock-up example, based on the "wooded" prediction,

Table 7-2. A mock-up showing the PSU selection process based on grid sample cumulative predictions using a resource of interest.

APOLLO STRATA F

	Wooded			Not wooded		
Sample cell	Predicted (% of cell)	Cumulative (%)	Integer randomly selected	Predicted (% of cell)	Cumulative (%)	Integer randomly selected
C-10	30	30		70	70	
C-11	50	80	47	30	100	
C-12	--	--		100	200	159
D-11	60	140		40	240	
D-12	10	150		--	---	
D-13	5	155		95	335	245
D-14	50	205		50	385	378
E-9	100	305	285	--	---	
E-10	30	335		40	425	
E-11	50	385	385	50	475	
H-1	40	425		50	525	
H-2	40	465		60	585	526
H-3	10	475		30	615	

there would be a 20 times greater chance of selecting Cell E-9 over D-13 because of the relative proportion of woods in each cell.

The total number of PSU's chosen was based on the total cumulative predictions for "wooded" and "not wooded" vegetation in each strata (Table 7-3). Beyond allocating PSU's on the basis of "wooded" versus "not wooded" predictions from space photo examinations, no further use was made of this vegetation differentiation. The allocation of PSU's, incidentally, amounted to approximately two PSU's per thousand count (total cumulative prediction for each strata). However, the consideration of the number of PSU's to select was based primarily on the desirability of sampling most mapping units of each strata. The probability of such an event was created by at least doubling the number of selected PSU's for each mapping unit within a stratum. The last column of the table shows the number of mapping units which did contain PSU's and were further sampled. It is evident that most mapping units were sampled for both ERTS and Apollo. Those units not sampled were relatively small.

High Altitude Photo Selection for Subsampling

Subsampling was conducted by using the same high altitude imagery for both the Apollo and ERTS sampling schemes. This approach was designed to hold variation constant beyond space photo sampling. Prior to initiation of the study, the decision was made to examine the suitability of small scale, high altitude photography when used for sampling in conjunction with space imagery. Selection of which imagery to use was based on (1) availability of existing imagery; (2) the need to have a scale or scales of imagery of sufficient resolution to enable (a) transfer of PSU's from space imagery to the high altitude imagery, and (b) helicopter ground recognition of subsamples as plotted on the high altitude imagery; and (3) the need for having imagery with characteristics (resolution and scale) suitable for vegetation mapping while consistent with the intensity and scale of sampling.

A single scale (1:120,000) of high altitude photography met the above requirements. Several dates of color infrared photography were available for the Test Site (Table 7-4). Several dates of color

Table 7-3. Allocation of PSU's based on space photo cell derived predictions of "wooded" and "not wooded" lands.

APOLLO

Mapping units of strata	Cumulative prediction (% of area) Wooded	Not Wooded	Total	No. of PSU's drawn Wooded	Not Wooded	Total	No. mapping units containing PSU's
3 of B	1,410	2,530	3,940	3	5	8	3 of 3
1 of F	445	1,705	2,150	1	4	5	1 of 1
4 of H	3,625	2,435	6,060	7	5	12	4 of 4
6 of J	2,880	1,895	4,775	6	4	10	4 of 6
Total = 14	8,360	8,565	16,925	17	18	35	12 of 14

ERTS

Mapping units of strata	Cumulative prediction (% of area) Wooded	Not Wooded	Total	No. of PSU's drawn Wooded	Not Wooded	Total	No. mapping units containing PSU's
8 of F	2,140	6,330	8,470	4	13	17	6 of 8
5 of 1	1,555	2,865	4,420	3	6	9	5 of 5
4 of L	2,795	1,850	4,645	6	4	10	3 of 4
Total = 17	6,490	11,045	17,535	13	23	36	14 of 17

Table 7-4. Relatively cloud-free, good quality, 9 x 9 inch 1:120,000 scale, high altitude, transparent photography available for the Southern Arizona Test Site by 1 Oct 73.

Date & source	Mission number	Scale	Film/Filter
(NASA-Houston provided)			
11 SEP 70	141	1:120,000	2443 color IR/-blue
8 NOV 70	146	1:120,000	2443 color IR/-blue
(NASA-Ames provided)			
12 DEC 72	72-213	1:120,000	2443 color IR/-blue
2 MAY 73	73-068	1:120,000	2443 color IR/-blue

were also available for the Site; however, the decision to use color infrared photography was based on its high potential for displaying seasonal foliage changes. This, of course, has value in distinguishing vegetation types on aerial photography.

For purposes of practical operation, a single viewing of high altitude photography was judged desirable and satisfactory. Through stereoscopic examination, two photo dates were simultaneously viewed. The dates chosen for viewing were 11 SEP 70 and 2 MAY 73. These dates occur during the seasons when seasonally green species normally reach peak foliage development. The high altitude photography was not interpreted as to vegetation subject; however, it was classified, in the process of subsampling, into categories that were hoped would be vegetationally related.

Secondary Sample Unit Image Classification and Selection

PSU's (from the space imagery) were square cells representing approximately 2 mile x 2 mile ground areas. Through the use of square gridded acetate overlays, the 35 Apollo and 35 ERTS PSU's were identified and transferred to the 11 SEP 70 high altitude photo transparencies. The size of the PSU's on the high altitude photographs was one inch square. These were gridded into 16 equal size, square subdivisions which became the secondary sample units (SSU's). These ¼ x ¼ inch SSU's represented approximately quarter mile squares (½ x ½ mile) on the ground. The quarter mile square areas were satisfactory from two standpoints. First, areas of this size often were small enough to contain a single vegetation subject at the level of vegetation classification of interest. Second, quarter mile squares are sufficiently large to permit ready helicopter examination.

Using two-date stereo examination of the 1:120,000 high altitude transparencies, every SSU in the selected PSU's was classified. Classification was done on a within stratum basis. That is, no attempt was made to associate classified SSU's between strata. Classification consisted of photo interpretive judgements as to the similarity among SSU's. Where more than one image was present in an SSU, the image occupying the greatest proportion was classified. Images of lesser extent were disregarded. There was no active attempt to relate photo images to specific vegetation classes; however, area familiarity and interpretation experiences with similar photography would be expected to contribute to the creation of vegetationally related classes. The classification system was open ended, i.e., as many classes were established as needed for all SSU's to fit.

Allocation of SSU's and Helicopter Reconnaissance

The number of SSU's allocated for helicopter ground checking (also called ground sampling and helicopter sampling) was 105 for Apollo and 103 for ERTS. These sample sizes represent an attempt to approximate 100 samples each. The *SIPS program (Guthrie, Avery, and Avery, 1973) was used to select randomly the designated number of SSU's for sampling from the candidate SSU's (classified subcells) which were available for each image class. The decision to ground check 100 samples each for Apollo and ERTS sampling was based on a complex chain of events.

First, contractual obligations called for a comparison of ERTS imagery when both (or all) space photos were used in a sampling scheme. As previously mentioned, the comparison was narrowed to the Apollo versus ERTS.

Then, prior to entering the field, sampling approaches and alternatives were considered in conferences with Oregon State University personnel, Dr's. Norbert Hartmann of the Statistics Department, and William Pyott of the Rangeland Resources Program. The alternatives listed by priorities are given in Table 7-5. The first and second

Table 7-5. Alternative sampling tasks arranged prior to field sampling.

Priority	Helicopter sampling tasks
1 st	150 samples each from Apollo & ERTS
2 nd	100 samples each from Apollo & ERTS
3 rd	200 samples from ERTS alone
4 th	150 samples from ERTS alone

priority sampling would allow for a comparison of the relative value of Apollo and ERTS when used as the first stage in sampling. In the event there had been poor ground subject to high altitude image class correlation, the Apollo versus ERTS comparison would had to have been dropped. This would have shifted all ground samples to those drawn from ERTS only. Depending on time available, 200 samples would have been drawn from ERTS (third priority) or 150 samples also from ERTS (fourth priority). In either of the latter two cases, assessment of the sampling approach would have been limited to the relative value of using ERTS in sampling. Fortunately, the more meaningful second priority task was accomplished.

Further, the estimated number of SSU's to be allocated for ground checking by helicopter reconnaissance was based on: (1) expecting approximately 15 vegetation types in the sample areas; (2) having 14 delineations for four strata from Apollo and 17 delineations for three strata from ERTS; and finally (3) an estimated time requirement of six minutes/ground site when using helicopter reconnaisannce for ground checking. For 200 sites, this would require 20 hours of helicopter time, and would consume all of the budgeted funding which was available.

Finally, the decision as to which of the priority tasks to follow was to have been made at the end of the first day of helicopter sampling by taking into consideration the apparent consistency between image classes and vegetation types as well as sample time per ground check. However, by midday of the first day, it was apparent that there was reasonably good subject to image class correspondence for the ERTS samples checked to that point. Thus, we were able to proceed throughout the rest of the sampling time and gather approximately 100 samples (second priority) from Apollo as well as from ERTS.

The actual number of SSU's which were ground checked is shown in Table 7-6. These deviate somewhat from the number which were allocated to the sampling. This deviation is a result of navigation errors which were made during the ground checkings. That is, on four occasions the SSU's which were sampled by mistake were intended to be sampled only if greater than 100 samples were to be drawn per space photo type. On another occasion, a sample which was intended to be checked was missed. Table 7-6 also shows the proportion of the total area which was sampled both by PSU's and SSU's. For both Apollo and ERTS, approximately 16 percent of the total sample areas were present in PSU's and about 3.6 percent of the total areas were represented by ground checked SSU's.

Site to site helicopter navigation was accomplished by using 9 x 9 1:120,000 black and white photo prints on which the sites had been plotted. With the exception of about six sites, landmarks were recognized that enabled confident location of sites. For the questionable six, terrain and vegetation were uniform enough to be of minimal concern in terms of site information which was recorded. The on-site flight objective was to maintain a ¼ to ½ mile diameter circle at an altitude above the terrain of 40 to 300 feet and at a minimum safe air speed (40-50 nautical miles per hour). On two of the three days of helicopter reconnaissance, moderately strong and gusty winds prevented close site inspection; however, we were able to get close enough for accurate identification of large shrubs and trees. The information gathered at each site consisted of recording major species present and their relative ranking. At about 60 of the sites, 35 mm photographs were also obtained.

Analysis

Vegetation analysis began with the identification of ground sites in terms of the vegetation classification previously developed. For most sites this was a straightforward process based mostly on an

Table 7-6. Number of sample units and proportions of study areas which were sampled.

Strata	Total area (Sq. miles)	Percentage of total area in PSU's	Percentage of total area Ground checked	Number of PSU's	Number of Checked SSU's
Apollo B	155	17.41	3.87	8	24
F	87	20.40	4.89	5	17
H	251	17.23	3.88	12	39
J	197	13.32	3.30	10	26
Total/average	690	16.56	3.84	35	106
ERTS F	336	13.91	3.20	16	43
I	208	16.47	3.85	9	32
L	190	17.89	3.95	10	30
Total/average	734	15.67	3.58	35	105

examination of species presence. Often prominence values had to be considered in order to achieve the "best fit." For a restricted number of sites there was difficulty in determining which of two closely related vegetation types gave the better fit even when considering a combination of species presence and prominence.

