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AN ABSTRACT OF THE THESIS OF

BARRY JAMES SCHRUMPF for the degree of DOCTOR OF PHILOSOPHY
(Name of student) (Degree)

in RANGELAND RESOURCES presented on March 5, 1975
(Major Department) (Date)

Title: MULTISEASONAL-MULTISPECTRAL REMOTE SENSING OF PHENOLOGICAL CHANGE FOR NATURAL VEGETATION INVENTORY

Abstract approved: ______________________
Dr. C. E. Poulton

The advent of the Earth Resources Technology Satellite system (ERTS) brought with it the prospects of multispectral and multiseasonal views of the earth. The imaging capabilities of the system have provided current and repetitive pictures of the earth of such scale, extent and detail as to reveal surficial features in a manner that was heretofore unavailable.

The repetitive aspects of the system's operations enable two significant capabilities: 1) monitoring changes occurring on the earth's surface and 2) identifying surficial subjects through recognition of characteristic chronological patterns of change that are repeated both in time and space. This latter capability was explored for the purpose of discriminating kinds of natural vegetation.

A test site in southern Arizona was selected which contained a wide variety of vegetation including Sonoran and Chihuahuan desert shrub, desert grassland, savanna-like intergrades, juniper-oak woodlands, chaparral, and mixed coniferous forest. This vegetation exists under two rainy seasons/year with the result that there are two "greening up" periods/year. In addition, there are several species which

retain a green appearance throughout the year. Thus there were three convenient phenological classes to which most of the plants which were encountered could be assigned: evergreens (EVGN); winter dormant (WIND); and winter-spring dormant (WISP). Discrimination criteria based on the phenological differences among these classes provided the means for stratifying the landscape into phenologically distinct areas.

Spectral radiance (ERTS multispectral scanner data) from three vegetation types was associated with seasonal changes in plant foliage. The vegetation types were: 1) mixed coniferous forest; 2) mesquite bosque; and 3) tobossa grass swale. The physiognomy of each was tree, shrub, and herbaceous, respectively. When all were in leaf (late summer) they had similar spectral radiance patterns. The evergreen coniferous forest had nearly the same pattern on the summer, winter, and spring sampling dates. The pattern varied substantially, however, for the shrub type after the mesquite leaves dropped, and for the tobossa grass when the leaves and culms were dried. Spectral radiance from the flat top of a copper mine trailings pile represented a surface which did not undergo temporal changes between the sampling dates. This provided a standard of "no change."

Several schemes for classifying radiance data were successfully used for discriminating the phenological patterns of the three vegetation types and the "no change" subject. The classification schemes utilized ERTS radiance data (MSS Bands 4, 5, 6, and 7), and values derived from that data: 1) MSS 5 ÷ MSS 7; 2) (MSS 7 - MSS 5) ÷ (MSS 7 + MSS 5); and 3) date to date change factors for the derived values. Seventeen areas representing the four subjects were correctly identified with all schemes except the change factor scheme which misidentified two areas.

Radiance in red wavelengths which was strongly absorbed by green leaves, and radiance in the near infrared which was strongly reflected by those leaves were the best for discriminating amont the phenological classes. Furthermore, data from two or more seasons permitted better identification results than data from one date.

Two test areas, each containing EVGN plus either WIND or WISP, were successfully stratified with the MSS 5 ÷ MSS 7 scheme. Vegetation stands representing the same plant community were classified into one phenological class when there was uniformity among the stands in their physiognomic appearances. This stratification provided a demonstration of a practical application of synoptic, multiseasonal, and multispectral remote sensing for characterizing a landscape. Furthermore, the stratification was accomplished with a small percentage (0.2%) of the available ERTS data points.

Multiseasonal--Multispectral Remote Sensing of Phenological Change for Natural Vegetation Inventory

by

Barry James Schrumpf

A THESIS

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Dean of Graduate School

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REFLECTIONS & ACKNOWLEDGEMENTS

Remote sensing began for me in a high school geology class in Colorado. Aerial photographic images of glaciated mountains, volcanic cones, fault lines, dikes, and drainage patterns sparked an interest in the view from above. That perspective tied the landscape together in a way that was difficult to imagine with both feet on the ground.

My interest was rekindled six years later by participation in a resource inventory and analysis project directed by Charles E. Poulton of the Rangeland Resources Program, Oregon State University. His dedication and hard work created the opportunity for me and several graduate student colleagues to achieve our advanced degrees. We found ourselves in the midst of the challenging, fast moving, demanding, and ofttimes frustrating Earth Resources Survey Program of the National Aeronautics and Space Administration. We benefited from and suffered through a seemingly interminable progression of proposals, budgets, progress reports, final reports, and command performances.

Achievement of my doctorate certainly does not stand as the only reward for my endeavors of the past several years. I equally value the professional and personal associations which developed during that time. Throughout the years of work with Charles Poulton, he served as a rare example of creativity, tremendous energy, commitment and vision. That association was a profound privilege. Friends and associates in the Rangeland Resources Program and at the Center for Remote Sensing Research, University of California, Berkeley provided ideas and encouragement whenever they were needed. Raymond Turner of the U.S. Geological Survey, Tucson, Arizona, also contributed substantially in this vein. I am particularly appreciative of the completely dependable and thoroughly considered assistance which I received from James R. Johnson, and of the sincere friendship that Jim and his wife Judy gave to me.

The hard work of the program was not met without sacrifice. Many, many evenings, nights, weekends and vacations were yielded to the work. But always, my wife Elaine was encouraging, contributing and confident, and our parents, Henry and Ivy Schrumpf and Milton and Dorothee Hunt were continuously supportive of our endeavor and understanding when we couldn't participate in family activities. Their patience and backing were always there and deeply appreciated.

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INTRODUCTION

Remote sensing can be undertaken with greatly differing degrees of sophistication. It can be as simple and natural as appraising with one's senses some phenomenon without having direct contact with it. Remote sensing can also involve photographic cameras and electronic sensors mounted in aircraft and space vehicles. The use of these sensors may be in conjunction with and supported by communications hardware, data management, communications, information and pattern recognition theories, computer science, and electronic image enhancement. This technology has developed in response to needs in such diverse activities as inventory of natural resources, military surveillance, weather forecasting, forest fire fighting, disaster assessment, and monitoring air and water pollution, snow pack, and water levels of lakes and reservoirs.

Both active and passive systems of remote sensing have been developed. The former, such as radar, serves as the source and receiver of electromagnetic energy. The latter only detect reflected energy impinging on a variety of detectors sensitized to specific portions of the electromagnetic spectrum. The detectors may be the emulsion layers of photographic film, or photo multiplier tubes, or other photo sensitive surfaces utilized in multispectral scanners. Typical wavelength bands that are detected are the ultraviolet, blue, green, red, near (reflected) infrared, and the three to five and eight to fourteen micron ranges of the thermal infrared. Sensing in a combination of these bands is implied by the phrase "multispectral remote sensing."

In the past decade, the use of high flying aircraft and earth orbiting man-made satellites as remote sensing platforms has provided two additional information gathering capabilities: synoptic and repetitive coverage of the earth's surface. The synoptic view is of a large area and is acquired under nearly constant irradiation and atmospheric conditions. For example, approximately one-fifth of Oregon, or 19,400 square miles can be photographed from a plane flying at 65,000 feet in two and one-half hours. The same area, if oriented along the orbital track, could be imaged by the sensors of the Earth Resources Technology Satellite-1 (ERTS-1) in 75 seconds. Repetitive coverage for special projects became feasible with the availability of high flying aircraft and was an obvious capability to be included in a satellite remote sensing system. Repetitive views are, for example, afforded by ERTS-1 on an 18 day cycle, cloud cover permitting. Repetitive coverage provides the potential for monitoring changes on the earth's surface and identifying features on the basis of their characteristic temporal variations.

Both multispectral and repetitive or multidate remote sensing imagery have been used for crop identification. Such analysis make use of the crop calendar concept. Temporal changes in the agronomic crops are associated with changes in image characteristics. In that manner, the recognition of the convergence and divergence in the appearances of geographically associated crops is used to achieve higher levels of accuracy in crop identification than is usually possible with a single date of imagery. In the inventory of natural vegetation with multidate remotely sensed images, the progression of plant phenological stages offers a parallel approach to the identification of vegetation types. From the management point of view, phenological development of the vegetation is of great significance. The detection of areas displaying similar phenological development tends to define areas within which certain parallels in management strategy may be appropriate.

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

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

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

Consideration of the foregoing discussions of multispectral, synoptic, and repetitive remote sensing, plant phenology, and the inherent variation in natural vegetation raised the following two questions: 1. Can vegetation types be characterized in terms of phenological patterns of change detected with multidate remote sensing? 2. Can apparent phenological patterns be utilized for stratifying synoptic, multidate remotely sensed imagery? This investigation explored the answers to those questions, and included the following: 1. Selection of a study area and classification of the natural vegetation therein; 2. Observation of selected plant species to determine patterns of phenological changes, particularly those changes associated with leaf development and senescence; 3. Analysis of ERTS-1 imagery for phenological pattern recognition and image stratification technique.

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

The investigation reported in this dissertation was funded by the National Aeronautics and Space Administration, contract NAS5-21831, Task 1 entitled "Inventory and Monitoring of Natural Vegetation and Related Resources in an Arid Environment by the Use of ERTS-A Imagery".

THE STUDY AREA

The area utilized for this investigation was a region located to the south and east of Tucson, Arizona (Figure 1). Over the past seven years this area has been designated as NASA Test Site 220 and has served as the principal southern Arizona study area for a series of investigations conducted under the auspices of the Rangeland Recourse Program, Oregon State University. The initial selection of the area was strongly influenced by the excellent photographic coverage procurred during the Gemini IV mission on June 5, 1965. From that time forward this southern Arizona region has been successively photographed from Gemini V and XII, Apollo 6, 7, and 9, a series of high altitude aircraft flights, and from August, 1972 to present by the Earth Resources Technology Satellite (ERTS-1). During this time the staff of the Rangeland Resources Program have used the study area and the available imagery for developing resource inventory and analysis techniques which integrate ecological principles, concepts of vegetation classification, and remote sensing.

Four characteristics of the region were most pertinent to this multiseasonal study of plant phenology. They were:

1. the rich variety of vegetation occurring within the study area,
2. a broad spectrum of phenological patterns of development,
3. a bimodal, annual precipitation pattern, and
4. a minimum of cloud and smog problems which would interfer with multidate data acquisition.

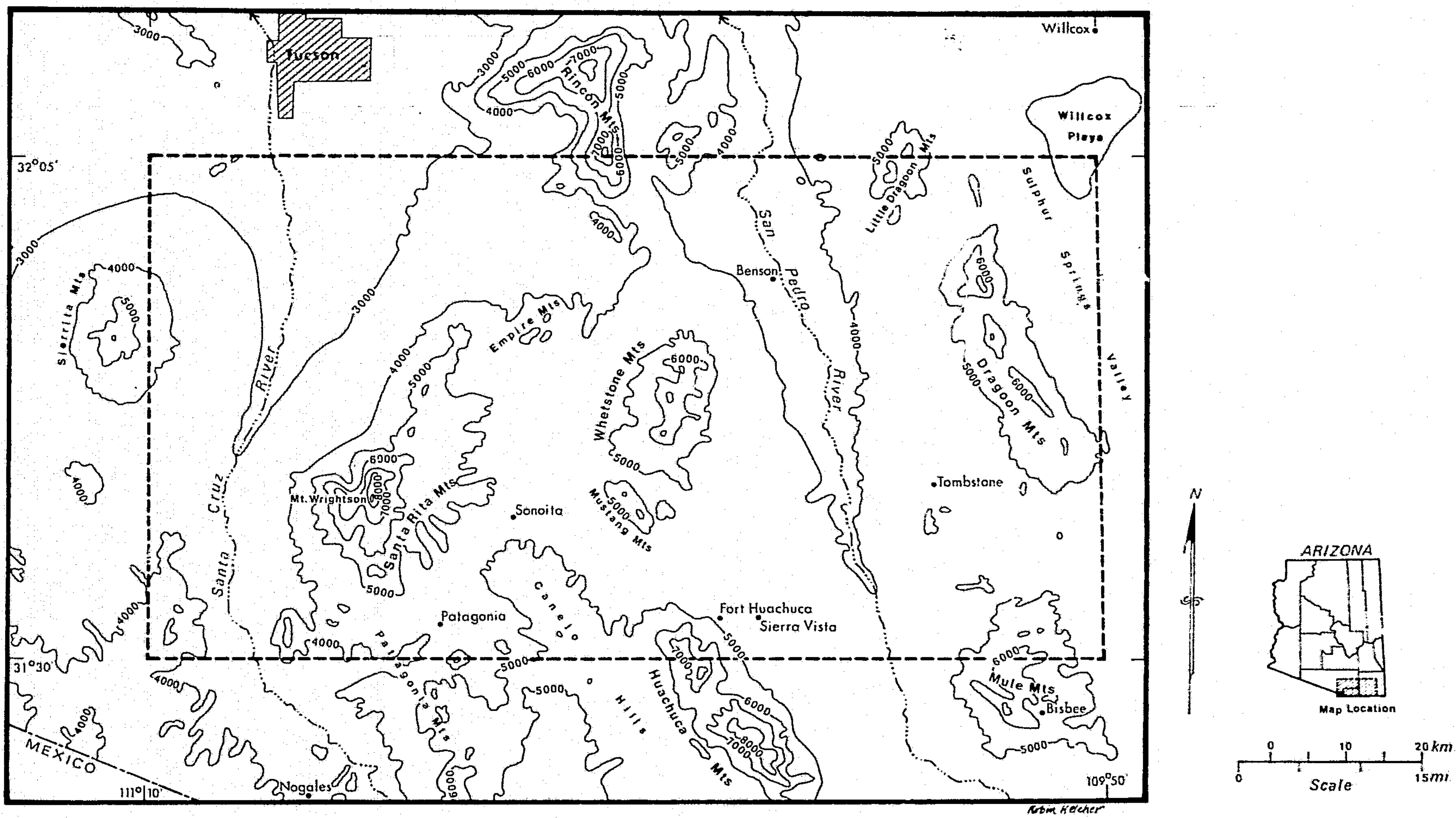

Figure 1. Map of the study area. Features on this map may be compared with the photographic images produced from the electronic sensors of the Earth Resources Technology Satellite. (Fig. 4)

The diverse nature of the vegetation was as much a stimulus to the conceptualization and evolution of this investigation as was the anticipated values to be realized by integrating ecological resource analysis and remote sensing. Desert shrub communities represent both the Sonoran and Chihuahuan desert vegetation. Extensive grasslands and desert grasslands occupy portions of the basins between the mountain ranges. Chaparral, encinal woodlands, and mixed coniferous forests occur on the hills and mountains.

Two recently prepared maps show classifications and identification of vegetation for the study area. Brown (1973) prepared a map of plant communities of Arizona. The types he recognized for the study area were montane conifer forest, chaparral--interior chaparral, encinal and oak--pine woodland, plains and desert grassland, Sonoran desert scrub--Arizona upland subdivision, and Chihuahuan desert scrub.

A map of the Tucson, Arizona area recently prepared by Turner (1974), includes the western half of the study area. Descriptions of the vegetation types from Turner are as follows:

Chihuahuan Desert

> "The characteristic shrubs are from three to six feet tall and include *Flourensia cernua*, *Mortonia scabrella*, *Acacia vernicosa*, and *Larrea tridentata*. Barrel, prickly pear, and pin cushion cacti are common. Trees are absent except along washes. The soil generally is calcareous and is derived from limestone."

Sonoran Desert

Creosotebush community: "Larrea tridentata is the dominant shrub. The even stature and spacing of the plants and the floristic simplicity of the community produce a monotonously uniform landscape. The community occupies flat terrain on the slightly tilted plains and lower bajadas surrounding the mountains. Caliche is common particularly where the soils are derived from basalt."

Paloverde-saguaro community: "The Cercidium microphyllum--Cereus giganteus community is a complex assemblage of plants. The community occupies bajadas and mountain slopes." The soil is usually coarse.

Grassland

Woody and grassy phases are recognized; the former generally occur at lower elevations than the latter. "Below about 3,000 feet the grassland occurs mainly in low flat areas subject to seasonal flooding. Typically there is a sparse to dense grass cover and a scattering of shrubs. Shrub-free grassland occurs at altitudes of from 4,500 to 5,000 feet, where the soil is deep and the terrain is smooth to gently rolling. About 35 species occur, the most common of which are Bouteloua eriopoda, B. gracilis, B. curtipendula, and B. rothrockii, Sporobolus cryptandrus, S. airoides, and Leptochloa dubia. Many grassland shrubs are those that occur in moist Sonoran desert situations: Prosopis juliflora, Acacia constricta, Cercidium floridum, and Celtis palida. At its upper altitudinal margin the grassland interfingers with the oak woodland."

Evergreen Woodland

"The evergreen woodland is a forest composed of evergreen trees from 15 to 20 feet tall and widely spaced. Grass or shrubs occupy the space between the trees. Grass is absent or inconspicuous only where chaparral species grow densely. At altitudes of between 4,000 to 5,000 feet, the oak woodland is open and has a grass matrix; the typical tree species are Quercus oblongifolia, Q. emoryi, and Q. arizonica." Toward the upper limit "the vegetation becomes more dense and Q. hypoleucoides and Q. reticulata" are present. A phase of the

> evergreen woodland dominated by *Juniperus deppeana* and *J. monosperma* is most common in the upper half and "generally is confined to steep slopes that have shallow soil. The most dense evergreen woodland community is present mainly at the higher altitudes in hilly or mountainous terrain. *Arctostaphylos pungens* and *Garrya wrightii* are the dominant plants."

Evergreen Conifer Forest

> "The evergreen conifer forest is present in the high mountains and comprises several distinct plant communities. The largest is the *Pinus ponderosa* community. *P. reflexa* and *P. chihuahuana* are also present. *P. latifolia* occurs at the lower margin. *Quercus hypoleucoides*, *Q. arizonica*, and *Q. reticulata* occur generally as shrubs rather than trees. Forests of *Pseudotsuga menziesii* and *Abies concolor* occur only on the cool moist north slopes or in canyons of the higher mountains.

The dominant climate of the area is semiarid, but humid uplands occur within the semiarid regions. These uplands receive 20 to 25 inches of precipitation annually whereas the majority of the study area receives from 10 to 20 inches. There are two distinct rainy seasons each year, or expressed in another manner, there are "two seasons of the year when drought conditions are less noticeable than usual" (Green and Sellers, 1964). The winter precipitation is brought by migrating cyclones originating in the northern Pacific and is considerably more variable from year to year than that of the warm season. The summer rainfall is of a monsoon nature, occurring as ephemeral thunder-and-lightning storms that drench small areas. Although precipitation from this source is patchy, the entire area will normally receive precipitation in the course of the summer rainy season from these frequent storms. Southeastern Arizona receives apporximately 70% of its annual rainfall during the summer months.

The plant species which occupy the area exhibit various mechanisms for withstanding or avoiding drought and responding to moisture when it is available. Some species (the cacti) are able to store water. Others (Larrea tridentata and Prosopis juliflora) have deeply penetrating root systems for taping underground water. Larrea tridentata can also drop portions of branches (self pruning) presumably in response to drought. Cercidium species and Fouquieria splendens drop their leaves during times of drought and quickly put forth a new flush of leaves following rainfalls. Annuals "avoid" drought by germinating after sufficient soil moisture has accumulated to permit the plants to pass through a complete life cycle.

These are only a few examples of how plants in the study area can respond to weather that dominates their environment. Recurring weather patterns such as the summer/winter precipitation regime is accompanied by recurring plant development patterns. This provides much of the basis for the diversity in phenological expression exhibited by the vegetation of the study area.

SELECTED LITERATURE

VEGETATION INVENTORY

Vegetation inventory activities may include field work, aerial photographic interpretation, vegetation classification, compilation of statistics of kinds and amounts of vegetation types in a given area, and map preparation.

Procedures for vegetation inventory are numerous and quite varied, many have been reviewed by Küchler (1967). He noted that the procedures for vegetation mapping and the characteristics of the map may be determined by the proposed use of the map. An ecological resource inventory, which accounts for vegetation-soil systems, was described by Poulton, Faulkner, and Martin (1971). They sought to obviate the task specificity of a vegetation inventory, and instead, to produce one which can be interpreted and reinterpreted over and over for each new purpose which develops. The value of being able to make inferences about the environment and suitability thereof for various uses is well documented. Sampson (1939) provided a comprehensive review of the concepts pertaining to plant indicators. He concluded that plant communities are better indicators than are individual species. Recognition of plant variation according to environment is not new. Theophrastus of Eresus wrote of the close relationships among plant species distributions and habitat characteristics. He noted vegetation distributions associated with north and south slopes, frigid summits, lowlands, mountains, plains, drylands, and several kinds of wetlands (_History of Plants_ cr. 300 B.C.

as cited by Greene, 1909, p. 125-127). Pliny, a Roman naturalist, utilized natural vegetation for locating suitable soils for good wheat growing land (Kelley, 1922). This same approach was recently utilized by Webb, Tracy, Williams, and Lance (1971) for inferring agricultural potential from forest vegetation.

Remote sensing has been used for 30-35 years in vegetation mapping. The extent to which the final product depended on remote sensing techniques has varied greatly during that time from use as just a map for finding and recording the locations of field samples, to providing a source of basic data through photo interpretation (Poulton, Faulkner, and Martin, 1971). During the past decade, earth satellite and small scale aerial photographic products have been used on an experimental basis for vegetation mapping. The relationship of the scale of imagery to information need was recognized and recommendations pertaining thereto were provided by Poulton, Driscoll, and Schrumpf (1969). Thus, scales of imagery acquired from satellites, high flying aircraft (ca. 65,000 ft. m.s.l.), and aircraft flying at moderate and relatively low altitude were recognized as being more useful for acquiring and portraying information at distinct levels of specificity or generality depending on the nature of the information need. Legend schemes have been developed for use with this diversification of data formats. The schemes are being developed with an hierarchical structure, having a pyramid effect. Higher levels are general; lower levels are more specific (Anderson, Hardy, and Roach, 1972; Poulton, 1972). The relatively new forms of remote sensing imagery may be used, with appropriate legends in multistage sampling schemes (Johnson, 1975; Langley, 1971). Such sampling designs can be employed to efficiently gather information pertaining to the kinds and amounts of vegetation of a chosen region. A vegetation map could be provided from the information compiled at each stage of the multistage sampling, or the product may be limited to tables of resource statistics derived from the sampling scheme.

