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AN ABSTRACT OF THE THESIS OF

JAMES RUSSELL JOHNSON for the DOCTOR OF PHILOSOPHY
(Name of student) (Degree)

in Rangeland Resources presented on May 17, 1974
(Major) (Date)

Title: SMALL SCALE PHOTO PROBABILITY SAMPLING AND VEGETATION CLASSIFICATION IN SOUTHEAST ARIZONA AS AN ECOLOGICAL BASE FOR RESOURCE INVENTORY

Abstract approved: ______________________
Dr. C. E. Poulton

Increasing demands on earth resources require the need to know how much resource is present. A new technology, which is developing partially with the support of the National Aeronautics and Space Administration, will help to inventory and monitor surface resources in a more comprehensive manner than previously possible. Research in southeastern Arizona for the past six years has been developing methodology that would permit the use of space and high altitude imagery for natural vegetation and related resource investigations.

This paper reports on three meaningful research contributions in remote sensing of natural vegetation. They are (1) a natural vegetation classification suitable for remote sensing use, (2) a technique for objectively comparing space imagery for relative

information content, and (3) a sample scheme for using small scale photography to identify and estimate areas of vegetation types.

The natural vegetation classification contains 31 "vegetation types" that were developed for a 3, 200 square mile area. The types are ecologically determined from association tables, and are, therefore, suitable for use in remote sensing applications. This is possible primarily because the types are related to photo identifiable landform variables. The classification is suitable for generalized levels of land use planning, but this was not tested.

Three types of space imagery were evaluated for apparent photographic information content. The technique avoided subject-image relationships by concentrating directly on image characteristics. The approach, coined "image groupability", should be a worthwhile contribution to the larger problem of comparative imagery interpretations. An example demonstrates an approach to objective photo stratification based on image groupability results.

The third accomplishment involved design and execution of a comparative two stage sampling scheme to estimate kind and extent of vegetation types. The comparison was between two space photos substituted at the first sampling stage. At the second stage (high altitude photography) potential secondary sampling units were categorized by image similarity rather than by the more complicated process of ground subject interpretations. Efficiency gains from space photo stratification were not substantial; however, the sample scheme was effective. Furthermore, clustering, a space photo sampling artifact, saved an estimated 32-35 percent in "working time" expenses when making ground checks by helicopter.

Small Scale Photo Probability Sampling and Vegetation Classification in Southeast Arizona as an Ecological Base for Resource Inventory

by

James Russell Johnson

A THESIS

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Typed by Velda D. Mullins for James Russell Johnson

ACKNOWLEDGEMENT

Five years ago, as a family, we began a journey that uprooted us from a peaceful existence in western South Dakota for the demanding rigors and uncertainties of the future that came to mark our life on campus. In retrospect, the years were rewarding and highlighted with several accomplishments, including an advanced university degree by my wife and completion of my dissertation and degree.

The first expression of gratitude belongs to Judy, my wife, who has been as dedicated to our goals as it has been possible to be.

One person, Charles E. Poulton, was responsible for creating the stituation which enabled me to come to Oregon State University to study remote sensing and range resource inventory and analysis. Not only did he afford the normal leadership of a major professor, but his inspiration and dedication were essential ingredients of my success.

The Arizona remote sensing research team, in its entirely, provided major contributions. From the beginning, Barry J. Schrumpf was a constant influence. Without Barry, the task would have been considerably more difficult and probably impossible to accomplish. During the past two years, William T. Pyott spent many hours in helping to develop the two stage sampling scheme. Other team members who contributed to the research, especially in vegetation classification, included David P. Faulkner, Edmundo Garcia-Moya, and David A. Mouat. Yet another member, Carolyn M. Sawtelle, unselfishly and skillfully mapped, charted, graphed, calculated, photo processed, and typed until the job was done.

Additional assistance was granted by several who helped refine sampling objectives and explore suitable approaches. They are W. Scott Overton, Oregon State University, Department of Statistics, who provided early direction. Later, James D. Nichols, University of California, Forestry Remote Sensing Laboratory, Berkeley, clarified concepts of multistage sampling. Finally, Norbert A. Hartmann, Oregon State University, Department of Statistics, as consulting statistician, offered advice in the imagery comparison analyses, and developed the formulas used in the sampling phase of the research.

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DEVELOPMENT OF SPACE AND HIGH ALTITUDE PHOTO SAMPLING FOR A SOUTHEAST ARIZONA VEGETATION CLASSIFICATION TO PROVIDE RESOURCE INFORMATION

INTRODUCTION

BACKGROUND

In 1966, Dr. Charles E. Poulton, Rangeland Resources Program, Oregon State University, and Mr. Edwin Roberts, Forestry Remote Sensing Laboratory, Berkeley, California, took the opportunity to examine a frame of Gemini IV space photography. The frame imaged an area in southeastern Arizona. On that frame could be seen image differences which Poulton and Roberts believed were related to natural features of the landscape. Following a field trip to Arizona they determined that natural vegetation and associated soil features could be related to space photo images (Carneggie, Poulton, and Roberts, 1967, as reported by Poulton, 1972). This effort initiated one of the first intensive efforts to exploit space photography for natural vegetation inventories.

A proposal was later submitted to study the feasibility of using space photography for inventorying natural vegetation resources in southern Arizona. The proposal[1/] was granted by the Earth

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1/ NASA, Earth Resources Contract Number R-09-038-002.

Resources Survey Division of the National Aeronautics and Space Administration (NASA). Since that time, remote sensing research in Oregon State University, Rangeland Resources Program, has demonstrated feasibility in using space and supporting high altitude photography for inventorying natural vegetation and displaying the information in photo maps (e.g., Poulton et al., 1970). Efforts have continued with attempts to exploit further the two new types of imagery, space and high altitude. Progress has gone from the general feasibility stage to that of developing methods for efficiently gaining and portraying information about natural vegetation.

With the expectation that an Earth Resources Technology Satellite (ERTS) Program would become a reality, we recognized the potential opportunity to evaluate imagery received from the ERTS-1 in the setting of remote sensing classification and inventory of natural vegetation and related resources. At that time, April, 1971, several of us [2/] who were involved in remote sensing activities in the Rangeland Resources Program prepared and submitted a proposal to the NASA for continued grant research support for activity in southern Arizona. Southern Arizona was chosen as the field laboratory because (1) we all had an interest and understanding of the resource base

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[2/] Barry J. Schrumpf, James R. Johnson, and David A. Mouat, former graduate research assistants; and David P. Faulkner, former research assistant.

in the region, and (2) the previous remote sensing activity and accumulation of ground information gave us a strong competitive advantage for having a proposal accepted. The proposal [3/] was accepted, thereby creating an avenue for evaluating imagery from the ERTS-1 Program.

PROBLEMS AND OBJECTIVES

In natural vegetation applications, it is my judgment that vegetation classification is prerequisite to the development and use of remote sensing technology for solving most natural vegetation resource problems. Additionally, vegetation characteristics are not always linked to classification, but they can be related to photographic image or signature changes. These characteristics determine the use of remote sensing in a natural vegetation setting, but they also complicate remote sensing use when relationships between vegetation characteristics and photo images are not clearly understood.

The conceptual research framework for the joint southern Arizona effort is shown in Figure 1. My emphasis has been on "natural vegetation classification", "space and high altitude photo

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3/ Proposal number 311 of NASA contract NAS 5-21831; Barry J. Schrumpf, Principal investigator.

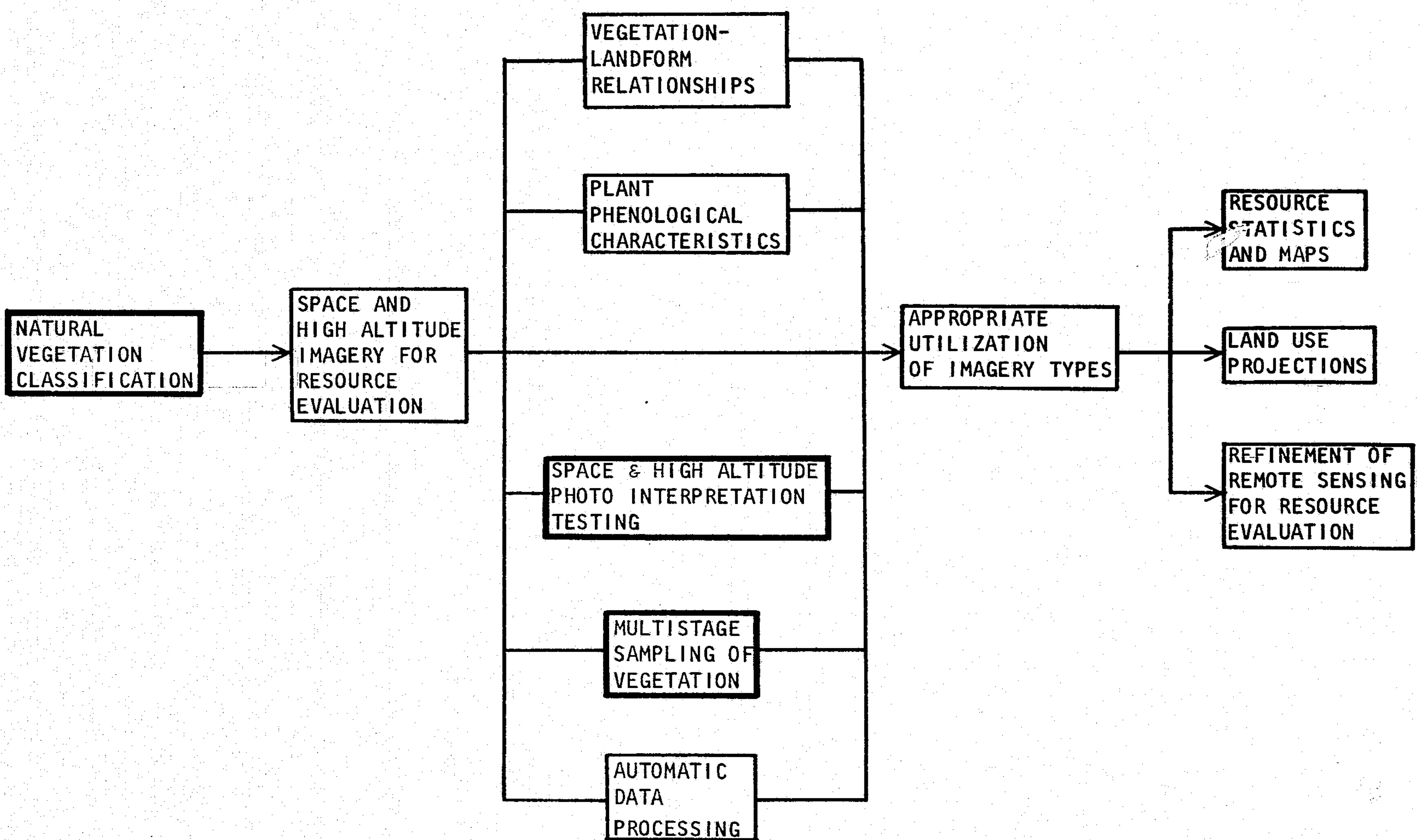

Figure 1. Interrelationships of tasks for research conducted in southern Arizona.

interpretation testing", and "multistage sampling of vegetation". The ultimate goal is to provide information which would be of value in land use applications. The approach to problem solving has been to use available space (ca. 1:750, 000 - 1:1, 000, 000), high altitude (ca. 1:120, 000) photography, and space digital information in developing natural vegetation remote sensing technology.

The problem and objective statements which provided direction for this dissertation are given below.

I. Natural Vegetation Classification.

Problem: For the study area, existing natural vegetation classifications were highly generalized and not compatible with remote sensing imagery.

Objective: Contribute to the development of a natural vegetation classification which would have the following characteristics:

(1) Ecologically based and suitable for hierarchical development;

(2) Compatible with remote sensing approaches;

(3) Suitable for broad scale planning and management needs;

(4) Compatible with selected existing agricultural and urban land use legends.

II. Space Photo Image Content Comparison.

Problem: The ERTS "photography" was the first digitally derived earth resources imagery. Because it is non-photographic in origin, there was interest in comparing it to photographic space imagery to assess relative differences in potential for earth resources investigations.

Objective: Develop an approach to objectively and quantitatively compare the ERTS-1 photographic imagery to that of Apollo 6 and Gemini IV in terms of visually interpreted information content.

III. Two Stage Sampling of Vegetation Subjects.

Problem: One of the greatest advantages of small scale imagery is its benefit in sampling. The feasibility and magnitude of possible advantages had not been assessed for space photo sampling of natural vegetation types.

Objective: Develop a sampling methodology and compare the relative suitability of ERTS imagery to Apollo 6 photography when one replaced the other as the first stage in a two stage sampling scheme. The parameter being estimated was the areal extent of selected natural vegetation types.

JUSTIFICATION

Need for Resource Information

With an ever expanding population and a finite resource base upon which that population must depend, the awareness of the need to optimize resource use should be intuitive.

In the area of land use allocation, there are too many cases of poor planning resulting in serious depletion or loss of resources. For example, prime agricultural lands have often succumbed to urbanization (Winslow, 1972). In recognition of this and other problems, Holt suggested that science and technology need to incorporate ecological criteria as a basis for decisions:

> If our efforts at establishing appropriate control and utilization of public resources, e.g., air, water and land, are to succeeed, it would appear that more political decisions will have to be based on ecological criteria. For example, decisions could be based on the ultimate good a particular factor could contribute to the ecosystem. Top quality cropland would be preserved and not used, except as a last resort, for freeways or city expansion. Marginal land subject to erosion would be removed from cultivation and used for pasture, housing, or other needs not requiring the best agricultural lands. (Holt, 1972, p. 213-214)

An implication is that greater amounts of resource information will be required. One suspects that an overriding consideration in land development and use has all too often been that of short term economic gain. There is evidence that people are becoming more aware that land use planning and management should be based on additional considerations. In Oregon, for example, recent legislative action [4/] is forcing counties to develop land use plans. Counties will be zoned and one of the primary considerations in establishing zones will be "optimum" land use based partially on ecological characteristics of the landscape. 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

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[4/] Senate Bill 100 of Oregon Legislative Assembly, 1973, Regular Session.

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).

Value of Small Scale Photography

It is one thing to demand that land use planning and management be based in part upon an understanding of the landscape in terms of its potentials and reaction to land use, and quite another to provide such information over large areas such as counties or states. From a wide variety of experiences and research, much is already known about the potentials and responses to use of many vegetation-soil systems. However, the reservoir of information is not nearly adequate in light of increasing resource demands. Some of the more basic information can be gained by ". . . utilizing the full capacity of modern remote sensing in consort with a good understanding of resource ecology . . ." (Poulton, 1970, p. 1). Modern remote sensing includes the use of space and high altitude imagery, both of which are small scale.

Space imagery provides a synoptic view of large tracts of land that prior to the 1960's was only a dream of the future. In fact, the imagery from space is of such recent date that it has not been fully exploited. Some of the more obvious values of space imagery for vegetation inventory purposes have been demonstrated in agricultural land use monitoring (Johnson, 1969). In a natural vegetation resource area, one of the better known examples of space imagery value is the research reported by Langley (1969, 1971a) in estimating standing timber volumes. Recently available high altitude photography has also shown promise for agricultural monitoring and natural vegetation inventory (Pettinger, 1970). The object of the research described herein is to (1) demonstrate additional value in utilizing small scale imagery for natural vegetation inventory, and (2) develop procedures for using the imagery.