A stratified sampling approach was used for estimating vegetation type proportions and variances. The assumptions which were operative in the sampling and subsequent data analysis included: (1) SSU's represented only one image class (independence of image classes); (2) SSU's occurred in only one stratum (independence of stratum); and (3) SSU's represented only one vegetation type (independence of vegetation type). Theory of statistical sampling as applied in stratified sampling can be found in references such as Hansen, Hurwitz, and Madow (1953).

For both Apollo and ERTS sampling schemes, all potential SSU's were categorized by high altitude photo determined image classes within strata. A sample of SSU's was ground checked by helicopter and individual ground samples (SSU's) were identified by vegetation type. Because areas of SSU's were proportional to the entire sample area, this provided the means for estimating proportions of vegetation types as weighted by image class and strata and in relation to the total number of SSU's.

The formula for estimating the proportion ($\hat{E}$) of vegetation type k is:

$$\hat{E}_k = \frac{1}{N_{..}} \sum_i \sum_j N_{ij} \quad \hat{P}_{ijk}, \text{ where}$$

$N_{..}$ = the total number of SSU's

N_{ij} = the number of SSU's in the i^{th} stratum and j^{th} image class

$\hat{P}_{ijk}$ = the proportion of vegetation type k in image class j of the i^{th} stratum

Variance for vegetation types was an estimate of the degree of unique vegetation type to image class correspondence. For example, if only one vegetation type was identified for an image class (or for each image class in which the type occurred), variance for that type would be zero. Variances increased as the uniqueness of the type-class correspondence decreased. That is, as more and more vegetation types were identified for an image class, the less unique was the correspondence for any one type in the class. The variance calculations are based on multinomial distribution as presented by Mood and Graybill (1963).

The estimated variance ($\hat{v}$) of vegetation type k in stratum i, in image class j, is:

$$\hat{v}_{ijk} = \sum_k \hat{b}_{i\cdot k}^2 \hat{P}_{ijk} (1-\hat{P}_{ijk}) - 2 \sum_{k<k'} \hat{b}_{i\cdot k} \hat{b}_{i\cdot k'} \hat{P}_{ijk} \hat{P}_{ijk'},$$

where

$\hat{b}_{i\cdot k}$ = the proportion of vegetation type k in the i^{th} stratum.

k' = any type in the i^{th} stratum other than the k^{th} type.

The estimated variance of vegetation type k across the strata is:

$$\hat{v}_k = \frac{1}{N_{..}^2} \sum_i \sum_j N_{ij}^2 \hat{v}_{ijk}$$

The estimated variance of the sampling scheme is:

$$\hat{v} = \frac{1}{n_{...}^2 N_{..}^2} \sum_i \sum_j \sum_k n_{..k}^2 N_{ij}^2 \hat{v}_{ijk},$$

where

$n_{...}$ = the total number of SSU's which were ground checked.

$n_{..k}$ = the number of SSU's which were ground checked and identified as to the k^{th} vegetation type.

RESULTS AND DISCUSSION

Comparative Effectiveness of Apollo and ERTS Schemes

Efficiency: Apollo and ERTS provided the first stage sampling strata bases for a comparative two stage sampling scheme. The stratification enabled high altitude image classification at the second stage. From a combination of the stratification and subsequent image classification, areal estimates and related statistics for vegetation types were developed. The successes of the two sampling schemes ultimately rest in the evaluations of those statistics.

One of the methods for predicting sampling effectiveness is by comparing proportionate stratified sampling to simple random sampling.

This is accomplished by establishing ratios between the mean square errors for samples drawn proportionately (MSE pps), to mean square errors for samples drawn with equal probability (MSE eq). Such expression by ratios often shows substantial efficiency gains by stratified sampling, although it is not uncommon in forest applications to have virtually no gain due to stratification (see especially Kulow, 1966). The formula is given by Snedecor and Cochran (1967, p. 534-536) for the ratio of averages $\frac{\overline{\text{MSE eq}}}{\overline{\text{MSE pps}}}$. For the research reported here, Apollo had a six percent gain in "efficiency" and ERTS about five percent over equal probability sampling. Since sampling costs were fixed, efficiency is defined as an increase in sampling precision over equal probability sampling (Hansen, Hurwitz, and Madow, 1953, p. 34). These same authors point out that "If stratification does not result in strata which are homogeneous with regard to the characteristic to be measured (<u>not</u> the characteristic employed in setting up the strata), there will be no gain from its use," (p. 41). The ratio formula seems inadequate to estimate strata homogeneity for this sampling because the ratio is based on strata areas that do not necessarily directly reflect vegetation type areas.

The stratification resulted in three benefits:

(1) It enabled high altitude photo image classification of potential SSU's. This was an integral part of the sampling scheme, and could not have been accomplished readily without some means of reducing the number of SSU's for image class placement.

(2) It created a base (the strata themselves) suitable for small scale vegetation mapping as discussed later in this section.

(3) It provided a means of cluster sampling which had a direct effect on helicopter expenses. This, too, is discussed later.

<u>Variance</u>: Relative precision between Apollo and ERTS sampling was examined by variance determinations. Variance calculations for the two schemes were over all strata and vegetation types:

Apollo variance ($\hat{v}$) = 0.000,00786;

ERTS variance ($\hat{v}$) = 0.000,06152.

Variances for both schemes appear extraordinarily small; however, it must be kept in mind that the variances were derived from sample area proportions; this produced smaller than usual variances. Two further points are warranted: (1) overall variance for both sampling schemes would be judged small; and (2) variance for ERTS was 7.8 times larger than for Apollo. In other words, sample dispersion around the mean proportion estimates for vegetation types was small for both schemes, but considerably smaller from sampling with Apollo.

More detailed analysis of variation between the two sample schemes was seen by considering variation for each vegetation type (Table 7-7). Of the 16 types sampled in common, it was possible to compare 14 [7-1/] of the types. As seen in the table, $SE_{\hat{E}}$ were larger for estimates derived from ERTS sampling in 12 of the 14 types. For Apollo sampling, $SE_{\hat{E}}$ were larger for two of the 14. Although differences often were not great, sampling from Apollo generally was more precise than from ERTS.

One can only speculate as to the exact nature of the nearly consistent difference in sampling precision between the two schemes. Based on the space photo comparisons of the preceding chapter, the conclusion was reached that for mountainous macrorelief classes (3 and 4), ERTS showed an advantage over Apollo (Table 3-12). This was determined from the ability of observers to group representative photo images into the appropriate mountainous classes. However, it was also shown that Apollo had greater image complexity than did ERTS. This resulted in

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7-1/ In the analysis of the type used, variance calculations (and, therefore, standard errors) sometimes result in "zero" variance when variance actually does exist. For the sampling reported here, the errors occurred when, within an image class (as determined on high altitude photography) of a stratum, there was complete balance between any two vegetation types within that image class and the total number of samples for the same two types in the stratum. For example, for an image class, if vegetation types 13 and 21 both had two ground samples drawn, and they both also had a total of two ground samples for the stratum, the variance calculations for the two types from that stratum would be zero, although the types would actually have variances. Errors of this sort are a result of the multinomial nature of the vegetation classification and subsequent ground sampling approach. They have been termed "artifact errors" for this presentation. For similar sampling, artifact error occurrence can be minimized or eliminated by (1) increasing sample size; (2) creating fewer image classes; and/or (3) recognizing fewer vegetation types.

differential study area stratification for Apollo and ERTS (Figure 3-4 and Table 3-14). It follows that the greater image complexity of Apollo (which infers greater ground subject discrimination) resulted in greater sampling precision when compared to ERTS.

There are two apparent implications of the comparison. First, although ERTS sampling was more variable than Apollo sampling, it is our evaluation that both produced satisfactory results. The bases for this judgment are the (1) areal estimates for vegetation types; (2) implications for mapping based on those estimates and the space photo stratifications; and (3) cost reductions for helicopter ground sampling. All of these are discussed later in this chapter.

Vegetation Type Area Estimates

Vegetation type area estimates are given in Table 7-8 for Apollo and ERTS sampling. The mean area values in the table were calculated directly from the proportional means of Table 7-7. Upper and lower values were calculated from 95 percent confidence interval estimates using standard procedures (Steel and Torrie, 1960, p. 22-23). Judgments regarding relative acceptability of the ranges would be the responsibility of those who might be making use of the statistics. It is not surprising to see that ranges, relative to their respective means, tend to decrease as the means (and number of ground samples) increase. However, some of the smaller areas have narrow ranges about their means; these cases represent excellent correspondence between high altitude image class and vegetation type. Most types showed a rather strong similarity between estimates from the two schemes. The linear correlation (Snedecor and Cochran, 1967, p. 172-175) between the sample schemes for vegetation types revealed a value of r = 0.88. This is further indication that the two schemes performed similarly in areal estimation.

Sampling Statistics Used in Mapping

Resource maps are among the more useful products derived from resource inventories. The vegetation area statistics from the Apollo and ERTS sampling could be used readily in small scale map production. A logical approach would be to use the delineated strata (with or

Table 7-7. Standard errors ($SE_{\hat{E}}$) and proportional mean areas ($\hat{E}$) for vegetation type sample estimates.

Vegetation Type		Apollo		ERTS	
No.	Name	$\hat{E}$	$SE_{\hat{E}}$	$\hat{E}$	$SE_{\hat{E}}$
4	Cemi-Cegi-Enfa			.0120	.00080
7	Acve-Latr-Rhmi			.0478	.00000
8	Alwr-Fosp-Acco	.0572	.00998	.0447	.02296† 1/
9	Mosc	.0308	.00629	.0103	.00844†
10	Mosc-Rhch	.0719	.00822	.0565	.02094†
13	Acco-Prju	.0699	.00777† 2/	.0185	.00043
14	Caer-Acco-Prju	.0095	.00502	.0456	.01068†
15	Caer-Prju-Mimosa	.0204	.00222	.0091	.02030
16	Caer-Eptr-Yucca			.0065	.00000
18	Prju-Bout	.0205	.00473	.0141	.00000 2/
19	Bout-Arist-Nomi	.0107	.00378†	.0087	.00094
20	Prju bosque	.0044	.00000	.0065	.00000
21	Himu-Prju	.0120	.00000 2/		
22	Spwr-Prju			.0087	.00429
23	Prju-Quercus	.1795	.00916	.2040	.02757†
25	Quercus-Nomi	.0782	.00733	.0200	.02030†
26	Quercus-Mimosa	.0477	.00374	.0765	.00743†
27	Quercus-Arpu-Mibi	.1236	.01067	.1854	.01993†
28	Quercus-Arpu-Pice	.0461	.00344	.0197	.00973†
29	Cebr	.1376	.01064	.1462	.02532†
31	Pinus	.0799	.00137	.0591	.00755†
	Σ	.9999		.9999	

1/ indicates the larger $SE_{\hat{E}}$ for the vegetation type.

2/ artifact error; values are larger than indicated; see text footnote 7-1.

Table 7-8. Apollo and ERTS derived vegetation type area estimates. Lower and upper values are based on 95% confidence interval calculations.