PLANT PHENOLOGY

Most plants pass through a series of developmental stages during the course of a year which may be called phenophases. These may include initiation of growth, leafing out, flowering, developing fruit, dissemination of seed, dropping leaves, and dormancy; they constitute a plant's phenological development. That development may be characterized rather grossly as I have just provided, or may be considerably refined as French and Sauer (1973) and Sauer (1973) have recognized for modelling studies of grasslands. Their information requirements included the recognition of first and middle leaf expansions, various stages of floral development, and component mixtures of buds, flowers, green fruit, ripe fruit, etc.

The sequence of change may differ among plant species, as well as the time of year when an analogous development occurs. However, for any one species, the sequence remains fairly consistent, with timing subject to local climatic conditions and internal factors of the plant. Water, temperature, and day length are particularly important environmental factors. Important internal conditions include the species genetic make-up, dormancy, correlative effects among organs, and internal water relations (Berg and Plumb, 1972; Meyer, Anderson, and Böhning, 1960; and Romberger, 1963).

Some relationships of annual growth and development to local climatic conditions have been recognized, although they may not be readily evident (Daubenmire, 1959). For example, Coupland (1950) documents plant development in the tall grass prairie in relation to temperature and moisture conditions. Daily maximal and minimal temperatures can show close correlation to date of first flowering (Lindsey and Newman, 1956), and Newman, et al. (1967), have shown net heat accumulation to be closely related to the time required from bloom to maturity of Valencia oranges. Caprio (1971) utilized radiant energy received in the .3-.4 micron wavelengths and the mean temperature for calculating solar-thermal units, the accumulation of which relates closely to seasonal development of a large number of plant species.

Mapping of plant phenological events has been undertaken in the U.S. International Biological Program for correlating such events with meteorological variables for portraying regional variations in climatic conditions and for providing guidelines to the geographical applicability of resource management models (Lieth and Radford, 1971). Hopkins (1918) states in his "Bioclimatic Law" that "other conditions being equal, the variation in the time of occurrence of a given periodical event in life activity in temperate North America is at the general average rate of four days to each one degree of latitude, five degrees of longitude, and 400 feet of altitude, later northward, eastward, and upward, in the spring and early summer, and the reverse in late summer and autumn." Caprio (1966, 1967) provides a detailed mapping of a phenological event (begin bloom of commom blue lilac) in the western United States. That work shows the influence that features, such as the Pacific Ocean and various mountain ranges have on the rates of change of the timing and the compass direction of change for a phenological event, thus graphically portraying the deviations which may occur to Hopkins Law. The principles elucidated by Hopkins in 1918 and 1938, and applied since by many others provide testimony to the utility of phenological calendars for indicating the character of local climates and for managing natural and cultural vegetation. Thus, the seasonal development of phenological indicator plant species can provide readily viewed and dependable keys to range readiness. Even species of little importance as domestic animal forage can be extremely useful in this context (Sampson and Malmsten, 1926). Recognition of such indicator techniques is extremely important when considered in relation to the substantial year to year variation in the timing of plant development (Blaisdell, 1958; Costello and Price, 1939), and the correlation between above ground growth and development of plants and their storage of root reserves (McCarty and Price, 1942; Stoddart, 1946). Jardine and Anderson (1919) recommended noting plant phenological development of forage plants for an indication of proper time to commence grazing and to avoid soil compaction. The timing and intensity of grazing on crested wheatgrass (*Agropyron cristatum* and *A. desertorum*) can be coordinated with those species' annual development to provide for continued vigor of the individual plants, early spring grazing, fairly nutritious late summer feed, and also to minimize the normal development of coarse, woody culms which reduce the utility of the plants by the grazing animals (Hyder and Sneva, 1963; Sharp, 1970). Not only can animal preference for a plant be related to its phenological development, but the nutritive value of the plant can fluctuate through a sequence of phenophases as well (Laycock and Price, 1970; and Skovlin, 1967). Successful chemical control of plants can be highly dependent on the stage of plant development at the time of chemical application. Recognition of the proper stage and the use of phenological indicator plants as correlative evidence of optimum timing is recommended for big sagebrush (Artemisia tridentata) and green rabbitbrush (Chrysothamnus viscidiflorous) control (Hyder, et at., 1958, 1962). The foregoing set of citations documents some of the useful applications of plant phenology. The phenological phenomena of primary importance for this investigation are those dealing with foliar development and senescence. These provide relatively dramatic changes in plant appearance which frequently are readily detected in remote sensing imagery (Carneggie, DeGloria, and Colwell, 1974).

SOLAR RADIATION

The spectral distribution of energy detected by remote sensors is influenced by the: 1) emission spectra of the energy source (frequently the sun; 2) spectral selectivity of the earth's atmosphere for absorbing, transmitting, scattering, reflecting, and emitting electromagnetic energy; 3) spectral reflectivity of the target;

and 4) spectral sensitivity of the detector. Currently, most remote sensing procedures deal primarily with the last two factors and utilize the sun as the energy source. The spectral distribution of the sun's emission is assumed constant, and attempts to provide spatial and/or temporal corrections for atmospheric influences are not yet common. Variations in detector sensitivity (as among batches of color infrared film) are frequently not accounted for.

The sun is a sphere of gas heated by nuclear reaction. The solar characteristics of size, density, temperature, and radiant emissions are determined by gravitational force and heat which cause compression and expansion of the gasses respectively (Rush and Evans, 1960). Solar energy is primarily radiated as electromagnetic (e-m) radiation. The region of nuclear energy reaction constitutes most of the mass. Surrounding this are several layers distinguished by differences in temperature, density, etc. The inner most layer is the photosphere, surrounded by a reversing layer and the chromosphere. Beyond the chromosphere extends the corona which includes the earth's orbit in the solar atmosphere. Attenuation of energy even to the fringes of the coronal region exceeds that of more rarified regions of interstellar and intergallactic space (Thekaekara, 1965).

For many purposes, remote sensing activities included, the sun is considered to be a black body emitting a continuous spectrum with an intensity peak at 0.47 microns. The solar energy incident on a plane normal to the direct solar beam outside the atmosphere and at the mean sun-earth distance is called the solar constant. This concept was introduced by A. Pouillet in 1837 and a method for its determination provided by Langley in 1881 (Robinson, 1966). The solar constant has been approximated from measurements made at various altitudes within the earth's atmosphere. There are, however, large uncertainties involved in extrapolating these observations to zero air mass. Consequently, several approximations are available for use (Thekaekara, 1965).

The solar constant may be corrected for the actual earth-sun distance on any particular day. At the time of perihelion (in January) the value would be approximately 3.4 percent larger; at aphelion (in July), 3.4 percent smaller than the standard value (Gast, 1960). The spectral distribution of the solar energy outside the atmosphere extends from wavelengths of a fraction of an Angstrom to hundreds of meters with 98 percent falling within the range of 0.25 to 3.0 microns (a range including ultraviolet, visible, and near infrared radiation) (Robinson, 1966).

ATMOSPHERIC EFFECTS AND IRRADIATION OF EARTH'S SURFACE

The earth's atmosphere represents a heterogeneous medium through which solar e-m radiation must pass to reach the earth's surface, and through which reflected and emitted e-m radiation from that surface must pass to reach the detector of a remote sensing instrument. The energy of the direct solar beam is reduced during that passage by atmospheric absorption, scattering, reflection, refraction, and diffraction. The first two are of particular importance in remote sensing, and the extent to which they are operative depends in part on the composition of the atmosphere and the length of the direct beam pathway through the atmosphere. The gaseous and particulate matter which envelope the earth may vary with time and altitude. Examples of atmospheric composition are available in the Handbook of Geophysics (Miller and Junge, 1960). When the solar angle of elevation (height above the horizon) is small, the direct beam traverses a longer path through the atmosphere than if that angle is large. The maximum solar elevation is 90 degrees when the sun is at its zenith (directly overhead). At this position, the optical air mass is taken as unity; with any divergence from the zenith, the optical air mass increases. That mass corresponding to different solar zenith angles are available in the Smithsonian Meterological Tables, Table 137 (List, 1949), or approximated by the secant of the zenith angle (Robinson, 1966). As the length of path increases, there is a larger optical air mass containing those atmospheric constituents which cause partial extinction of the solar beam. The passage of e-m radiation through the atmosphere is described mathematically by the radiative transfer function. That extremely involved function has been investigated theoretically and experimentally by the following, among others, Chandrasekhar (1950), Deirmendjian and Sekera (1954), Deirmendjian (1969), Hulst (1957) and Murray and Jurica (1973).

The scattering phenomena are effective over a broad continuum of radiation wavelengths, whereas absorption is specific for several well defined bands of wavelengths. A type of atmospheric constituent may contribute both absorption and scattering effects, and may participate in both types of scattering phenomena commonly recognized: Rayleigh and Mie scattering.

While scattering phenomena account for most of the atmospheric attenuation of solar radiation in the ultraviolet and visible regions of the spectrum, absorption accounts for the greater portion of attenuation to the solar infrared radiation. There are some significant absorptions in the shorter wavelength regions as well. The main absorbing components of the atmosphere are O_2, O_3, H_2O, CO_2, N_2, N, O, NO, N_2O, CO, and CH_4. Absorptions by atomic and molecular oxygen and nitrogen, and by ozone occur chiefly in the ultraviolet. Absorptions resulting from vibration and rotation of polyatomic molecules (e.g., water, carbon dioxide) occur in the infrared. There is little absorption in the visible region; that which does occur is attributable to oxygen, ozone, and water (Gast, 1960; Robinson, 1966).

Rayleigh scattering was proposed and described by J. W. Strutt (Lord Rayleigh) in 1871 (Strutt, 1871; Rayleigh, 1881, 1899). The theory accounts for scattering caused by particles having radii less than or equal to one-tenth of the incident wavelength; the particles are assumed to be spherical and that they scatter independently of one another. For the case of a single scatter (multiple scattering actually occurs in the atmosphere and analysis of it is much more complicated), green radiation is scattered more than red, and scatter in the forward and backward directions is twice that at 90° to the solar beam. Atmospheric particles having radii which are greater than one-tenth the incident wavelength can also scatter e-m radiation, as approximated by the theory put forth by Gustav Mie (1908). The direction of scattering due to the Mie process is predominately foward; back and side scattering are considerably less (Murray and Jurica, 1973).

That energy removed from the direct solar beam by scattering becomes diffuse sky radiation. This is short wave radiation eminating from all parts of the sky as distinguished from long wave atmospheric thermal radiation (Liu and Jordan, 1960). The spectral composition of sky radiation differs from that of the direct solar beam because Rayleigh scattering is inversely proportional to the fourth power of the wavelength (Robinson, 1966). This radiation is therefore relatively rich in ultraviolet and blue wavelengths and poor in red (Gates, 1965). Due to multiple scattering, a part of the sky radiation is directed upward from the earth's atmosphere. Coulson (1959) calculated that seven percent of the earth's albedo can be attributed to scattering by a clear atmosphere. Part is directed downward and impinges on the earth's surface where it may be absorbed or reflected. The reflected portion may again undergo partial scattering and a corresponding increase of the diffuse sky radiation (Deirmendjian and Sekera, 1954).

Direct solar and diffuse sky radiation constitute the global radiation which irradiates the earth's surface. The sky radiation restores much of the shortwave radiation that was removed from the direct beam by scattering so that the global radiation is quite similar in spectral distribution but not in magnitude to the extraterrestrial solar radiation. This holds true over a wide range of solar zenith angles. The spectral distributions of both the direct solar and sky radiation shift toward longer wavelengths as the solar elevation lowers (air mass increases). There is also an accompanying decrease of radiation intensity on a horizontal surface. The shift however is so gradual that the spectral distribution of the global radiation is practically constant during the day (Deirmendjian and Sekera, 1954; Robinson, 1966). From measurements in five discrete wavelength bands, Robertson (1966) found that the combination of solar and sky radiation varied very little in spectral composition for solar elevations above nine degrees. Larger air masses caused greater depletion of energy in the shorter solar radiation wavelengths, but there was no increase in the energy of the corresponding wavelengths of sky radiation.

Under conditions of Rayleigh scattering, the sky radiation may account for six to eight to twenty-three percent of the global radiation over a surface having an albedo of 0.25 as the solar zenith angle progresses from zero to 53.3 to 84.3 degrees. The remaining global radiation is contributed by the direct solar beam. An earth surface albedo of 0.25, in comparison to a non-reflecting surface, increases the intensity of scattered sky radiation by 37 percent when the solar zenith angle is zero degrees. That increased intensity results in a 1.6 percent increase of global radiation; the sky radiation component would increase from four to six percent, and the direct solar radiation would show a corresponding decrease from ninety-six to ninety-four percent (Deirmendjian and Sekera, 1954).

The atmospheric transmission of direct solar and diffuse sky radiation is a function of solar altitude and atmospheric content of water vapor, dust, ozone, etc. When only gas molecules are present, primarily the short wave energy is being scattered. When larger particles are present (water vapor, etc.) then green and red wavelengths are also scattered. In a non-industrial locality, the variation in transmission may be attributed primarily to water vapor (Liu and Jordan, 1960). When skies become overcast, the infrared is terminated by strong water vapor absorption and the ultraviolet and visible wavelengths are scattered producing a gray toned sky (Gates, 1965). Robertson (1966) found that haze from forest fire smoke had about the same effect as increasing the air mass - a relatively evenly distributed decrease throughout all wavelengths.

In 1940, Moon proposed standard curves for the spectral distribution of direct solar radiation and provided methods for their calculation for any altitude and air mass. Gates (1966) provides graphs of the spectral distribution of direct solar radiation for various air mass thicknesses, amounts of atmospheric aerosol concentrations, total amounts of atmospheric water vapor, and for various altitudes. He also provided a graph of global radiation at sea level for various air mass thicknesses. A review of these materials shows the dramatic difference among wavelength dependent effects that water vapor imposes in comparison to the impacts that altitude, air mass, and aerosol concentrations may have. The impacts of this latter group are continuous throughout solar wavelengths and cause a relatively even decrease in energy throughout the solar spectrum and a gradual shift in spectral distribution. Suraqui (1972) provided examples of actual incoming radiation measured on clear and partially cloudy days which clearly showed the attenuation of radiation by clouds.

Insolation on slopes varies with such factors as slope azimuth, angle of inclination, latitude, and time of year and day. Formulas and/or look up tables for determining the direct solar irradiation of slopes with no intervening atmosphere are available in Buffo, Fritschen, and Murphy (1972), Fons, Bruce, and McMasters (1960), Frank and Lee (1966), Gates (1965), Reifsnyder and Lull (1965), and Robinson (1966). The flux of scattered and reflected radiation to slopes is considerably more complicated to estimate and has received less attention. Methods for estimating these components of the total incoming radiation to slopes are discussed in Kondrat'yev and Manolova (1960) and Robinson (1966).

The atmospheric effects of scattering and absorption processes are of significant importance to remote sensing. They may subtract from and add to the energy stream traversing from target to sensor, adversely affecting the fidelity of a target's spectral signature and spatial resolution. The resultant remotely sensed image represents, therefore, an apparent radiance (spectral signature), size, and shape. Murray and Jurica (1973) briefly review the components of the atmospheric effect in which the atmosphere may either serve as a signal generator or filter. Thus, a photon may be: a) scattered into the field of view of a sensor prior to or after surface reflection; b) emitted into the field of view by the atmosphere; or c) removed from the field of view by absorption or scattering either prior to or after surface reflection. Stanhill, Fuchs, and Oguntoyinbo (1971) determined that errors in reflectivity measurements might reach twenty percent for solar elevations of sixty degrees, and thirty percent for elevations of ten degrees. Apparent reflectivity increased with increasing solar zenith angle. Horvath, Braithwaite, and Polcyn (1970) found that 1) target apparent radiance could increase or decrease with altitude of the detector (increasing atmospheric pathway); 2) the tendency to increase was inversely related to wavelength and directly related to atmospheric haze, and 3) those targets with high radiances showed less tendency to increase in apparent radiance with altitude than those targets of low radiance. A basic review of matter and energy relationships relative to those atmospheric effects and target absorptions and reflections involved in remote sensing was provided by Colwell (1963).

REFLECTION OF RADIANT ENERGY

E-m radiation impinging on a surface may be absorbed, transmitted, or reflected. Myers and Allen (1968) discussed examples of nearly complete absorptance and reflectance:

> Reflectance of a non-absorbant medium approaches unity with increasing medium thickness. Reflectance does not exist for a non-scattering medium. Liquid water is an example of a relatively non-scattering substance. Light simply attenuates with depth of penetration in water. Snow is an example of a relatively non-absorbant medium. Reflectance of snow approaches unity with depth, and transmittance of snow simultaneously approaches zero.

Reflectance (R) is the ratio of reflected e-m energy to incident e-m energy; it can be a value in the range $0 \leq R \leq 1$, and it has no units. Percent reflectance is Rx100. Similarly, transmittance (T) and absorptance (A) are ratios of the transmitted and absorbed e-m energy respectively to the incident e-m energy. Therefore, R + T + A = 1. Absorptance is sometimes determined indirectly: A = 1 - (R + T). Each can be specified for a given wavelength; the value is then called, for example, the spectral reflectance and designated R_λ. The symbol "λ" indicates "wavelength." The actual energy level being reflected by a surface in a given wavelength is the spectral radiance and would be designated with units of measurement. The spectral radiance of a subject may appear to vary depending on the quality of the medium between subject and sensor. For that reason, the reflected energy recorded by the sensor may be called "apparent spectral radiance." The irradiance is that e-m energy impinging on a surface.

An opaque material either absorbs or reflects incident radiation, and the reflected radiation may be distributed to all parts of the hemisphere above the reflecting surface. That which is reflected back, along the path of the incident beam is termed the reflex reflection (Howard, 1971). That which is reflected with an angle of reflection equal to the angle of incidence is the specular reflection, as from a mirror or a calm water surface. Breece and Holmes (1971) reported specular reflection from individual leaves at wavelengths of strong absorption (e.g., visible red wavelengths); however, Coulson (1966) found little such reflection from the natural soil, sand, and vegetation surfaces he sampled. The energy returned to the rest of the hemisphere is the diffuse reflection. The distribution (bidirectional reflectance) of reflected energy on the hemisphere may be anisotropic

(Nicodemus, 1965); from his review of the literature, Colwell (1973) concluded that the only point of agreement was that bidirectional reflectance varies with look angle, especially at larger solar zenith angles. It may also vary with solar zenith angle, wavelength, relative azimuth between the plane of the incident beam and the plane of the look angle, and surface characteristics such as vegetation canopy structure. Few materials reflect incident radiation equally in all directions, i.e., as a Lambertian surface. Freshly fallen snow is cited as an example of one that does (Colwell, 1973). Reports of anistropy in reflected solar energy are provided by Brennan and Bandeen (1970); Colwell (1973); Coulson (1966); Egbert and Ulaby (1972); Howard (1966, 1971); Krinov (1947); Salomonson and Marlatt (1971); Scott, Menalda, and Brougham (1968); Shul'gin, Khazanov, and Kleshnin (1961); and Tageeva and Brandt (1960) for a variety of soil and vegetation surfaces. Surfaces may also polarize reflected radiation. Coulson (1966) found that dark surfaces may have strong polarizing properties while highly reflecting surfaces cause relatively weak polarization. He provided polarization data for various soil, sand, and vegetation surfaces. Egan (1970) investigated bidirectional reflectance and bidirectional polarization for several field crop samples and concluded that these phenomena provided diagnostic information for crop identification. Gates (1970) reported that those wavelengths most strongly absorbed by plant leaves are also polarized the greatest when reflected. More research is required to determine the usefulness of polarization phenomena as a discrimination tool for earth resources studies (Holter, 1970).

Extensive reflectance data of natural formations were published by Krinov (1947). Currently a reference bank of reflectance, transmittance, and emittance spectra for rock and mineral, vegetation, soil, and water subjects is being maintained in the NASA Earth Resources Spectral Information System (Leeman, et al., 1971; Vincent, 1971).

There are several reports of reflectance spectra for soils which support the early findings of Krinov (1947) that soil reflectance increased with increasing wavelength through the visible and near infrared regions of the e-m spectrum (Coulson, 1966; Kondrat'yev, Mironova, and Otto, 1964; Myers and Allen, 1968; Obukhov and Orlov, 1964; and Scott, Menalda, and Brougham, 1968). Orlov (1966) and Chia (1967) attributed the character of soil reflectivity to chemical composition, moisture content, and structure. The former also cited the solar zenith angle, the latter discounted this variable. Obukhov and Orlov (1964) found the intensity of reflectance in the 0.5 to 0.6 μ band to be inversely proportional to iron content. Hovis (1966) noted that most natural surface minerals show absorption bands at 1.45, 1.95, and 2.90 μ due to water of hydration. Orlov (1966) concluded that reflectivity appeared to be independent of particle size, if the particles were nearly spherical. The interaggregate spaces among irregularly shaped particles, however, acted as radiation "traps" which caused a reduction in reflectance. Several investigators have documented a reduction of spectral reflectance with increased soil moisture (Krinov, 1947; Bowers and Hanks, 1965; Scott, Menalda and Brougham, 1968; Myers and Allen, 1968; and Condit (1970). Planet (1970) ascribed the darkening of soil surfaces which accompanied their wetting to the optical effects (reflection and refraction) of the thin liquid layer covering the particle surfaces. Parks and Alexander (1973) did not find the same relationship between soil reflectivity and moisture as cited above but did not compare their findings with those of others nor offer explanations of their findings. Perhaps their results may have been due to technique or their results may suggest an indirect effect of soil moisture on reflectivity through accompanying changes in the soil surface structure. Bowers and Hanks (1965) also found that oxidation of the organic matter of several soil samples caused an increased reflectivity. Myers and Allen (1968) note that the usually lower reflectance of fine compared to coarse textured soils which results in darker toned aerial photographic images may be attributable to higher water retention, and/or higher organic matter content both of which have a greater impact on reflectance than do changes in soil texture. Fine-textured soils may also have a structure resulting in aggregates coarser than sand, thus creating a greater radiation "trap" effect as cited above. From spectra of 160 soil samples, Condit (1970) determined that soils could be classified into three general types based on the shape of their reflectance curves as determined from reflectance measured as 0.44, 0.54, 0.64, 0.74, and 0.86 μ.