Need for a Vegetation Classification

One has only to turn to the literature on vegetation classification to learn that "Many attempts have been made to classify and regionalize the vegetation of the earth and all of them have their limitations" (Eyre, 1963, p. 10). One of the primary reasons for this is expressed by Küchler (1967, p. 31) when he said,

> "But the marvelous variety of forms which plant life assumes on all continents has been a major stumbling block in the development of a simple and universally accepted classification, and the problem of classifying vegetation remains an unending one."

Küchler also points out that a vegetation map does not show vegetation in all its aspects, which ". . . implies that their usefulness must necessarily be restricted, that any individual map serves only a small number of purposes . . ." (Küchler, 1967, p. 53).

Our experiences with legend development and, therefore, classification, strongly parallel these thoughts. The approach we have taken is to establish a hierarchical legend, based primarily on vegetational characteristics. Simultaneously, we have considered the impact of our decisions in terms of suitability for (1) computer storage and retrieval; (2) map display on several scales of photography; and (3) providing information in planning and management decisions.

Our efforts in attempting to develop the best vegetation classification that we could appear justified when the thoughts of Küchler (1967, p. 30) are considered; ". . . the quality, and hence the value, of a vegetation map rests more heavily on the selected system of classification than any other feature."

Why a Sampling Approach

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 Nielsen, 1971). In the natural vegetation resources area, beyond forestry, little application is made of small scale photography and refined sampling techniques. Recently, Carneggie (1971) demonstrated the potential of using very large scale aerial photography for estimating selected parameters of shrubs. The suggestion was made that multistage sampling could be used to advantage. However, 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.

EXPERIMENTAL AREA

LOCATION

The region between latitudes of about 32°N and 32°S was first imaged from space platforms. The study area (Figure 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, 110°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, and Sonoita. Parts of three counties are in the area. They are Cochise, Pima, and Santa Cruz.

CLIMATE

It is possible to accurately characterize the southeastern Arizona climate as warm and arid. The inadequacy of such a statement would be realized as one examines precipitation (its intensity, its variation, its seasonal distribution, and its amount) in relation to temperature and with modification imposed by extreme and abrupt topographic features (after Hastings and Turner, 1965).

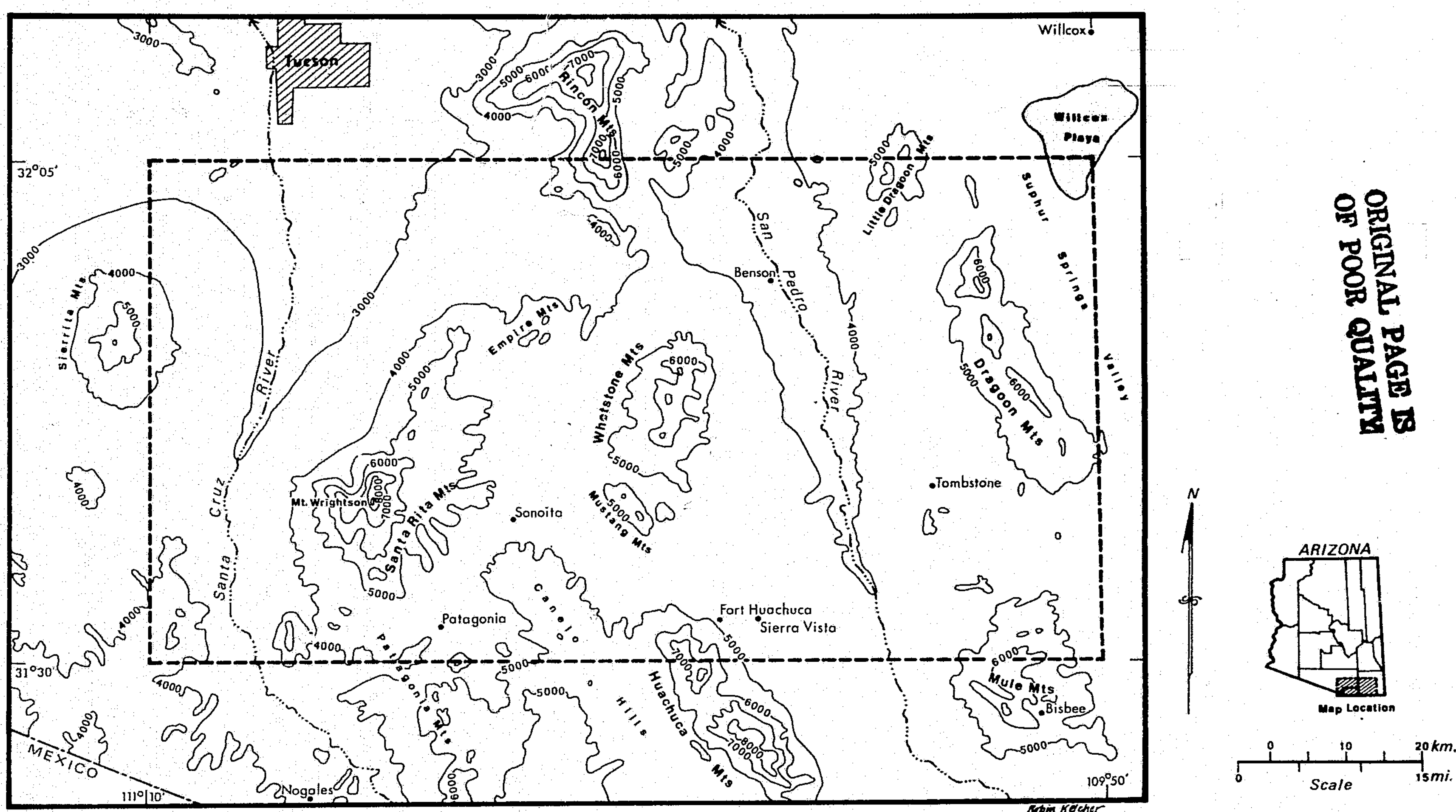

Figure 2. Map of the study area.

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The following information was gleaned from Green and Sellers (1964). Precipitation in southeastern Arizona averages 14.4 inches per year with 65 percent falling during July, August, and early September. Ranges in precipitation are from a low of about 10 inches near Tucson to over 25 inches in the high reaches of the Santa Rita and Huachuca Mountains. Across this range are superimposed yearly fluctuations of considerable variation. For example, Tombstone with an average of 14.1 inches of precipitation per year has recorded a low of 7.4 inches and a high of 23.8 inches. Summer moisture mostly comes from warm tropical air which flows from the Gulf of Mexico. Rain is deposited as high intensity, short duration storms created partially as a result of convection currents from strongly heated mountainous terrain. During the summer season, because of the regular buildup of clouds and cooling caused by the rain, the region is uncommonly pleasant for a semi-arid environment. However, the humidity is often high enough to create sultry conditions. Cool season precipitation originates from Pacific Ocean cyclonic storms, and is more variable (less dependable) than the summer precipitation. Over the years, cool season precipitation has been rather evenly distributed from October through March. The driest season is during April, May, and June.

Summer temperatures in the basins range from normal lows of about 65° F to highs of 90° F. Winter normal ranges are 35 to 60° F.

The net result is that the region is quite heterogeneous with respect to climate, and consequently in relation to vegetation. Non-climatic influences such as soil and topographic differences further act to create multitudes of plant communities (Hastings and Turner, 1965).

PHYSIOGRAPHY, GEOLOGY, VEGETATION AND SOILS

Southeastern Arizona is occupied by a portion of the Mexican Highland basin and range section (West. Land Grant Univ. & Coll., 1964). Elevation ranges from about 2, 500 feet near Tucson to about 10, 000 feet in the Santa Ritas and Huachucas. There are four major broad valley basins in the section (Green and Sellers, 1964), three of which occur in or adjacent to the study area. They are the Santa Cruz, the San Pedro, and the Sulphur Springs. The Santa Cruz and San Pedro Rivers, both of which are mostly dry streams, drain north into the Gila River, while the Sulphur Springs Valley drains south into Mexico. The broad basins consist of gently sloping, often deeply dissected plains composed of coalesced alluvial fans (bajadas) and often deep valley fill. The valley basins extend to about 5, 000 feet at the mountain bases. The mountains consist mostly of eroded, tilted fault blocks. In addition to the high Santa Rita and Huachuca Mountains several other ranges of considerable extent occur in the study area. They are the Rincons, the Patagonias, the Mules, the

Dragoons, and the Whetstones, all of which approach 7, 000 feet elevation. Several lesser mountains or major hilly sections are also present.

Geologic information was taken primarily from Zimmermann (1969, p. 4-6). The geology of the region is complex, consisting of substantial amounts of metamorphic, sedimentary, and volcanic rock types, and further complicated by extensive faulting. Volcanics, mainly rhyolite and andesite, as well as sedimentary rocks, mostly sandstone, shale, and conglomerate, are common. They tend to resist erosion, forming tableland, or jagged hills and mountains. Sedimentaries, like limestone and quartzite, commonly form small peaked hills. Granitic rocks, granite gneiss, and schists are common. The granite often exfoliates to form massive, rounded boulders. Zimmermann (1969, p. 5) stated that the alluvial fills in the basins have been considered "undifferentiated" conglomerates, because "agreement on the differentiation of the alluvium has not yet been achieved." However, he cites an attempt of one worker to distinguish valley fill based on age of the fill.

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 West. Land Grant Univ.

and Coll. (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 cactii. Characteristic species [5/] 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.,

[5/] List of scientific and common names is given in Appendix F.

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 drainage ways). 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, Emery 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 (Calcustolls) 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 from 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 indurate 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.

SELECTED LITERATURE

Only that literature which has special relevance to the research has been included. Although the controversies relating to various approaches in vegetation classification are recognized, literature relating to alternative approaches is not included. In the area of photo image comparisons, to the best of my knowledge, there is no reported parallel approach. However, traditional photo interpretation testing approaches have used methods of analysis which strongly influenced image comparison analysis. Particularly meaningful examples of the photo interpretation literature are included. Many volumes of literature exist for multistage sampling with photography, and those references which provided substantial research direction are discussed. In the areas of photo interpretation and sampling approaches, three extensive bibliographies, two of which are annotated, proved to be especially helpful in the initial literature search. They were Bonner (1972), Murtha (1969), and Nielsen (1971).

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 will 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 classifications and legends in eastern Oregon for natural 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 . . . (Kuchler, 1967, p. 227).

Further, the stands were considered for classification in a straight forward 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.

IMAGERY CONTENT COMPARISON

> 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 photographic quality, namely, tone (or color) contrast, sharpness, and stereoscopic parallax (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 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 those derived from another for the three vegetation types identified (conifers, brush, and dry site hardwoods).

This contrasted to their results at the Northern Coastal Zone Test Site 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 1 error (omission); or (3) a wrong decision, Type II error (commission). A Type 1 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 nypothesis and the alternative is true (Steel and Torrie, 1960, p. 70). As applied to interpretation testing, comparisons are made between interpretations (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

$$\% \text{ Correct} = \frac{\text{Number of A's that agree with B's}}{\text{Total number of B's}} \times 100$$

$$\% \text{ Errors of Omission} = \frac{\text{Number of A's like B's that were rejected}}{\text{Total number of B's}} \times 100$$

$$\% \text{ Errors of Commission} = \frac{\text{Number of A's not like B's but were accepted}}{\text{Total number of A's}} \times 100$$

PHOTO SAMPLING

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, as 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 long 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.

A two stage representation of the sampling and variance formulas (Langley, 1971a, p. 131) would be

$$e = \frac{1}{m} \sum_{j}^{m} \frac{1}{p_i n_i} \sum_{j}^{n_i} \frac{v_{ij}}{p_{ij}}$$

in which e = the estimate of the resource quantity

m = the number of primary units included in the sample

p_i = the probability of selecting the ith primary unit

n_i = the number of observations included in the ith primary unit

e_{ij} = the resource quantity measured in the jth subunit of the ith primary unit

p_{ij} = the conditioned probability of selecting the jth subunit given the ith primary unit has been selected.

The variance (b) calculation is

$$v = \frac{1}{m(m-1)} \left(\sum^{m} \frac{e_i^2}{p_i^2} - me^2 \right)$$

From this, then, sampling errors can be calculated.

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).

A considerable amount of other literature on sampling was reviewed in the process of selecting a sampling approach. Most of it dealt with forest related inventories; indeed, it appeared to me that the greatest contributions to aerial sampling approaches have developed in forestry applications. However, none of them appeared as applicable, or any more applicable, than did the various papers by Aldrich, Heller, and Langley. Other papers did, however, exhibit a rather consistent commonality regarding two aspects of sampling, accuracy and efficiency.

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 I drifted toward 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 AND PROCEDURES

VEGETATION LEGEND DEVELOPMENT

Background

The test site was selected in part for the natural vegetation diversity which is present in the area. The vegetation includes components of the Sonoran and Chihuahuan desert shrub, grassland, chaparral, mixed needleleaf and broadleaf woods, and needleleaf forest vegetation (Schrumpf, Johnson, and Mouat, 1973). No uniform natural vegetation classification existed for the area, and because of the nature of the resource inventory and analysis procedures being explored, the need for developing a vegetation classification was apparent. The earliest efforts began in 1966 (Poulton, Schrumpf, and Garcia-Moya, 1968) and continued into 1973 (Schrumpf, Johnson, and Mouat, 1973). The natural vegetation classification is tailored to be compatible with a comprehensive, unified legend which includes land use, water resources, and natural vegetation along with more specific physical features of the landscape that may be resource or land use related (Poulton, 1972).

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, and 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 (Figure 3). The four letter symbols on the card each stand for a particular plant species. "P" is relative prominence, "C" is cover, and "S" is sociability or gregariousness. Least prominent species are 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 are indicated by sociability class 1. Details of these expressions are presented in Appendix D. 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 sites were used in developing the vegetation classification for the test 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, 1960, 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,

Slide Number: 1948 Date: 29 July 70 By: Garcia-Johnson Color (✓) B&W (_)

Purpose: Veg-Resource State: Arizona Area:

Ecological Unit: Symbolic legend 321.21 County: Maricopa

Title:

Location: Pediment along western edge of McDowell Mts.
420,000 mE 3,722,500 mN T4N, R5E

Delineation nos:
space p. 5i
H.F. 2781-12

Descriptive Information:

	P	C	S
Cagi	2	1	1
Cemi	4	2+	1
Fede	4+	3	1
Olte	4	2+	1
Opsp	4	2+	1
Opbi	3	1	2
Cholla	4	2	1
Latr	3	1	1
Feac	3	2	1
Fewi	2	1	1
Annuals	2	2	1

Macrorelief = 1a
Soil color 10 YR 6-7/4
Regional slope 3%
Runnels 2'-4' deep
Side slopes 5%
200' between runnels
Quail seen in area
Stones class 5⁻ (4"-8")
Gravel class 3+ < 1/4"
Rhyolyte = P.M.

Figure 3. A field record card example showing the type of information gathered at each sample location.

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 [in the Results and Discussion]. 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).

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 1). Both of these photographs, Gemini IV and Apollo 6, were chosen for photo image content comparisons with an ERTS-1 photographic reconstitution. The nature of the evaluations is summarized in Figure 4.