Veg. type		Apollo				ERTS			
		No. of ground samples	Square miles			No. of ground samples	Square miles		
			Area est.	Lower	Upper		Area est.	Lower	Upper
4	Cemi-cegi-Enfa					1	8.78	7.63	9.92
7	Acve-Latr-Rhmi					4	35.10	35.10	35.10
8	Alwr-Fosp-Acco	6	39.49	26.00	52.98	5	32.83	0.0	65.86
9	Mosc	3	21.26	12.75	29.78	1	7.58	1.26	13.90
10	Mosc-Rhch	8	49.64	38.52	60.75	6	41.49	11.36	71.61
13	Acco-Prju	7	48.23	(37.72	58.74)1/	2	13.56	12.94	14.18
14	Caer-Acco-Prju	1	6.54	0.0	13.33	5	33.51	(18.14	48.85)1/
15	Caer-Prju-Mimosa	2	14.09	11.09	17.10	1	6.70	0.0	35.91
16	Caer-Eptr-Yucca					1	4.79	4.79	4.79
18	Prju-Bout	2	14.16	7.76	20.55	2	10.37	(10.37	10.37)1/
19	Bout-Arist-Nomi	1	7.36	2.22	12.50	1	6.38	5.03	7.74
20	Prju bosque	1	3.02	3.02	3.02	1	4.79	4.79	4.79
21	Himu-Prju	1	8.30	(8.30	8.30)1/				
22	Spwr-Prju					1	6.38	0.21	12.55
23	Prju-Quercus-Jude	18	123.86	111.47	136.25	21	149.73	110.07	189.39
25	Quercus-Nomi	9	53.96	48.90	59.02	2	14.68	0.0	43.89
26	Quercus-Mimosa	6	32.91	27.85	37.98	8	56.11	45.42	66.81
27	Quercus-Arpu-Mibi	14	85.26	70.83	99.69	20	136.12	107.44	164.79
28	Quercus-Arpu-Pice	5	31.83	27.18	36.48	2	14.47	0.47	28.47
29	Cebr	14	94.97	87.63	102.31	15	107.28	70.86	143.71
31	Pinus	8	55.11	53.26	56.96	6	43.35	32.48	54.22
	Σ	106	689.99			105	734.00		

1/ Artifact error; see text footnote 7-1.

without a photo base) to indicate the locations of the type(s) being mapped. Each mapping (delineated) unit of a particular strata would contain the same vegetation type(s) in the same proportion(s). Based on need for portraying detail, only those types which exceeded specified proportions would be included in the mapping. The proportion of each type can also be indicated if desired.

For purposes of illustration, proportions for mapping from the Apollo or ERTS derived statistics might be arbitrarily set at five to nine or ≥ 10 percent occurrences for each vegetation type in a stratum. Table 7-9 contains the essence of the information which would be needed in mapping if proportions of each type were not to be presented.

For Apollo based mapping, at five to nine percent occurrence, 13 vegetation types would be mapped as compared to 10 types with ERTS based mapping (Table 7-9). By contrast, nine and six types would be mapped at ≥ 10 percent occurrence for Apollo and ERTS, respectively. In either case, the larger number of types displayed in mapping would be derived from Apollo sampling.

It is also informative to study the Table 7-9 entry, "% of Area not Represented." In mapping at the five to nine percent level of occurrence, 13 and 15 percent of the total area sampled had vegetation types that would not be represented in mapping. At the ≥ 10 percent level, 31 percent of Apollo and 41 percent of ERTS sample areas would not be represented. Particularly for ERTS this would represent a considerable information loss.

The difference in strata numbers appeared to contribute directly to the greater mapping information loss from ERTS sampling as contrasted to Apollo sampling. This would be expected to occur for two reasons. First, as strata numbers increase, the number of vegetation types per stratum decreases. This increases the proportion of types by stratum, and therefore increases the number of vegetation types that are eligible for mapping when based on percentage occurrence criterion. Second, because of the increase in vegetation type proportions, there would be a corresponding decrease in the "% of Area not Represented." Whatever the cause of differential information content in mapping, it would generally be desirable to have the option of maximizing the number of vegetation types displayed and minimizing the amount of sample area not represented in mapping.

Table 7-9. Comparison of vegetation types which would be mapped at the indicated levels of occurrence from Apollo (A) and ERTS (E) sampling.

Veg.	Level of occurrence		Number of strata where found			
			Apollo (4 possible)		ERTS (3 possible)	
types	5-9%	≥ 10%	5-9%	10%	5-9%	≥ 10%
4			-	-	-	-
7	E		-	-	1	-
8	A, E	A	1	1	2	-
9	A		1	-		
10	A, E	A, E	2	1	1	1
13	A, E	A	2	1	1	-
14	A, E		1	-	1	-
15	A		1	-	-	-
16						
18						
19						
20						
21						
22						
23	A, E	A, E	4	4	3	2
25	A	A	2	1	-	-
26	A, E	A, E	1	1	2	1
27	A, E	A, E	3	2	3	1
28	A		2	-	-	-
29	A, E	A, E	4	4	2	2
31	A, E	A, E	1	1	1	1
Σ Veg. types	13 10	9 6				
% of Area not represented	13 15	31 41				

Another desirable aspect of stratified sampling and subsequent mapping is when vegetation types tend to be concentrated by strata. Statistical testing for normal distribution (non-concentration) of types among strata is possible under certain circumstances, but not for the Apollo and ERTS data sets. The reason is that too few strata and often too few samples existed. However, a cursory comparison for apparent concentrating was accomplished by simply tallying the number of samples by strata and by vegetation type (Table 7-10). The three types found in greatest quantity, Types 23, 27, and 29, also showed the least tendency for strata concentration. The implication might be that these three, in addition to their frequent occurrence in the area samples, also tended to be widely scattered throughout the area. Some of the types, especially Type 31, showed strong concentrations by strata. These two constrasting examples might be suspected of representing vegetation types which had differential subject (vegetation type)-image class correspondence. That is, Types 23, 27, and 29 might have had poor correspondence with high altitude photo image classes, whereas Type 31 might have had strong correspondence. However, this is not borne out by examination of the appropriate standard errors of Table 7-7. It would seem that there simply were not enough strata available to make a substantive comparison regarding relative vegetation type concentration by strata for the two schemes. Cursory evidence suggested some types displayed concentration tendencies while others did not.

Helicopter Time and Cost Analysis

Based on the discussion put forth by Hansen, Hurwitz, and Madow (1953, p. 48), the type of sampling scheme employed was cluster sampling within stratified sampling. The clustering was a product of space photo sampling. This probably increased sampling error over simple random sampling. However, ". . . the main purpose of cluster sampling is not to get the most reliable sample in terms of the number of elementary units included, but to get the most reliable results per unit of cost," (Hansen, Hurwitz, and Madow, 1953, p. 51). An examination of helicopter time and cost demonstrated the advantages of the cluster sampling which was employed compared to random sampling which might have been employed if space photography had not been used.

Table 7-10. Occurrence of ground samples by vegetation type and strata.

Veg. type	Apollo Strata					ERTS Strata			
	B	F	H	J		F	I	L	
4					-			1	1
7					-	3	1		4
8	1	4		1	6	2	3		5
9		1	2		3		1		1
10		1	4	3	8	5		1	6
13	4		1	2	7	2			2
14		1			1	4	1		5
15				2	2	1			1
16					-		1		1
18	1		1		2		1	1	2
19			1		1		1		1
20		1			1	1			1
21			1		1				-
22					-	1			1
23	5	2	5	6	18	16	2	3	21
25		5	3	1	9	1	1		2
26			1	5	6	3	1	4	8
27	9		2	3	14	3	15	2	20
28	2		3		5		1	1	2
29	3	2	6	3	14	1	3	11	15
31			8		8			6	6
Σ	25	17	38	26	106	43	32	30	105

Based on our experience and time estimates for vegetation inventory sampling of the type conducted, it was possible to effect a reasonable approximation of helicopter expenses with time partitioning (Table 7-11).

Table 7-11. Empirically derived helicopter time partitioning from combined ERTS and Apollo sampling.

Assumptions: Helicopter cost, @ $100/hour
Ave. site-to-site speed of 50 m.p.h.
Ave. on-site time of 4 minutes
Ferry and refuel time is equivalent to 25% of site-to-site time plus on-site time

Working time

On-site time: 211 sites @ 4 minutes each = 844 min

Site-to-site time:

$$\frac{1.10 \text{ mi}}{\text{site}} \times \frac{211 \text{ sites}}{1} \times \frac{1}{50 \text{ mi/hr}} \times \frac{60 \text{ min}}{\text{hr}} = \frac{278 \text{ min}}{1122 \text{ min}}$$

Ferry and refuel time: 1122 min (.25) = 280 min

1402 min total

or 23.3 hrs total

Estimated time partitioned helicopter expenses $100/hr (23.3 hr) = $2330

The "211 sites" used in the table calculations represent the sum of the Apollo (106) and ERTS (105) ground-checked SSU's. They were concentrated in about 780 square miles; this had the effect of reducing site-to-site travel time, because all samples were ground checked without regard to their origin (Apollo or ERTS sampling schemes). However, the reduced travel time was offset by unusually high ferry time incurred with the necessity of maintaining Tucson as the home base.

The "Site-to-site time" calculation in Table 7-11 is based on distance measurements between sites. The 1.10 miles/site value is an average between Apollo and ERTS site-to-site minimum distances. The helicopter speed, 50 miles/hour, is a reasonable cruising speed for the aircraft used. The "On-site time" of four minutes is our best estimate of the time required to locate accurately a site from navigational photography and to gather the necessary vegatational information at the site.

"Ferry and refuel time" (Table 7-11), in a large measure, is a function of working time (site-to-site time plus on-site time). For that reason, in order to estimate the ferry and refuel time component, it is derived as a portion, 25 percent, of working time. When calculated in this manner, the estimated helicopter expense ($2,330) closely approximates the actual expense ($2,397). Based on our helicopter field sampling experiences and the close approximation of expenses, the time partitioning is considered to represent reasonable allocations.

By using the partitioning of time and related inputs of Table 7-11, it was possible to demonstrate the value of cluster sampling versus random sampling. The magnitude of the difference can be quantitatively expressed by approximating the average distance between consecutive ground sample sites when random sampling is employed. The distance formula used is from Hansen, Hurwitz, and Madow (1953, p. 274):

$$d = \sqrt{\frac{A}{n}}$$

where:

d = average distance between any pair of consecutive sample sites

A = total area sampled

n = total number of equally spaced sample sites in area

The reason the distance calculation is only an approximation for random sampling is that the values thus derived are based on equally spaced sample sites, whereas randomly drawn sample sites would not normally display a perfect pattern of equal spacing among all sites. When applied to Apollo and ERTS sampling schemes, the distance estimates for randomly drawn sample sites were calculated as shown below:

Apollo

$$d = \sqrt{\frac{690 \text{ sq miles}}{106 \text{ sites}}}$$

= 2.551 miles from site to site

ERTS

$$d = \sqrt{\frac{734 \text{ sq miles}}{105 \text{ sites}}}$$

= 2.644 miles from site to site

For the SSU's actually helicopter checked in the sampling, the average minimum site-to-site distance (elevation changes ignored) as calculated on 1:120,000 photo maps was 1.10 miles for Apollo and 1.09 miles for ERTS. Distances were calculated as though helicopter checking of SSU's had been done separately for both space photo sampling schemes.