REFLECTIVITY OF PLANT LEAVES

A leaf is a heterogeneous highly complicated structure which engages in a multiple of interactions with incident e-m radiation (Tageeva and Brandt, 1960). Some leaves have a highly glossy cuticle causing a specular reflection; others have a matte surface and have a nearly diffuse reflectance; most present both kinds of reflectance, that from lower surfaces usually being more diffuse than that from the upper surface (Myers and Allen, 1968; Methy, 1972). Knipling (1970) states that little incident radiation is reflected directly from a leaf surface due to the nearly transparent nature of cuticular wax to visible and near infrared radiation. Instead, the radiation is transmitted into the internal structure of the leaf where it is diffused by multiple reflections and refractions at air/water interfaces. The air is that of cavities within and between cells; air has a refractive index of 1.0. The water is that of the hydrated cellulose walls, and has a refractive index of 1.4. It is the total area of these interfaces rather than the volume of the air cavities that is critical to the internal scattering of radiation. Knipling (1970) concludes that the internal reflection from leaves due to scattering processes is similar for wavelengths in the visible and near infrared spectral regions. Gates, et al. (1965), suggested that the scattering mechanism may also involve mitochondria, ribosomes, nuclei, starch grains, and plastids having dimensions similar to those of the impinging wavelengths of radiation. Scattering caused by these structures would be primarily of the Mie type. Energy scattered upward is called "reflected," that scattered downward is "transmitted;" because the same mechanism partitions most incident energy into reflected or transmitted components, the spectral curves of those two components are usually quite similar (Knipling, 1970). Energy entering a leaf may also be absorbed. In the visible and near infrared wavelengths, absorption is due to pigments and water, respectively. French and Young (1956) and French (1960) provided reviews of the spectra of photosynthetic pigments. List (1949, Table 156) provided the absorption coefficients for pure liquid water.

There is considerable diversity of reflectance, transmittance, and absorptance among leaves (see Leeman, et al, 1971). There are also similar characteristics in the spectra of green leaves (Myers and Allen, 1968). Absorption maxima occur at 0.47μ (blue) and 0.68μ (red) due to chlorophyll. A reflectance peak occurs in the green (0.55μ), between the two chlorophyll absorption bands. Beyond 0.7μ there is a sharp increase in reflectance which stays quite high between 0.8μ and 1.3μ. Beyond 1.3μ, absorption by water increases; there are minor absorption bands at 0.97μ and 1.21μ, and major water absorption bands at 1.45μ and 1.95μ.

Significant early work on the visible reflectance of plant leaves was performed by Shull (1929). Rabideau, French, and Holt (1946) extended reflectance measurements to include the near infrared. The work of Krinov (1947) included both visible and near infrared reflectance but was not readily available until translated. Billings and Morris (1951) also extended measurements to include the near infrared, and Gates and Tantraporn (1952) determined reflectance for some deciduous trees and herbaceous plants in the spectral region of 2.0μ to 25μ. Absorption spectra of selected plant leaves were also reported by Moss and Loomis (1952).

In general, leaves reflect about ten percent of incident radiation in the visible wavelengths and 40% to 60% in the 0.7μ to 1.3μ portion of the near infrared (Knipling, 1970). Kleshnin and Shul'gin (1959) provided more detailed data for visible reflection determined for 80 species, mostly mesophytes: they reported seven, fifteen, and six percent reflection in the 0.46μ to 0.48μ, 0.54μ to 0.56μ, and the 0.66μ to 0.68μ spectral ranges, respectively. Absorption data was reported by Loomis (1965): 80 to 95 percent absorption in the 0.4μ to 0.5μ band, 60 to 80 percent in the 0.5μ to 0.6μ band, 80 to 90 percent in the 0.6μ to 0.7μ band, approximately five percent between 0.8μ and 1.2μ, and nearly 100 percent beyond 3μ. Gates and Tantroporn (1952) and Wong and Blevin (1967) reported generally less than five percent reflection in the infrared beyond 2μ and 3μ respectively. Shul'gin and Kleshnin (1959) found the least variation among species in reflectance, transmittance, and absorptance at wavelengths of maximum absorptance, and greatest variation at wavelengths of least absorption. Latimer and Rabinowitch (1956) and Latimer (1958) reported selective scattering by pigments of radiation at wavelengths slightly longer than those absorbed by the pigments. Gates, et al (1965) cited this scattering phenomenon as responsible for apparently broadening the fairly sharp absorption bands of pigments. Kleshnin and Shul'gin

(1959) also observed that the absorption curve for a leaf was not as sharply defined as it was for pigment extracts. French (1960) reported that chlorophyll and its derivatives give a brilliant red fluorescence having maximum intensity at slightly longer wavelengths than the red peak of the absorption curve. The intensity of the fluorescence drops rapidly to zero on the short wavelength side of the peak. This fluorescent emmission is quite small.

Chlorophyll snythesis, photosynthesis, phototropism, and photomorphogenesis involve mainly the pigment absorption of photons of highest energy levels; these are the shorter solar radiation wavelengths. Evaporation and heating processes involve mainly the lowest energy photons, the infrared wavelengths. The Dutch Committee on Plant Irradiation recognized specific spectral bands corresponding to various physiological and developmental activities of plants, as follows (Wassink, 1953):

1st Band: radiation with a wavelength longer than 1.0μ. No specific effects of this radiation upon plants are known. It is acceptable that this radiation, as far as it is absorbed by the plant, is transformed into heat without the interference of biochemical processes.

2nd Band: radiation between 1.0μ and 0.72μ. This is the region of the specific elongating effect upon plants. Although the spectral region of the elongating effect does not coincide precisely with the limits of this band, one may provisionally accept that the radiant flux in this band is an adequate measure of the elongating activity of the radiation.

3rd Band: radiation between 0.72μ and 0.61μ. This is almost the spectral region of the strongest absorption of chlorophyll and of the strongest photosynthetic activity in the red region. In many cases it also shows the strongest photoperiodic activity.

4th Band: radiation between 0.61μ and 0.51μ. This is a spectral region of low photosynthetic effectiveness in the green and of weak formative activity.

5th Band: radiation between 0.51μ and 0.40μ. This is virtually the region of strong chlorophyll absorption by yellow pigments. It is also a region of strong photosynthetic activity in the blue-violet and of strong formative effects.

Gates, et al. (1965), compared thinner, lighter colored leaves with thicker, darker leaves and found that absorptance increased from lighter to darker leaves and that transmittance exceeded reflectance for near infrared radiation while the opposite was true for thicker leaves. Leaf reflectance may also vary with moisture content. Visible and near infrared reflectance can increase for a dehydrating leaf with the greatest changes occurring in the water absorption bands and the least change occurring in the visible region; these changes are reversible (Thomas, et al., 1966). Myers, et al. (1966), and Thomas, Wiegand, and Myers (1967) found that stacking cotton leaves one on top of another did not affect reflectance in the visible and the water absorption wavelengths in the near infrared. Those highly reflected near infrared wavelengths however, showed large increases in reflection from multiple layering. Similar findings for eucalyptus leaves were reported by Howard (1966). This phenomenon is sometimes referred to as the reinforcement or enhancement of the near infrared reflection from a vegetation canopy. The reinforcement refers to the comparison of canopy (multiple layers) versus single leaf near infrared reflectance.

From his early work, Shull (1929) noted differences in leaf reflectance with leaf age, there was an enormous difference in the visible reflectance of spring and fall foliage in comparison to dark green summer foliage. Thomas, et al. (1966) determined reflectance change for developing cotton leaves: green reflectance decreased with age presumably due to increased chlorophyll content, near infrared reflectance increased, and change with age was minimal in the water absorption bands. Shul'gin and Kleshnin (1959) found initial visible reflectance, transmittance, and absorptance changes with increasing chlorophyll content up to a certain critical level; increased content beyond that level did not alter the spectra. Knipling (1969) reported an increased visible and near infrared reflectance for the initial stages of leaf senescence followed by a decrease with advanced stages, probably due to a breakdown or deterioration of cell walls. Olson and Good (1962) found distinct differences between seasonal patterns of change in visible reflectance from leaves of conifers and hardwoods. Reflectance of the former increased steadily until late in the growing season due probably to the higher reflectance of the developing current year's needles. The broad leaves of the hardwoods presented much greater variation than the conifers, but did have a distinct temporal pattern of change. Reflectance for this group decreased during the early growing season, then increased during the late season. There was also a decreasing contrast between green and red reflectance with advancing season and relatively little change in blue reflectance. Tageeva, Brandt, and Derevyanko (1961) measured absorption of visible radiation by birch and linden throughout a growing season: absorption in the blue remained high while that of green and red radiation decreased sharply with decreases in chlorophyll content below 2 mg/100 cm^2 of leaf area. Gates, et al. (1965), followed the pattern of visible and near infrared reflectance of a deciduous oak leaf through the growing season: initially, photochlorophyll determined the pigment absorption, and this was at wavelengths slightly shorter than the red chlorophyll absorption band. Increased chlorophyll pigmentation was accompanied by increased green and decreased red reflectance. With further development, green reflectance decreased while that of the near infrared increased. They cited the increasing chlorophyll content as the cause of a broadening of the chlorophyll absorption bands with a resulting decrease in green reflectance and a systematic shift to longer wavelengths of the characteristic sharp increase of reflectance in the near infrared.

Several investigators have reported variations in spectra among different plant groups. From measurements of leaves from 300 plants, it is evident that the reflection/transmission ratio is lower for mesophytic than for xerophytic plants (Shul'gin, 1961). Gates et al. (1965), reported that the succulent and non-succulent desert species sampled reflected substantially more radiation at all wavelengths than did the more mesophytic plant species studied. They also stated that absorptance by coniferous species was higher than by mesophytic and xerophytic broad leaved species and desert succulents. Billings and Morris (1951) collected leaves from plant species of several ecological groups and found distinct differences in reflectance among the groups. Those of the desert group had the highest visible and near infrared reflectance. Leaves from subalpine species had lower reflectance than those of the desert group, especially in the visible spectral region. Species from west-facing and north-facing pine types showed similar reflectances. They were also similar to the subalpine group in near infrared reflectance, but exhibited lower visible radiation reflectance.

REFLECTIVITY OF PLANT CANOPIES

An understanding of the optical properties of leaves is basic to the study of radiation interactions with plant canopies; there are, however, qualitative and quantitative differences between single leaf and canopy interactions with radiation. Knipling (1970) attributed these differences to the nonuniformity of incident solar radiation, plant structures other than leaves present in the canopy, leaf areas and orientations, shadows, and non-foliage background surfaces (e.g., soil, rocks, stones, water, snow). Vinogradov (1969) observed that reflectance of vegetation decreases with increasing complexity of the plant community structure and the resulting roughness of the canopy. The levels of visible and near infrared reflectance can be 40 percent and 70 percent respectively of the spectrally comparable levels from a leaf (Steiner and Gutermann, 1966, as cited by Knipling, 1970). Presumably, the slighter reduction in the near infrared is attributable to the reinforcement of reflection in those wavelengths by the multiple leaf layers of a canopy (Knipling, 1970). Several investigators have reported an increased reflection from plant canopies as the solar zenith angle increases (distance of the sun from a position directly overhead, indicated in degrees) (Monteith, 1959, 1965; Graham and King, 1961; Bray, Sanger, and Archer, 1966; and Stewart, 1971). The rate of increase may not be constant and may increase faster at larger zenith angles. At very large angles, the reflectivity may again decrease, however, these angles are usually avoided during remote sensing activities. From theoretical considerations, Cowan (1968) predicted that for a dense canopy with randomly oriented leaves, reflectance would increase with increasing solar zenith angle. Monteith (1959) concluded from measurements over various crops that plants having leaves arranged vertically would interact differently with radiation of varying incidence angles than plants with horizontally arranged leaves. He reasoned that the reflectivity of plants having predominately vertically arranged components (especially leaves) would decrease with increasing solar zenith angle due to the longer shadows that would be cast among the plant parts. In contrast, a plant with horizontally positioned leaves would exhibit an increased reflectivity with increasing solar zenith angle because of less radiation penetration into the canopy. A mathematical reflectance model for a canopy relating remotely-sensed effects with their causitive factors (e.g., biological components of the canopy, canopy structure, angle of irradiation, and angle of observation) has been prepared by Suits (1972a, b). The model was applied and compared to field and laboratory measurements by Suits and Safir (1972), and Colwell (1973). The following are selected from Colwell's conclusions drawn from reflectance determinations for two species of grass grown in a laboratory:

The reflectance of an all-green canopy is largely due to the percent vegetation cover.

Depending upon the reflectance contrast between vegetation and soil, the red spectral region often possesses the greatest sensitivity to changes in percent cover and biomass for all-green canopies at low to intermediate values of percent cover.

The IR spectral region generally possesses the greatest sensitivity to changes in percent cover and biomass at high values of percent cover.

Variations in soil reflectance can cause large variations in canopy reflectance at low values of biomass.

The IR/red reflectance ratio is effective in normalizing the effect of soil reflectance, including leaf litter, in a canopy.

The ratio is less effective at normalizing the effect of amount of shadow and standing dead vegetation.

The red reflectance varies the most with vegetation maturity (if senescence is included).

The IR reflectance varies least with maturity.

Colwell (1973) also found that IR/red ratioing will only reduce angular (bidirectional) reflectance "when the angular trends of both spectral bands are highly positively correlated. When the angular effects are negatively correlated, ratioing will enhance the differences."

In comparison to the amount of spectroreflectivity data available for plant leaves and soil samples, that for naturally occurring vegetation is relatively scarce. Krinov's (1947) contribution apparently remains as the most comprehensive array of reflectance data for a wide variety of vegetation. Two groups of subjects which he investigated were forest and shrubs and grass. He noted some strong similarities among spectroreflectance curves for different vegetation types, especially in comparison to those of non-vegetation groups (bare soil, etc.). There were also notable differences among curves for vegetation that permitted distinction of some groups of vegetation (e.g., coniferous and deciduous types) and seasonal development of vegetation. Spectral reflectance differences in both the visible and near infrared regions for green and dead vegetation were also reported by Scott, Menalda, and Brougham (1968). Krinov's work documents the temporal aspect of spectral signatures of natural vegetation. Photo-interpreters have recognized that changes in the appearance of subjects with time can both aid and hinder the process of correctly identifying those subjects. Brunnschweiler (1957) and Schepis (1968) capitalized on these changing appearances, due to plant development and management practices, for identifying agricultural crops. They utilized image characteristics such as texture, shape, and height in addition to tone for feature identification. The concept of a "crop calendar" was utilized by Carneggie, Pettinger, and Hay (1971) for summarizing the developmental patterns of agricultural crops. This provided a photo interpretation tool for crop identification on the basis of tone and color contrasts among agricultural fields as imaged on multiband, multidate small scale aerial photography. Plant phenology was recognized by Sayn-Wittgenstein (1960, 1961) as an important aid for forest tree species identification. Differences among species in the timing of their seasonal development provided the opportunity for selecting specific dates on which to procure aerial photography which would image the species of interest at a time of maximum contrast among them.

Variation in the appearance of a feature from one date to another complicates the image analysis problem in that it requires a knowledge of the dynamic nature of the feature. On the other hand, change can provide the opportunity for making some feature distinctions as indicated above for tree species. The emphasis in that case being on the correct selection of the date for acquiring imagery. That still stresses analysis of a single date of imagery. It was not practical to capitalize on the patterns of change that features could exhibit until the advent of a system such as the Earth Resources Technology Satelitte (ERTS-1).

The following are several publications which provide significant compilations and/or reviews of literature pertaining to solar radiation, basic radiation-matter interactions, radiation-vegetation interaction, and remote sensing of the vegetation, soil, and water of the earth's surface: Anderson (1964), Colwell (1963), Coulson (1966), Gates (1965), Gates, et al. (1965), Knipling (1970), Myers and Allen (1968), Robinson (1966), and Reifsnyder and Lull (1965).

METHODS AND PROCEDURE

PLANT PHENOLOGY

Field Data Collection

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

Leaves	new: Λ———	mature: —Λ—	senescent: ———Λ
Flowers	bud: ∪———	mature: —∪—	dry: ———∪

Examples: Λ—Λ—— Leaves are present, most are mature, some are new.

Λ————Λ Leaves are present, equal amount of new and senescent (perhaps persistent from the previous season).

———— No leaves present.

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

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

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

were gathered for 47 species.

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

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

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

VEGETATION CLASSIFICATION

The classification prepared for the study area was developed through a team effort, and was used for various remote sensing applications experiments (Johnson, 1975; Mouat, 1974; Schrumpf, Johnson and Mouat, 1973). Data from 500 locations were analyzed in developing the classification. The data included species lists, prominance[1/] and cover ratings, slope, aspect, and landform. From previous publications on the vegetation in Arizona, six broad classes were defined and characterizied by their prominent species components (Darrow, 1944; Humphrey, 1960a, 1963, Interagency Technical Committee (Range), 1963; Lowe, 1964; Nichol, 1937; Pond and Bohning, 1971; Shreve, 1942; Shreve

[1/] "Prominence" is an evaluation of the visual impact that a species gives within a specific vegetation stand. The growth form, size, stature, ground cover, density, etc., of each species at that location all contribute to each species' prominence. Prominence ratings are provided in Appendix A.

and Wiggins, 1964). The field samples were then placed into these classes according to the comparability of the prominent species. The data records were then sorted according to species presence or absence and prominence to produce subgroups based on the similarities and differences among the records. Work by Garcia-Moya (1972) provided useful guidelines for this sorting activity. Association tables were then prepared to finalize discussions of vegetation types and to identify the characterizing species of each.

EARTH RESOURCES TECHNOLOGY SATELLITE (ERTS-1) DATA

The ERTS-1 System

ERTS-1 was launched on 23 July 1972. It included two remote sensing systems: a return beam vidicon (RBV) and a multispectral scanner (MSS). The RBV was deactivated early in the life of the satellite; only data from the MSS was utilized in this investigation. The two systems were designed to detect the same portion of the electromagnetic spectrum, with the RBV providing three channels of data and the MSS, four. By convention the four MSS spectral channels were designated "MSS 4, 5, 6, and 7." The regions of the spectrum to which the MSS detectors were sensitive were (NASA, 1972):

MSS 4: 0.50 - 0.6μ (green radiation)

MSS 5: 0.60 - 0.7μ (red radiation)

MSS 6: 0.70 - 0.8μ (near infrared radiation)

MSS 7: 0.80 - 1.1μ (near infrared radiation)

The spectral response of the MSS detectors is shown in Figure 2.

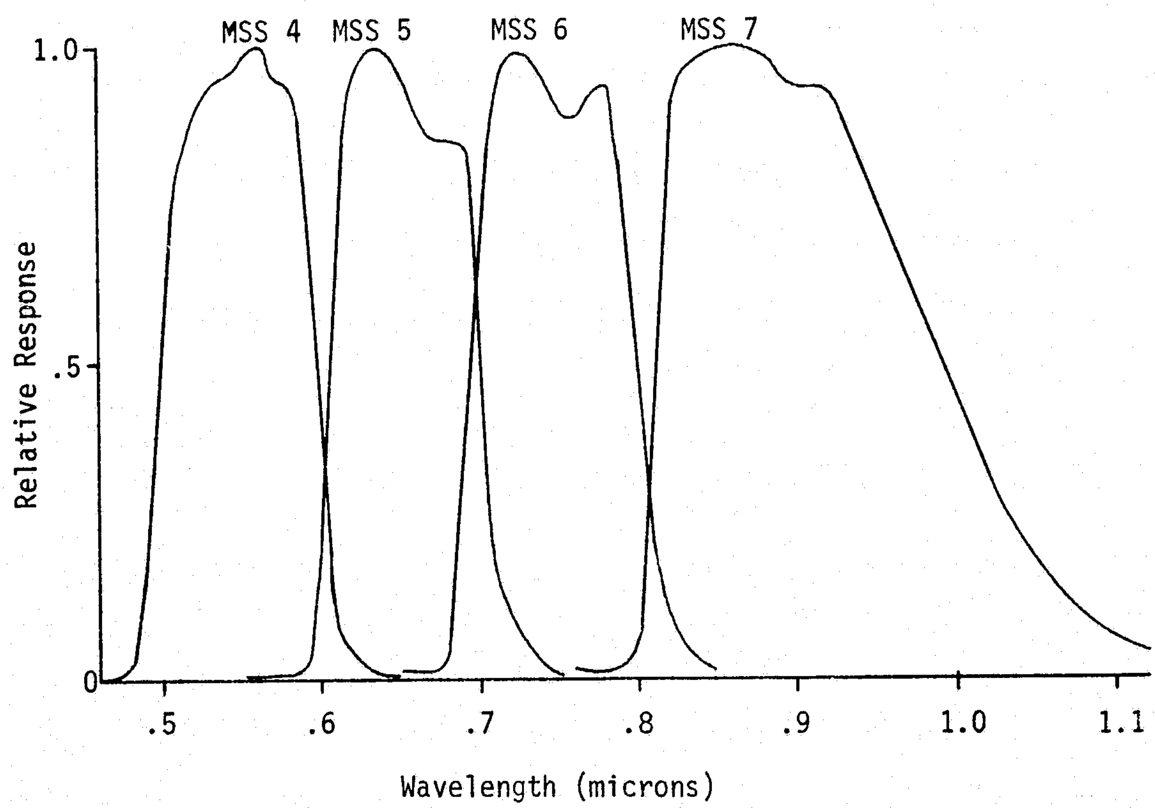

Figure 2. The average spectral response of the six detectors for each band of the MSS system (plotted from data in Potter, 1972).

Synchronization of the satellite's orbit with the earth's revolution about its axis permitted the acquisition of data over approximately the same location on the earth at essentially the same local time every 18 days. The local standard time of each pass over the study area was about 10:28 a.m.

As implied by its name, the MSS "scanned" the earth's surface. A mirror, oscillating perpendicularly to the direction of spacecraft travel, received reflected energy from a strip of the earth's surface 185 km (115 miles) long. The stream of energy directed into the detectors was continuously sampled to produce a line of resolution elements, each representing approximately 0.4 hectare (1.1 acres). Associated with each element were radiance values for energy in the spectral regions indicated above.

Following transmission of scanner data to the ground, the continuous north-south band of imagery was divided into discrete "scenes." Each scene represented a ground area of 185 km x 185 km, and consisted of 2340 parallel scan lines averaging 3220 resolution elements each (Thomas, 1973). Each scene, therefore, was composed of over 7.5 million resolution elements, each of which could be uniquely identified as a specific element along a specified line.