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 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 data diazo composite (see discussion below and Footnote 7) accompanied by a

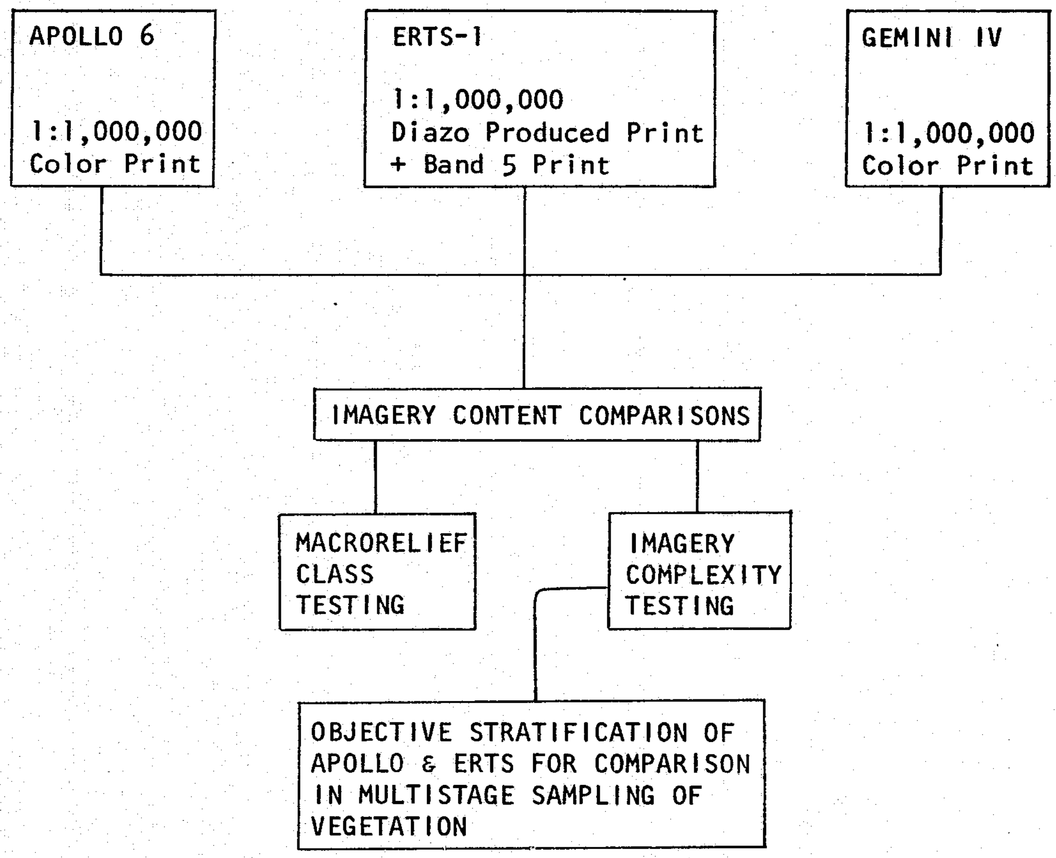

Figure 4. Comparative image evaluations of space imagery.

Table 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, and simulated color infrared
ERTS-1	2 NOV 72	1102-17280	
*ERTS-1	26 DEC 72	1156-17280	

black and white photo print of ERTS band 5 [6/] 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

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[6/] Band 5 corresponds to the "visible red" portion of the electromagnetic spectrum and encompasses the wavelength range of 580 to 680 millimicrons. It is an optimum wavelength for detecting vegetational and geologic formations (Colwell, 1970).

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 multi-spectral ERTS transparencies using diazo film transparencies [7/] 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

[7/] Diazo film is a projection film, which is exposed by ultra-violet light and developed by ammonia. Developed film color is determined by the particular dye associated with the diazonium molecule. When exposed to ultraviolet radiation, the molecule is decomposed, leaving a product which is practically colorless even after exposure to volatilized ammonia (Neblette, 1962; p. 149). The non-exposed portion of the diazo film, that which is protected from radiation by images on the photographic film, forms the dye, in effect producing a single colored film which duplicates the photo film image. When photographic transparencies of selected segments of the electromagnetic spectrum are duplicated by the appropriate diazo films, and the films are simultaneously registered, simulated color infrared composites can be produced.

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 5. The purpose of the figure is to give a visual impression of the nature of the photographs compared.

Test Material Preparation

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 "image groupability" [8/] testing, was designed to (1) minimize human

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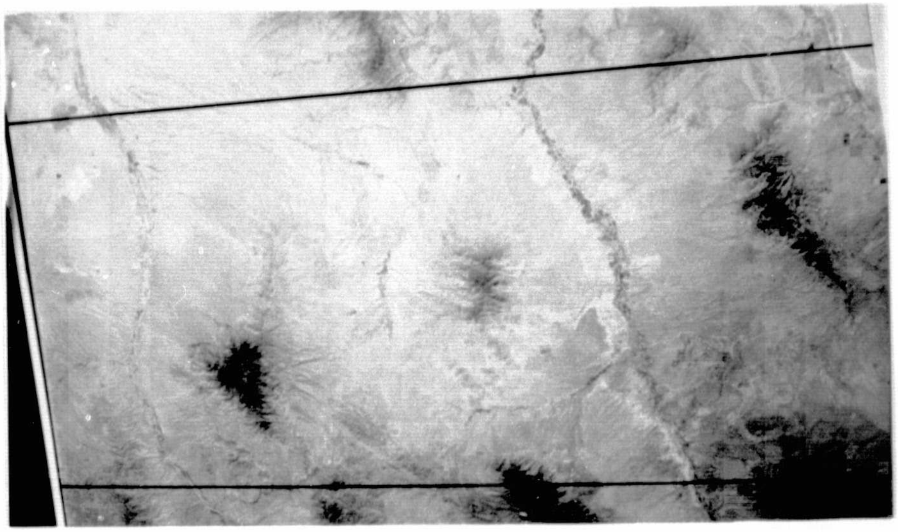
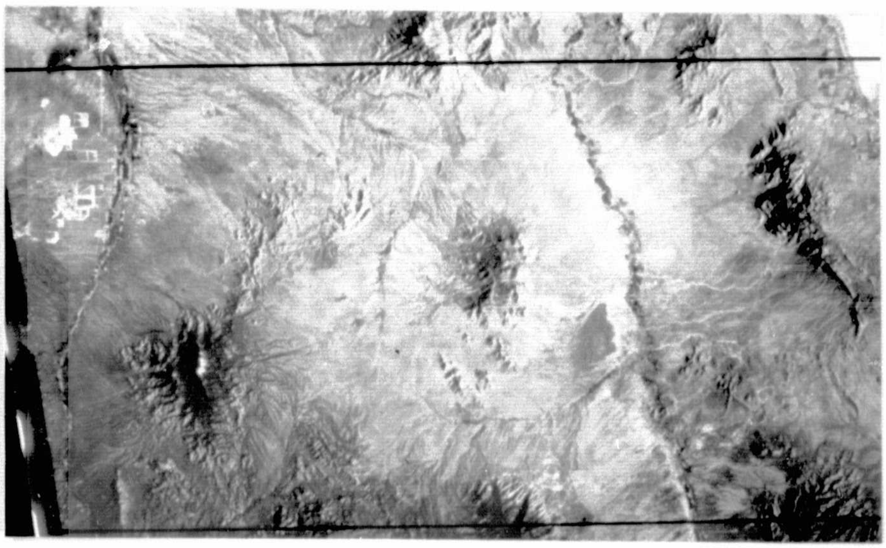
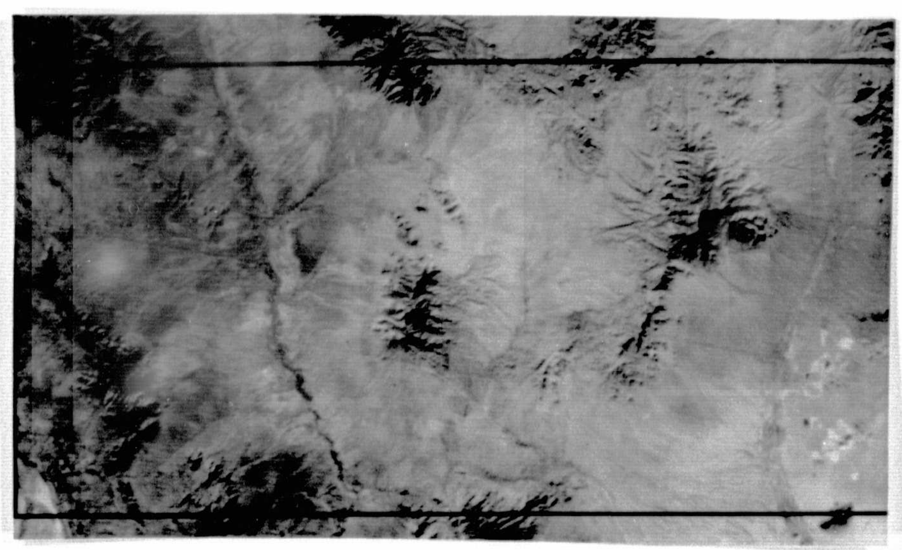
[8/] The terminology "image groupability" is coined here to distinguish from "photo interpretation". In photo interpretation testing, the observers are required to predict the relationship between the photo image and ground subject and from such predictions (interpretations), image samples are grouped. 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 5. Reduced scale (1:350, 000) copies from top to bottom of Gemini IV, Apollo 6, and 26 DEC 72 ERTS-1 space images. The relative differences in quality are comparable to the quality differences of the test materials. Test materials were in color at scales of about 1:1, 000, 000.







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 part of Figure 6. 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 reliance 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 2). Appendix A provides a more detailed description of the macrorelief classes.

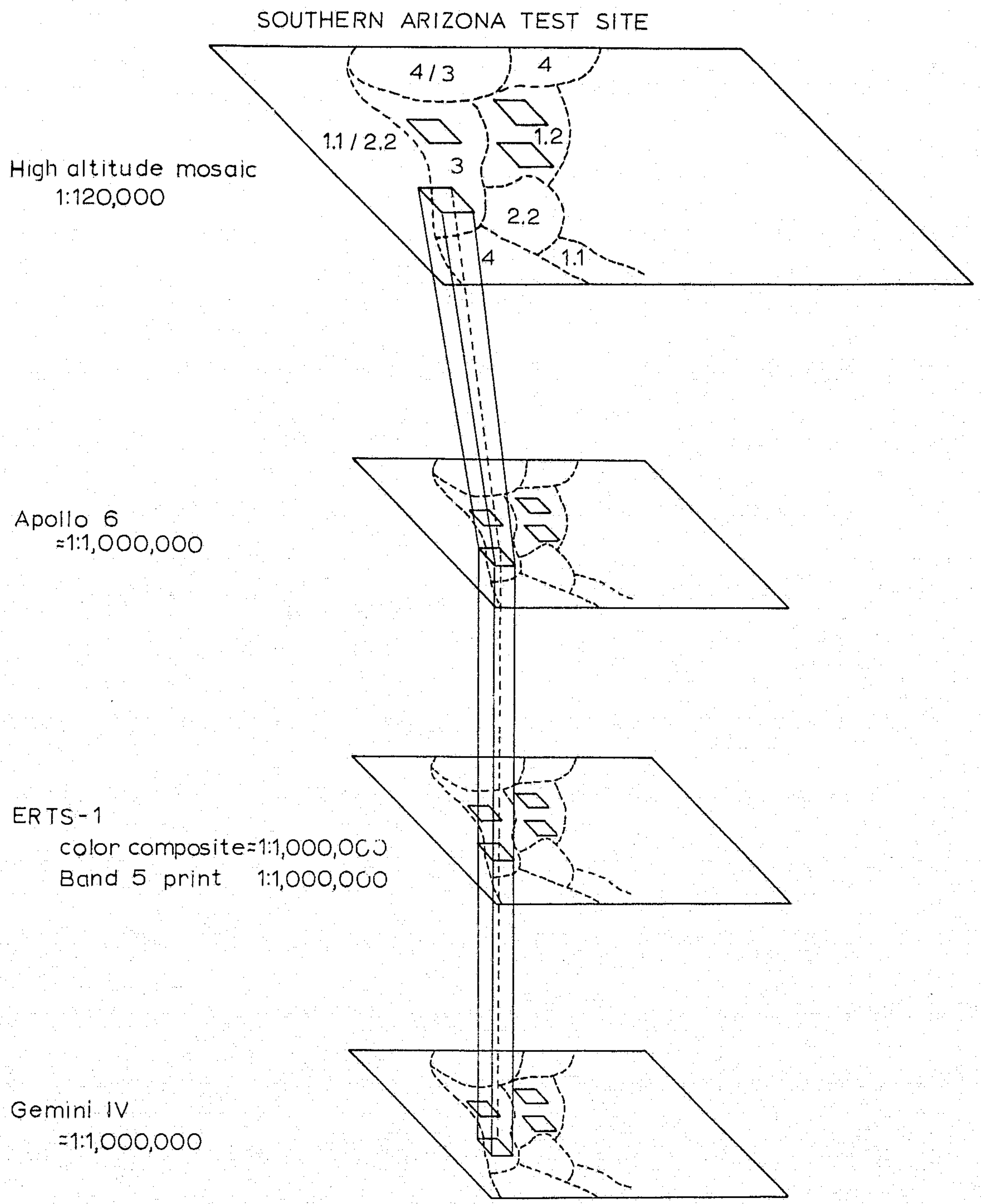


Figure 6. Image selection scheme used in space photo comparison. Image samples were drawn based on macro-relief mapping of high altitude photography. All image samples from each space photo represent the same piece of land.

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

Macrorelief class [a/]		No. 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 1,000' relief	12	4
4	Mountains, > 1,000' relief	9	1
Total		45	13

[a/] See Appendix A for more detailed macrorelief class descriptions.

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 macrorelief 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 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.

Testing Procedure

A total of 13 observers was chosen for the testing. Selection was based on (1) my 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). A summary of the observers' experience statements is presented in Appendix B.

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 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 instructions for both tests are presented as part of Appendix C.

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. Specifically, testing on Gemini began a month behind testing on Apollo and ERTS, and frequently the two tests for a space photo were taken the same day. On one occasion an observer took both ERTS tests between the first and second tests for Apollo. Appendix C contains the test schedule.

Analysis

Test 1 (unrestricted) was analyzed by analysis of variance (ANOVA), developed by me 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 portion of the research.

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.

TWO STAGE SAMPLING OF VEGETATION SUBJECTS

Based on the "Space Photo Image Content Comparison" research of this paper, 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 summarizes the sampling process.