With this site-to-site distance information, it was possible to calculate comparative sampling costs for the clustered, stratified, two stage sampling which was used, as opposed to random, one stage sampling which would have been a logical choice if high altitude photography only (no space photography) had been used. Details of the comparison for ERTS sampling are shown in Table 7-12 where particular attention is called to the "Working time" estimates of 557 minutes for clustered sampling versus 753 minutes for random sampling. Estimates of this sort, for the type and mode of sampling which was conducted, can be viewed as representing reasonable approximations for other sampling tasks of a similar nature. That is, working time increases based on random sampling as contrasted to clustered sampling amounted to 35.2 percent for ERTS derived figures and 32.5 percent for Apollo figures.

The "Total time" figures and "Helicopter expense" figures of Table 7-12 should be viewed as project specific, because ferry and refuel time, as well as helicopter expenses may be highly variable from project to project. These figures for ERTS are summarized in Table 7-13 along with those for Apollo. As one views these features of the two sampling schemes, it is apparent that there is little difference between the two. The reason for the strong similarity, of course, is that cluster sampling derived from stratification of the two space photographs resulted in almost identical site-to-site distances (Apollo at 1.10 miles and ERTS at 1.09 miles). This feature, plus the fact that stratifications for the two sampling schemes were independently derived, lend substantial credence to relative comparisons between the clustered and random sampling derived figures of Table 7-13.

Successful Helicopter Reconnaissance

The helicopter reconnaissance activity undertaken was highly successful; however, it was not undertaken without considerable risk of failure. The two basic factors which can contribute to failure are (1) cost that is prohibitive; and (2) inability of the reconnaissance

Table 7-12. Hypothetical helicopter sampling with time partitioning and expenses for ERTS based clustered versus random sampling schemes.

	Clustered	Random
No. of samples	105	105
Area covered	734 sq.mi.	734 sq.mi.
On site time (4 min/ea)	420 min.	420 min.
Site-to-site distance	1.09 mi.	2.64 mi.
Site-to-site time		
$\frac{1.09\ \text{mi}}{50\ \text{mi/hr}} \times \frac{60\ \text{min}}{\text{hr}} \times \frac{105\ \text{sites}}{1}$	137 min.	
$\frac{2.64\ \text{mi}}{50\ \text{mi/hr}} \times \frac{60\ \text{min}}{\text{hr}} \times \frac{105\ \text{sites}}{1}$		333 min.
Working time	557 min.	753 min.
Ferry and refuel time		
557 (.25)	139 min.	
752 (.25)		188 min.
Total time	696 min.	941 min.
	11.50/hr	15.68/hr
Helicopter expense @ $100/hr	$1150	$1568

Table 7-13. Summarized features of clustered versus random helicopter sampling.

		Apollo	ERTS
Average site-to site distance	As sampling was conducted	1.10 miles	1.09 miles
	If sampling had been random	2.54 miles	2.64 miles
Estimated helicopter working time	As sampling was conducted	569 min.	557 min.
	If sampling had been random	754 min.	753 min.
Estimated helicopter expenses	As sampling was conducted	$1185	$1150
	If sampling had been random	$1550	$1568
Helicopter expense per site	As sampling was conducted	$11.07	$10.95
	If sampling had been random	$14.49	$14.93

observers to record accurate and pertinent plant species information. Inasmuch as this type of reconnaissance is, in a sense, research developmental, is accompanied by high risk failure, and was successfully accomplished in our vegetation sampling, it seems appropriate to detail considerations and observations which we made that beneficially contributed to the mission. Although there is no attempt to extrapolate beyond the research setting of the project, many of the comments listed below would obviously have broader applicability.

In addressing the cost factor, there are several points to be made:

(1) Stratification would appear to be a valuable asset for reduction of sample variation. Without stratification, sample size would be expected to be larger to achieve the same level of confidence as was achieved when sampling with stratification. This would be expected to contribute to increased total cost;

(2) As opposed to random sampling, clustered sampling, which is really a product of two stage or multistage sampling, has the potential of greatly reducing site-to-site travel time as discussed in the preceding cost analysis section.

(3) Navigation aids that allow site locations to be rapidly located are essential for reducing site-to-site travel time. The high quality, 1:120,000, black and white photography which we used proved ideal.

(4) Flight plans which carefully consider ferry time and site-to-site time are valuable. As schedules slip, flight plans need to have sufficient flexibility to enable revision. In regions where sampling transcends considerable elevational differences, minimum site-to-site distance flight plans may have to be altered to prevent frequent elevation changes which are costly.

(5) Helicopter choice is another cost related factor of considerable magnitude. Helicopters vary in terms of performance capability, including payload capacity, maximum operational ceiling, cruising speed, and travel range. All of these variables need to be considered on a project to project basis if there are choices available in helicopter selection. Careful balancing of need versus capability should eliminate the costly temptation of contracting for helicopters which are either inadequate or overly adequate for the job.

(6) Contractual arrangements for helicopters are another cost consideration that should be made. Considerable differences in helicopter charges are often present among competing corporations. Further, differences should be considered in the type of contract that a particular corporation may be able to offer. Making the best choice on contract options requires rather accurate estimates of total helicopter time requirements.

The success of the vegetation sampling can be attributed to a number of factors, many of which are related to capabilities of the species observer:

(1) Perhaps it is self evident, but the helicopter occupants cannot be subject to acrophobia or to motion sickness. This is especially true for the species observer who can function best by frequently leaning out of the cockpit doorway. People who suffer from either malady could not be depended upon for doing the best possible job.

(2) The species observer needs to know those plant species of importance. It is highly advantageous to have pre-sampling identification experience from the air. This latter capability can be developed in a relatively brief period during sampling as long as the ability to field identify species is present.

(3) The species observer can increase identification confidence if he is familiar with species assemblages. That is, for the area being sampled, if the observer knows which of the species can be expected to be found together and which cannot, fewer errors in identification are likely to result.

(4) Ground speed and altitudes above terrain contribute to sampling success, and to some degree are controllable. Minimum safe air speeds and altitudes vary by location with atmospheric conditions. When possible to make a choice, slowest ground speeds and lowest altitudes can be achieved when air temperatures are cool and winds are non-gusty but steady at about 10-20 knots per hour. However, satisfactory sampling can be accomplished, and indeed often must be, when conditions of atmosphere are less than optimum.

(5) Knowing the stage of plant phenological development at the time of sampling is important for airborne species identification. This can be accomplished by surface transportation and careful examination of plants in the sample area prior to sampling.

(6) Selection of a season when phenologic development is of benefit in identification can be highly important. Where deciduous woody species are of concern, this might be in autumn. By way of example, in the Southern Arizona Test Site, autumn coloration can highlight aspen and Arizona walnut, both of which display yellow. Cliffrose and mountain mahogany, which often occur together, can be distinguished in late summer or autumn by the mountain mahogany having abundant fruits with attached and conspicuous plumose styles. Several of the leaf succulent species are made readily visible and distinguishable following the summer months because of their conspicuous and distinctive flowering stalks. At a considerable distance, Agave, Yucca, and Dasylirion are identifiable. In fact, Agave might often be overlooked if not for the presence of flower stalks.

SUMMARY

The Apollo and ERTS photos were compared for relative suitability as first stage stratification bases in two stage proportional probability sampling. High altitude photography was used in common at the second stage. At the first stage, "wooded" versus "not wooded" predictions were made for the purpose of allocating subsamples. At the second stage, sample units were classified by image class - not interpreted as to vegetation type. On the ground, sampled units of the image classes were identified as to vegetation type. By applying the multinomial distribution concept to probability sampling, it was possible to estimate areas and variances for several vegetation types.

Sampling efficiency gains over equal probability sampling were small, about six percent for Apollo and five percent for ERTS. However, the stratification resulted in three benefits:

(1) It enabled high altitude photo image classification which was an integral part of the sampling scheme.

(2) It created a base (the strata themselves) suitable for small scale vegetation mapping.

(3) It provided a means of cluster sampling which reduced helicopter expenses had clustering not been present.

Overall variance for the Apollo and ERTS sampling was small; however, variance for ERTS was 7.8 times larger than for Apollo. In comparing standard deviations of individual vegetation types, ERTS usually had larger values than did Apollo. It would appear that the greater image complexity of Apollo resulted in greater sampling precision when compared to ERTS. In spite of these differences, sampling with both space photo types was judged satisfactory.

Vegetation type area estimates from both schemes were comparable. Vegetation type statistics and space photo strata from both schemes could be used satisfactorily for mapping. In general, mapping from Apollo derived statistics provided greater information than from ERTS. This difference was attributed primarily to the difference in strata number.

A helicopter was used to gain access to the ground samples which were selected from the high altitude image classes. The technique proved satisfactory for gaining the plant species information required for vegetation type identification. The clustering provided by space photo stratification resulted in large reductions of site-to-site travel time as compared to travel among randomly located sample sites. The result was that working time (site-to-site plus on-site time) was reduced by an estimated 32 percent for Apollo and 35 percent for ERTS sampling as compared to random sampling. These reductions represent substantial monetary savings when sampling with a helicopter. As a result of the successful ground sampling, some guidelines were developed for helicopter sampling of the type employed.

CHAPTER 8

DIGITAL DATA ANALYSIS

OBJECTIVE 7

INTRODUCTION

Our original intention was to contribute to solution of the problem of identification of ground features from ERTS by determining multispectral signatures from MSS digital data of some vegetation systems in an arid environment. It soon became apparent, however, that with only slightly more time, effort, and expense we could further extend the objective. Thus, we decided to determine the level of vegetation classification appropriate to the scale and resolution of ERTS-1 MSS digital data. The expected results would, therefore, be an indication of the level of vegetation detail in the digital data.

MATERIALS

The study area is in the Southern Arizona Test Site, in the vicinity of Tombstone (Figure 1-2). Land marks bounding the area include Willow Wash on the north, San Pedro River to the west, Mule Mountains to the southeast, and Dragoon Mountains to the northeast. Included within the study area are more or all of the watersheds of Walnut Gulch and Government Draw.

The data analyzed in this investigation were acquired by the ERTS-1 satellite on 22 August 1972 (Frame Number 1030-17271). All four multispectral bands (4, 5, 6, and 7) were used. This date of data was selected because the summer growing vegetation (which predominated in the area) was about at its annual peak of development. The area was also cloud free on this date.

The facilities of the Data Processing, Center for Remote Sensing Research (CRSR), University of California, Berkeley, were used for analysis of the data. These included a NOVA computer, tape drives, input-output devices, and a TV like color display, in-house, as well as access to a CDC 7600 computer at the Lawrence Berkeley Laboratory.

We used a maximum likelihood discrimination procedure (CALSCAN[8-1/]) to analyze the data. This required an existing classification as input. We had available a floristic vegetation classification for the Tombstone, Arizona vicinity (Garcia-Moya, 1972). This was the major consideration for selection of the area.

The vegetation classification was hierarchical, with the basic classes (vegetation associations) established through computer analysis of species composition and vegetation ground cover recorded at approximately 475 locations. The computer programs were developed at Oregon State University as a part of Western Regional Project W-89, Characterization of Habitat Types of Sagebrush Ranges (Pyott, 1972). A polythetic-agglomerative[8-2/] procedure was used. The measure of similarity was squared Euclidean distance (for presence-absence data). The classification algorithm was one which minimizes the error (within groups) sum of squares. The associations were then grouped into alliances by visual inspection on the basis of common species (Table 8-1). For the ERTS analysis, we used the associations (A-M), a variant of one association (A1a) and a cultural feature (brush clearings) as the initial input classes (15) for CALSCAN.