Catalog of ERTS-1 Imagery of the Study Area

The first date of ERTS-1 data acquired of the study area was on 22 Aug. 1972. Eighteen additional dates of data were available for this study. The data were made available by NASA on computer compatible tapes and as reconstituted photographs. The data from an area

185 km on a side (approximately 115 miles square) was represented as a single "scene" in both data formats. Each scene had a unique identification number. That number for the 22 August 1972 imagery was 1030-17271, which indicated:

1	ERTS-Mission = ERTS A;
030	days since launch;
17th	hour of the day at time of observation (GMT);
27th	minute of the hour; and
1	sixth of the minute (10 seconds).

Information for the 19 dates of imagery is given in Table 3.

MULTIDATE RADIANCE DETERMINATIONS FOR PLANT PHENOLOGICAL CLASSES

Of the nineteen dates of imagery listed in Table 3, seven could be considered for this study. Other dates were rejected due to cloud or snow cover over areas of interest. Three dates were selected for analysis: 22 August and 2 November 1972; and 13 April 1973. This selection was based on an evaluation of the photographic formats of the ERTS data. Known examples of the three phenological classes - evergreen (EVGN), winter dormant (WIND), and winter-spring dormant (WISP) - were evidently in leaf at the time of the 22 August 1972 imagery (see "Results and Discussion, Plant Phenology" for explanation of phenological classes). Only EVGN showed any evidence of having green foliage on 2 November 1972. On 13 April 1973, both the EVGN and WIND vegetation examples showed evidence of green foliage, however, the latter was probably in an early stage of foliar development. Thus,

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

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

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a/ Measured eastward from north.

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

these three dates of imagery depicted the vegetation of the three phenological classes in the three possible combinations of being in leaf or not in leaf.

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

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

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

The selected stands were:

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

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

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

In addition, a fourth subject class, named TAIL, was also represented. This class was established to represent a "no change" subject, and was constituted by three piles of copper mine tailings. A study of aerial photography acquired over the mining area on 1 August 1972, 5 September 1972, 12 December 1972, 20 March 1973, and 19 April 1973[2/] revealed that only one of the three piles remained unchanged and of stable appearance throughout the sampling period. The images in the 1:120,000 color infrared photography showed that one "pile" was actually two completely enclosed settling ponds. Compared to the other two piles, the settling ponds' bottoms were extremely reflective in late summer and the following spring, but the December photography showed a darkened surface presumably due to moisture accumulation. The other two "piles" were in fact tailing piles with very broad, horizontal tops. They supported little, if any, vegetation and were therefore not subject to changes of appearance due to foliar developments. However, during the fall of 1972, a substantial amount of new material was added to the east and north sides of one pile; the new material appeared more highly reflective than the old as represented on the photography. Consequently, only one of the three provided a

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

suitable surface to represent "no change". It evidently retained consistent spectral reflectance characteristics over the dates of concern.

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

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

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

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

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

PHENOLOGICAL PATTERN RECOGNITION AND IMAGE STRATIFICATION

Having selected multiseasonal ERTS-1 radiance data representing the three phenological classes it remained to determine if (1) a meaningful apportionment of the landscape could be achieved based on apparent phenological changes in the vegetation; and (2) if vegetation types of the area could be characterized in terms of their apparent phenological changes.

MSS Data Classification Schemes

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

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

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

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

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

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

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

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

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

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

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

Change Evaluation: Given three dates of data, three changes may be considered: between the first and second dates, between the second and third dates, and between the first and third dates. The actual changes may be an increase, decrease, or no change in the values being compared. An idealization of the possible combinations of changes between the first and second, and second and third dates are shown in Figure 8. The patterns suggest one method of change evaluation, a qualitative method that considers only the direction of change.

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

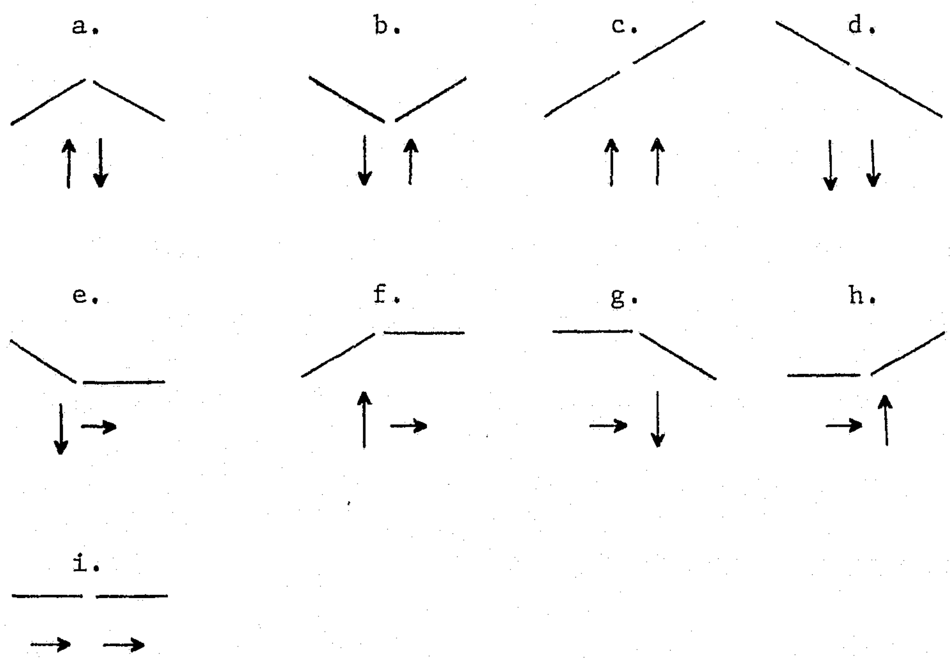


Figure 3. Patterns of radiance variation among three dates. These idealized patterns show increase (arrow up), decrease (arrow down), and no change (arrow across) of radiation between the first and second, and the second and third dates. A third change, between the first and third dates, is achieved by connecting the end points. Values of band ratios may follow these same patterns of change.

Classification of Training Field Elements

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

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

Stratification of an ERTS-1 Scene

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

Two areas of the region to the south and east of Tucson, Arizona, were chosen for the evaluation of stratification techniques. Those areas are outlined on an ERTS-1 scene in Figure 4. They were designated as the Canelo and Rincon grid areas and were known to contain extensive areas which supported vegetation representing the three phenological classes. The Canelo grid primarily contained WISP and EVGN; the Rincon grid, WIND and EVGN. These identifications were verified in the field, from aircraft, and through the interpretation of aerial and ERTS photography.

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

One set of class standards was derived from the radiance values for the EVGN, WIND, WISP, and TAIL training classes (Table 4). These were the Primary standards because they were based on the radiance from vegetation types which provided the best examples of the phenological classes. However, those vegetation types were relatively unique in that most of the vegetation in the study area was more heterogeneous and had considerably lower total vegetative ground cover.

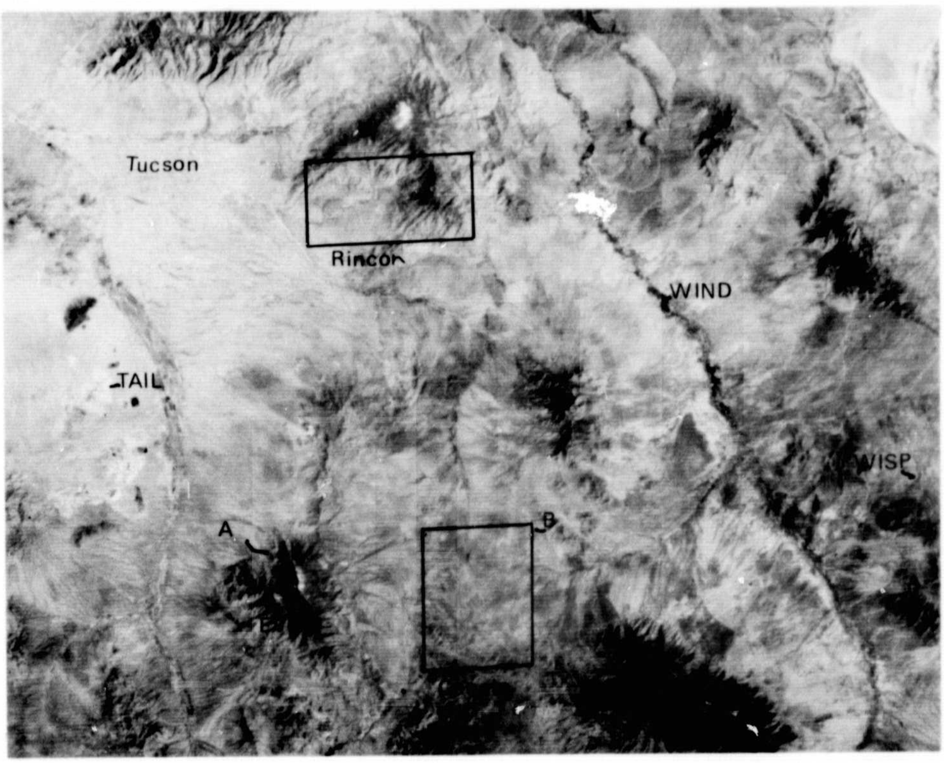


Figure 4. Portions of ERTS-1 MSS scene 1264-17283 used for stratification technique evaluation. Compare the image details with those of the map presented in Figure 1. This scene was acquired by the satellite on 13 April 1973.

For this reason, an alternate set of class standards was derived from the evergreen and winter-spring dormant vegetation types of the Canelo grid, and from the winter dormant vegetation of the Rincon Grid (Table 5).

Table 4. Radiance data for Primary standards.

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

Table 5. Radiance data for Alternate standards.

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

The Canelo area was represented by a grid of ERTS data consisting of 206 scan lines, each with 229 resolution elements. The Rincon grid was 131 lines by 382 elements. The total number of elements in the two grids was 47,174 and 50,042 respectively. Rather than to classify every element in achieving a stratification, a systematic sample was extracted from each grid. One sample consisted of four by four element fields (called grid fields) spaced at regular intervals throught the grids. Twenty-one lines and 21 elements spearated each grid field;

each field contained 16 elements and represented a ground area of approximately 6.4 ha. The Canelo grid was represented by an array of 90 grid fields; Rincon, by 96 grid fields.

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

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

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

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

VEGETATION STAND CLASSIFICATION

Converting Density Measurements to MSS Counts: Computing time availability and the wide geographic distribution of the vegetation stands to be classified necessitated the use of a different method of data extraction than was used for the grid field classifications. The second method involved the determination of radiance values from densitometric measurement of the ERTS-1 MSS photographic reconstitutions. Those photographs were in positive transparency form with a scale of 1:1,000,000. The procedure was modified from instructions given in the ERTS-1 Data User's Handbook, Appendix F (NASA, 1972). A density measurement of a portion of the transparency was made with a Welch

Densichron-One. This instrument measured the diffuse density to white light. A one millimeter lucite aperture was used which provided a measurement that respresented approximately 75 hectares or 185 acres on the ground. Each measurement was corrected by means of a calibrated step wedge, converted to a transmission value, and then converted to a scaled MSS sensor count by using a table such as the one given in Table 6.

The gray scale provided with each ERTS-1 MSS transparency is composed of 15 steps of progressively decreasing transmission. A "rise" was taken to be the change in transmission from one step to another. Rise values varied among pairs of steps, but their corresponding MSS count differences were constant. That count difference between steps was 4.5 counts. There were 15 steps, 14 rises between steps, and therefore 14 x 4.5 counts = 63 counts represented by the density range of the gray scale. To calculate the MSS count value which corresponded to a measured transmission value, the rise number and fractional rise corresponding to the transmission value were determined from the table and multiplied by 4.5 counts/rise. In practice, it was easier to expand the table to include an MSS count value for each consecutive transmission value calculated to the nearest tenth of a percent. A table was constructed for each date of ERTS-1 data being analyzed. Gray scale steps one through six in Table 6 gave ambiguous transmission values. Had transmission values in the scene been encountered which exceeded 39.4 percent for Band 5 or 43.6 percent for Band 7, they would have been ignored because they would have been in the range of the ambiguous first

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

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

six steps. This situation was not encountered. This reversal was only found associated with gray scales on the earlier dates of ERTS-1 imagery.

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

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

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

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

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

13 Apr 73: $y = .868x + .059$

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

RESULTS AND DISCUSSION

PLANT PHENOLOGY

Temporal Patterns of Change

The 47 species or genera for which phenological information was gathered included five tree, 19 shrub, eight leaf, or stem succulent, and 15 grass species. Of these, *Prosopis juliflora*, a deciduous, leguminous shrub commonly known as mesquite, was most ubiquitous. Data for this species are shown in Figure 5 to demonstrate the temporal nature of a plant species' annual development, variations among sites within a year, and variations among years. *Prosopis juliflora* is not portrayed as typical of other species. However, other species displayed similar temporal patterns of development; most also underwent year to year variations in the timing of their development. During the first quarter of the year, mesquite may have a few dried leaves persisting from the previous year. New leaves may begin to develop early in the second quarter and individuals can have combinations of new and mature leaves during April-June. Mature foliage is retained through the third quarter, although leaves may begin to dry and turn light brown in early and mid summer due to drought, and again in September. Combinations of mature and senescent leaves may be present from September into November. Plant phenology check stations one, two, and three were the lowest in elevation. Leaf development had usually progressed further at these sites during early spring than at the other more elevated sites. Notes from one field check

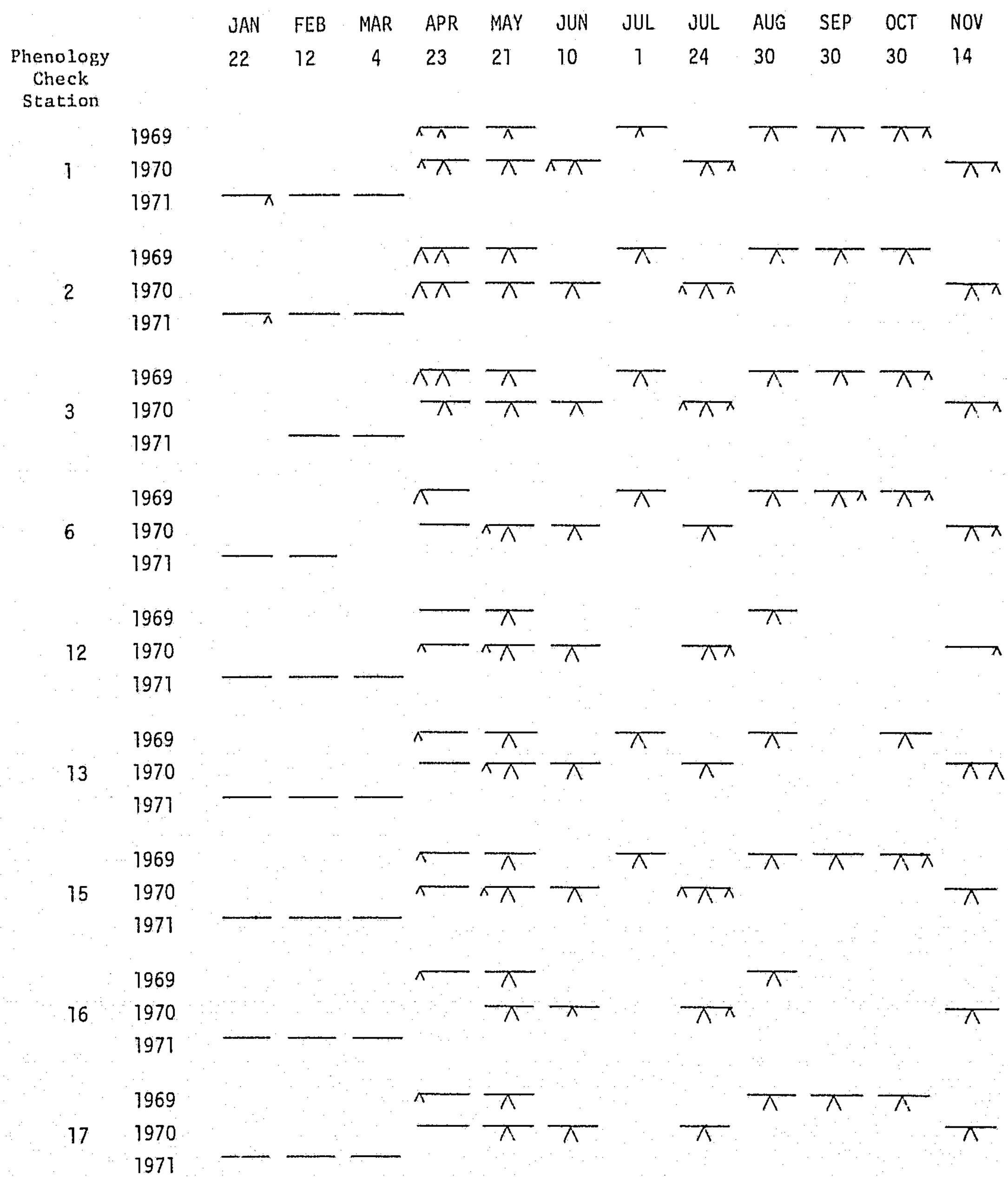


Figure 5. Foliage development and senescence for Prosopis juliflora.

indicated the presence of new leaves in late July following the onset of summer rains. The frequency of occurrence of new leaves at that time of year needs corroboration.

Analysis of the phenology data indicated three classes to which species in the area could be assigned according to the presence of foliage at certain times of the year. The classes were: 1. those plants retaining green leaves or maintaining a relatively stable green appearance throughout the year - evergreen (EVGN); 2. those in which foliage growth occurs primarily in the spring - winter dormant (WIND); and 3. those in which foliage growth occurs primarily in the summer - winter-spring dormant (WISP). Species and two genera representing each class are included in Figure 6 which summarized the data collected for each species or genus at all locations where it occurred, and for the portions of three years that field notes on phenology were taken.

The following additional phenological observations are relevant to the interpretation of multispectral, multiseasonal imagery:

1. There may be different rates of development exhibited by individuals of the same species growing side by side.

2. A change in the spectral reflectivity of the outer ends of branches may occur prior to leaf bud breaking, and may last for several weeks. This was evident in color infrared photographs of *Prosopis juliflora* and *Acacia vernicosa*.

3. There was an apparent loss of brilliance in the red color of color infrared photographic images acquired during a summer drought. The photographs were of *Prosopis juliflora* and *Larrea tridentata*.

4. Leafing out of *Prosopis juliflora* growing in drainage ways was later in the spring than that of the same species growing on adjacent uplands. The slower rate of development may be attributable to cold air drainage.

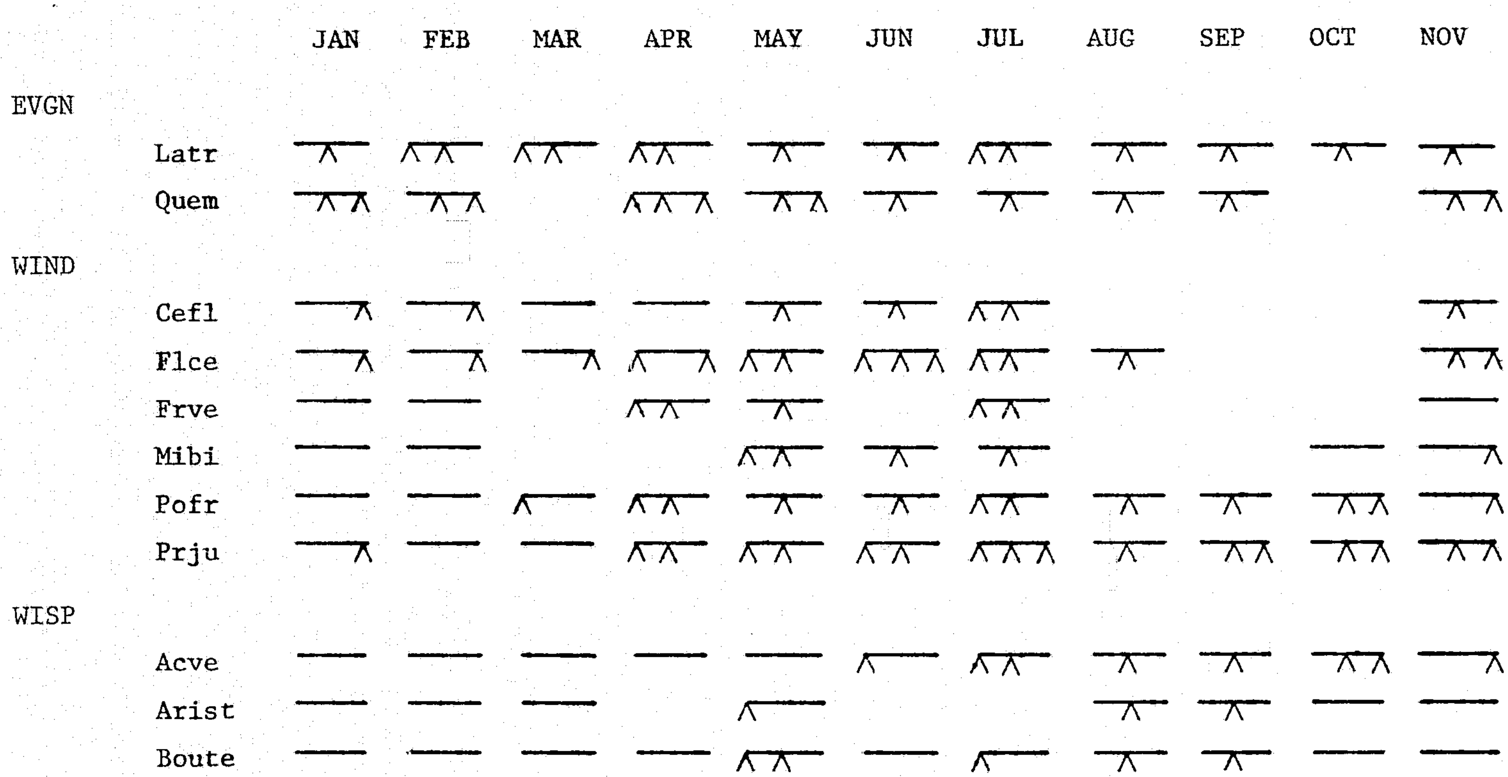


Figure 6. Summary of phenological data for nine species and two genera representing evergreen (EVGN), winter dormant (WIND), and winter-spring dormant (WISP). The species are *Larrea tridentata* (Latr), *Quercus emoryi* (Quem), *Cercidium floridum* (Cefl), *Flourensia cernua* (Flce), *Fraxinus velutina*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

5. There was a greater contrast on color infrared film among individuals of *Prosopis juliflora* (Prju) and those of *Cercidium floridum* (Cefl) when the plants were leafless than when they were in leaf. When in leaf, they evidently have similar spectral reflectivities; visually they are green. When leafless, the visual appearance of the branches of Prju is dark brown and appear dark on the color infrared film. In comparison, Cefl branches are green and appear light pink on the film.