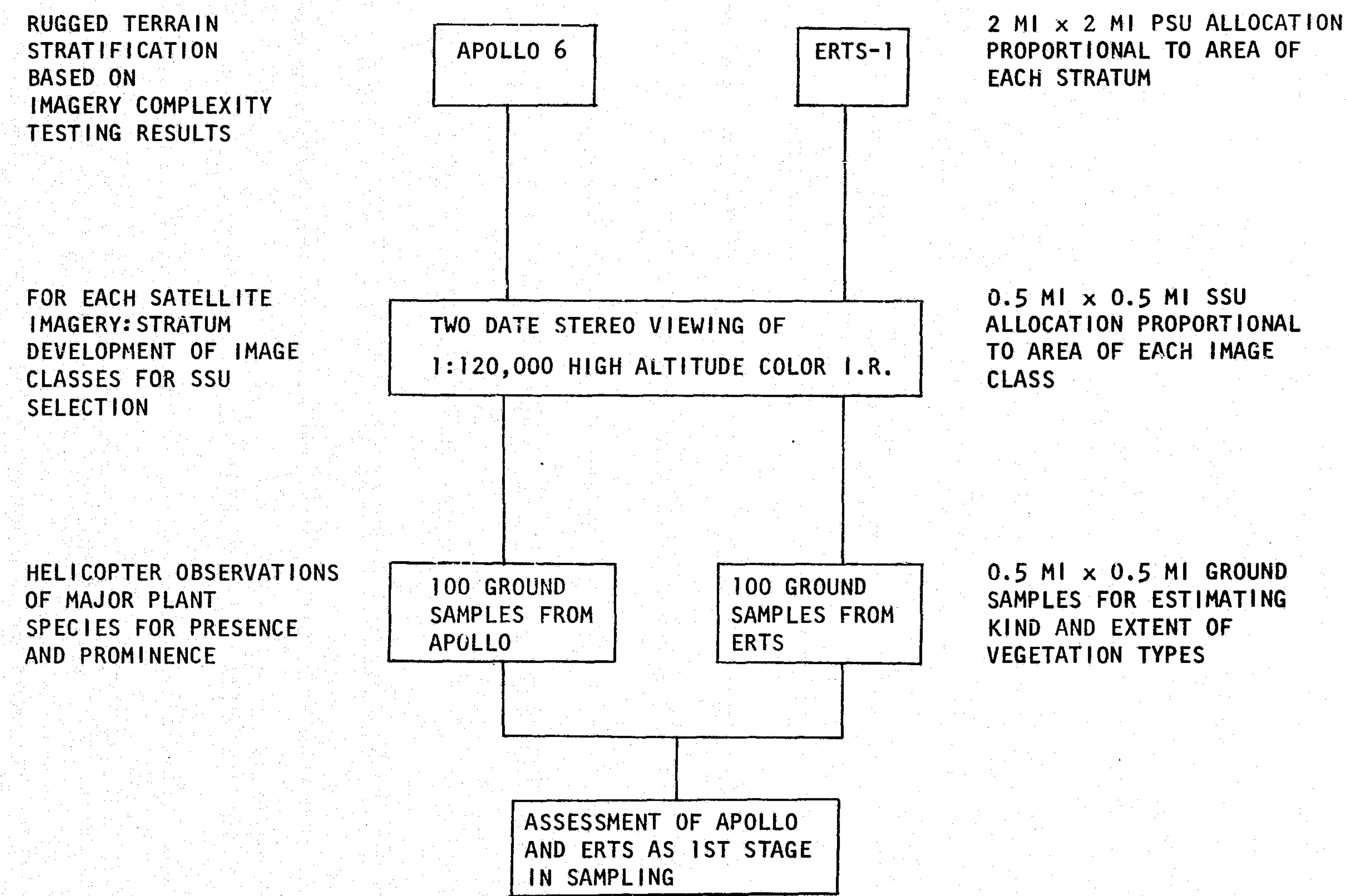


Figure 7. Comparative two stage sampling conducted for estimating the extent of vegetation types.

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 checking accuracy of photo interpretation 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 same sample comparison by reduction of 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 [9/]. From the stratification 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 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 DEC 72

[9/] See "Photo Stratification" in the image comparison section of Results and Discussion for strata maps and details relative to development of the strata.

ERTS-1 photography, I photo interpreted the entire sample areas 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. My 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 (see Footnote 9), 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 my 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 9x9 transparency was viewed monocularly through an Old Delf 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 3) were chosen to help make the predictions. The 2 NOV 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 (see Footnote 9) and the 2x2 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, I had considerably more confidence with ERTS as compared to Apollo in making the dichotomous decisions.

Following the predictions on the space photos, PSU's were drawn for further subsampling. This was accomplished by using the OSU Statistical Interactive Programming System (*SIPS), subsystem Monte Carlo (Guthrie, Avery, and Avery, 1973). This subsystem randomly and with equal probability selects the designated number of sample integers from an assigned range of integers.

Table 3. 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 integer ranges were determined on a stratum-by-stratum basis with cumulative totals of predicted "wooded" and "not wooded" vegetation (Table 4). 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, D-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, 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 5). Beyond allocating PSU's on the basis of "wooded" versus "not wooded" predictions from space photo

Table 4. 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	

Table 5. Allocation of PSU's based on space photo cell derived predictions of "wooded" and "not wooded" lands.

Mapping units of strata	Cumulative prediction (% of area)			No. of PSU's drawn			No. of mapping units containing PSU's
	Wooded	Not wooded	Total	Wooded	Not wooded	Total	
Apollo							
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							
8 of F	2,140	6,330	8,470	4	13	17	6 of 8
5 of I	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

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 6). Several dates of color photography 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 steroscopic 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.

Table 6. Relatively cloud-free, good quality, 9x9 inch 1:120,000 scale, high altitude, transparent photography available for the Southern Arizona Test Site by 1 OCT 73.

Date and source	Mission No.	Scale	Film/filter
(NASA-Houston provided)			
11 SEP 70	141	1:120,000	2443 color infrared/-blue
8 NOV 70	146	1:120,000	2443 color infrared/-blue
(NASA-Ames provided)			
12 DEC 72	72-213	1:120,000	2443 color infrared/-blue
2 MAY 73	73-068	1:120,000	2443 color infrared/-blue

<u>Secondary Sample Unit Image Classification and Selection</u>

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 1/4 x 1/4 inch SSU's represented approximately square quarter miles (1/2 x 1/2 mile) on the ground. The square quarter mile 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, square quarter miles 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 my photo interpretive judgment 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. The number of image classes created and SSU's per class are shown in Table 7.

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 (Table 7). 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 sample 100 locations 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.

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Table 7. High altitude interpretive image classifications and subsequent allocation of SSU's for ground checking.

Apollo				ERTS			
Strata	High altitude image class	Number of SSU's/ image class	Allocated a/ number of SSU's for ground checking	Strata	High altitude image class	Number of SSU's/ image class	Allocated a/ number of SSU's for ground checking
B	1	18	4	F	1	5	1
	2	8	2		2	17	4
	3	36	8		3	63	14
	4	1	1		4	35	8
	5	28	6		5	3	1
	6	8	2		6	7	1
	7	9	2		7	4	1
		108	25		8	4	1
					9	8	2
F	1	23	5		10	16	3
	2	26	6		11	12	3
	3	2	1		12	13	3
	4	19	4			187	42
	5	1	1				
		71	17	I	1	13	3
					2	3	1
H	1	39	9		3	5	1
	2	13	3		4	5	1
	3	10	2		5	3	1
	4	5	1		6	33	7
	5	14	3		7	7	2
	6	36	8		8	19	4
	7	17	4		9	8	2
	8	15	3		10	14	3
	9	8	2		11	5	1
	10	11	2		12	16	4
	11	5	1		13	6	1
		173	38			137	31
J	1	3	1	L	1	11	2
	2	35	8		2	17	4
	3	14	3		3	29	6
	4	3	1		4	22	5
	5	24	5		5	15	3
	6	25	6		6	3	1
	7	1	1		7	4	1
		105	25		8	9	2
					9	26	6
						136	30
Total		457	105			460	103

a/ Ground check allocation was proportional to the total number of SSU's associated with ERTS or Apollo, but with a minimum of one ground check unit per image class. Allocations deviated from actual ground checks due to navigation difficulties.

Then, prior to entering the field, sampling approaches and alternatives were considered in conferences with Oregon State University personnel, Drs. Norbert Hartmann of the Statistics Department, and William Pyott of the Rangeland Resources Program. The alternatives listed by priorities are given in Table 8. The first and second 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 from three strata from ERTS; and finally (3) an estimated time requirement of six minutes/ground site when using helicopter

Table 8. Alternative sampling tasks arranged prior to field sampling.

Priority	Helicopter sampling tasks
1st	150 samples each from Apollo and ERTS
2nd	100 samples each from Apollo and ERTS
3rd	200 samples from ERTS alone
4th	150 samples from ERTS alone

reconnaissance 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 consistence 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 9. These deviate somewhat from the number which

Table 9. Number of sample units and proportions of study areas which were sampled.

Strata		Total area (sq. miles)	Percentage of total area		Number of	
			In PSU's	Ground checked	PSU's	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

were allocated (Table 7) 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 9 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 9x9, 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 1/4 to 1/2 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 accuate identification of large shrubs and trees. The information gathered [10/] 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 straight forward process based mostly on an 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

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[10/] Barry J. Schrumpf was responsible for obtaining and recording site information. Since 1968, Barry has been developing taxonomic and field identification capability of plant species in southern Arizona. His capability for species recognition from the air has been cultivated by several fixed wing and helicopter reconnaissance missions over the Test Site.

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).[11/]

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

$$\hat{E}_k = \frac{1}{N_{..}} \sum_i \sum_j N_{ij} \hat{P}_{ijk}, \text{ where}$$

$N_{..}$ = the total number of SSU's.

11/ Dr. Norbert A. Hartmann, Department of Statistics, and Dr. William T. Pyott, Rangeland Resources Program, both at Oregon State University, were instrumental in developing the sampling scheme.

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

$$\hat{v}_{ijk} = \sum_{k} \hat{b}_{i \cdot k}^{2} \hat{P}_{ijk} (1 - \hat{P}_{ijk}) - 2 \sum_{k<k'} \hat{b}_{i \cdot k} \hat{b}_{i \cdot k'} \hat{P}_{ijk} \hat{P}_{ijk'}, \text{ where}$$

$\hat{b}_{i \cdot k}$ = 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

$$\hat{v} = \frac{1}{n_{...}^2 N_{..}^2} \sum_i \sum_j \sum_k n_{..k}^2 N_{ij}^2 \hat{v}_{ijk}, \text{ where}$$

$n_{...}$ = 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

NATURAL VEGETATION CLASSIFICATION

The existing natural vegetation classification for the Southern Arizona Test Site is presented in this section. The classification is a major contribution to the research project under which this dissertation took form. The classification was produced through the collaborative efforts of Barry J. Schrumpf, David A. Mouat, and myself, and it represents an essential ingredient of our respective research responsibilities. It is, therefore, being presented in all three dissertations. The classification has been published previously (Schrumpf, Johnson, and Mouat, 1973) and is presented here as Figure 8 through 38 with minor revision. Table 10 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 E. A list of scientific and common names is presented in Appendix F.

The "vegetation types", as they are called, are not structured in this presentation by a hierarchical arrangement. Hierarchical

Table 10. Reference table of vegetation types and corresponding figure numbers.

Figure No.	Type No.	Abbreviated alpha title
8	1	Latr-annuals
9	2	Latr-Prju
10	3	Atca-Prju
11	4	Cemi-Cegi-Enfa
12	5	Coca-Zipu-Fosp
13	6	Acve-Latr
14	7	Acve-Latr-Rhmi
15	8	Alwr-Fosp-Acco
16	9	Mosc
17	10	Mosc-Rhch
18	11	Prju-Hate-Cholla
19	12	Prju-Hate
20	13	Acco-Prju
21	14	Caer-Acco-Prju
22	15	Caer-Prju-Mimosa
23	16	Caer-Eptr-Yucca
24	17	Bout-Arist
25	18	Prju-Bout
26	19	Bout-Arist-Nomi
27	20	Prju bosque
28	21	Himu-Prju
29	22	Spwr-Prju
30	23	Prju-Quercus-Jude
31	24	Come
32	25	Quercus-Nomi
33	26	Quercus-Mimosa
34	27	Quercus-Arpu-Mibi
35	28	Quercus-Arpu-Pice
36	29	Cebr
37	30	Pofr, Plwr, Chli
38	31	Pinus

Figure 8. 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.

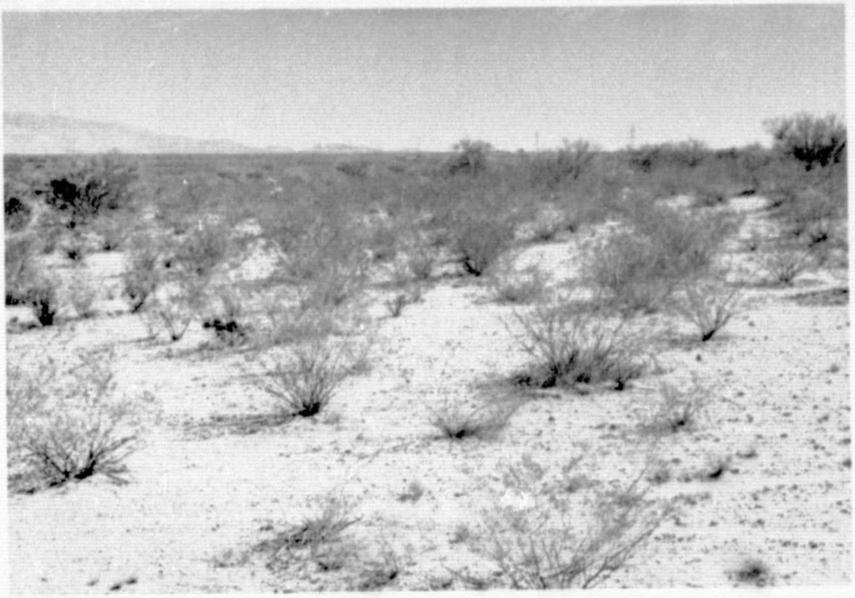

Figure 9. Larrea tridentata with Prosopis juliflora and/or Opuntia (cholla).

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."

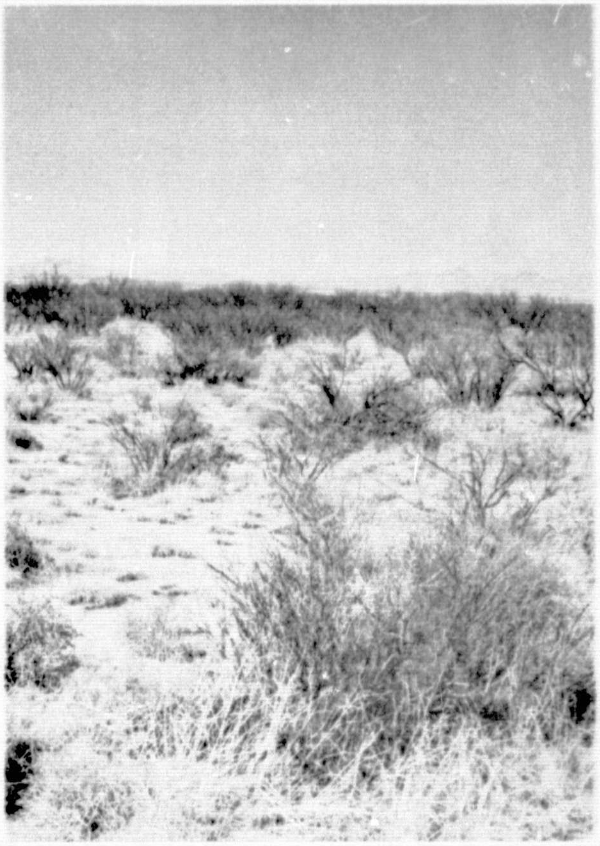

Figure 10. Atriplex canescens and Prosopis juliflora.

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 quite variable (2-5), but in general one or the other or both tend to rank highest in prominence value.

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 11. 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.