PROCEDURES AND INTERMEDIATE RESULTS

Since this investigation was carried out in a stepwise fashion with the results of one step input data for the next, this report is constructed in the same way. The major steps were (1) data preparation; (2) selection of training and test fields; (3) evaluation of training fields; (4) assessment of level of separability of given vegetation classes; (5) classification and display of whole study area; and (6) interpretation of results of classification in relation to surface physical environmental features.

8-1/ A modification of LARSYSAA developed by the former Forestry Remote Sensing Laboratory, University of California, Berkeley, California.

8-2/ Polythetic indicates many characters (i.e., species) were used; agglomerative indicates the synthesis of classes from individuals and subclasses.

Table 8-1. Summary of the floristic vegetation classification for the vicinity of Tombstone, Arizona (Garcia-Moya, 1972).

Alliance I (*Acacia vernicosa*-*Larrea tridentata*-*Flourensia cernua*)

- Association A (*Panicum hirticaule*/*Tidestromia lanuginosa*-*Boerhaavia coulteri*) Including one variant (Ala) with high prominence of *Prosopis juliflora.*
- Association B (*Rhus microphylla*-*Dalea formosa*)

Alliance II (*Yucca elata*/*Bouteloua eriopoda*)

- Association C (*Gutierrezia sarothrae*/*Eriogonum abertianum*)
- Association D (*Menodora scabra*/*Tridens grandiflorus*)
- Association E (*Hilaria belangeri*)
- Association F (*Gilia rigidula*-*Rhynchosia texana*)

Alliance III (*Fouquieria splendens*-*Acacia constricta*-*Aloysia wrightii*)

- Association I (*Ayenia pusilla*/*Eragrostis intermedia*)
- Association J (*Cnidoscolus angustidens*)
- Association K (Typical of the alliance)

Individual Associations (Differing substantially from the alliances):

- Association G (*Hilaria mutica*/*Eriochloa gracilis*/*Crotalaria pumila*)
- Association H (*Haplopappus tenuisectus*/*Eragrostis lehmanniana*)
- Association L (*Agave palmeri*-*Agave parryi*/*Haplopappus laricifolius*)
- Association M (*Mortonia scabrella*)

Data preparation involved reformatting the ERTS tapes and then extracting the data for the study area from the one quarter scene tapes. This was done using a NOVA computer and a TV type color display. The latter was used to provide geographical orientation in extracting just the data desired. Three bands of data can be superimposed on the display with a different color (red, green, or blue) for each band if desired. We used bands 4, 5, and 7 with blue, green, and red respectively. We found this combination gave the best contrast among vegetation images.

Since CALSCAN is a discrimination procedure rather than a classification constructing procedure, it must be "trained" to recognize the classes of the given classification. Thus, training fields to characterize each of the 15 classes were selected using the previously described equipment.

A training field is a small, homogeneous area of known identity and ground location, as is a test field. Except for the brush clearing class, the training and test fields we used were selected to represent some of Garcia-Moya's field sampling locations. Representatives of the brush clearing class were selected from areas which he had mapped as such.

The field sampling locations were plotted on 9"x9" color infrared aerial photo transparencies (1:120,000 scale). These photos were then used to locate the sampling areas on the color display of the ERTS data. We found a very good correspondence between the ERTS color display and the color IR photos in terms of feature identification and, thus, geographic orientation. Those sampling areas which could be located on the display of the ERTS data with certainty and which fulfilled the homogeneity criterion were selected as training or test fields. We were very careful in defining the boundaries of the training fields in terms of what was included. We were not so careful with the test fields, because at the time we wanted to determine what CALSCAN could do with slightly heterogeneous areas. We found out, as will be explained later.

With the selection of the training and test fields, we were ready to use the CALSCAN Program package. The CALSCAN analyses were done on a CDC 7600 computer to which CRSR (Lawrence Radiation Laboratory, Berkeley, California) has access. CALSCAN has four major parts: STAT, SELECT, CLASSIFY, and DISPLAY. STAT calculates statistics and plots histograms and spectral plots for the training fields. SELECT calculates interclass divergences, allowing for the selection of the ERTS band combinations (<4) best for class separation. CLASSIFY examines all of the specified data and places each resolution element into one of the given classes on the basis of the training field statistics. DISPLAY takes the output from CLASSIFY and displays it in map form with various options available for symbolization, reclassification, regrouping of classes, assessing training or test field performance, etc. All areas in the data to be processed by CALSCAN (e.g., training fields) are identified by coordinates obtained from the program during the process of extracting the data and selecting the training and test fields.

The training fields were evaluated by inspection of the statistics and histograms generated by STAT. Training fields were eliminated if they departed greatly from the class mean, exhibited excess internal variation, or both. We used a cutoff for training field deletion of (1) a standard deviation greater than five; of (2) contribution to class standard deviation greater than five. Six training fields were deleted in this way, leaving 93.

SELECT calculated the interclass divergences based on the training field statistics. The divergences were used as part of the criteria for determining the level of vegetation classification compatible with ERTS data. The best combination of these ERTS bands which maximized the average interclass divergence was that of bands 4, 5, and 7 thus apparently confirming our earlier visual assessment from the color display.

CLASSIFY and DISPLAY were next used on sample areas selected to assess the performance of the training fields and to get additional information concerning the level of separability of the given classes using ERTS data. The total criteria considered for assessing the vegetation classification level of separability using ERTS data were the following: (1) interclass divergences; (2) summaries of training field performance (from analysis of sample areas); (3) comparison of field vegetation writeups; and (4) visual interpretation of available ground photographs of training fields.

Low divergences of some of the class pairs indicated poor separation in the ERTS data. Coupled with this was poor performance of some of the training fields, summarized by class in Table 2: overall, 43.1 percent; and average per class, 43.2 percent. Reclassification of each resolution element according to the class of its nearest neighbors improved the results slightly overall, 44.2 percent and average per class, 46.7 percent.

Predominant misclassifications, as well as interclass divergences, suggested new groupings for the classes (Table 8-2). These new classes were confirmed by comparing vegetation writeups and available ground photographs of the training fields. Inspection of the writeups suggested that the new classes were held together floristically by highly prominent perennial species (usually shrubs). Comparison of the ground photographs illustrated the physiognomic similarity among the original classes suggested for grouping by the results of CALSCAN. The new class names (Table 8-3) are connotative of the integrating characteristics. Note that new classes ACACIA, BOER, and AGAVE correspond (with some deviation) to Garcia-Moya's alliances I, II, and III respectively (Table 8-1).

The last step in our use of the CALSCAN package was to process the data for the entire study area by CLASSIFY and DISPLAY. The new classes were identified to the programs and training field performance assessed on this new basis. Also, test fields were identified in the context of the new classes.

Classification of the entire data set with the new classes resulted in considerable improvement in performance of the training fields - from 43.1 percent to 69.3 percent overall and from 43.2 percent to 69.8 percent average per original class to 74.4 percent average per new class (Tables 8-2 and 8-3). Three of the original classes were retained as originally given: Association G (Hiliaria mutica, tobosa bottoms) and M (Mortonia scabrella, sandpaper bush shrubland) and brush clearings. These classes are apparently as distinct in the ERTS data as they are

Table 8-2. Training field performance summarized by class.

Class	Performance	Predominant Misclassification
A	82.5	-
B	16.4	A
K	4.0	A
C	75.0	-
D	33.3	C
E	46.3	D
G[8-3/]	-0-	F
Ala	84.6	-
F	-0-	Ala
H	29.2	Ala
I	57.1	-
J	35.0	Ambiguous
L	3.2	1
M	85.0	-
Brush clearings	95.8	-
Overall performance	43.1	
Average per class	43.2	

[8-3/] The poor performance of F and G was due chiefly to an inadequate sample: 3 resolution elements for F and 4 for G.

Table 8-3. Regrouping of training fields.

Original Class	New Class	% Performance with Regrouping: By Original Class	% Performance with Regrouping: By New Class
A	ACACIA	80.0	60.9
B		43.6	
K		37.8	
C	BOER	87.5	77.8
D		54.3	
E		90.2	
G	HIMU	68.4	68.4
Ala	PRJU	100.0	75.3
F		21.4	
H		100.0	
I	AGAVE	69.4	61.4
J		54.0	
L		63.4	
M	MOSC	79.2	79.2
Brush clearings		97.9	97.9
Overall performance		69.3	69.3
Average per class		69.8	74.4

in aerial photography (1:120,000 color IR and 1:30,000 black and white) and on the ground.

The test fields were selected to provide a more definitive determination of CALSCAN's performance in discriminating among vegetation classes at association level than evaluation of training field performance. We did this because the latter has some elements of circular reasoning since the vegetation classes were defined for the computer program by the training fields.

Because of our allowance of greater heterogeneity in the test fields than in the training fields, test field performance was lower. Overall performance was 50.5 percent and average per class was 55.6 percent (Table 8-4).

The final step in the analysis was to interpret the results of the classifications in terms of physical features of the ground surface. These data were available for the Walnut Gulch Experimental Watershed which occurs in the study area (Gelderman, 1970).

This interpretation was carried out by plotting the ground locations of the training and test fields of the vegetation classes occurring in the area on the soils map (1:24,000). The soil mapping unit was noted for each location, and the soil series identified by topographic position from interpretation of black and white aerial photography (1:30,000). The data were then extracted from the soil series descriptions in the soil survey report (Gelderman, 1970).

FINAL RESULTS

Data for some ground surface features arranged according to the original vegetation classes within the generalized classes from CALSCAN are presented in Table 8-5. There is apparently some tendency toward grouping of the data both in relation to the original classes (A, B, K, C, D, and E) as well as to the new classes (ACACIA and BOER). This lends some weight to the validity of both classifications.

Table 8-4. Test field performance summarized by class.

Class	Performance
ACACIA	49.1
BOER	35.5
HIMU	57.1
PRJU	61.5
AGAVE	26.0
MOSC	66.7
BRCLR	93.5
Overall performance	50.5
Average per class	55.6

Table 8-5. Ground surface physical data for training fields arranged according to vegetation classes.

Generalized type	Training field	Soil series	Parent material	Surface texture	Surface dry	Color moist	% of slope
ACACIA	A-4	Rillito	Ca old alluv.	grl	10YR6/2	10YR4/3	8-15
	B-1	"	"	"	" "	" "	3-8
	-2	"	"	"	" "	" "	"
	-3	Cave	"	"	" 5/3	" "	"
	-4	Cave	"	"	" "	" "	"
	-8	Hathaway	"	"	" 5/2	" 3/3	8-15
	-9	"	"	"	" "	" "	"
	K-6	Graham	And. & Basalt	cocl	" 4/2	" 2/2	"
	-7	"	"	rocl	" "	" "	15-30
	-9	"	"	cocl	" "	" "	8-15
	-10	"	"	rocl	" "	" "	15-30
BOER	C-1	Hathaway	Ca old alluv.	grl	10YR5/2	10YR3/3	8-15
	-2	"	"	"	" "	" "	"
	-4	Bernardino	Old alluv.	"	7.5YR4/2	5YR "	"
	D-1	Hathaway	Ca old alluv.	"	10YR5/2	10YR "	"
	-2	"	"	"	" "	" "	"
	E-2	Bernardino	Old alluv.	"	7.5YR4/2	5YR "	"
	-3	"	"	"	" "	" "	"
	-4	"	"	"	" "	" "	"

Table 8-5 (continued). Ground surface physical data for test fields arranged according to vegetation classes.