6. *Prosopis juliflora* may slightly preceed *Mimosa biuncifera* in leaf development and leaves persisted longer on Prju in both the mature and senescent stages.

7. *Haplopappus tenuisectus* is a low, frequently rounded shrub with ascending branches. Leaves form along the full length of the branches and persist, in a dried state, into the following growing season. The concentration of these dried leaves moves toward the base of the plant as the seasons progress from winter through summer. The dried leaves closer to the base stay on the plant longer into the following year. The concentration moves back toward the crown as the current year's leaves begin to dry.

Classification of Species by Phenological Criteria

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

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

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

Year to year fluctuations of climatic factors, particularly precipitation, apparently can impose considerable variation in the timing of phenological events and the color of leaf material. Cercidium microphyllum and Larrea tridentata were noted above as examples. Given the availability of sufficient moisture and appropriate temperatures, perennial grass species which usually grow in the summer, may put forth considerable spring growth. Conversely, summer drought may severely hamper the growth of these same species during their usual active growth period.

Perhaps the most dramatic variations in the appearance of the desert landscape that can be attributed to foliage development are caused by the annual forbs and grasses. They may carpet the desert floor, be completely absent, or occur at any degree of density between those extremes. They may be present in the spring and/or summer, although different species will occur at the two different times (Shreve and Wiggins, 1964). The study area was expected to be less subject to the vacillations of the annuals than might have been the case further out in the Sonoran Desert; for the most part, this was true. Annuals, when present in great abundance, can dominate the spectral signature for the vegetation stand they accompany, and completely override the contribution to the integrated spectral reflection that the more stable perennial species give[3/]. However, the occurrence of annuals cannot be predicted long in advance. Detecting the presence of annuals may potentially be useful for distinguishing specific vegetation/soil systems. However, little is currently known about the affinities, if any, that annual species may be showing for specific plant communities in this study area. This study sought to capitalize on the phenological development exhibited by the perennial species rather than the annuals. This could only be accomplished by using a study area where annuals, if present, were less likely to dominate the spectral energy return from the landscape.

[3/]The impact that annual vegetation may have on space and aircraft imagery was noted on Apollo 9 and sequential NASA aircraft photography reviewed by Carneggie, Pettinger, and Hay (1971). Carneggie, DeGloria, and Colwell (1974) also used ERTS-1 imagery for studying the seasonal changes of the California annual grasslands.

Figure 7 diagramatically depicts the time of the year when plants are either dormant or have green leaves, and the timing of the two rainy seasons. The start and end of those seasons vary, as do the amounts of precipitation, in both space and time. There may be accompanying variations in the development and growth of many plants. Some of the variations and uncertainties are depicted by the figure: annuals may or may not be present; there is variability in the timing of leaf growth and scenescence, and summer drought may cause some warm season deciduous species to drop their leaves. Evergreens usually have a period when both new and old green leaves are present on the plant.

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

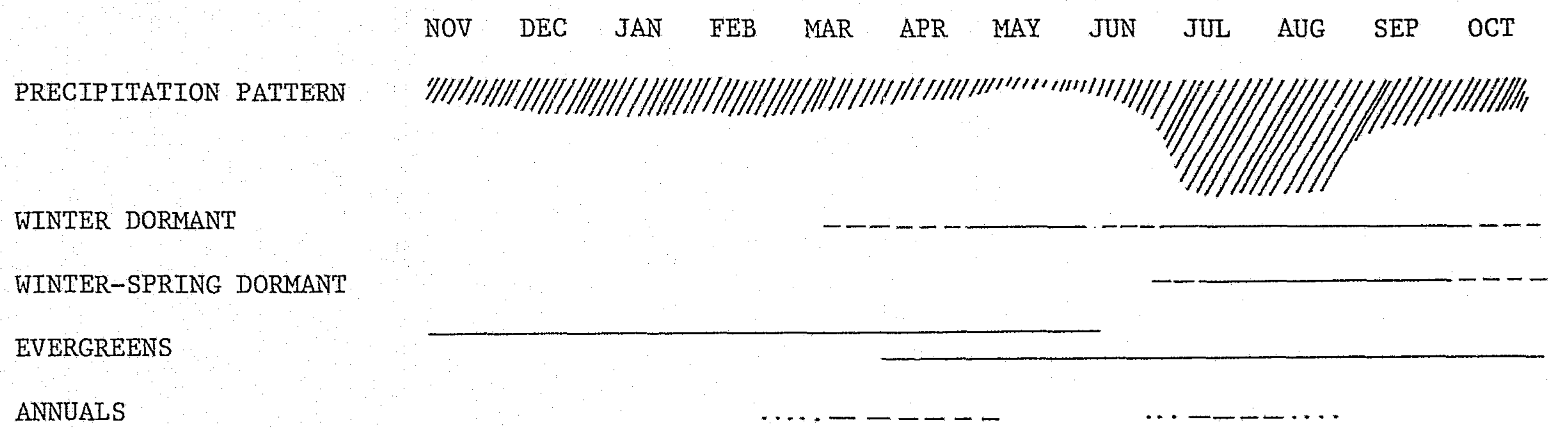


Figure 7. Seasonal occurrence of precipitation and foliage development. Solid horizontal lines indicate periods when green vegetative material was most likely to be present; the associated dashes indicate that the onset of leaf initiation and senescence was variable. Annual species were sometimes present. The overlapping lines for evergreens indicate the time period when old and new green leaves were present. (Evergreen oaks are the principal group represented.)

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

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

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

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

Shrubs

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

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

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

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

c, 2

they do undergo a pronounced change in appearance when their leaves develop and expand. This change was noted from direct visual observation and a review of color infrared ground photographs.

VEGETATION CLASSIFICATION

Six broad classes of vegetation occurring in the study area were defined from information given in the publications of previous workers. Those classes were characterized in the literature by their most common species. From that pool of information we compiled the brief lists of species shown in Table 10. The lists were thought to best typify the broad groups as they were represented in the study area, and they provided the first approximation of a vegetation classification for the area. In this manner, the knowledge of the vegetation gathered by several vegetation ecologists and other scientists was tapped to expedite this classification work. Our team efforts identified 31 vegetation types that occurred in the study area. The types are illustrated and described in the figures that follow. The physiognomy of each type is specified plus a brief description of the character species and other common species.

The 31 vegetation types are organized into the three plant phenological classes identified in the previous section:

evergreen: Figures 8 through 19,

winter dormant: Figures 20 through 31,

winter-spring dormant: Figures 32 through 38.

A vegetation type was assigned to a phenological class following a consideration of the content of the type's association table in

Table 10. Typical plant species representing six broad vegetation classes in the study area. The species lists were derived from a synthesis of earlier studies reported in the literature and our own field observations.

Sonoran Desert:	Cercidium floridum, C. microphyllum, Cereus giganteus, Encelia farinosa
Chihuahuan Desert:	Acacia vernicosa, Flourensia cernua, Mortonia scabrella
Grassland:	Baccharis pteronioides, Bouteloua curtipendula, B. eriopoda, B. gracilis, B. hirsuta, B. rothrockii, Hilaria belangeri, H. mutica, Nolina microcarpa, Sporobolus wrightii, Yucca elata
Chaparral:	Arctostaphylos pungens, Ceanothus greggii, Cercocarpus breviflorus, Cowania mexicana, Quercus rugosa, Rhus choriophylla
Woods:	Fraxinus velutina, Juniperus deppeana, Pinus cembroides, Platanus wrightii, Populus fremontii, Quercus arizonica, Q. emoryi, Q. hypoleucoides, Q. oblongifolia, Yucca schottii
Forest:	Pinus ponderosa, Pseudotsuga menziesii

conjunction with the phenology of species as indicated in Tables 7, 8, and 9. This assignment was therefore based on the phenology of the more prominent species. No regard was given to whether a vertical view from a satellite might suggest the same or a different phenological class. This point is made here, because some discrepancies do occur between this grouping of types and a second grouping based solely on radiance values acquired by ERTS-1. The second grouping is presented in "Classification of Vegetation Stands."

Plant species nomenclature follows Benson (1969) for the Cactaceae, Gould (1951) for Gramineae, and Kearney and Peebles (1964) for all other plants.

Most of the desert shrub types were designated as winter dormant; the notable exceptions were those having Larrea tridentata and Mortonia scabrella as most prominent. The desert grassland and grassland types were designated as winter-spring dormant. The chaparral, woods, and forest types were evergreen, except the riparian woods which were winter dormant.

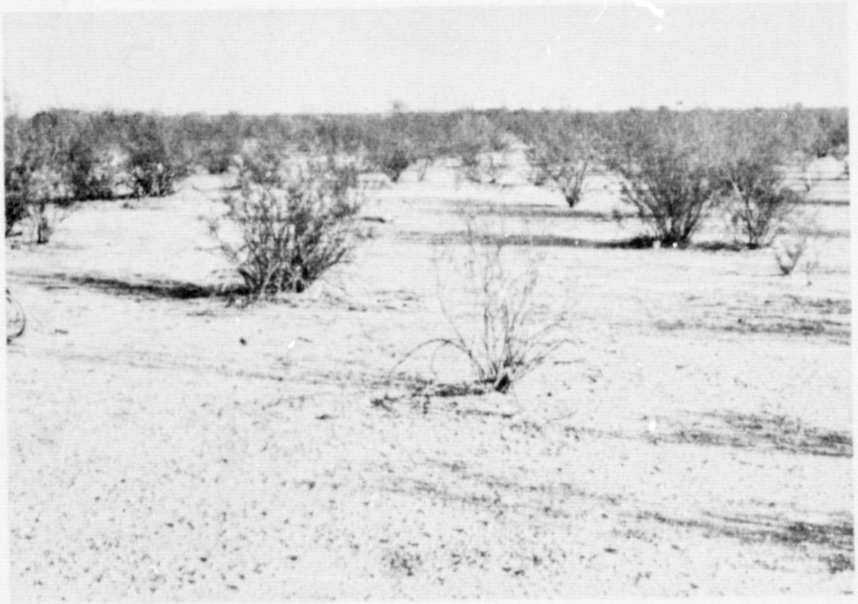


Figure 8. Larrea tridentata with or without annuals.

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.

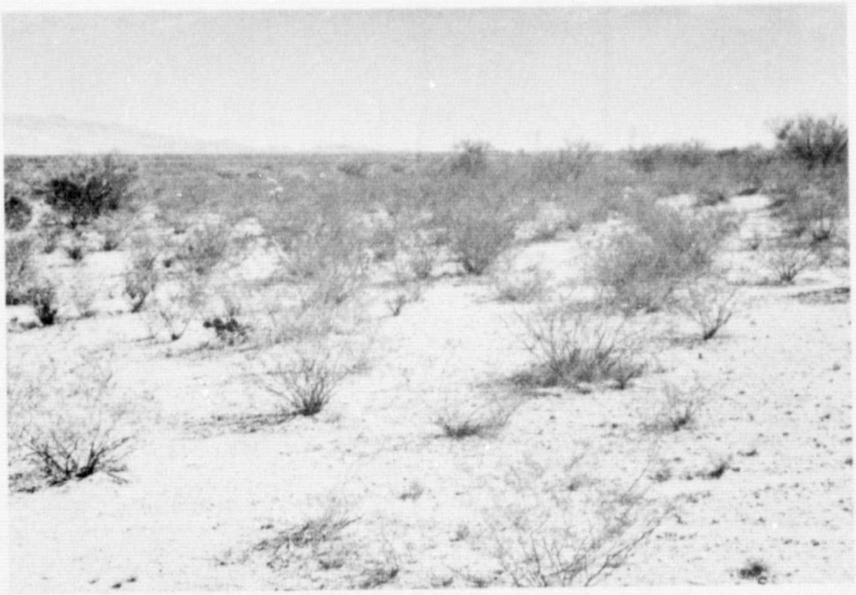


Figure 9. Larrea tridentata with Prosopis juliflora and/or Opuntia (cholla).

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."

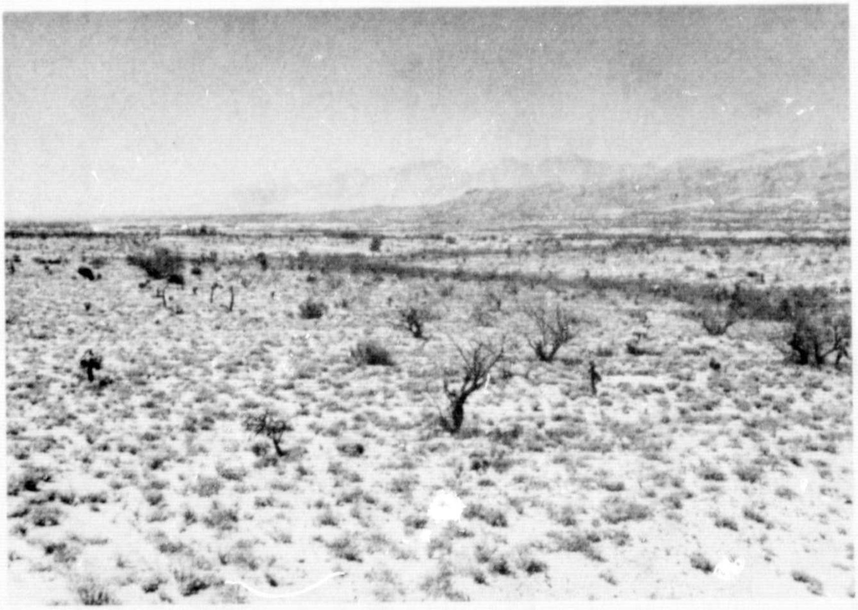


Figure 10. Coldenia canescens, Zinnia pumila, Fouquieria splendens, and Tridens pulchellus.

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.

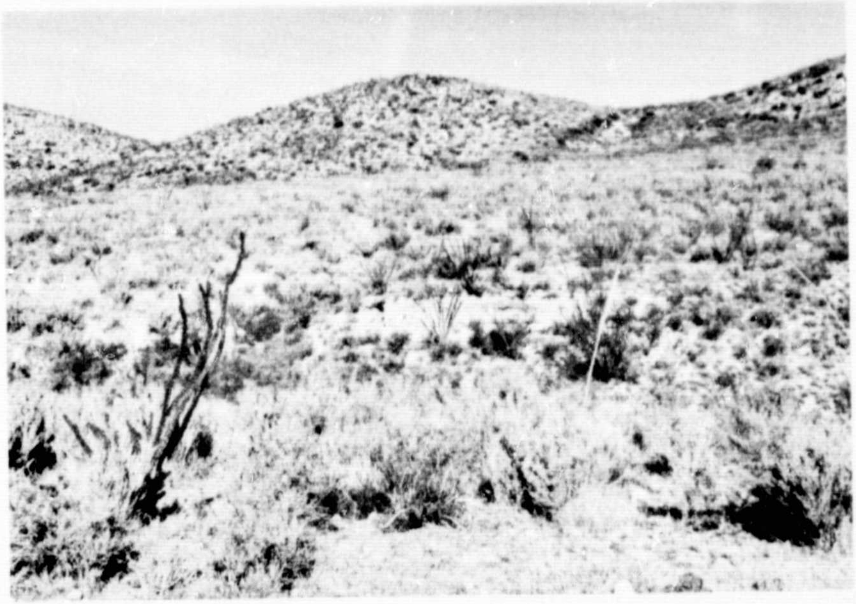


Figure 11. Mortonia scabrella without Rhus choriophylla.

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."

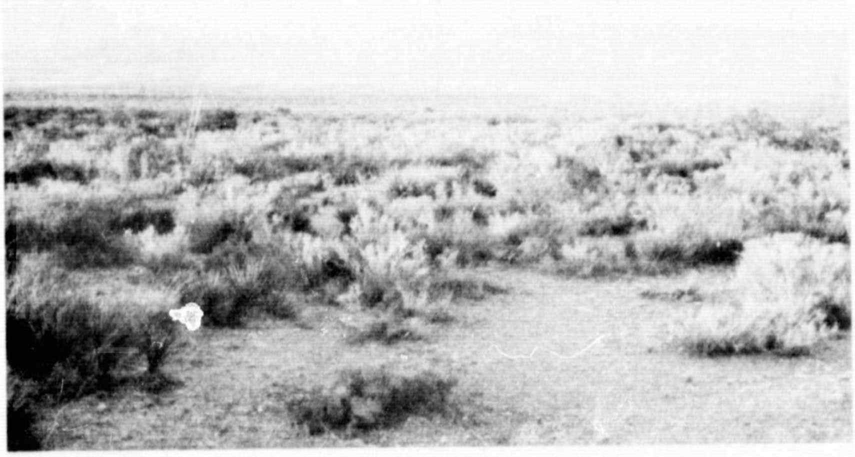


Figure 12. Mortonia scabrella with Rhus choriophylla.

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 13. 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 14. 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 15. 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 16. 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 17. 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 18. 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 19. 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.

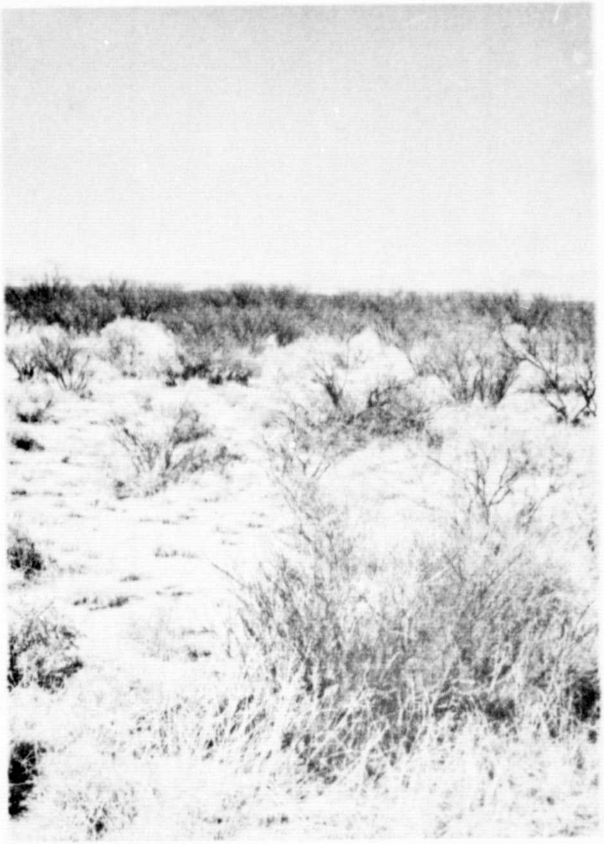


Figure 20. Atriplex canescens and Prosopis juliflora.

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.

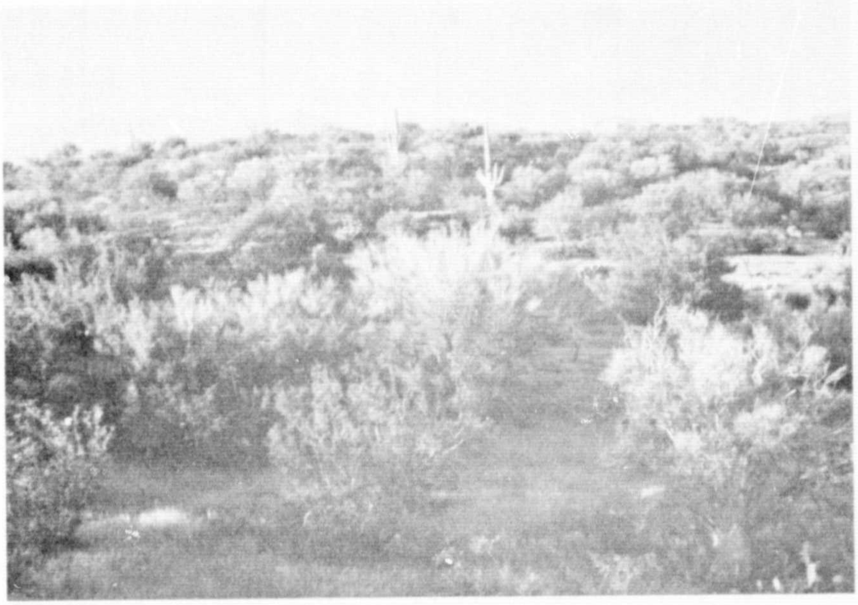


Figure 21. Cercidium microphyllum and Cereus giganteus often with Encelia farinosa and Opuntia spp., and without Franseria deltoidea.

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 22. 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."

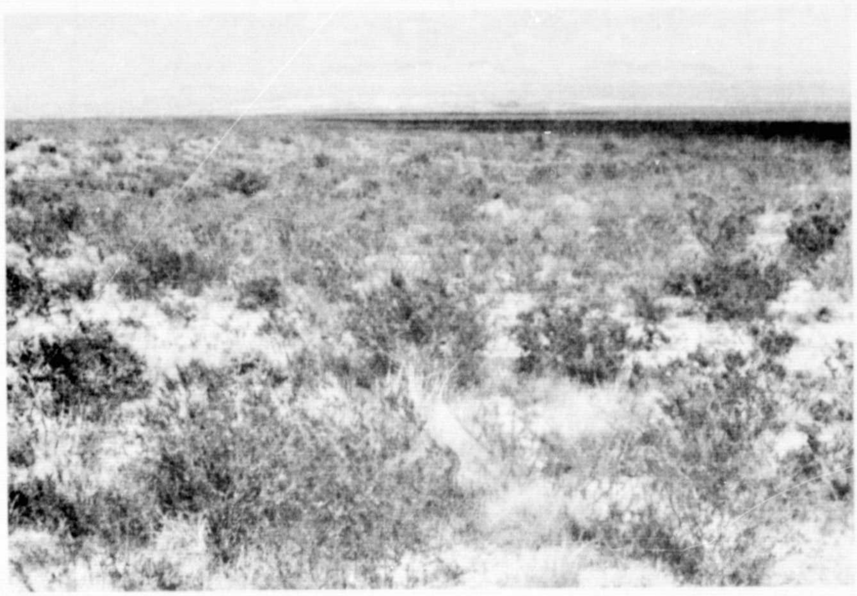


Figure 23. Acacia vernicosa, Flourensia cernua, Larrea tridentata, and Rhus microphylla.