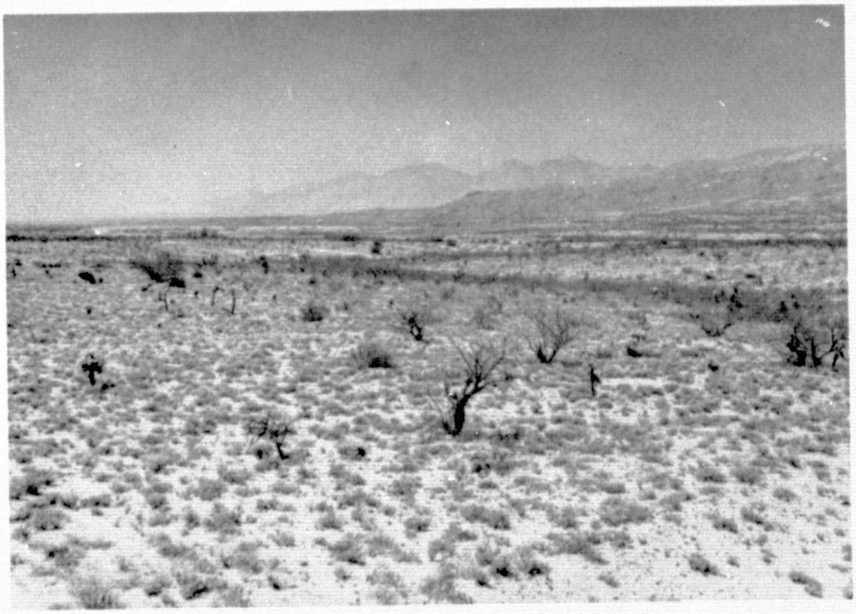

Figure 12. Coldenia canescens, Zinnia pumila, Fouquieria splendens, and Tridens pulchellus.

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 sparse.

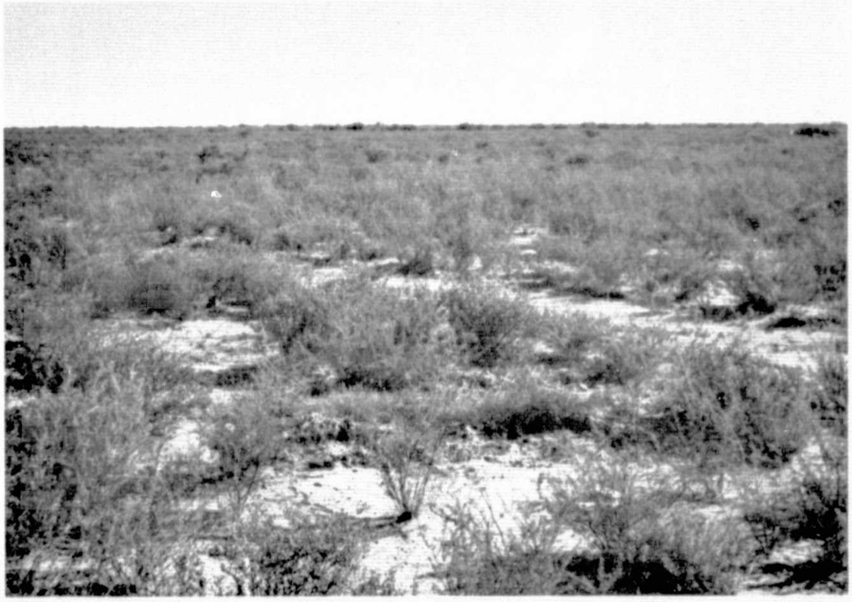

Figure 13. Acacia vernicosa, Flourensia cernua, and Larrea tridentata, without Rhus microphylla and Dalea formosa.

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 occasionally, 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."

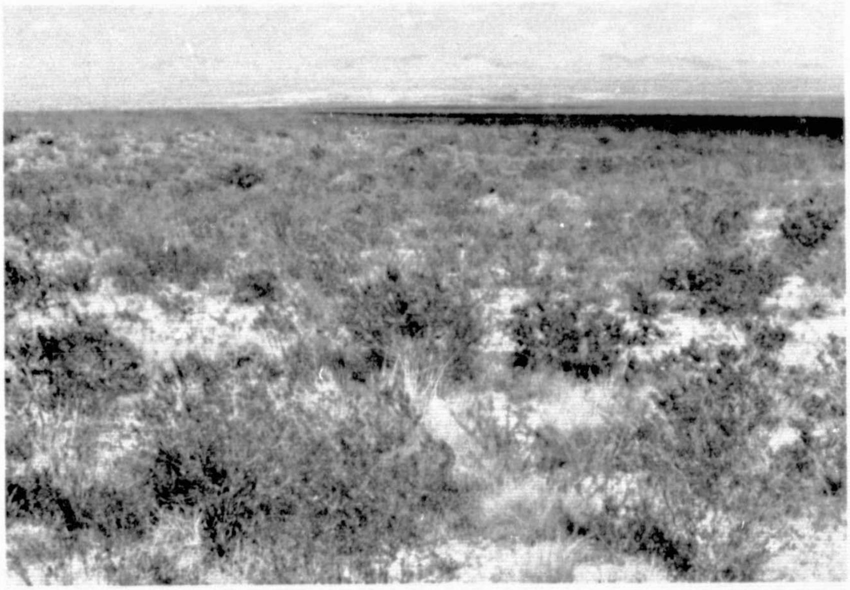

Figure 14. Acacia vernicosa, Flourensia cernua, Larrea tridentata, and Rhus microphylla.

"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 15. 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 no 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.

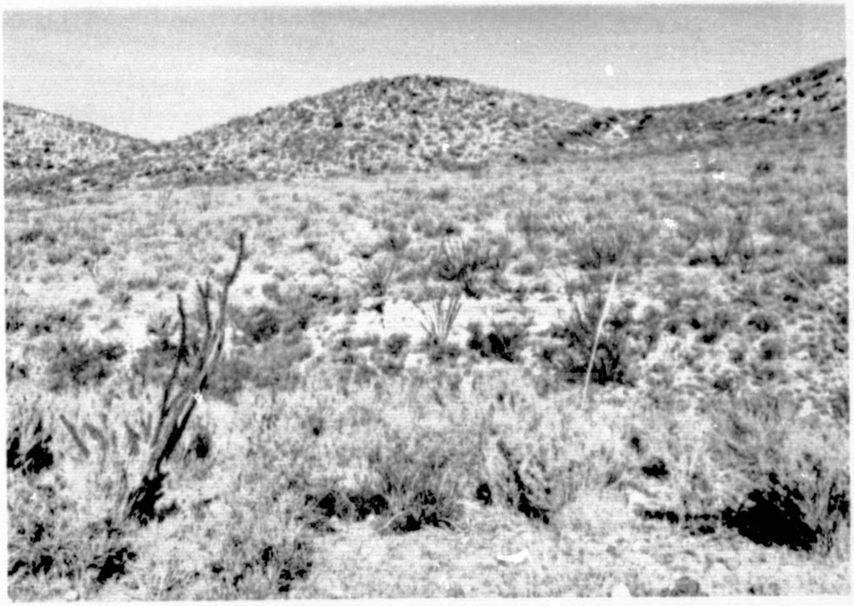

Figure 16. Mortonia scabrella without Rhus choriophylla.

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."

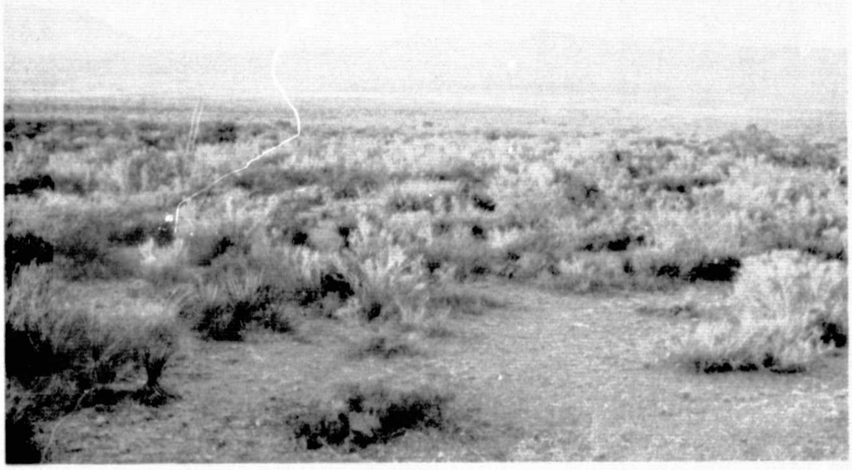

Figure 17. Mortonia scabrella with Rhus choriophylla.

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."

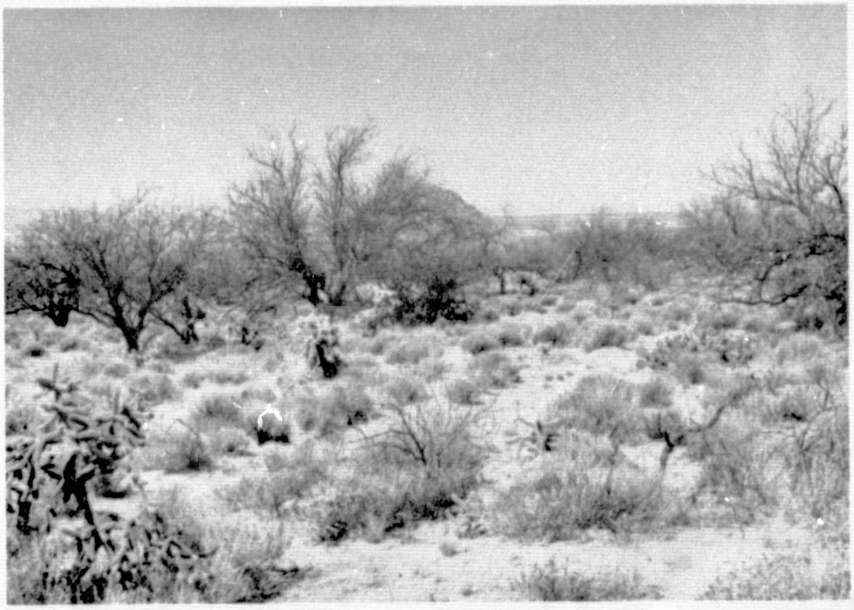

Figure 18. Prosopis juliflora and Haplopappus tenuisectus with Opuntia (cholla) and without Acacia constricta and Calliandra eriophylla.

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."

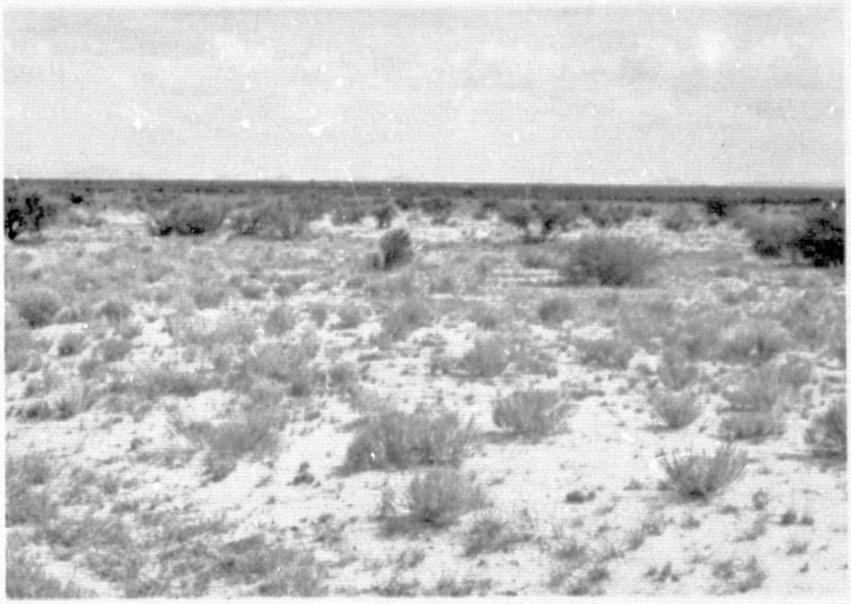

Figure 19. Prosopis juliflora and Haplopappus tenuisectus; without Acacia constricta, Opuntia (cholla), and Calliandra eriophylla.

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."

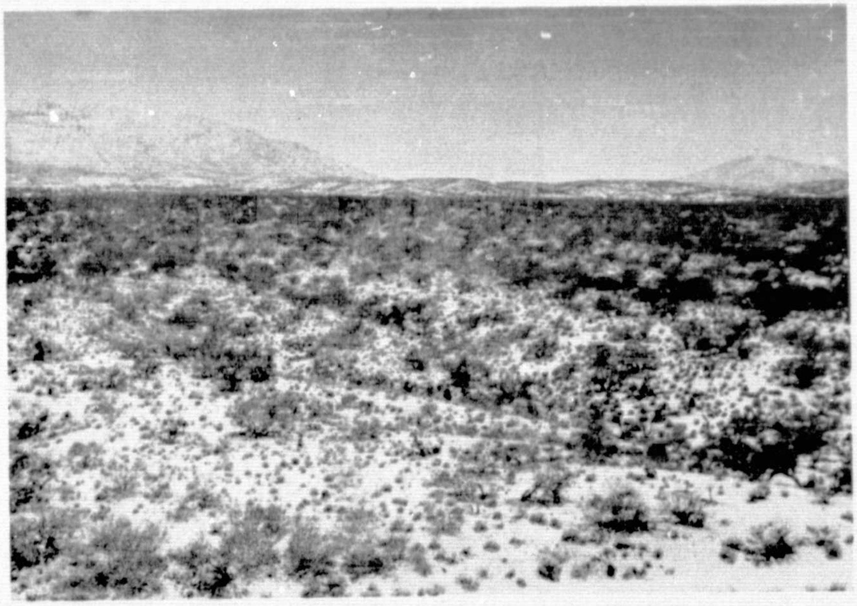

Figure 20. Acacia constricta and Prosopis juliflora usually with Opuntia; without Calliandra eriophylla.

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 21. 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 22. 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."

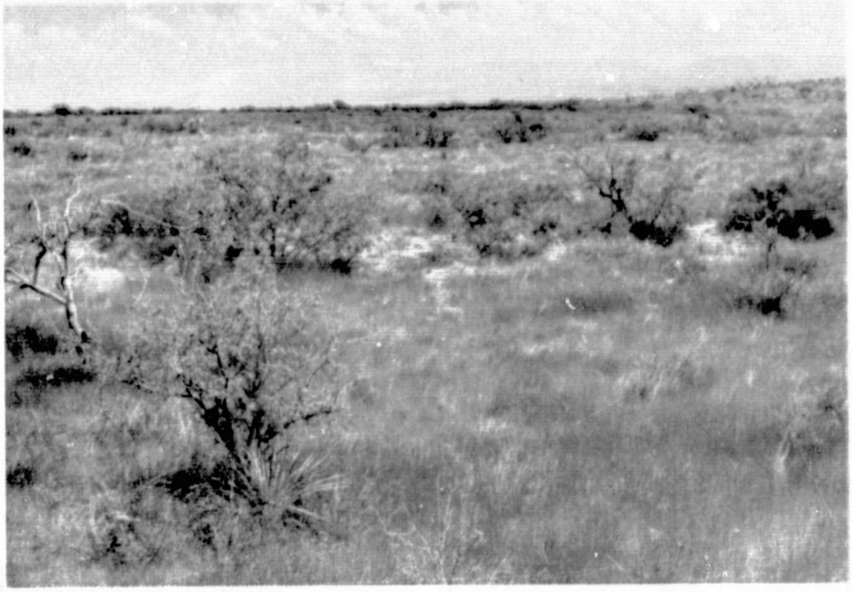

Figure 23. Calliandra eriophylla and Bouteloua with any or all of Ephedra trifurca, Yucca baccata, Y. elata, Prosopis juliflora, and without Acacia constricta.

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, the 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 24. *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 prominence value (5). The most common species are *Bouteloua curtipendula*, *B. gracilis*, *B. chondrosioides*, and *B. eriopoda*. Perennial *Aristida* 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 is *Andropogon barbinodis*.

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

Figure 25. 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 prominence (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.