Generalized type	Training field	Soil series	Parent material	Surface texture	Surface dry	Color moist	% of slope
ACACIA	B-1	Rillito	Ca old alluv.	grl	10YR6/2	10YR4/3	3-8
	-2	"	"	"	" "	" "	"
	-3	"	"	"	" "	" "	"
	-4	"	"	"	" "	" "	"
	-8	Hathaway	"	"	" 5/2	" 3/3	8-15
	K-5	Loamyland	Recent alluv.	1	None Reported		0-3
	-6	Graham	Basalt & and.	cocl	10YR4/2	10YR2/2	8-15
	-6	"	"	rocl	" "	" "	15-30
	-7	Bernardino	Old alluv.	grl	7.5YR"	5YR3/3	3-8
	-7	Graham	Basalt & and.	cocl	10YR "	10YR2/2	8-15
	-8	"	"	rocl	" "	" "	15-30
BOER	C-1	Bernardino	Old alluv.	grl	7.5YR4/2	5YR3/3	3-8
	-2	"	"	"	" "	" "	"
	D-1	"	"	"	" "	" "	8-15
	-2	"	"	"	" "	" "	"
	E-1	"	"	"	" "	" "	"
	-2	"	"	"	" "	" "	"
	-3	"	"	"	" "	" "	"
	-6	"	"	"	" "	" "	"

CONCLUSIONS

We conclude from these results that vegetations with high contrast images can be discriminated in ERTS MSS digital data at association level. Other vegetations with low contrast images appear to be separable at about alliance level. Similarities between the soil classification (to series) and the original vegetation classification on the one hand and between patterns in the soil data and the CALSCAN results at a broader hierarchical level on the other reinforce this conclusion.

Thus, ERTS data appear to be integrative for alliance level vegetation. However, these results also suggest that the given vegetation classification should be reexamined. It is based to some extent on annual species from data collected in only two consecutive years and is, therefore, somewhat questionable.

The points at issue are two. First, while the associations appear valid, the species which characterize them may need reevaluation. Second, the major problem appears to be in the way some of the associations were grouped into alliances and the alliances characterized. Removal of the annual species from consideration may change some of the affinities and lead to new groupings.

APPENDIX A

DESCRIPTIONS OF PLANT SPECIES INFORMATION GATHERED IN THE FIELD

Prominence rating system is from
Poulton, Faulkner, and Martin (1971)

Prominence Rating: Past usage or the common five-unit scale of "Abundance" involved vague meanings of "very abundant," "common," "rare," etc. We have more precisely defined five "prominence classes" to facilitate rapid but meaningful recording of the visual appearance, aspect or physiognomy of the plant community. The usefulness of the system has been tested and proved satisfactory in many kinds of vegetation. It is a particularly useful technique for the field man who is in a hurry, yet data taken by different people is sufficiently consistent for accurate ecological classification. These ratings are to be based on the entire community taken as a unit, not on the separate layers.

Prominence Rating	Description of Class or Meaning of Symbol
5	The most prominent species in the stand; the most obvious species in terms of amount present. Impression on the observer is that there is clearly more of the subject species than any other. Some stands may not have a species that clearly rates "5" and the class would be omitted. A stand can have only one species with this prominence level.
4	Clearly the second most prominent species in the stand or one of a group of species that share about equally in being most prominent (in which case each is accorded a prominence of "4"). All remaining species are definitely less prominent than the subject species. May have more than two species in this class but usually only one or two. If the subject species seem more prominent than all others in the stand but observer has difficulty deciding which one would rate a "5," the guideline is to assign each member of the group a prominence of "4" without using class "5."

Prominence Rating	Description of Class or Meaning of Symbol
3	A rather uniformly distributed species that is easily seen by standing at one place in the stand and looking casually around. Do not have to look intently to see the species. Species may fall into this class if they are initially hard to see because of small stature but once located are easy to see. Usually there are numerous species accorded a prominence of "3". Definitely not in prominence "4" or "5"; the species blends among the mass of species in the stand.
2	A species that can be seen only by looking intently while standing in one place or by moving around in the stand. Species occurring in patches encountered by moving about would be rated in prominence class "2" even though, within a patch, they may rate a higher prominence score. Not so rare that one must look in and around other plants to see species.
1	Species that can be seen only by searching for them in and around other plants. Considerable care is required to find species rating prominence class "1". Species which occur in extremely wide-scattered small patches or clumps or individuals would rate a prominence "1" provided they do not represent an "Inclusion" of a different plant community.

Cover class index from Poulton, Faulkner, and Martin (1971)

Cover classes: These are normal crown-spread cover values recorded for each species individually without mentally or otherwise compressing the foliage. All area within the peripheral circumference is assumed to be completely covered. The estimate is a total of the vertical projection of these values for the species. According to this system, total cover percent may exceed 100 percent. This is frequently the case except in desert and deteriorated steppe environments. Such cover totals can be taken as a relative index of site productivity.

Cover Percent	Cover Class	Mid-Point Value
1	0+ - 1	0.5
2	1+ - 5	3.0
3	5+ - 10	7.5
4	10+ - 25	17.5
5	25+ - 50	37.5
6	50+ - 75	62.5
7	75+ - 95	85.0
8	95+ - 100	97.5

The sociability rating is a mode of expressing the aggregation of members of a species. The system used is based on Braun-Blanquet (1951) as reported by Hanson and Churchi'l (1961).

Class	Description
1	Shoots growing singly.
2	Small groups of plants or scattered tufts.
3	Small, scattered patches or cushions.
4	Large patches or broken mats.
5	Very large mats or stands of nearly pure populations that almost completely cover a large area.

APPENDIX B

TECHNICAL LEGEND ON PHYSIOGNOMIC AND STRUCTURAL CHARACTERISTICS OF VEGETATION (excerpts from Poulton, 1972, with modifications)

NATURAL VEGETATION subclasses

Herbaceous types

- prominently annuals
- bunchgrass steppe
- sodgrass and mixed sodgrass-bunchgrass steppe and prairie
- undifferentiated complexes of herbaceous types

Shrub-scrub types

- microphyllous, non-thorny scrub, generally with succulents
- microphyllous thorn scrub
- succulent scrub
- microphyllous saltsage and related scrub types
- shrub steppe (single species or simple mixtures of shrubs)
- evergreen sclerophyll shrub
- deciduous macrophyllous shrub

Intergrade types

- scattered tall shrub
- scattered broad-leaved tree) over herbs
- scattered needle-leaved tree)
- scattered needle-leaved tree) over low shrubs
- scattered broad-leaved tree)

Forest and woods types

- needleleaf
- broadleaf
- mixed forests of needleleaf-broadleaf

APPENDIX C

PLANT SPECIES LIST

Kearney and Peebles (1964) was the source of scientific names in this list, except for Cactaceae (Benson, 1969)

Growth Form	Scientific Name	Common Name
Trees	Chilopsis linearis	desert willow
	Fraxinus velutina	ash
	Juniperus spp.	juniper
	J. deppeana	alligator juniper
	J. monosperma	one-seed juniper
	Pinus spp.	pine
	P. cembroides	Mexican pinyon
	P. engelmanii	Apache pine, Arizona long-leaf pine
	P. leiophylla var. chihuahuana	Chihuahua pine
	P. ponderosa	Ponderosa
	P. strobiformis	Mexican white pine
	Platanus wrightii	Arizona sycamore
	Populus fremontii	Fremont cotton-wood
	P. tremuloides	quaking aspen
	Pseudotsuga menziesii	Douglas fir
	Quercus spp.	oak
	Q. arizonica	Arizona white oak
	Q. emoryi	Emory oak
	Q. gambelii	Gambel oak
	Q. hypoleucoides	silverleaf oak
	Q. oblongifolia	Mexican blue oak
	Q. reticulata	net-leaf oak
	Robinia neomexicana	New-Mexican locust

Growth Form	Scientific Name	Common Name
Shrubs, half shrubs, and herbs	Acacia constricta	white-thorn acacia
	A. greggii	catclaw acacia
	A. vernicosa	mescat acacia
	Aloysia wrightii	Wright's lippia
	Arctostaphylos pungens	point-leaf manzanita
	Atriplex canescens	four-wing salybush
	Ayenia pusilla	
	Baccharis pteronioides	yerba-de-pasmo
	Boerhaavia coulteria	
	Calliandra eriophylla	fairy duster
	Ceanothus spp.	
	Celtis spp.	hackberry
	C. pallida	desert hackberry
	Cercidium floridum	blue palo-verde
	C. microphyllum	little-leaf palo-verde
	Cercocarpus breviflorus	little-leaf mountain mahogany
	Cnidoscolus angustidens	
	Coldenia canescens	
	Condalia lycioides	gray-thorn
	C. spathulata	Mexican crucillo
	Cowania mexicana	quinine-bush
	Crotalaria pumila	
	Dalea formosa	feather dalea
	Encelia farinosa	brittlebush
	Ephedra trifurca	Mexican tea
	Eriogonum abertianum	
	Flourensia cernua	tarbush
	Fouquieria splendens	ocotillo
	Franseria deltoidea	triangle bursage
	Garrya wrightii	silktassel
	Gilia rigidula	
	Gutierrezia sarothrae	snake weed
	Haplopappus laricifolius	
	H. tenuisectus	burro goldenweed
	Koeberlinia spinosa	crucifixion thorn
	Krameria parvifolia	range ratany
	Larrea tridentata	creosote bush
	Lycium spp.	desert-thorn
	Menodora scabra	
	Mimosa spp.	
	M. biuncifera	wait-a-minute
	M. dysocarpa	velvet-pod mimosa
	Mortonia scabrella	mortonia
	Parthenium incanum	mariola
	Prosopis juliflora	mesquite
	Psilostrophe cooperi	paper flower

Growth Form	Scientific Name	Common Name
Shrubs, half shrubs, and herbs	Rhus choriophylla	
	R. microphylla	sumac
	R. trilobata	squaw bush
	Rhynchosia texana	
	Tidestromia lanuginosa	
	Zinnia pumila	desert zinnia
Leaf succulents	Agave spp.	century plant
	A. palmeri	century plant
	A. parryi	century plant
	A. schottii	amole
	Dasylirion wheeleri	sotol
	Nolina microcarpa	beargrass
	Yucca spp.	yucca
	Y. baccata	banana yucca
	Y. elata	soaptree yucca
	Y. schottii	Schott's yucca
Stem succulents	Cereus giganteus	saguaro
	Ferocactus wislizenii	barrel cactus, bisnaga,
	Opuntia spp.	cholla, prickly pear
	O. fulgida	jumping cholla
	O. phaeacantha	prickly pear
	O. spinosior	cane cholla
Grasses	Andropogon spp.	bluestem
	A. barbinodis	cane beardgrass
	Aristida spp.	three-awn
	Bouteloua spp.	grama
	B. chondrosioides	sprucetop grama
	B. curtipendula	side-oats grama
	B. eriopoda	black grama
	B. gracilis	blue grama
	B. hirsuta	hairy grama
	B. rothrockii	rothrock grama
	Eragrostis spp.	lovegrass
	E. intermedia	
	E. lehmanniana	Lehmann's lovegrass
	Eriochola gracilis	
	Hilaria belangeri	curly mesquite
	H. mutica	tobosa grass
	Muhlenbergia spp	muhly
	M. porteri	bush muhly
	Panicum spp.	
	P. hirticaule	
	Set ria spp.	bristle grass