"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 24. 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 25. 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."

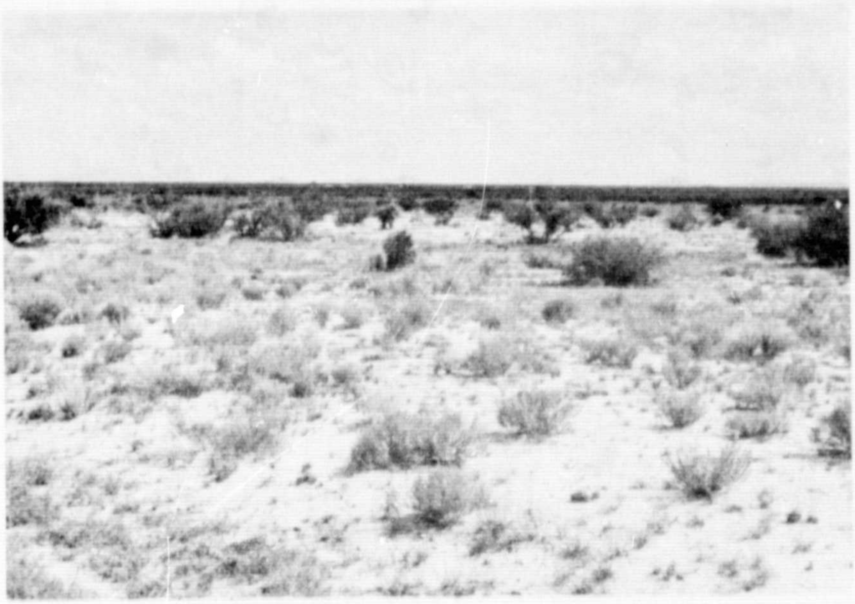


Figure 26. Prosopis juliflora and Haplopappus tenuisectus; without Acacia constricta, Opuntia (cholla), and Calliandra eriophylla.

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."

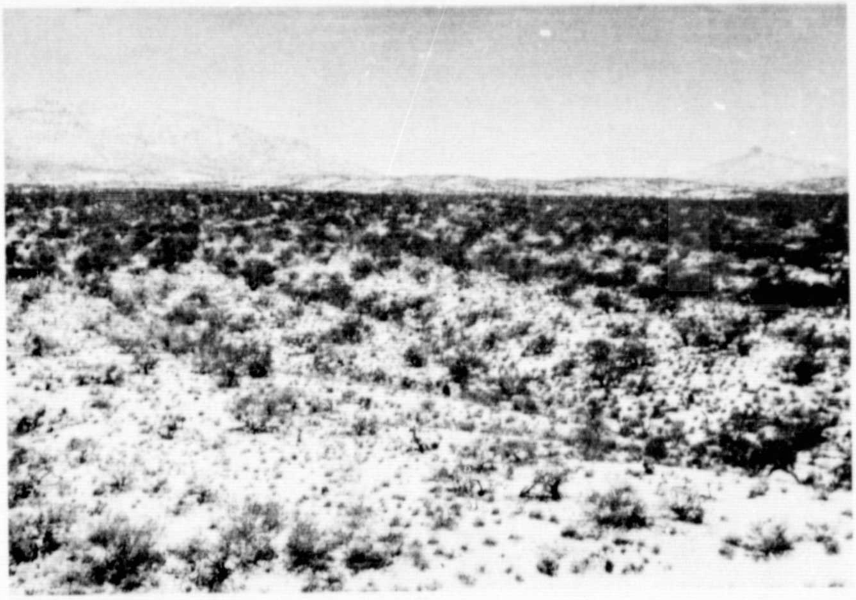


Figure 27. Acacia constricta and Prosopis juliflora usually with Opuntia; without Calliandra eriophylla.

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 28. 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 29. 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 30. 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 31. 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 32. 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."

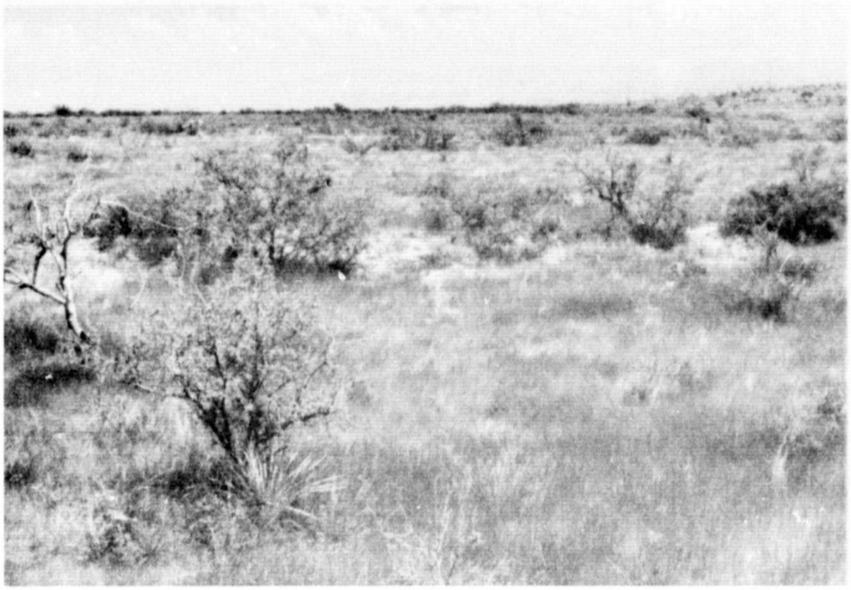


Figure 33. Calliandra eriophylla and Bouteloua with any or all of Ephedra trifurca, Yucca baccata, Y. elata, Prosopis juliflora, and without Acacia constricta.

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 34. 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 35. 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.

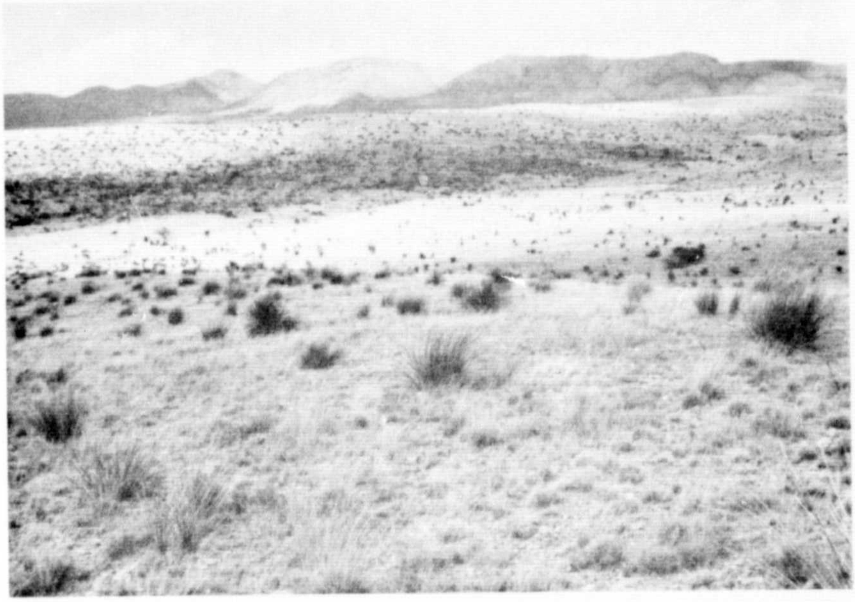


Figure 36. Bouteloua, Aristida, and Nolina microcarpa without Calliandra eriophylla.

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 37. 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.

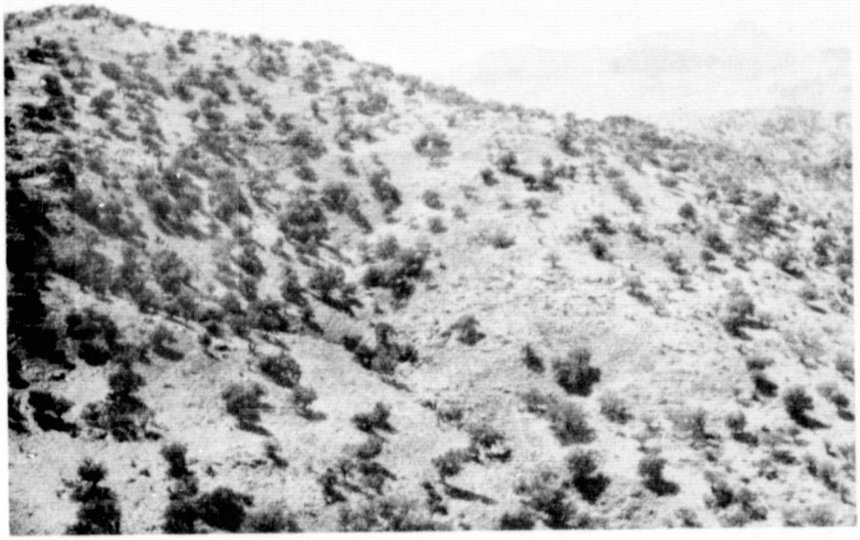


Figure 38. Prosopis juliflora and Bouteloua with Quercus (usually Q. oblongifolia) and/or Juniperus deppeana.

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.

MULTIDATE RADIANCE STANDARDS FOR PHENOLOGICAL CLASSES

ERTS-1 MSS data for the three plant phenological classes plus the "no change" class are given in Table 11. Those data were considered to represent the ultimate expression of phenological change and of "no change" in the case of the highly reflective mineral surface (mine tailings). "Ultimate expression" implies that insofar as was possible, these standards represented only their indicated class. For example, the standards for the class EVGN represented evergreen species almost exclusively. In reality there were probably a few winter dormant species also present and bare ground showing through the vegetation canopy when viewed from above. Each representative area, however, was carefully chosen to minimize the inclusion of bare ground areas and plant species belonging to other than the phenological class being represented. The values in Table 11 are the basic raw data representing multiseasonal spectral signatures as can be derived directly from the computer compatible tapes.

Comparisons of the data contained in Table 11 can be conveniently made among classes within a single band and date. For example, among the four classes EVGN had the lowest MSS 4 value in August. The second lowest was WIND, then WISP; TAIL had the highest value. The same relationship held true for the MSS 5, 6, and 7 values. Also, the vegetated surfaces had much lower radiance values in the MSS 4, 5, and 6 bands than did the bare mineral surface, TAIL.

However, a straight forward comparison among bands and dates is difficult because real radiance differences are modified and may be

Table 11. Average ERTS-1 MSS computer compatible tape counts for plant phenological and "no change" classes. The STATS subprogram of CALSCAN provides the class mean calculated to the hundredths position.

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

obscured by temporal variations in angle of incidence by solar radiation and atmospheric attenuation. Real differences are also modified by differences among the response characteristics of the MSS detectors and the scales on which the values are portrayed.

For example: 1) the sun's elevation was lower on the November date than on either of the other two dates. That meant the solar radiation had to pass through a greater atmospheric mass in November with the probable result of greater atmospheric attenuation. The lower solar elevation also resulted in a less direct impingement of the solar radiation on most surfaces, and therefore a lower apparent radiance in November when viewed from ERTS. 2) The detectors for MSS 6 were most sensitive, those for MSS 7 were least sensitive. This influences the magnitude of the difference between radiance values in the two bands. 3) The detectors for MSS 4, 5, and 6 were each sensitive to the energy in a 0.1μ bandwidth, MSS 7 was sensitive to that in a 0.3μ bandwidth. This also influenced the magnitude of differences between MSS 7 radiance values and those of MSS 4, 5, and 6. 4) The radiance values in MSS 4, 5, and 6 were expressed on a scale of 0-127, those of MSS 7 were on an 0-63 scale. MSS 7 values were therefore lower relative to what they would have been had they been expressed on the 0-127 scale.

Analysis of ERTS data, such as a classification of radiance values with CALSCAN, or a classification of ratios of radiance values with a distance measure, can commence without regard for the variables noted above. Adjustments of the data usually retain the same relative differences among those features which are used for classification. If the appropriate spectral radiometric measurements were acquired in conjunction with the ERTS data, then a specific correction of the radiance values in each band would be possible prior to classification of the data. The necessary radiometric measurements were not available for this study. The analyses which were conducted were all performed on the raw ERTS radiance data.

The remaining discussion in this section considers radiance data that were adjusted for the variables noted above. The adjustments were approximations of specific corrections and were made solely for the purpose of inspecting the character of the multiseasonal spectral signatures of the phenological and "no change" class standards. A more detailed discussion of the sources of variation in ERTS data is included in Appendix C. The adjustments which account for these variations are discussed in Appendix D. For this consideration of adjusted data, it was necessary to substitute the radiance values for two training fields (Table 12) in place of means for EVGN and TAIL classes. The two substitutions were made for different reasons. Of the three phenological classes, EVGN was the only one represented by ground areas having significant slopes and aspects (see Appendix B). The angle of incidence of solar radiation on a surface is a function of both the sun's position above the horizon (elevation and azimuth) and the slope

Table 12. Average ERTS-1 MSS computer compatible tape counts for a selected ground area in each of the EVGN and TAIL classes.

Ground area	Month	CCT Counts			
		MSS 4	MSS 5	MSS 6	MSS 7
EVGN-4	Aug	27.14	23.26	40.83	22.46
	Nov	22.51	18.46	36.97	21.34
	Apr	18.94	12.43	27.69	15.86
TAIL-3	Aug	75.52	93.87	86.37	35.41
	Nov	60.09	69.38	63.86	26.57
	Apr	79.16	97.12	87.36	37.84

and aspect of the surface (see calculations for surface two in Appendix E). It was, therefore, necessary to select one of the EVGN training fields to represent the class because each of the fields in that class had different slope and aspect components. The training field selected to represent the TAIL class was that pile of mine tailings which remained unchanged and retained the same appearance throughout the sampling period.

The values in Table 13 can be compared among subjects, bands, and dates. The values have been adjusted for angle of incidence, atmospheric attenuation, detector response, differences in scale, and an apparent anomaly in the November data (the anomaly is also discussed in Appendix D). Differences among the values are due primarily to the reflectance characteristics of the subjects. The standard deviations associated with the mean radiance values in this table are contained in Appendix F. The date to date change factors for these adjusted radiance values are given in Table 14. By using the TAIL-3 change factors as a guide, it was evident that change occurred in the radiance of all plant phenological classes, between all dates, and in all portions of the electromagnetic spectrum being detected. These conclusions were based on average values. The one possible exception was the WISP August and November MSS-4 radiance; there may have been no appreciable change occurring in that case.

The adjusted radiance values were used for constructing the three dimensional block diagrams in Figures 39 and 40. These figures enable a visual assessment of the patterns of change within and among dates

Table 13. ERTS-1 MSS computer compatible tape counts adjusted for angle of incidence, atmospheric attenuation, an anomaly in the November data, detector response, and data scale.

		Adjusted CCT Counts			
Subject	Month	MSS 4	MSS 5	MSS 6	MSS 7
EVGN-4	Aug	49	34	52	151
	Nov	39	32	60	192
	Apr	34	18	35	104
WIND	Aug	56	37	63	187
	Nov	46	33	33	90
	Apr	66	51	54	142
WISP	Aug	60	40	71	211
	Nov	61	64	52	146
	Apr	86	76	65	160
TAIL-3	Aug	157	157	127	272
	Nov	166	166	132	292
	Apr	160	159	125	284

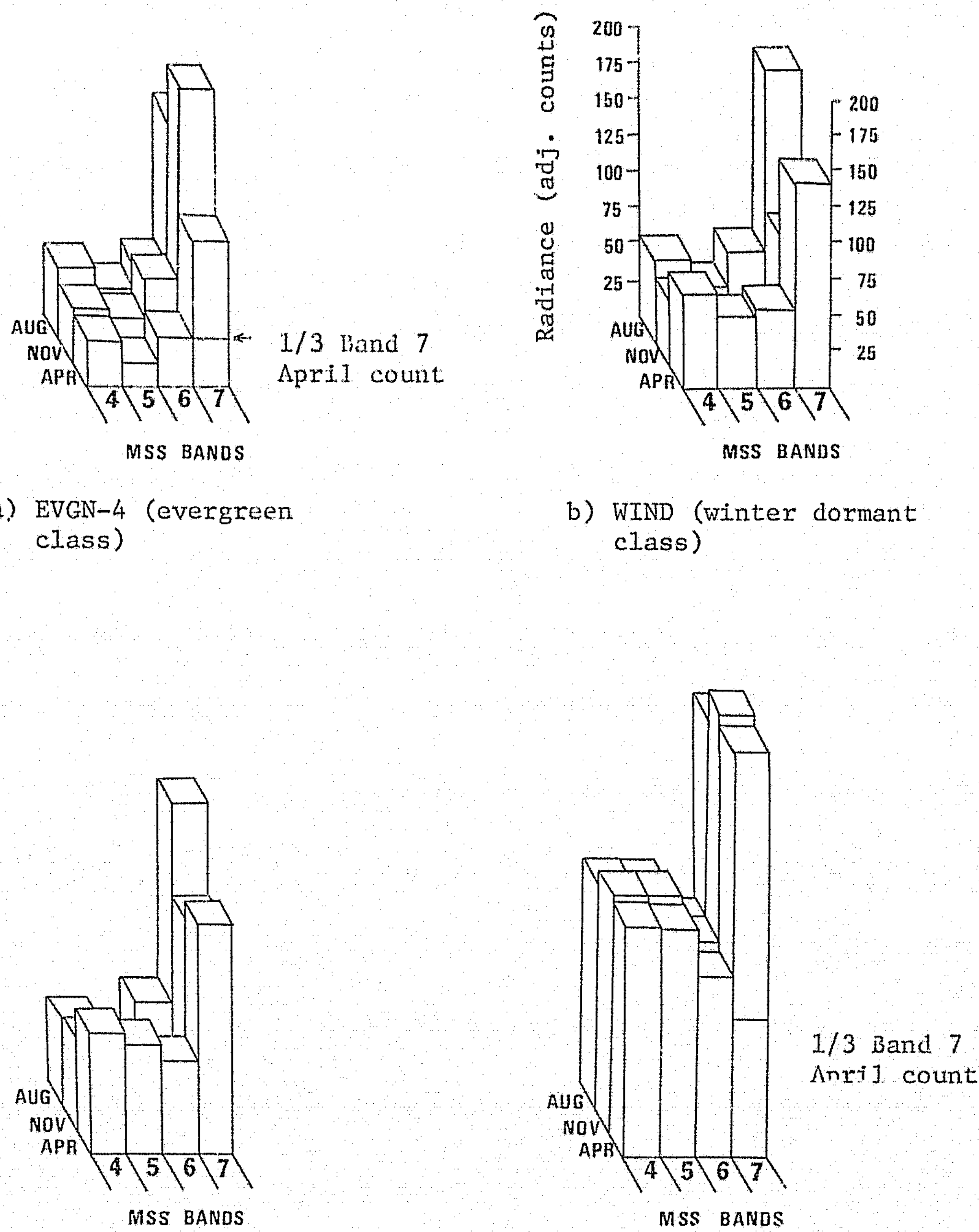
and spectral bands associated with the multidate, multiband radiance values for the phenological and "no change" classes.

The spectral radiance of EVGN-4 on the three dates and that of WIND and WISP in August showed the multiband pattern of radiance typical of green foliage. Theoretically, the WIND April radiance should have exhibited a similar pattern, apparently the foliar development had not proceeded sufficiently to achieve the expected spectral radiance levels. The green foliage spectral radiance pattern consistently had the highest adjusted count in MSS Band 7, second highest in Band 6, third in Band 4, and the lowest adjusted count in Band 5; Band 7 count was three times that in Band 6. There was some similarity between the green foliage spectral radiance pattern and documented reflectance spectra for vegetation. The latter is given in Figure 41. Comparisons between the radiance and reflectance patterns must be made with caution. Radiance is a measure of reflected energy whereas reflectance is the ratio of the reflected to the impinging energy. A subject having low radiance could conceivably have a high reflectance value, and vice versa. The primary point of comparison

Table 14. Ratios of radiance values within MSS Bands and among dates (date to date change factors). A factor of 1.0 equalled no change, >1.0 = increase, and <1.0 = decrease in radiance between the dates indicated; e.g., EVGN-4 showed a decrease in MSS 5 radiance from August to November, and a further decrease from November to April.

		MSS 4	MSS 5	MSS 6	MSS 7
EVGN-4	Nov/Aug	.80	.94	1.15	1.27
	Apr/Nov	.87	.56	.58	.54
	Apr/Aug	.69	.53	.67	.69
WIND	Nov/Aug	.82	.89	.52	.48
	Apr/Nov	1.43	1.55	1.64	1.58
	Apr/Aug	1.18	1.38	.86	.76
WISP	Nov/Aug	1.02	1.60	.73	.69
	Apr/Nov	1.41	1.19	1.25	1.10
	Apr/Aug	1.43	1.90	.92	.76
TAIL-3	Nov/Aug	1.06	1.06	1.04	1.07
	Apr/Nov	.96	.96	.95	.97
	Apr/Aug	1.02	1.01	.98	1.04

between the radiance and reflectance pattern is the apparent impact of chlorophyll absorption on the red wavelengths (MSS 5). In both types of patterns, the values for MSS 5 are low in comparison to those in the bands of shorter or longer wavelengths. The high radiance values in MSS 7 may be partially due to the high near infrared reflectance by green vegetation, however, the primary reason for these high radiance values was probably the bandwidth (0.3μ) being detected by the MSS 7 sensor. The bandwidth for the other three bands was 0.1μ. The high MSS 7 radiance values were characteristics of all the phenological classes, regardless of whether they had green leaves. The "no change" class also had a high MSS 7 radiance. If the radiance values from all detectors were expressed on a "per 0.1μ" basis, then Band 7 values would be reduced by two-thirds (see the one-third levels indicated in Figure 39). In the green foliage radiance pattern, this would put the Band 7 level approximately even with that of Band 6 and therefore only slightly higher than Band 4. In comparison to the graph of reflectance, this radiance level for Band 7 might seem too low, however, there is less energy per wavelength in the near infrared than in the visible green portion of the spectrum. Also, there was a substantial drop off of Band 7 detector sensitivity in the longer wavelengths of the 0.8 to 1.1μ spectral range. These two factors at least partially account for the Band 7 radiance level in comparison to that of Band 4 when compared on a "per 0.1μ" basis. The spectral radiance pattern for TAIL-3, in strong contrast to the pattern for green foliage, showed high radiance values in the visible wavelengths. This pattern bore



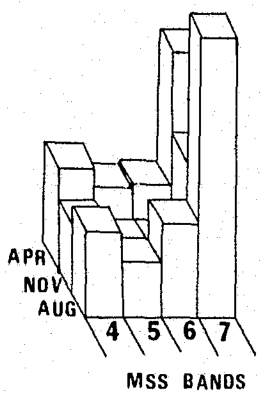
a) EVGN-4 (evergreen class)

b) WIND (winter dormant class)

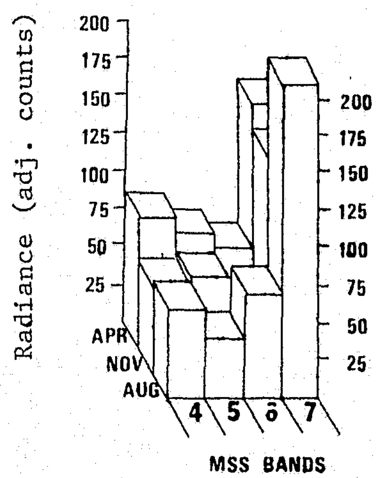
c) WISP (winter-spring dormant class)

d) TAIL-3 ("no change" class)

Figure 39. Adjusted counts (see Table 13) for phenological and "no change" classes. The tops of some columns are not visible. Radiance scale is the same for all graphs.



a) WIND (winter dormant class)



b) WISP (winter-spring dormant class)

Figure 40. Adjusted counts for WIND and WISP phenological classes. The data in these graphs are the same as presented in Figure 39b and 39c, only the arrangement has been altered. August radiance levels are displayed by the front row of columns; April by the back. This arrangement for these subjects made visible the tops of two columns that were hidden in Figure 39b, and two of three columns that were hidden in Figure 39c. Radiance is the same for both graphs.

semblance to the spectral distribution of global radiation as presented by Robinson (1966).