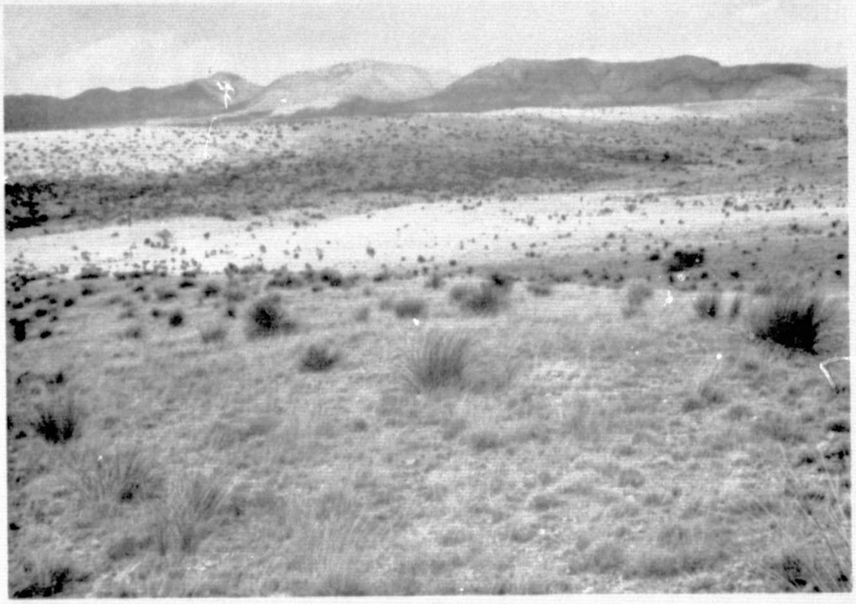

Figure 26. Bouteloua, Aristida, and Nolina microcarpa without Calliandra eriophylla.

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.

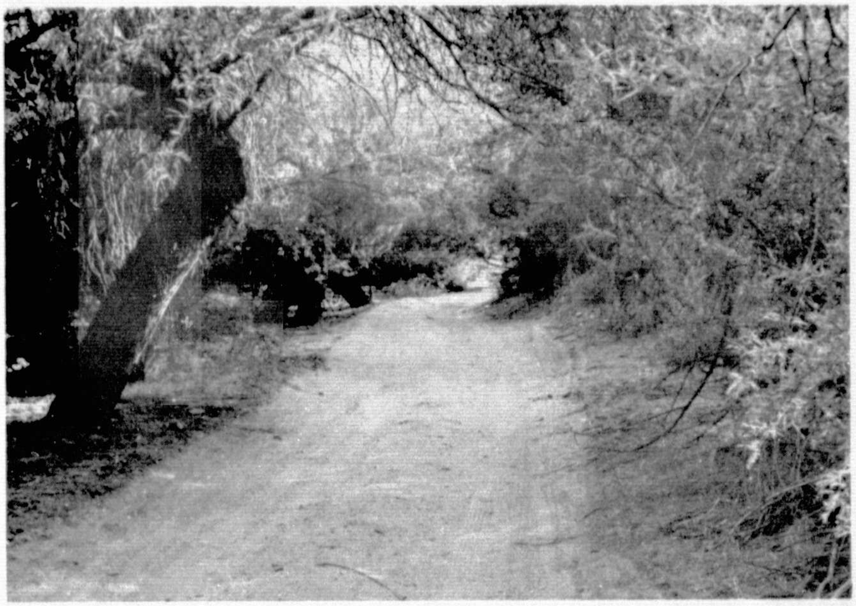

Figure 27. Prosopis juliflora bosque.

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 28. 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 29. 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.

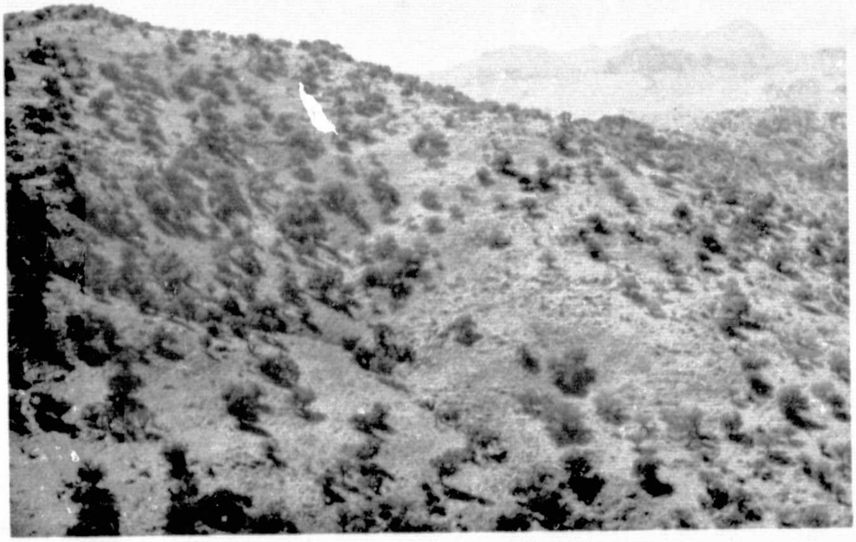

Figure 30. Prosopis juliflora and Bouteloua with Quercus (usually Q. oblongifolia) and/or Juniperus deppeana.

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 31. 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 32. 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.

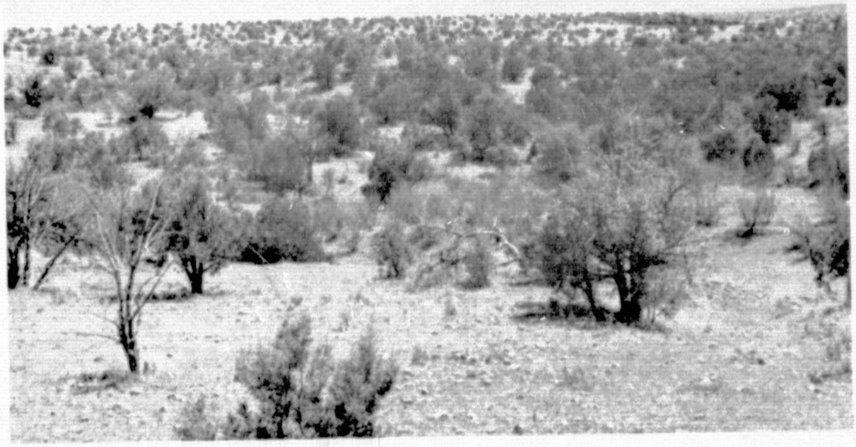

Figure 33. Quercus and Mimosa without Arctostaphylos pungens or Cercocarpus breviflorus.

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 34. _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.

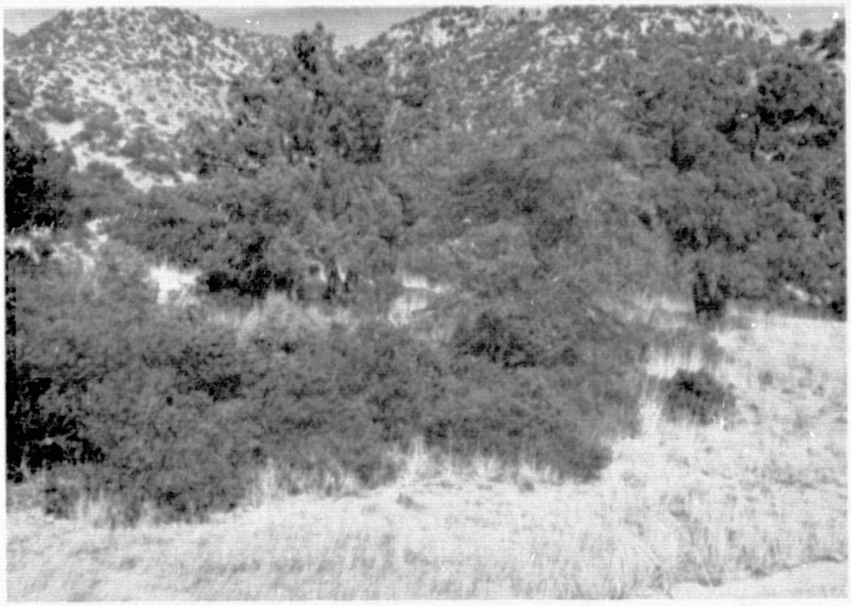

Figure 35. Quercus, Arctostaphylos pungens, Pinus cembroides, Juniperus deppeana; without Mimosa biuncifera.

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.

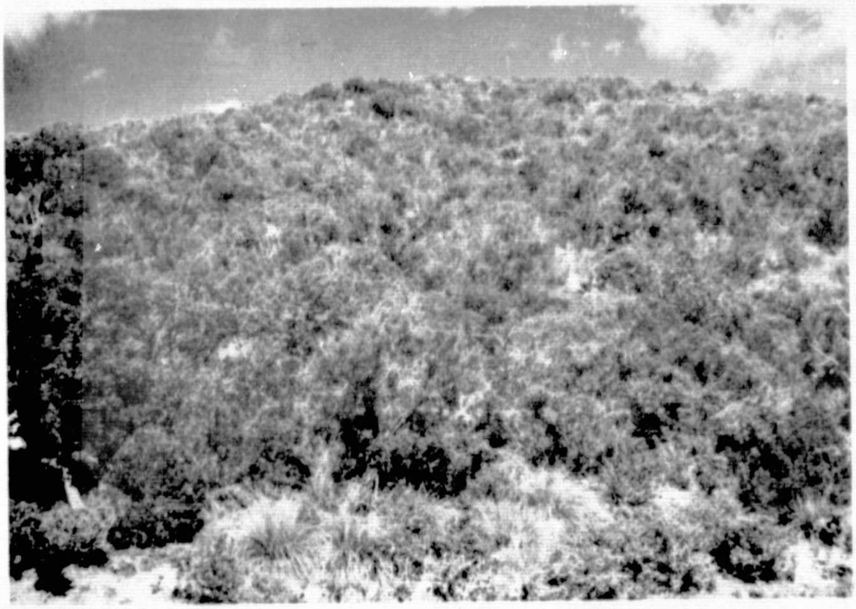

Figure 36. *Cercocarpus breviflorus* with *Juniperus deppeana* and/or *Pinus cembroides* and usually with *Quercus*.

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 *Cercocarpus 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 37. 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.

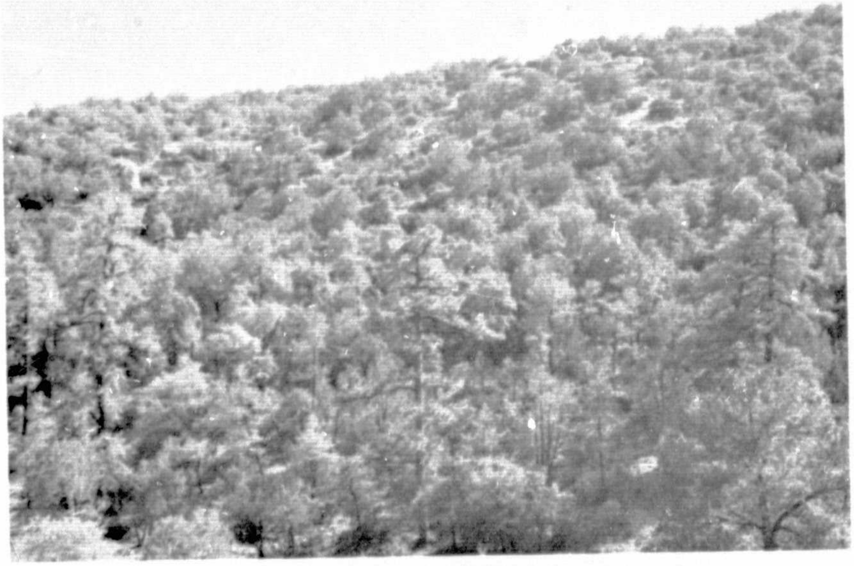

Figure 38. Pinus, with or without P. cembroides, often with Pseudotsuga menziesii, Quercus hypoleucoides, and Q. gambelii.

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 coprominent 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.

considerations become necessary as vegetation is coordinated throughout a region (Kuchler, 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 10) 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.

SPACE PHOTO IMAGE CONTENT COMPARISON

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 of the 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 straight forward, however, there are logistic problems of considerable dimension.

Although the primary concern addressed here is one of imagery information content, the problem of capability differences among photo interpreters 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.[12/] Although the use of associated image evidence is an essential portion of operational photo interpretation and mapping, it can disguise differences in image comparisons.

(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

[12/] 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.

groups developed are intended to represent ground subjects described in a hierarchial 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 11 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

Table 11. 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

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.

In Table 11, 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" shows 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 observers' primary 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 12). Table 13 is presented to illustrate the nature of the proportions used in the ANOVA.

One of the more obvious features of the ANOVA is that there was no difference ($P>0.05$) in groupability of image samples among the space photo types. This, of course, was expected from the "Total number correct" box tallies of Table 11. 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 12 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 $P<0.025$ [13/] in order to place much reliance

[13/] In making statistical inferences (when there is no known standard) about mean differences of this sort, it is better to error in the direction of not detecting slight differences rather than to error by suggesting differences which might be products of

Table 12. 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 ($P < 0.01$).

Table 13. Average proportions of "correct responses:expected responses" as derived from image groupability testing.

	Macrorelief classes					
Photo types	1.1	1.2	2.2	3	4	$\bar{x}$
Apollo	0.58	0.48	0.38	0.69	0.77	0.58
ERTS	0.27	0.35	0.55	0.85	0.85	0.56
Gemini	0.38	0.46	0.38	0.83	0.78	0.57
$\bar{x}$	0.39	0.43	0.44	0.79	0.80	0.57

on having detected real differences.

From Table 12 it was 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 14. 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 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

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statistical approaches. Therefore, the rejection level of ($P=0.025$) has been chosen instead of the more traditional ($P=0.050$).

Table 14. Single degree of freedom comparisons for main effects derived from ANOVA for image groupability testing.

Source of variation	DF		Mean squares
Observers (R)	12		
Inexperienced vs. experienced[a/]		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		
R x P x M	96		0.016
Total	194		

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

ns Not significantly different (P>0.025); see narrative Footnote 13.

*** Significantly different (P<0.005).

used for sampling in earth resource related surveys.

Even though differences among macrorelief class grouping were evidenced in Table 14, 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 12 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 15. The pattern of significant differences in Table 14 is strongly paralleled in the Table 15 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 16 is presented as an example of a method for drawing together the information expressed in Tables 12, 14, and 15, that is the ANOVA. Its 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 "easiest" to group macrorelief classes were in fact easier or better " >" grouped than the "hardest" classes. Further, directionality and reversal interaction inferences for comparisons not tested can be shown. For example, in the "ERTS vs. Apollo" column at the "hardest

Table 15. 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); see narrative Footnote 13.

*** Significantly different (P< 0.005).

Table 16. Summary and inferences from ANOVA, Tables 13, 14, and 15.

Tested components of ANOVA	Photo Comparisons			
	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 (easier to group vs. harder)[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.

class" row, the groupability of ERTS is greater than for Apollo. Just the opposite is true for the "easiest class" in the next row down.