Growth Form	Scientific Name	Common Name
Grasses	Sporobolus spp.	dropseed
	S. airoides	alkali sacaton
	S. wrightii	Wright sacaton
	Tridens grandiflorus	
	T. pulchellus	fluffgrass

APPENDIX D

MACRORELIEF CLASSES FOR SOUTHERN ARIZONA

(adapted from Poulton, et al., 1970)

Mapping Symbol	Technical Legend	Descriptive Legend
1	Flat lands	A generally flat landscape with prominent slopes less than 10 percent.
1.1		The landscape is essentially smooth. Dissection is minimal. The regional slope in this class is nearly always between 0 and 3 percent.
1.2		The landscape is relatively flat; however, dissection has progressed to a noticeable point. Dissection is either sharp and widely spaced (in which case side slopes may be over 10 percent), or gently rolling and more closely spaced. Where side slopes exceed 10 percent, macrorelief is generally less than 10 feet.
2	Rolling and Moderately Dissected Lands	A rolling or moderately dissected landscape with prominent slopes 10 to 25 percent (side slopes may exceed that figure in the case of dissected planar surfaces).
2.1		The landscape is rolling or hilly; a regional slope is not readily apparent - or a regional slope of 10 to 25 percent is present.
2.2		The landscape consists of a moderately to strongly dissected planar surface (i.e., pediment, bajada, valley fill, etc.). The regional slope is generally between 2 and 6 percent; side slopes must be steeper than 10 percent. If side slopes are steeper than 25 percent, relief must be less than 100 feet. The drainage network is finer than that of 1.2.

Mapping Symbol	Technical Legend	Descriptive Legend
3	Hilly lands	The landscape is hilly to submountainous; slopes are moderate to steep, predominantly exceeding 25 percent. Relief is generally over 100 feet but less than 1,000 feet. Where relief approaches 1,000 feet, the landform system appears to be relatively simple - with smooth slopes. Drainage systems generally have the same base level.
4	Mountainous Lands	The landscape is mountainous, having high relief, usually over 1,000 feet. Slopes are moderate to steep, frequently exceeding 50 percent. The landform and drainage systems are usually complex, with drainage networks having base levels quite independent of one another.

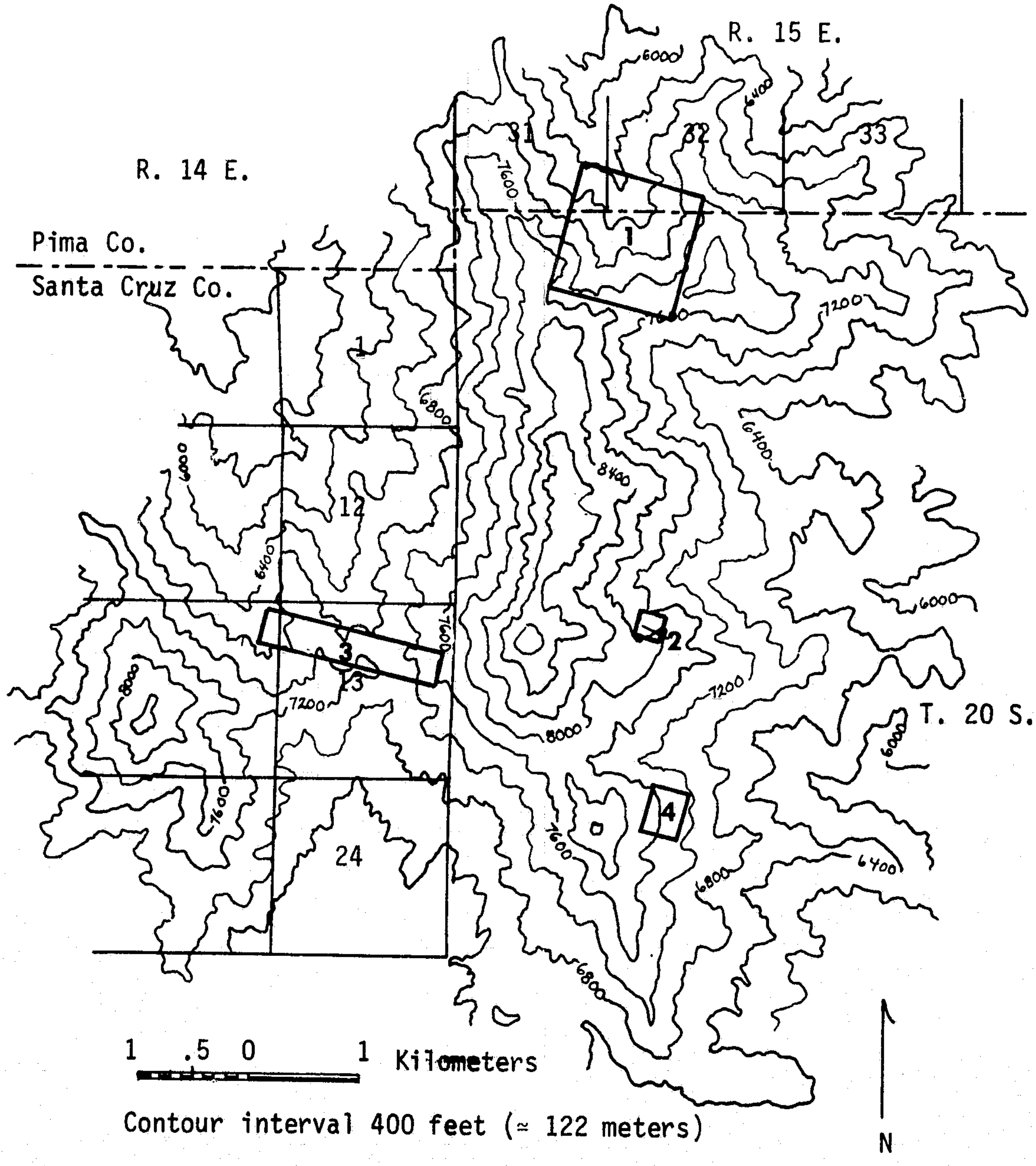
APPENDIX E

APPROXIMATE GROUND AREAS SELECTED TO REPRESENT THE PLANT PHENOLOGICAL AND "NO CHANGE" CLASSES

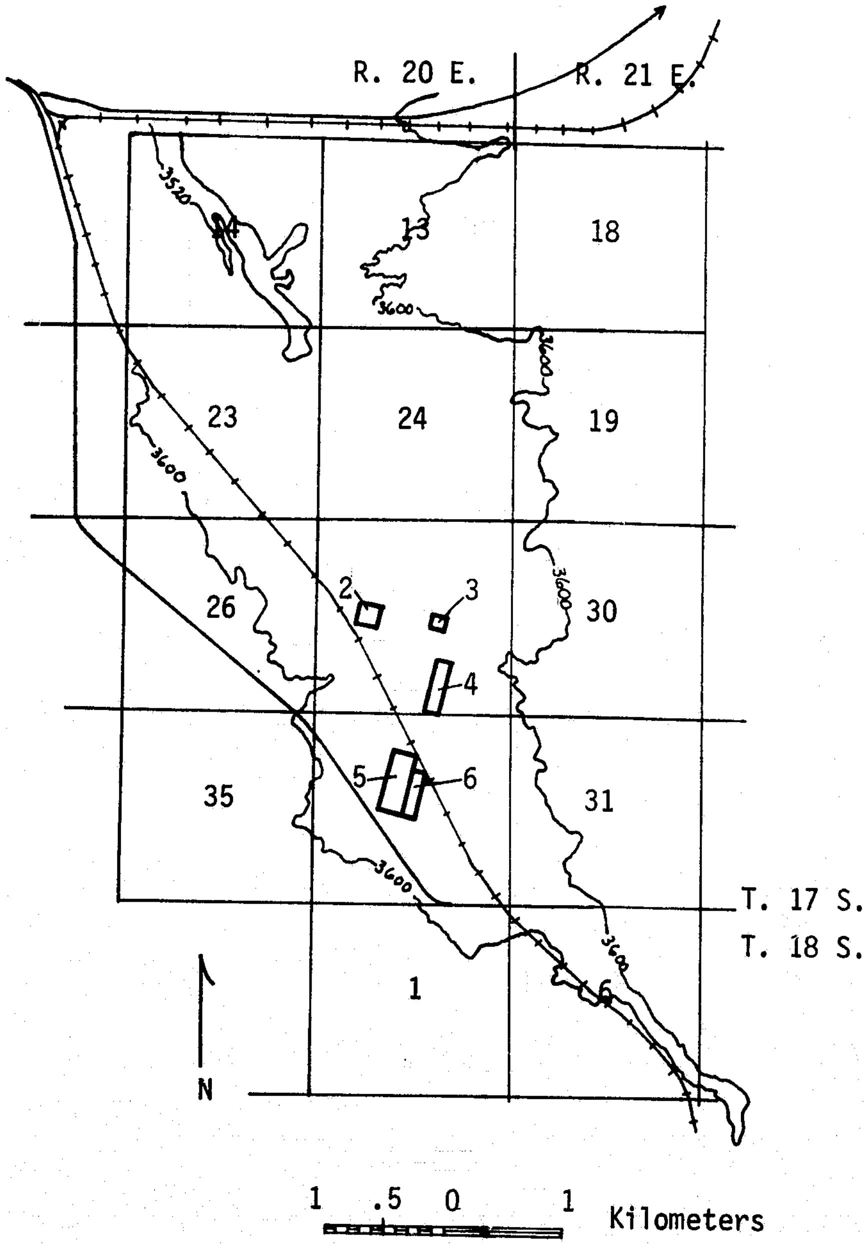
The Evergreen (EVGN) phenological class was represented by four ground areas. Areas 1, 2, and 3 were composites of several facets, most facing in a northerly direction. Area 4 was located on a uniform east facing slope (slope azimuth = 90°).

The Winter-dormant (WIND) and Winter-spring dormant (WISP) classes were represented by five ground areas each. All areas were on nearly horizontal surfaces.