The spectral radiance pattern described above for green foliage followed two different types of changes as leaves were dropped, as was the case with WIND (principally a deciduous shrub, *Prosopis juliflora*), and as leaves and clums bleached as occurred in WISP (principally grasses). The radiance leavels decreased in all four bands in WIND, and especially in Bands 6 and 7, between August and November. In the absence of leaves, the radiance from the WIND subjects represented the dark, bare branches of *Prosopis juliflora*, shadows, the soil background,

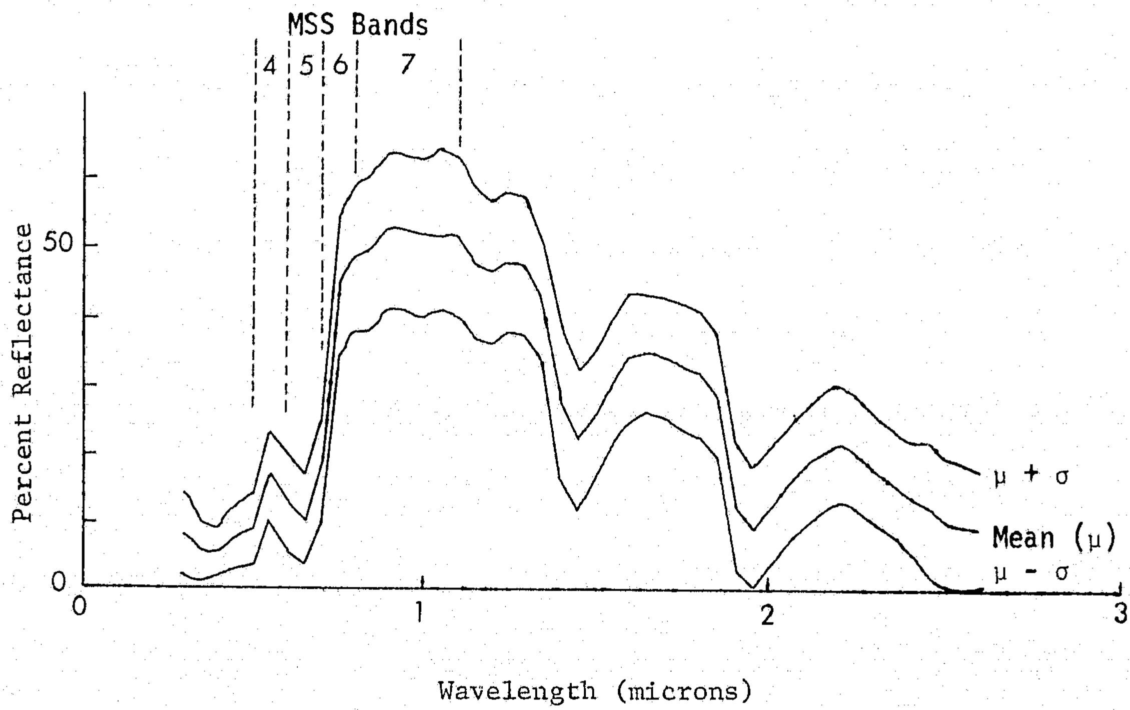


Figure 41. Mean and standard deviation of reflectance from 700 green vegetation spectra (Nalepka, 1970) with ERTS-1 MSS spectral bands superimposed.

and litter. The radiance levels representing the WISP subject decreased in Bands 6 and 7, increased in Band 5 (visible red radiation) and remained virtually unchanged in Band 4, between August and November. From November to April, the radiance levels for this subject increased in all the spectral bands detected by the MSS system.

The decrease of radiance levels in all bands for EVGN-4 between November and April remained a puzzle. This temporal pattern of change was displayed by two of the ground areas chosen to represent the EVGN class (areas Three and Four). Areas One and Two displayed the opposite trend. There was also no answer evident for the increased Band 6 and 7 radiance between August and November as exhibited by EVGN-4.

Changes in radiance, as presented in Figures 39 and 40, and Tables 13 and 14, were taken as indirect evidence of changes in spectral reflectance. Each phenological and "no change" class appeared to have a unique multidate spectral signature as indicated by the adjusted radiance values.

CLASSIFICATION OF ELEMENTS REPRESENTING CLASS STANDARDS

Classifications of multispectral data are seldom conducted which utilize all available channels of data. It is usually necessary to identify the subset of features (the four bands of MSS data from the three dates equal 12 features) which provides the optimal trade-off between classification costs and classification accuracy. One method for identifying an appropriate subset is through the use of divergence measurements (Swain, 1972).

Divergence is a measure of the dissimilarity of two data distributions. The dissimilarity depends upon the distance between the means of the two distributions and their variances. The divergence for two non-identical distributions is greater than zero, and the addition of more features never decreases the divergence. The measurements therefore provide a means for assessing the ability of the "maximum likelihood" classifier (CALSCAN) to discriminate between pairs of classes (data distributions).

Because divergence is defined for two classes, it was nessary to evaluate the merits of feature combinations for separating the classes in a pairwise fashion (i.e., EVGN-WIND, EVGN-WISP, EVGN-TAIL, WIND-WISP, WIND-TAIL, and WISP-TAIL). One possible strategy was to consider the average divergence value. This procedure was followed in selecting the best six of 12 features for discriminating the four training classes. The six features selected in this manner were: MSS Bands 5 and 7 from August, Bands 4, 5, and 7 from November; and Band 4 from April data.

All the ERTS resolution elements which constituted the training classes were classified with CALSCAN using the training class statistics for those six features. The resultant classification had an overall performance of 99.8 percent correct. In the EVGN class, one of 546 resolution elements was misclassified as WISP. Of the 64 elements in the WIND class, one was also misclassified as WISP. All elements in the WISP and TAIL classes were correctly classified. This merely served to indicate that the four classes, as represented by the ERTS-1 MSS data, were distinct, and that the resolution elements were good representatives of their respective classes.

The six features selected on the basis of average divergence probably were not in fact the best combination. The reason for this could be seen in Figure 42, a spectral plot showing the count intervals (mean ± one standard deviation) for each feature in each class. Within each feature, the TAIL class was distinct from the other three, with the one exception of WISP in the August Band 7 data. The best six features should have been selected on the basis of the separability of the three phenological classes without regard for the "no change" class. When the selection of bands was conducted in this manner there were nine combinations of the twelve features that were better, in terms of

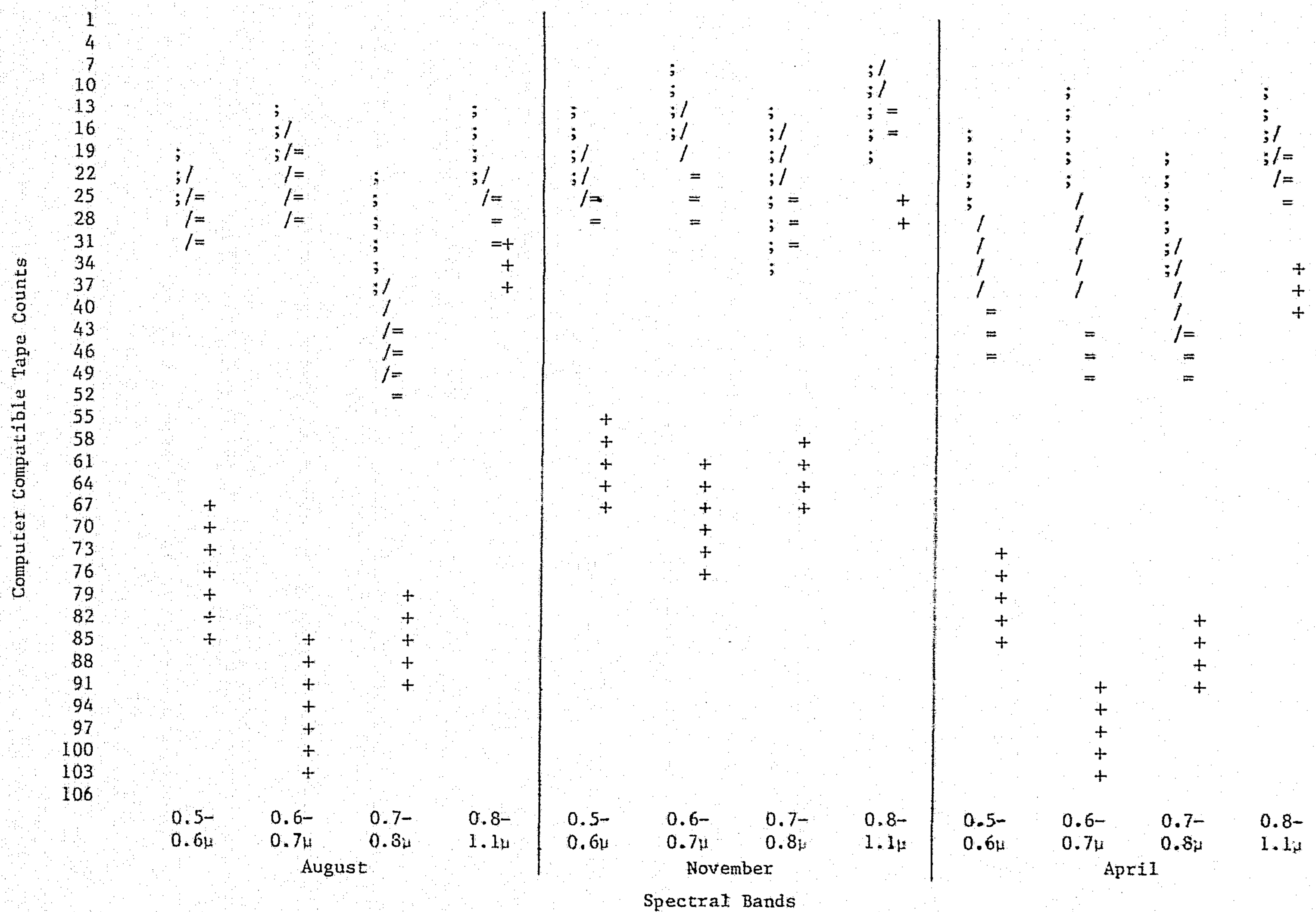


Figure 42. Spectral plots for EVGN (;), WIND (/), WISP (=), and Tail (+). Each plot indicates the mean count ± one standard deviation for data from the ERTS-1 MSS system on 22 Aug 72, 2 Nov 72, and 13 Apr 73.

average divergence, than the "best six" given above. Those combinations of features are given in Table 15. The values in the bottom row of Table 15 were the "best six" features when TAIL data were considered in the divergence calculations.

The selection of the best feature combination may be additionally modified by a strategy for maximizing the minimum divergence. From Table 15 it was evident that there was least dissimilarity between the WIND and WISP class regardless of the feature combination being considered, and that the divergence values for those two classes were considerably lower in every instance than the values for any other pair of classes. Table 16 contains several combinations of features which, if used for classification, would have provided a greater likelihood of discriminating the WIND and WISP classes. All of the combinations in this table provided a better divergence of the WIND-WISP pair than did any of the combinations of the previous table.

There are eight combinations of six features listed in Table 16. Seventy-three percent of the features selected for those eight combinations were either Bands 5 or 7 from the three dates; the other 27 percent were either Bands 4 or 6. Bands 5 and 7 are perhaps the most useful of the four bands for detecting changes in the development and cover of vegetative material. The energy in Band 5, the red wavelengths, is absorbed by chlorophyll; the near infrared radiation of Band 7 is strongly reflected by green foliage. In contrast, the green wavelengths of Band 4 are reflected by green leaves, but not nearly as strongly as are the near infrared wavelengths. And Band 6 includes a range of wavelengths, some of which are strongly absorbed by green leaves, others

Table 15. Divergence between phenological classes with selected feature combinations.

	August	November	April
MSS Bands	4 5 6 7	4 5 6 7	4 5 6 7
Feature No.	1 2 3 4	5 6 7 8	9 10 11 12

Feature Combination	DIVERGENCE EVGN/WIND	EVGN/WISP	WIND/WISP	Average
4,5,6,8,10,12	224	363	66	218
3,6,8,9,10,11	174	408	69	217
4,5,6,8,9,12	227	359	62	216
4,5,6,7,8,9	235	354	60	216
4,5,6,8,10,11	217	357	67	214
3,5,6,8,10,12	214	360	64	213
3,5,6,7,8,9	227	352	57	212
4,5,6,8,9,11	220	354	63	212
3,5,6,8,9,12	215	358	59	211
2,4,5,6,8,9	217	344	66	209

Table 16. Combinations of features which maximize the minimum pairwise divergence of WIND and WISP.

	August	November	April
MSS Bands	4 5 6 7	4 5 6 7	4 5 6 7
Feature No.	1 2 3 4	5 6 7 8	9 10 11 12

Feature Combination	DIVERGENCE			
	EVGN/WIND	EVGN/WISP	WIND/WISP	Average
2,4,6,8,10,11	182	356	72	203
2,4,5,8,10,11	171	341	72	195
2,4,8,9,10,11	110	289	72	157
2,4,6,8,10,12	186	362	71	206
2,4,5,8,10,12	176	353	71	200
2,6,8,9,10,11	158	364	70	197
2,4,6,7,10,11	124	329	70	174
2,4,5,7,10,11	125	307	70	167

are strongly reflected (see Figure 41). It would seem, therefore, that those bands containing wavelengths which were critically interacting with green foliage were the most appropriate bands for use in discriminating among the three vegetation types considered here. Each of those types presented a nearly continuous cover of green foliage to the satellite's detectors on one or more of the three dates from which imagery was acquired for analysis. Upon considering the tradeoffs between minimum and average divergences in Table 16, I would select the combinations of features 2, 4, 6, 8, 10, and 11, and features 2, 4, 6, 8, 10, and 12 as being the best two combinations of six features.

The divergence measurements provided further insights into the radiance data for the phenological types. For example (Table 17), the single feature which provided the best average divergence among the classes was the MSS Band 5 acquired in April. The April Band 4 provided the best (largest) minimum divergence with a single band. In contrast to those two features, the August Band 5 provided no separability of the WIND and WISP classes (divergence = 0). The mean radiance count for WIND in Band 5 for August was 22.42; that for WISP was 24.20.

The best average and minimum divergence measurements with a pair of features were provided respectively by features eight and ten, and eight and nine. When the best pair was selected from one date, April data provided the best separability among classes. The best four features are similarly reviewed in Table 17. Also, as the number of features increased from one to four without regard to date, both the average divergence and the minimum divergence values increased. However, when the best two or four features were restricted to one date rather than being selected from all the features from three dates there was a definite decrease in the divergence values. This was particularly noticeable in the comparison of the average divergence (180) by four features selected from three dates with the ave. divergence (107) by the four features of one date (Table 17).

The August data was the poorest for discriminating among the three phenological types. This was reasonable because August was the season when the most prominent species of the three types had green foliage. There was therefore much greater similarity in the appearance of the three types in August than on either of the other two dates. The April data provided the best possibility for distinguishing WISP from EVGN and WIND when two or four features were considered. The November data provided the best discrimination of EVGN and WIND.

In summary, where more than one feature was to be used for performing a classification of these EVGN, WIND and WISP vegetation types there was a definite advantage to be realized from utilizing radiance data from more than one date. A consideration of phenological change will definitely enhance the discrimination of some vegetation types.

Table 17. Divergence values for various feature combinations. These combinations provide the best average or minimum divergences for classes EVGN, WIND, and WISP.

	August	November	April
MSS Bands	4 5 6 7	4 5 6 7	4 5 6 7
Feature No.	1 2 3 4	5 6 7 8	9 10 11 12

Feature Combination		Divergence			
		EVGN/WIND	EVGN/WISP	WIND/WISP	AVERAGE
Best ave. w/single	10	16	146	36	66
Best min. w/single	9	19	143	31	64
Best ave. w/pair	8, 10	38	183	44	88
Best min. w/pair	8, 9	40	180	41	87
Best ave. w/pair from one date	10, 12	21	171	43	78
Best min. w/pair from one date	9, 12	23	147	32	67
Best ave. w/four features	5, 6, 8, 9	185	305	50	180
Best min. w/four features	2, 4, 8, 10	96	199	59	118
Best ave. w/one date (November)	5, 6, 7, 8	187	111	24	107
Best min. w/one date (April)	9, 10, 11, 12	27	187	47	87
Poorest date (Aug)	1, 2, 3, 4	27	39	11	26

CLASSIFICATION OF TRAINING FIELDS

Radiance data from the training fields representing the three phenological classes and the "no change" class were classified using the schemes involving ratios of radiance values, change factors, and direction of change. The radiance data in Bands 5 and 7 for training fields and classes are given in Appendix G. The performance of the various classification schemes was apparent from the results contained in Table 18. CALSCAN classification results were included to complete the comparisons among schemes. In addition to CALSCAN, perfect classifications were also achieved with the MSS 5 ÷ MSS 7 and the Vegetation Index (V.I.) schemes.

MSS 5 Count ÷ MSS 7 Count

A 5/7 ratio was calculated from each mean training field response in Bands 5 and 7 for each of the three dates. In that manner, each training field was characterized by a triad of 5/7 ratios: one each for 22 Aug 72, 2 Nov 72, and 13 Apr 73. Each ratio in the triad had a corresponding ratio in the triads for the four classes: EVGN, WIND, WISP, and TAIL. A training field was assigned to a class by comparing the field's triad to those of the four classes and assigning it to the class to which it was most similar. Similarity was determined by the Euclidean distance measure.

Vegetation Index, (7-5)÷(7+5)

As was the case with the 5/7 ratio, the Vegetation Index (V.I.) indicates the "greenness" of a scene in relation to the amount of green

Table 18. Performance of classification schemes applied to training fields. The EVGN class included four training fields; WIND, five; WISP, five; and TAIL, three. A field classified as EVGN was assigned the symbol (;). Symbols for the other classes were: WIND(/), WISP (=), and TAIL(+).

Classification Scheme	Training Fields EVGN(;) 1	2	3	4	WIND(/) 2	3	4	5	6	WISP(=) 1	2	3	4	5	TAIL(+) 2	3	4
CALSCAN (best six features)	;	;	;	;	/	/	/	/	/	=	=	=	=	=	+	+	+
MSS 5 ÷ MSS 7	;	;	;	;	/	/	/	/	/	=	=	=	=	=	+	+	+
Two 5/7 change	;	;	;	;	+	+	+	+	+	+	+	+	+	+	;	;	;
Three 5/7 change	;	;	+	+	/	/	/	/	/	=	=	=	=	=	+	+	;
Direction of 5/7 change	;	;			/	/	/			=	=	=	=	=	+	+	
Vegetation Index	;	;	;	;	/	/	/	/	/	=	=	=	=	=	+	+	+
Two V.I. change	;	;	;	;	;	;	;	;	;	+	+	+	+	+	;	;	;
Three V.I. change	;	;	;	+	/	/	/	/	/	=	=	=	=	=	+	+	/
Direction of V.I. change	;	;			/	/	/	/		=	=	=	=	=		+	

vegetative material that is present. "Greener" scenes are associated with smaller 5/7 values and larger V.I. values than all scenes depicting less green vegetation. Extremes which demonstrate this can be calculated from the August MSS Band 5 and 7 data for EVGN, WIND, and WISP compared to the data for TAIL:

	$\frac{\text{MSS 5}}{\text{MSS 7}}$	$\frac{\text{MSS 7 - MSS 5}}{\text{MSS 7 + MSS 5}}$
EVGN	.905	.050
WIND	.923	.040
WISP	.884	.062
TAIL	2.679	-.456

When Euclidean distance was used to determine the appropriate class assignment of a training field a distance measurement was made between the data for each field and each class. There were four classes, therefore four measurements were calculated for each training field. The field was assigned to the class to which it was the "closest" (smallest distance measurement). It was also possible to see which class was "second closest" to each field. In the class of both the 5/7 and V.I. classifications, the class which was second closest to the EVGN training fields was WIND. The second closest class to WIND training fields was WISP, and second closest class to WISP training fields was WIND. The second closest class to TAIL training fields was WISP. Schematically, the second closest class relationship was:

$$\text{EVGN} \rightarrow \text{WIND} \overset{\leftarrow}{\rightarrow} \text{WISP} \leftarrow \text{TAIL}$$

EVGN and TAIL were at the extremes; the former always green, the latter never green. Evidently, the tendency for misclassification would be for the extremes to look like one of the intermediate classes.

Change Factor Classifications

Change factors indicate the manner in which characteristics vary from date to date. A characteristic may be an MSS 5 ÷ MSS 7 ratio or a Vegetation Index; these may also be called features much the same as radiance values were considered features for CALSCAN.