Information such as that in Table 16 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 39. Relative differences are seen among imagery types for each marcorelief 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

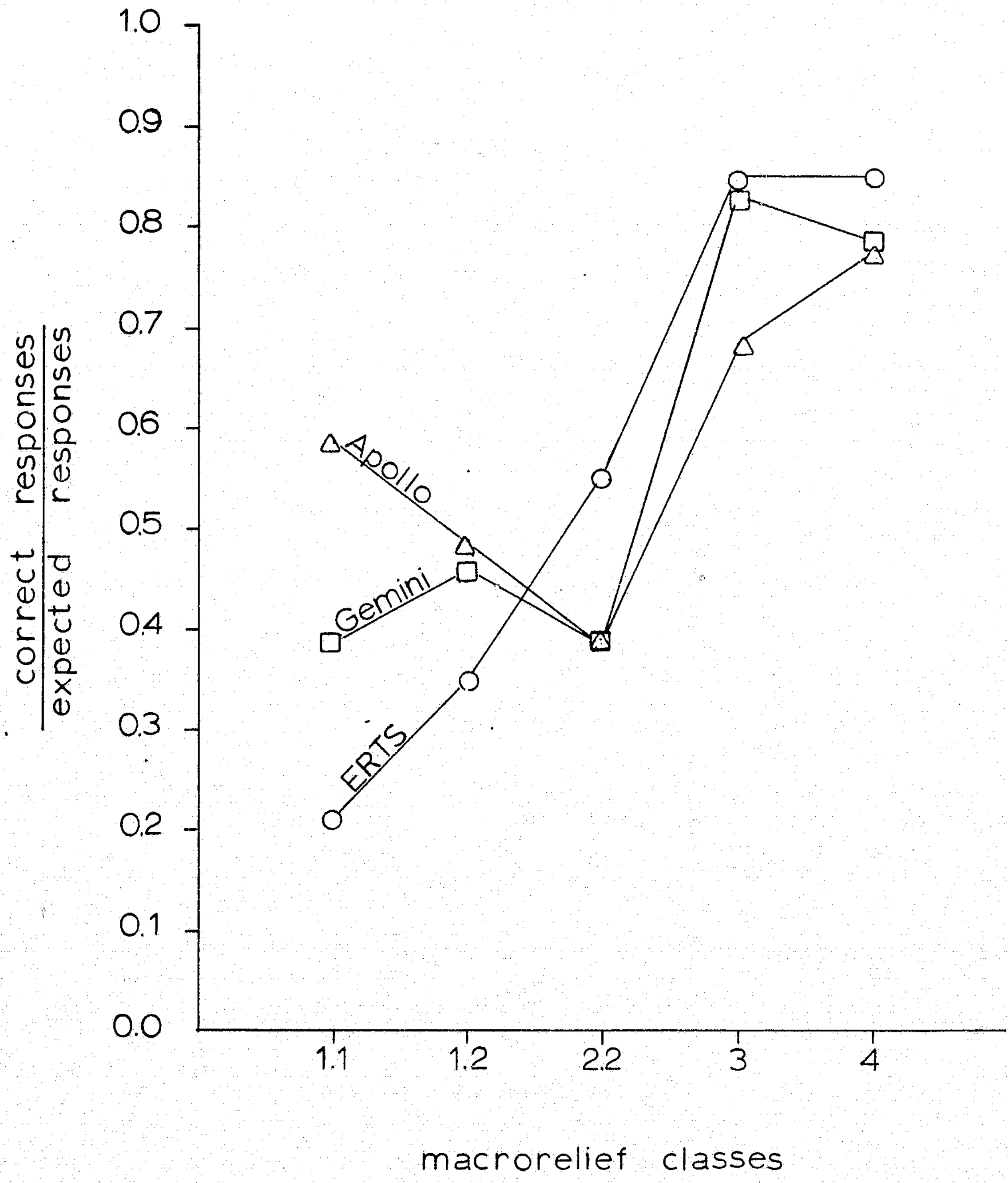


Figure 39. Image groupability testing of space photo images by macrorelief class.

Table 17, 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 18). No differences were detected in the comparison. Earlier significant values were determined among macrorelief classes (Tables 12, 14, and 16). 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.

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 (Appendix C, Test I instructions). Testing is based on the contention that the relative number of groups established is an

Table 17. 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); see narrative Footnote 13.

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

Table 18. 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:[a/]			
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		

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

ns Not significantly different ($P>0.025$); see narrative Footnote 13.

complexity are possible (Table 19). From the table, it is apparent that the mean 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 20. Modal and range statistics suggest that 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 con-

Table 19. 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$_{x}$ ($P > 0.10$)

Table 20. 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

ditions of the test, Apollo had greater information content than did either ERTS or Gemini. The latter two 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 21, 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.

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

Table 21. Ranking of space photo types as generalized from ANOVA.

Component [a/]	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

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

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 22). 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.[14/]

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 samples 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 in Table 23 and Figure 40. Although number of strata and number of mapping units are similar, major differences in the nature of the strata are apparent in the figure.

[14/] The validity of using image sample pairs recognized by as few as seven observers is given in this chapter in the section, "The probability of image sample pairings".

Table 22. 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.

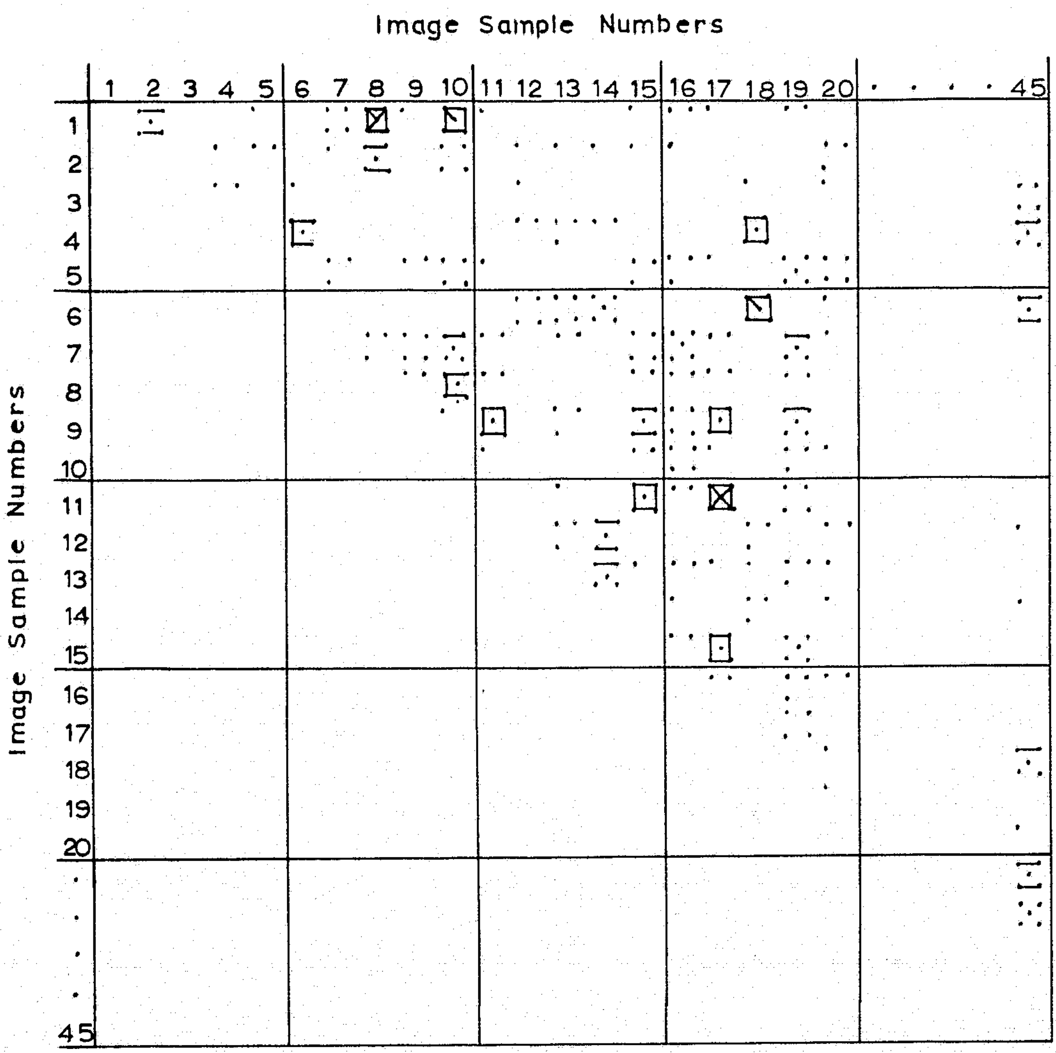
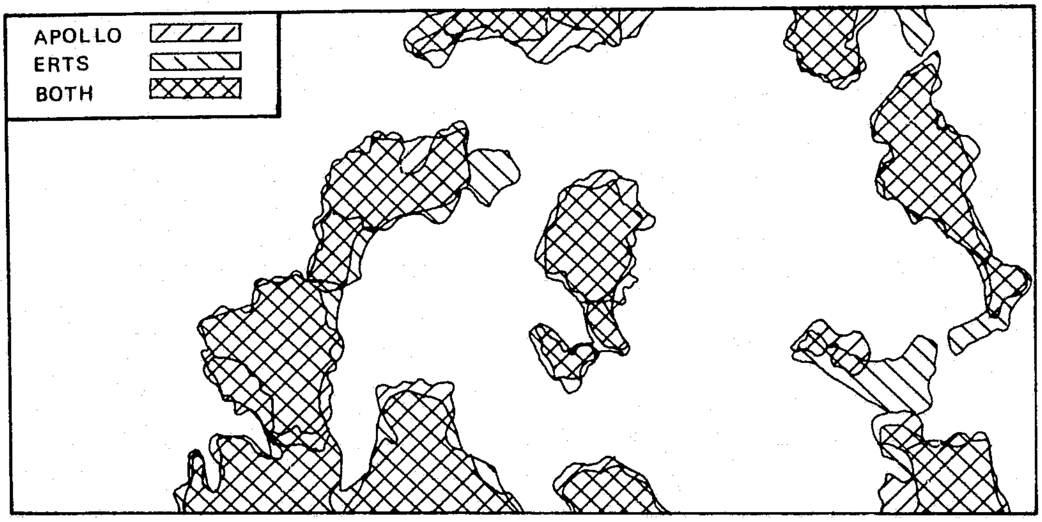


Figure 40. Objectively developed, space photo stratification from image groupability testing involving 13 photo observers. The top sketch illustrates the areas which were sampled in two stage sampling comparison of Apollo and ERTS. The middle (Apollo) and bottom (ERTS) sketches represent the entire study area stratifications. In these, the unshaded portions represent the areas involved in the two stage sampling.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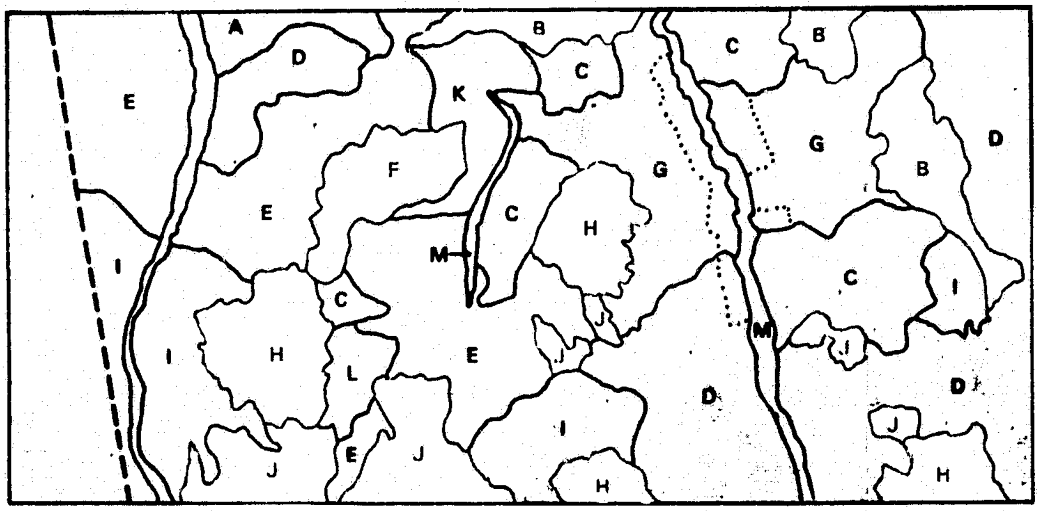
ERTS
BOTH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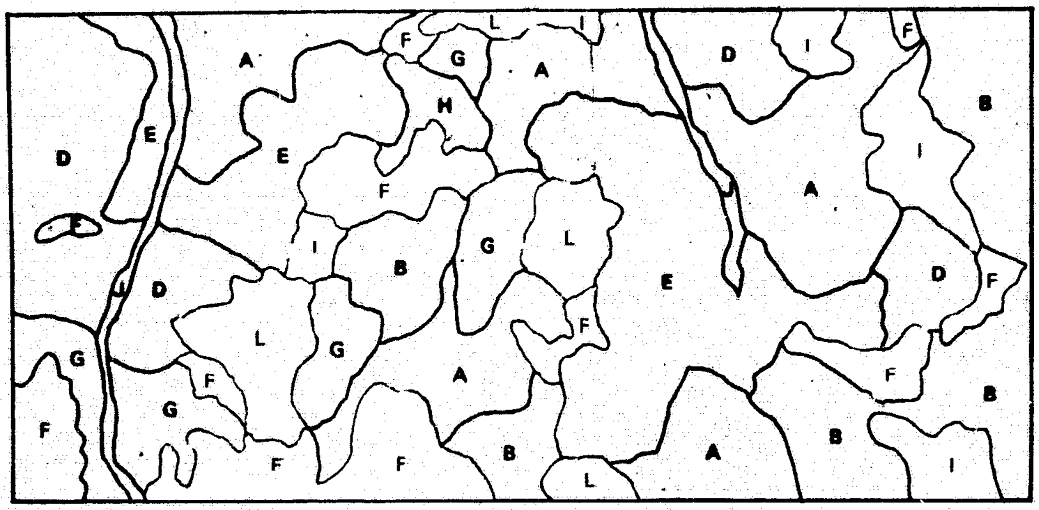
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Table 23. A comparison of the number of new strata and mapping units created as a result of imagery complexity testing on space photography for the Southern Arizona Test Site.

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

<u>The Probability of Image Sample Pairings:</u> The above photo stratification of Apollo and ERTS photography resulted from agreement by 7 of 13 observers on the pairings of 45 image samples. Valid use of image pairs as stratification mechanism existed only if the pairings were non-random events.

The random probability calculation of 13 observers drawing the same pair from 45 samples becomes unreasonably difficult; however, an approximation can be achieved. Assume the observers established a mean of nine strata. Since there were 45 photo image samples, this is an average of five samples per stratum.

Looking at the first observer, the random probability (P_1) of his establishing a pair (from any of the five samples which make up a stratum) in any strata is:

$$P_1 = (1/45 \cdot 1/44) + (1/44 \cdot 1/45) + 2(1/45 \cdot 1/43)$$
$$+ 2(1/45 \cdot 1/42) + 2(1/45 \cdot 1/41) + 2(1/44 \cdot 1/43)$$
$$+ 2(1/44 \cdot 1/42) + 2(1/44 \cdot 1/41) + 2(1/43 \cdot 1/42)$$

$$+ 2(1/43 \cdot 1/41) + 2(1/42 \cdot 1/41)$$

$$\approx 8(1/40)^2 + 6(1/40^2 + 4(1/40)^2 + 2(1/40)^2$$

$$= 8/1600 + 6/1600 + 4/1600 + 2/1600$$

$$= 20/1600$$

$= 1/80$ which is the random probability of the first observer creating a pair in one stratum.

Therefore,

$$\frac{1}{80} \times 9 \text{ strata}$$

$= 9/80$ which is the random probability of the first observer creating a pair in any of the nine strata.