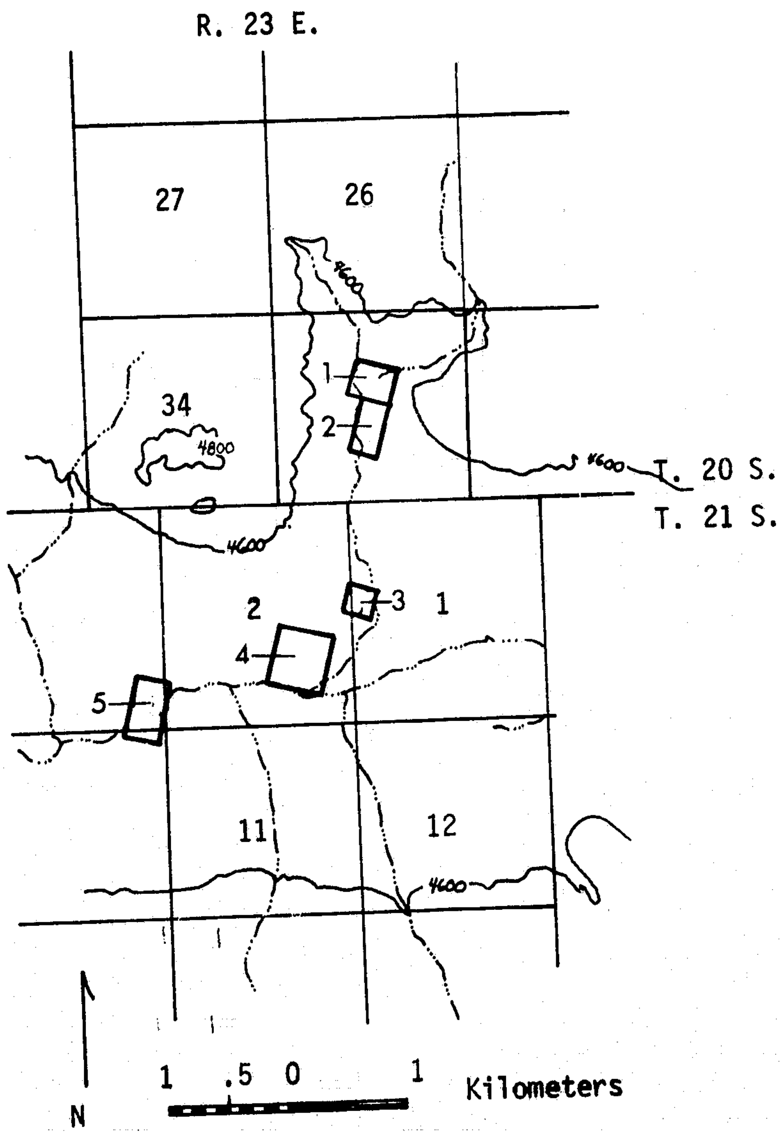
The TAIL class representatives were located in Section 32, of T. 16 S., R. 13E., and in T. 17 S., R. 13 E., Section 5, NW¼ (Twin Buttes Quadrangle, Arizona; 15 minute series).



Approximate ground areas representing the Evergreen phenological class. Map is from the Mount Wrightson Quadrangle, Arizona; fifteen minute series.



Approximate ground areas representing the Winter dormant phenological class. Map is from the Happy Valley and St. David Quadrangles, Arizona; fifteen minute series.



Approximate ground areas representing the Winter-spring dormant phenological class. Map is from the Gleeson Quadrangle, Arizona; fifteen minute series.

APPENDIX F

CALCULATION OF INSTANTANEOUS IRRADIATION OF SELECTED SURFACES AT THE TIME OF ERTS-1 DATA ACQUISITION

The following calculations did not consider the interaction of the atmosphere with electromagnetic radiation. The calculations pertained, therefore, to an equivalent surface above the atmosphere or in the case of no atmosphere. The calculations followed those of Frank and Lee (1966); explanation of the equation of time (ephemeris of the sun) was given by Robinson (1966); data for solar declination, equation of time, and the radius vector of the earth were from List (1949); latitude, slope, and aspects for surfaces of interest were determined from USGS topographic maps (scale = 1:62,500) for the study area; and Greenwich Mean Time at the moment of ERTS data acquisition was from the ERTS-1 scene annotation blocks.

Instantaneous irradiation, I_s of a horizontal surface is given by:

$$I_s = \frac{I_o}{R^2} (\sin \Theta \cdot \sin \delta + \cos \Theta \cdot \cos \delta \cdot \cos \omega t)$$

where:

I_o = solar constant {1.94 ly min^{-1} (List, 1949)}

R^2 = radius vector

Θ = terrestrial latitude

δ = solar declination (+, north of the equator; -, south)

ω = angular velocity of the earth's rotation, 15 degrees per hour ($360^o \div 24$ hrs)

t = number of hours before (-) or after (+) true solar noon - the moment the geometric center of the sun crosses the meridian (longitude) of the observer.

Local standard time (zone time) is the mean solar time of the time zone in question. Time zones basically are 15^o longitudinal zones; Mountain Standard Time, for example, is 105th Meridian time (the study area was in this zone). The mean solar time for a specific location in the zone is earlier or later than the local standard time; add four minutes to the local standard time for each degree of longitude the location is east of the standard meridian, or subtract four minutes for each degree west of the standard meridian. True solar time at the specified location differs from its mean solar time by varying amounts through the year as given by the Equation of Time. The value for the Equation of Time is added algebraically to the location's mean solar time to obtain the true solar time.

Three dates of ERTS-1 data were selected for analysis; pertinent specifications for those data are as follows:

Date	22 Aug 72	2 Nov 72	13 Apr 73
Time (MST)	10.45 hrs	10.47 hrs	10.48 hrs
Equation of Time	-0.051 hrs	0.273 hrs	-0.013 hrs
Solar Declination	12.05°	-14.50°	8.77°
Radius vector	1.01141	0.99224	1.00276

Surface 1: a level surface on the campus of the University of Arizona, Tucson (latitude = 32.23°N, Longitude = 110.95°W, aspect and slope = 0°).

Calculation of "t" for 22 Aug 72:

Subtract four minutes for each degree west of the standard meridian to determine mean solar time for this location.

$110.95^\circ - 105^\circ = 5.95^\circ$

$5.95^\circ \times 4\ \text{min}/1^\circ = 23.80\ \text{min} = 0.40\ \text{hrs}$

10.45 hrs (MST) - 0.40 hrs = 10.05 hrs (mean solar time).

Add algebraically the value for the Equation of Time:

10.05 hrs + (-0.05 hrs) = 10.00 hrs (true solar time)

Subtract from 12:00 noon:

12.00 hrs - 10.00 hrs = 2 hrs

t = -2 hrs (the sign is minus because the time preceeded noon).

In a similar manner, "t" for 2 Nov 72 and 13 Apr 73 are calculated to be -1.66 hrs and -1.93 hrs respectively.

Calculation of I_s for 22 Aug 72:

$$I_s = 1.896\ \text{ly/min}\ \{\sin 32.23^\circ \cdot \sin 12.05^\circ + \cos 32.23^\circ \cdot \cos 12.05^\circ \cdot \cos (15^\circ/\text{hr} \cdot -2\ \text{hrs})\}$$

Similarly, I_s for 2 Nov 72 = 1.201 ly/min

I_s for 13 Apr 73 = 1.568 ly/min

Surface 2: an east facing mountain slope having slope inclination (k) = 21.8°, slope azimuth (h) = 90°, latitude = 31.7°N, and longitude = 110.8°W. (EVGN-4, see Appendix E).

In the case of an inclined surface, an "equivalent" horizontal surface (Lee, 1962) is calculated having an adjusted latitude and longitude. The new values are used in the calculation of I_s.

$$\Theta' = \sin^{-1} (\sin k \cdot \cos h \cdot \cos \Theta + \cos k \cdot \sin \Theta) \; \underline{1/}$$

$$\omega t' = \omega t + \alpha$$

$$\alpha = \tan^{-1} \{(\sin h \cdot \sin k) \div (\cos k \cdot \cos \Theta - \cos h \cdot \sin k \cdot \sin \Theta)\}$$

Substituting Θ' and $\omega t'$ for Θ and ωt, I_s for this slope on 22 Aug 72, 2 Nov 72, and 13 Apr 73 was respectively: 1.807, 1.424, and 1.804 ly/min.

1/ "$\sin^{-1}$" notation is read: "The arc (angle) whose sin is ...," also called "arcsin," "inversesin," and "inverse function."

APPENDIX G

STANDARD DEVIATIONS ASSOCIATED WITH THE MEAN RADIANCE OF PLANT PHENOLOGICAL AND "NO CHANGE" CLASSES (Table 13)

		MSS 4	MSS 5	MSS 6	MSS 7
EVGN-4 (n=35)	Aug	6.79	5.51	3.56	8.04
	Nov	4.02	4.64	7.48	18.07
	Apr	3.55	4.18	5.87	18.58
WIND (n=65)	Aug	7.11	9.08	7.52	14.76
	Nov	8.07	9.37	7.63	20.69
	Apr	7.77	9.79	7.17	15.39
WISP (n=170)	Aug	5.22	7.47	7.49	27.14
	Nov	5.73	8.05	7.26	17.83
	Apr	4.21	4.85	5.40	17.34
TAIL-3 (n=56)	Aug	6.16	6.37	6.71	14.84
	Nov	7.61	8.45	6.89	16.11
	Apr	6.37	9.25	7.83	19.59

APPENDIX H

ERTS-1 MSS COMPUTER COMPATIBLE TAPE COUNTS FOR TRAINING FIELDS AND CLASSES

		22 Aug 73		2 Nov 72		13 Apr 73	
Subject	Samples	0.6–0.7μ	0.8–1.1μ	0.6–0.7μ	0.8–1.1μ	0.6–0.7μ	0.8–1.1μ
EVGN-1	361	13.98	16.14	7.87	9.42	17.81	15.90
EVGN-2	16	19.12	21.81	12.31	17.06	22.12	22.44
EVGN-3	135	18.97	19.91	15.44	20.59	9.01	11.72
EVGN-4	35	23.26	22.46	18.46	21.34	12.43	15.86
EVGN		15.96	17.64	10.55	13.16	15.42	15.06
WIND-2	9	18.44	22.78	13.78	8.22	30.78	18.56
WIND-3	6	24.00	24.17	17.83	9.17	26.50	19.83
WIND-4	14	21.14	24.86	13.86	7.79	29.57	19.00
WIND-5	24	21.67	23.87	15.50	8.75	30.17	17.83
WIND-6	12	27.58	25.67	19.58	10.83	37.50	20.67
WIND		22.42	24.29	15.88	8.89	31.14	18.89
WISP-1	30	21.30	31.83	25.97	13.43	46.97	23.10
WISP-2	28	23.21	30.11	22.07	12.50	46.29	22.79
WISP-3	16	23.13	26.81	23.81	14.50	45.44	20.12
WISP-4	56	26.91	25.14	24.91	14.14	45.91	20.30
WISP-5	40	23.70	25.47	23.02	14.38	47.85	20.87
WISP		24.20	27.38	24.08	13.84	46.57	21.32
TAIL-2	85	90.60	43.16	67.74	25.58	95.60	37.29
TAIL-3	56	93.87	35.41	69.38	26.57	97.12	37.84
TAIL-4	12	113.25	38.17	60.42	26.00	106.25	38.00
TAIL		93.58	34.93	67.76	25.97	96.99	37.55

APPENDIX I

SUMMARY OF OBSERVER EXPERIENCE STATEMENTS

At the time observers took the first test, they were asked to indicate from the following list which category best described their level of experience:

"Experience statement, check one:

____ Have never more than casually viewed aerial and/or space photography, if at all.

____ Have limited experience, with a single course in which photo interpretation was used, or with other interpretation experience.

____ Have interpretation experience with several types of photography, however, interpretation skills have been developed only for a limited number of subjects and then not on a production basis.

____ Am an experienced photo interpreter, and have been on a job which required considerable amounts of photo interpretation on a day-to-day basis."

From this, the listing was developed:

	Level of experience			
	None	Limited	Moderate	Extensive
Alexander		X		
Cornwell				X
Faulkner				X
Jaques			X	
McDaniel			X	
Miller			X	
Pyott		X		
Ross			X	
Schrumpf			X	

Level of experience

	None	Limited	Moderate	Extensive
Steers		X		
Stuth		X		
Thetford		X		
Williams			X	

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