Now, the random probability of the second observer creating the same pair is:

$$P_2 = P_1 \cdot P_2$$

$$= 9/80 \cdot 9/80$$

$$\approx 1/9 \cdot 1/9$$

$$= (1/9)^2$$

The random probability of the third observer creating the same pair is:

$$P_3 = P_1 \cdot P_2 \cdot P_3$$

$$\approx 1/9 \cdot 1/9 \cdot 1/9$$

$$= (1/9)^3$$

etc.

.

.

.

$P_7 = (1/9)^7$ which is an approximation of the random probability of seven observers creating the pair.

This is represented graphically in Figure 41. We can conclude that in terms of creating strata on the basis of paired observations, there is not much need to have greater than two or three observers if the only concern is to minimize the likelihood of having a random event occur. However, in order to establish mutually exclusive groups of image samples, multiple repetitions of image sample pairings are highly desirable. This is so because if repetitions (observations) are few, one could expect to find numerous image samples that could not confidently be placed in one image group over another; therefore, there is a need for multiple observations beyond the need for minimizing the occurrence of a random chance event.

TWO STAGE SAMPLING OF VEGETATION SUBJECTS

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

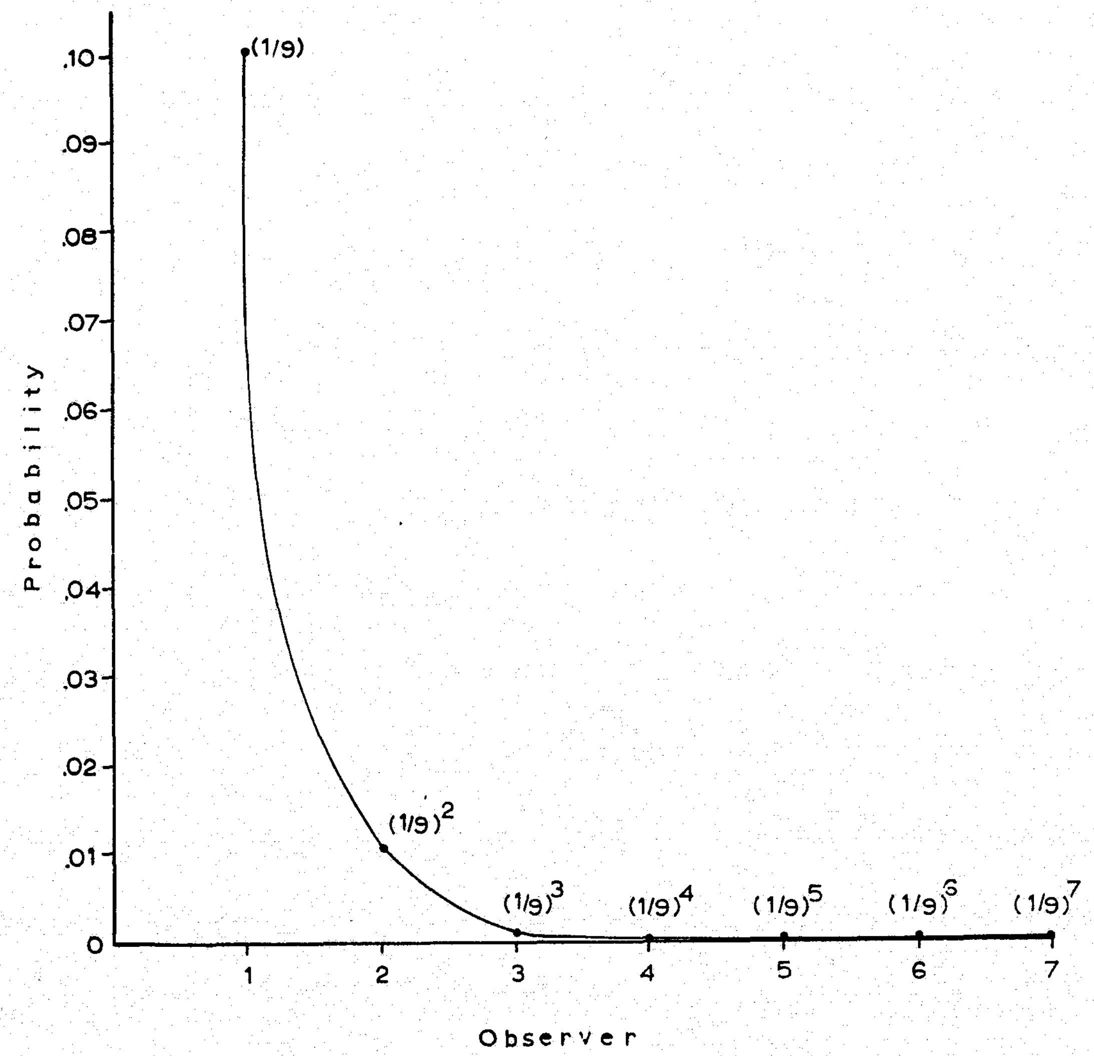

Figure 41. Probability curve of successive photo observers randomly drawing the same photo image sample pair. Assumptions include having 45 image samples and an average of 5 samples per image group (stratum).

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 (not 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.

Variance: 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 24). Of the 16 types sampled in common, it was possible to compare 14 [15/] 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.

[15/] 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.

Table 24. Standard errors ($SE_{\hat{E}}$) and proportional means 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[a/] ↑
9	Mosc	.0308	.00629	.0103	.00844 ↑
10	Mosc-Rhch	.0719	.00822	.0565	.02094 ↑
13	Acco-Prju	.0699	.00777[b/] ↑	.0185	.00043
14	Caer-Acco-Prju	.0095	.00502	.0456	.01068[b/] ↑
15	Caer-Prju-Mimosa	.0204	.00222	.0091	.02030 ↑
16	Caer-Eptr-Yucca			.0065	.00000
18	Prju-Bout	.0205	.00473	.0141	.00000[b/]
19	Bout-Arist-Nomi	.0107	.00378 ↑	.0087	.00094
20	Prju bosque	.0044	.00000	.0065	.00000
21	Himu-Prju	.0120	.00000[b/]		
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	

a/ ↑ indicates the larger $SE_{\hat{E}}$ for the vegetation type.

b/ Artifact error; values are larger than indicated. See text Footnote 15.

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 21). 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 differential study area stratification for Apollo and ERTS (Figure 40 and Table 23). 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 my 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

Area estimates for vegetation types are given in Table 25 for Apollo and ERTS sampling. The mean area values in the table were calculated directly from the proportional means of Table 24. 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

Table 25. 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 15.

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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 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 $\geq$ 10 percent occurrences for each vegetation type in a stratum. Table 26 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 through nine percent occurrence, 13 vegetation types would be mapped as compared to 10 types with ERTS based mapping (Table 26). By contrast, nine and six types would be mapped at $\geq$ 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 26 entry, "% of Area not Represented". In mapping at the five to nine percent level

Table 26. Comparison of vegetation types which would be mapped at the indicated levels of occurrence from Apollo (A) and ERTS (E) sampling.

Veg. types	Level of occurrence		Number of strata where found			
			Apollo (4 possible)		ERTS (3 possible)	
	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				

of occurrence, 13 and 15 percent of the total area sampled had vegetation types that would not be represented in mapping. At the $\geq$ 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.

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 27). 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 sampled, also tended to be widely scattered throughout the area. Some of the types, especially Type 31, showed strong concentrations by strata. These two contrasting 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 24. 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

Table 27. Occurrence of ground samples by vegetation type and strata.

Veg. type	Apollo					ERTS			
	Strata					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

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.

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 28). 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 28 is based on distance measurements between sites. The 1.10 miles/site value

Table 28. Empirically derived helicopter time partitioning from combined ERTS and Apollo sampling.

Assumptions: Helicopter cost at $100/hr.
Avg. site-to-site speed ot 50 m.p.h.
Avg. 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:

$$\frac{1.10 \text{ mi.}}{\text{site}} \times \frac{211 \text{ sites}}{1} \times \frac{1}{50 \text{ mi./hr.}} \times \frac{60 \text{ min.}}{\text{hr.}} = \frac{278 \text{ min.}}{1,122}$$

Ferry and refuel time:

1, 122 min. (.25) = 280 min.

1, 402 min. total

or 23.3 hrs. total

Estimated time partitioned helicopter expenses @$100/hr. (23.3 hr.) = $2, 330.

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 vegetational information at the site.

"Ferry and refuel time" (Table 28), 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 compone-ent, 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 28, 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	ERTS
$d = \sqrt{\frac{690 \text{ sq. miles}}{106 \text{ sites}}}$	$d = \sqrt{\frac{734 \text{ sq. miles}}{105 \text{ sites}}}$
= 2.551 miles from site to site.	= 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 29 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

Table 29. Helicopter sampling with hypothetical 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. 11.50 hr.	941 min. 15.68 hr.
Helicopter expense @ $100/hr.	$1,150	$1,568

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 29 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 30 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 30.

Successful Helicopter Reconnaissance

The helicopter reconnaissance activity undertaken was highly successful; however, it was not undertaken without considerable

Table 30. 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	2.55 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	$1,185	$1,150
	If sampling had been random	$1,550	$1,568
Helicopter expense per site	As sampling was conducted	$11.07	$10.95
	If sampling had been random	$14.49	$14.93

risk of failure. The two basic factors which can contribute to failure are (1) cost that is prohibitive; and (2) inability of the reconnaissance 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 of failure, and was successfully accomplished in our vegetation sampling, it seems appropriate to detail considerations and observations which were 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 [16/] 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

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[16/] The helicopter which we contracted was totally adequate, even though it is one of the smaller models. The Bell 47G3B1 has a reciprocating engine and when turbo-charged, has an operating ceiling of about 9,000-9,500 feet. They can be equipped with extra fuel for extended range. Three people can be accommodated with all having good visibility.

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. Cliff-rose 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, <u>Agave</u>, <u>Yucca</u>, and <u>Dasylirion</u> are identifiable. In fact, <u>Agave</u> might often be overlooked if not for the presence of flower stalks.

SUMMARY

The objectives of this research were to develop (1) a natural vegetation classification which would be suitable for remote sensing use, (2) a visual interpretive technique for objectively comparing space imagery for relative information content, and (3) a sample scheme for comparing and using small scale photography to identify and estimate vegetation type areas and variances. The objectives were achieved with a high degree of success.

Vegetation Classification: The broad scale vegetation classification was developed for a 3,200 square mile area in southeastern Arizona. The 31 "vegetation types" were derived from association tables which contained information taken at about 500 ground sites. The types are not structured hierarchically, although they could be. The classification provided an information base that was suitable for use with small scale photography.

Image Comparisons: 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 error 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 classified.

(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.

<u>Two Stage Sampling:</u> 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 greater number of strata in Apollo.

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 times) 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.

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APPENDIX A

MACRORELIEF CLASSES ADAPTED BY DAVID A. MOUAT TO FIT THE GEOMORPHOLOGY OF 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, microrelief 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 B

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		
Cornwall				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	

APPENDIX C

OBSERVER TEST INSTRUCTIONS AND SCHEDULE OF TESTING FOR SPACE PHOTO COMPARISONS

The essence of the test instructions is given below. The same 45 image samples were used in both tests for a space photo.

Test 1 instructions:

"As you look at the accompanying image samples, decide which ones have similar appearance, and group the samples based on that similarity. Establish the number of groups that you think reasonable, however, fewer than three groups would not be very meaningful, nor would more than 20.

You are requested to do the sorting during a time when you are alert and receiving a minimal number of distractions. There are no rigid time constraints on the test, but it is hoped that 40 minutes will be adequate. If most of you are like mê, 40 minutes will be pushing the limits of your interest span. Further, this amount of time should be well within fatigue limits. Do not be concerned if considerably less or even more time is required for taking the test.

Also, to prevent bias in the testing, it would be appreciated if you do not talk about the testing with anyone who might be contributing to this or similar tests. Depending on whom I can con, these people may be anyone connected with the rangeland Resources Program, ERSAL, Oregon ERTS, etc. ...."

Test 2 instructions:

"In this exercise you are requested to place the image samples into five (5) groups. However, there is an additional restraint.

You will notice on the accompanying image standard card that image standards have been segregated into five groups. These standards are intended to serve as examples of allowable image variation within each group. Based on the image groups found on the card, please sort your image samples into as nearly identical groups as you can. Every sample must be placed into one of the five groups."

The testing schedule followed for the space photo comparisons deviated somewhat from the ideal and is shown below. All dates are 1973.

Observer	Apollo 1	Apollo 2	ERTS-1 1	ERTS-1 2	Gemini IV 1	Gemini IV 2
Alexander	8 May	1 Jun	10 Apr	26 Apr	11 Jun	12 Jun
Cornwell	6 Apr	23 Apr	17 May	17 May	6 Jun	12 Jun
Faulkner	10 Apr	23 Apr	5 Jun	13 Jun	8 May	17 May
Jaques	29 May	31 May	11 Apr	26 Apr	13 May	22 May
McDaniel	5 Jun	12 Jun	5 Apr	19 Apr	11 May	17 May
Miller	5 Apr	19 Apr	13 May	15 May	5 Jun	5 Jun
Pyott	4 Jun	11 Jun	10 Apr	25 Apr	14 May	16 May
Ross	9 Apr	24 Apr	4 Jun	12 Jun	9 May	15 May
Schrumpf	10 May	17 May	9 Apr	26 Apr	8 Jun	8 Jun
Steers	11 Apr	25 Apr	29 May	1 Jun	11 May	16 May
Stuth	3 Apr	23 Apr	8 May	14 May	7 Jun	7 Jun
Thetford	17 May	25 May	9 Apr	25 Apr	14 Jun	14 Jun
Williams	14 May	22 May	4 Apr	23 Apr	7 Jun	7 Jun

APPENDIX D

DESCRIPTIONS OF PLANT SPECIES INFORMATION GATHERED IN THE FIELD

[Prominence rating system is from Poulton, Faulkner, and Martin (1971)]

Prominence Rating: Past usage of 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 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 the 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 of 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 Churchill (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 E

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 F

PLANT SPECIES LIST

(Kearney and Peebles (1964) was the source of scientific names in this list)

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. engelmannii	Apache pine, Arizona long leaf pine
	P. leiophylla var chihuahuana	Chihuahua pine
	P. ponderosa	Ponderosa pine
	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 and half shrubs	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 saltbush
	Baccharis pteronioides	yerba-de-pasmo
	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 mahogony
	Coldenia canescens	
	Condalia lycioides	gray-thorn
	C. spathulata	Mexican crucillo
	Cowania mexicana	quinine-bush
	Dalea formosa	feather dalea
	Encelia farinosa	brittlebush
	Ephedra trifurca	Mexican tea
	Flourensia cernua	tarbush
	Fouquieria splendens	ocotillo
	Franseria deltoidea	triangle bursage
	Garrya wrightii	silktassel
	Haplopappus tenuisectus	burro goldenweed
	Koeberlinia spinosa	crucifixion thorn
	Krameria parvifolia	range ratany
	Larrea tridentata	creosote bush
	Lycium spp.	desert-thorn
	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
	Rhus choriophylla	
	R. microphylla	sumac
	R. trilobata	squaw bush
	Zinnia pumila	desert zinnia

Growth Form	Scientific Name	Common Name
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
	Hilaria belangeri	curly mesquite
	H. mutica	tobosa grass
	Muhlenbergia spp.	muhly
	M. porteri	bush muhly
	Panicum spp.	
	Setaria spp.	bristle grass
	Sporobolus spp.	dropseed
	S. wrightii	Wright sacaton
	Tridens pulchellus	fluffgrass