Two-5/7 Change Factor: Each training field and class was characterized by a pair of change factors calculated as follows: November 5/7 ratio ÷ August 5/7 ratio, and April 5/7 ratio ÷ November 5/7 ratio. Each field and class therefore had a pair of change factors for the same time intervals. A training field's change factors were compared to those of each class by the Euclidean distance measure, and assigned to the class for which it had the smallest distance value.

Three-5/7 Change Factor: This classification scheme was performed in exactly the same manner as the two change factor scheme, but with the additional consideration of the August to April change factor (April 5/7 ratio ÷ August 5/7 ratio).

Vegetation Index Change Factors: Calculation and classification of two- and three-V.I. change factors paralleled the treatment of the 5/7 change factors.

The misclassifications by the several change factor schemes were evident from the results entered in Table 18. The three-change factor schemes far out-performed the two-change factor schemes. The former correctly classified WIND and WISP training fields and missed some EVGN and TAIL fields. The latter nearly failed completely.

Direction of Change Classifications

Direction of 5/7 Change: Classification of training fields by this scheme considered whether the 5/7 ratio increased, decreased, or remained the same during the time intervals August to November, November to April, and August to April. This was a qualitative evaluation; no regard was given to the magnitude of change. The possible patterns of two-interval changes were displayed in Figure 3; three-interval changes would add the consideration diagramed by connecting the end points of each plot. One type of pattern was identified for each class based on the manner in which the class 5/7 ratios varied. The standards were: EVGN (decrease, increase, increase), WIND (increase, decrease, increase), WISP (increase, increase, increase), and TAIL (no change, no change, no change). If, for example, an August 5/7 ratio equalled the corresponding November 5/7 ratio, then their ratio would equal unity. In the purest sense, no change would be unity. This seemed unlikely to occur, and in fact did not even for the TAIL ("no change") class. No change was therefore defined as a range: 0.97 - 1.01; this was based on the actual performance of the TAIL class standards identified above in "MSS 5 count ÷ MSS 7 count."

Direction of V.I. Change: Treatment of this scheme was the same as that for "direction of 5/7 change." As could be expected from the relationship of the two types of ratios to the "greenness" of a scene, the standards for this classification were just the opposite of those given above for the 5/7 change. That is, EVGN (increase, decrease, decrease), WIND (decrease, increase, decrease), and WISP (decrease, decrease, decrease). The TAIL V.I. values showed greater variation than the TAIL 5/7 values. The "no change" range based on the performance of the TAIL class standards was: 0.89 - 0.98. Appropriate ratios of V.I.'s which fell in this range were taken to mean "no change:" the TAIL standards were therefore: no change, no change, no change.

The classification results of the direction of change schemes were nearly identical (Table 18). Where training fields could be classified, their classifications were correct. However, some fields could not be classified because they presented patterns of change that were different from any of the class standards. For example, if a training field had an increase-increase-increase or an increase-decrease-increase pattern of change for its Vegetation Index, then the field could not have been matched to any of the class standards specified in the preceeding paragraph. This failure of some fields to classify accounts for the blanks in Table 18.

CLASSIFICATION OF GRID FIELDS

The Canelo grid contained vegetation types having highly prominent evergreen or winter-spring dormant species. The grid included one section of grid fields belonging to the EVGN class and a second section of fields belonging to the WISP class. The evergreen species were primarily those of the juniper-oak woodland and chaparral vegetation types; the winter-spring dormant species were primarily perennial grasses. The northern and eastern portions of the grid were perennial grasslands, and the southern and western portions were woodland and chaparral shrub types of the Canelo Hills.

The Rincon grid also primarily represented two of the phenological classes: EVGN and WIND. The evergreen species included Pinus ponderosa, Pseudotsuga menziesii, and other pine species in addition to those of the juniper-oak woodland and the chaparral shrub vegetation types. The evergreens were located on the mid to upper elevations of the Rincon and Tanque Verde Mountains. These mountains also had large areas of rock outcropings. The WIND species were those of the desert shrub and desert grassland vegetation types. Some of the species were Cercidium microphyllum, Prosopis juliflora, Acacia constricta, and Fouquieria splendens. Some perennial grass species were present in mid-prominence on the lower slopes of the mountains. This was also the location of extensive patches of Agave schottii, a low growing leaf succulent which formed extensive dense mats. Given sufficient prominence the grass species could cause a grid field to be classified as WISP; on the other hand the presence of the Agave could cause a classification of EVGN if it were sufficiently dense and extensive.

A fairly thorough familiarity with the Canelo and Rincon grid areas provided the basis for assigning a classification to each 16-element grid field of the two grids. Each grid field was identified as EVGN, WIND, or WISP according to the best approximation of each field's location. That approximation was achieved with an overlay of the systematic sampling plots on a 1:250,000 color enlargement of an ERTS scene. This provided a "ground truth map" of both grids (Figure 43). Some grid fields fell in the area of transition from one phenological type to another. In these cases, the fields were identified as representing both types. If either of the two types were identified in a subsequent stratification analysis, then the classification was considered correct.

The following evaluation of the several stratification strategies does not include the results of every classification attempt. The results of those strategies which were most successful are shown, accompanied by some of the unsuccessful results for the purposes of comparison.

The blocking pattern achieved with the MSS 5 + MSS 7 classification scheme serves to illustrate the success achieved with the use of 1) the Primary versus Alternate standards, 2) 16-element versus single-element grid fields, and 3) a reclassification procedure known as "nearest neighbor weighting."

When used in conjunction with the Primary standards the MSS 5 + MSS 7 scheme produced an inadequate classification of the Canelo grid fields and a less than marginally acceptable classification of the Rincon grid fields (Figure 44). A partitioning of the Rincon grid in

Canelo Grid

	0	1	2	3	4	5	6	7	8	9
1	=	=	=	=	=	=	=	=	=	=
2	=	=	=	=	=	=	=	=	=	=
3	=	=	=	=	=	=	=	=	=	=
4	=	;	=	=;	=	=;	=;	=	=	=
5	=;	;	;	;	;	;	=;	=	=	=
6	;	;	;	;	;	;	=;	=	=;	=
7	;	;	;	;	;	;	;	=;	=;	=
8	;	;	;	;	;	;	;	;	;	=
9	;	=;	=;	;	;	;	;	;	;	;

Rincon Grid

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	/	;	;	;	;	;	;	;	;	;	;	;	;	;	;	/
2	/	;	/	;	;	;	/;	/;	/;	;	;	;	;	/;	/;	/
3	/	/	/	/	/	/	/	/	/	;	;	;	;	;	/;	/
4	/	/	/	/	/	/	/	/	/	;	;	;	;	/;	/	/
5	/	/	/	/	/	/	/	/	/	/	/;	;	/	/;	;	/
6	/	/	/	/	/	/	/	/	/	/	/	/	/	/;	/;	/

Figure 43. Identification of the 16 element grid fields in the Canelo and Rincon Grids: EVGN (;), WIND (/), and WISP (=). Some grid fields were suspected of containing two subjects, and were therefore identified with two symbols. A grid field was referenced by its column number first, then its row number. For example, Canelo grid field 5-4 was "=;". Rincon grid fiels 15-4 was "/".

Canelo Grid

	0	1	2	3	4	5	6	7	8	9
1	=	/	=	=	=	/	=	=	=	=
2	=	/	/	=	=	/	=	=	/	=
3	=	=	=	=	=	=	=	=	=	/
4	=	=	=	=	/	=	=	=	=	/
5	=	=	=	=	/	=	=	=	=	=
6	=	/	=	=	=	/	=	=	=	=
7	/	=	/	/	/	=	=	=	=	/
8	/	;	;	;	;	;	/	/	/	/
9	=	/	;	/	/	/	/	/	=	/

Rincon Grid

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	/	/	/	/	;	/	/	/	/	;	;	/	/	/	/	/
2	/	/	/	/	/	/	/	/	/	/	/	;	/	/	/	/
3	/	/	/	/	/	/	/	/	/	/	/	/	;	/	/	/
4	/	/	/	/	/	/	/	/	/	/	/	/	;	/	/	/
5	/	/	/	/	/	/	/	/	/	/	/	;	;	;	/	/
6	/	/	/	/	/	/	/	/	/	/	/	/	/	/	;	/

Figure 44. MSS 5 : MSS 7 classification of 16-element grid fields with <u>Primary</u> standards. EVGN (;), WIND (/), WISP (=).

accordance with these results would provide a very conservative estimate of the portion of the grid area which supported evergreens. In contrast, this same classification scheme when used with the Alternate standards produced quite acceptable classifications of the grid fields (Figure 45). The results obtained with both types of standards can be compared with the "ground truth map" in Figure 43. The Alternate standards give a slightly generous estimate of EVGN in the Rincon grid and a slight underestimate of EVGN in the Canelo grid. This was reasonable because of the manner in which the Alternate standards were constituted. The Alternate EVGN standards were based on the mean radiance of most of the Canelo EVGN fields in the "ground truth map" (a few grid fields were deleted due to high standard deviations associated with the mean radiance value of the 16 elements/field). The EVGN vegetation of the Canelo grid was not as distinct as that of the Rincon grid. Juniper-oak woodland, for example, frequently had a well developed herbaceous understory whereas the mixed pine and fir coniferous forest of the Rincon grid did not. Consequently, the Alternate standard based on the Canelo evergreens permitted more grid fields in the Rincon grid to be classed as EVGN than the "ground truth map" indicates. In effect the Alternate standard provided a broader interpretation of what constituted evergreen vegetation. The results of a classification obviously depend in great measure on the manner in which class standards are selected.

Canelo Grid

	0	1	2	3	4	5	6	7	8	9
1	=	/	=	=	=	/	=	=	=	=
2	=	=	=	=	=	=	=	=	/	=
3	;	;	;	=	;	=	=	;	;	/
4	=	=	=	=	/	=	=	=	=	/
5	=	/	=	=	;	=	=	=	=	=
6	;	;	=	;	;	;	=	=	=	=
7	;	;	;	;	;	;	;	=	=	/
8	;	;	;	;	;	;	;	/	/	/
9	;	;	;	;	;	;	;	;	;	;

Rincon Grid

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	=	=	;	;	;	;	/	;	;	;	;	;	;	;	/	/
2	/	;	;	;	;	;	;	/	/	;	;	;	;	;	/	/
3	=	/	/	/	/	/	;	;	;	/	/	;	;	;	;	;
4	/	/	/	/	/	/	/	/	/	/	;	;	;	;	;	/
5	/	/	/	/	/	/	/	/	/	/	;	;	;	;	;	;
6	/	/	;	/	/	/	/	/	/	;	;	;	;	;	;	;

Figure 45. MSS 5 ÷ MSS 7 classification of 16-element grid fields with <u>Alternate</u> standards. EVGN (;), WIND (/), WISP (=).

The results from classification of 16-element grid fields and single-element fields were quite similar. The MSS 5 + MSS 7 scheme with Alternate standards was used to classify the smaller fields in both grids (Figure 46). These results are comparable with those in the immediately preceeding figure. A very similar blocking was achieved by both techniques. Recall that the results of these two approaches were achieved by using samples of three percent and 0.2% respectively of all the resolution elements in the two grids.

Depending on the complexity desired from the partitioning procedure, the classification output may be simplified by a reclassification utilizing "nearest neighbor weighting." Care must be taken when using this approach because increasing the homogeneity of the output is only gained by eliminating detail.

The rules that were followed to achieve the reclassification were:

1. Tabulate the original classification of the nine fields immediately surrounding the field in question.

2. Assign the field in question to the class to which most of the surrounding nine fields were classified.

3. In the case of a tie (no class included the majority of fields surrounding the field in question), leave the field as it was classified, assuming that its original classification was into a class which participated in the tie. If this assumption is incorrect then proceed with the reclassification of all surrounding fields, and then return to the field in question and consider its reclassification in light of the reclassified identities of the surrounding nine fields.

Canelo Grid

	0	1	2	3	4	5	6	7	8	9
1	=	/	=	=	=	/	=	=	=	=
2	=	=	=	=	=	=	=	=	/	=
3	=	=	;	=	=	=	=	=	=	=
4	;	;	=	=	/	=	=	=	=	=
5	;	/	/	=	;	=	=	=	/	=
6	;	=	;	=	;	;	;	=	=	=
7	;	;	;	;	;	;	;	;	/	=
8	;	;	;	;	;	;	;	;	;	/
9	/	;	;	;	;	;	;	=	=	=

Rincon Grid

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	=	=	;	;	;	/	;	;	;	;	;	;	;	;	/	/
2	/	;	;	;	;	;	;	;	;	;	;	;	;	;	/	/
3	=	/	=	/	/	/	;	;	/	=	/	;	;	;	;	/
4	/	/	/	/	/	/	/	/	/	/	;	;	;	;	;	/
5	/	/	/	/	/	/	/	/	/	/	;	;	;	;	;	/
6	/	/	/	/	/	/	/	/	/	/	;	;	;	;	;	;

Figure 46. MSS 5 ÷ MSS 7 classification of single-element grid fields with Alternate standards. EVGN (;), WIND (/), WISP (=).

This reclassification procedure was used to simplify the stratification that was achieved with classifying the single-element grid fields. The output from the reclassification is portrayed in Figure 47 to depict the partitioning effect achieved through the blocking of grid fields according to phenological class.

The Vegetation Index when used with the Alternate standards produced a nearly identical blocking pattern as did the MSS 5 + MSS 7 scheme. For that reason those results are not presented.

An acceptable blocking of the Rincon grid fields was achieved with a CALSCAN classification utilizing the Primary standards (Figure 48). This classification was performed with the maximum likelihood classifier "trained" on the radiance of the training classes in MSS Bands 5 and 7 from August, November and April. This combination of features was one of the best for discriminating the phenological training classes (see Table 16 and attendant discussions). Unlike the MSS 5 + MSS 7 and the V.I. schemes which treated each grid field as a unit and based the classification on the mean radiance of the 16 elements which constituted the unit, CALSCAN classified each resolution element of a grid field. The grid field classification was then determined as being that class to which the majority of the 16 elements were assigned. There was the possibility of having an even number assigned to two classes. Classification ties did occur as evidenced by the double symbols for a few grids. The problem of ties could have been reduced if the grid field size had been chosen as an odd number of elements not evenly divisible by the number of

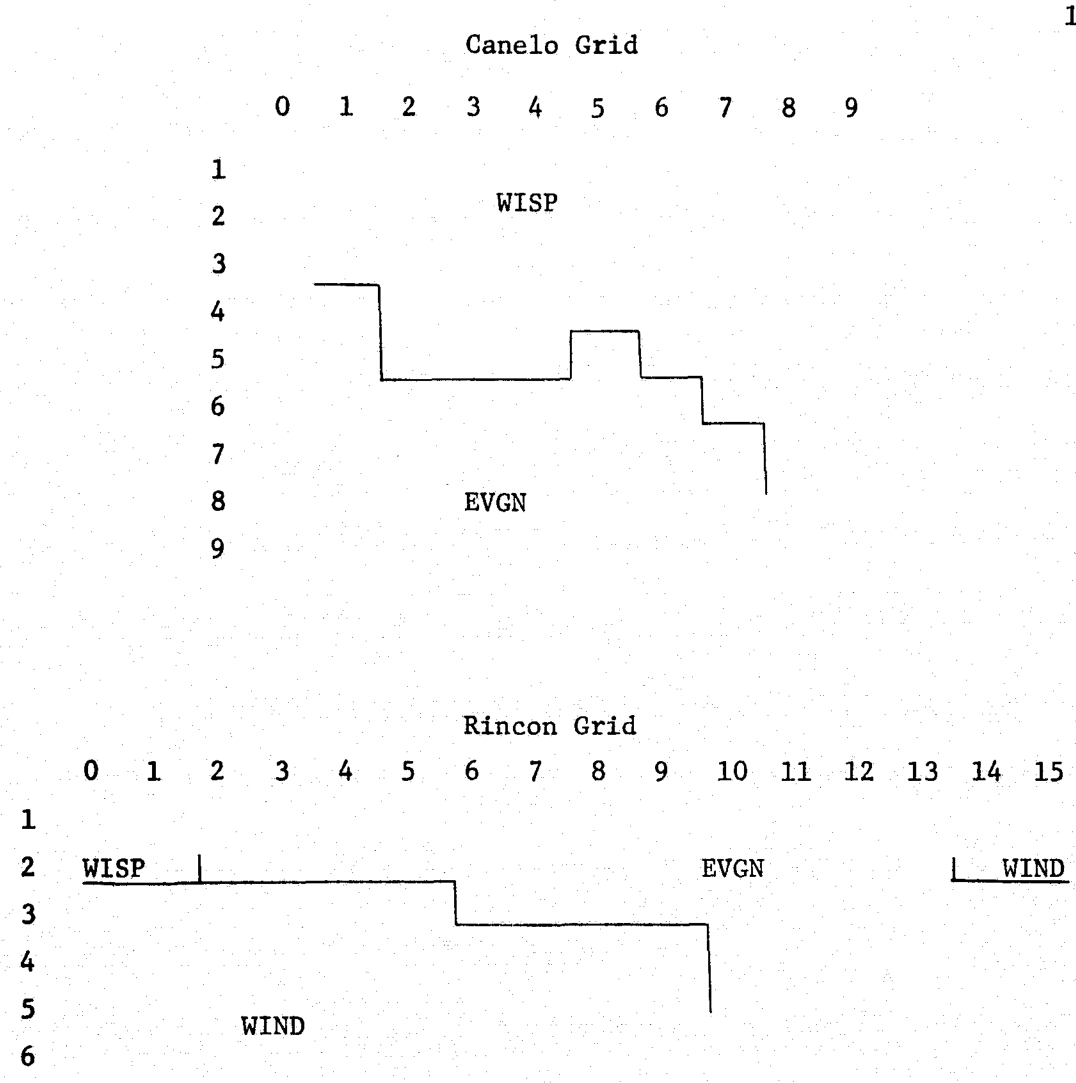


Figure 47. Stratification of the Canelo and Rincon grids. This partitioning effect was achieved with a strategy which employed: 1) Alternate standards; 2) MSS 5 + MSS 7 classification scheme; 3) single-element grid fields; and 4) reclassification with nearest neighbor weighting.

	6	7	8	9	10	11	12	13
1	/=	;	;	;	;	;	/	/
2	/=	=	=	/	;	;	/	/
3	/	/	=	=	=	;	;	/=
4	/	/	/	/	/	;	;	/
5	=	=	/	/	/	;	;	;
6	/=	=	/	/	=	=	;	/

1								
2		=	=	;	;	;	;	
3		/	/	/	;	;	;	
4		/	/	/	/	;	;	
5		/	/	/	/	;	;	
6								

Figure 48. Classification of Rincon grid fields using a "maximum likelihood classifier" trained on data in MSS Bands 5 and 7 from August, November, and April. The upper plot shows the results prior to reclassification of each field using a "nearest neighbor" weighting. The reclassified fields are shown in the lower plot. The partitioning effect is emphasized with lines. EVGN (;), WIND (/), WISP (=).

classes. Ties were resolved in an expedient manner; if one symbol of the pair was the correct classification then it was chosen to represent the field. The results were then reclassified to simplify the stratification (Figure 48). Only the data in Rincon grid columns six through 13 were classified. This reduction in number of grid fields was done to reduce computing costs.

The "red" and "IR" from three dates classification could not be considered successful however because of the performance on the Canelo grid fields. A definite partitioning of the field was not achieved. Ninety-two percent of the WISP grid fields were correctly identified, the remaining eight percent were misclassified as WIND. Actually, WIND classifications in some locations in the WISP portion of the Canelo grid could have been quite acceptable. There were drainageways located in this area which supported the winter dormant tree <u>Juglans</u> <u>major</u> (Arizona walnut) and perennial grass species which characteristically "green up" in the spring. Only 33% of the EVGN grid fields were correctly idenified; 19% were identified as WIND, and 48% as WISP.

The Canelo grid was partitioned into two distinct areas by the CALSCAN classifier trained on data from the MSS Band 5 from April. One area was correctly identified as WISP, however fields in the other area were incorrectly identified as WIND rather than EVGN. Band 5 from April was the band which provided the best average divergence among phenological classes.

The other stratification strategies, i.e., change factors and direction of change with Primary or Alternate standards, did not produce acceptable results. Classification of the Rincon grid fields with the three 5/7 change factor scheme produced the results in Figure 49. A stratification of the grid was not achieved. The change factors calcualted from the Alternate radiance standards for EVGN, WIND and WISP were:

	Nov/Aug	Apr/Nov	Apr/Aug
EVGN	1.05	1.24	1.30
WIND	1.01	.97	.98
WISP	1.18	1.07	1.27
TAIL	.97	.99	.96

Whenever Alternate standards were used for classifications the Primary standards for TAIL were used.

The 5/7 change factors indicate that WIND and TAIL were similar in that there was little date to date variation in the 5/7 ratios for those subjects. The classification results indicated that the 5/7 ratios for 77% of the grid fields under went little date to date variation. This included EVGN grid fields of dense conifers and WIND fields of sparsely scattered desert shrubs. In this case extremely different subjects were recognized as similar by virtue of their similar patterns of change.

The Vegetation Index change factor proved unsatisfactory as a basis for classification for at least two reasons. 1) The index can equal zero if the radiance count in Bands 5 and 7 are equal. This

Rincon Grid

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	=	=	=	=	/	;	/	/	=	/	;	/	/	+	+	+
2	/	;	/	/	/	=	=	/	/	/	/	/	=	/	+	/
3	=	/	/	/	/	/	=	/	/	/	/	/	+	/	/	/
4	/	/	/	/	/	/	+	+	/	/	/	/	;	/	=	/
5	+	+	+	+	/	/	/	+	+	/	=	+	=	=	/	/
6	+	+	/	+	+	+	+	+	+	+	;	;	;	/	/	;

Figure 49. Three 5/7 Change Factor classification with Alternate standards. The grid fields contained 16 elements. The three change factors were for the time periods August to November, November to April, and August to April Grid fields which were classified as TAIL are indicated with a (+); EVGN (;), WIND (/), and WISP (=).

potential never materialized, however several indices had values close to zero. Such a value when either in the numerator or the demoninator of a change factor calculation can result in an extremely small or large quotient. Either case was very unlike the Primary or Alternate standards for change factors. 2) The Vegetation Index gave an indication of the "greenness" of a scene. Larger values indicated a greener scene, and vice versa. Some V.I. values were negative. If the values were negative on two successive dates with the second being a smaller negative number than the first, then that would indicate that the scene was less green on the second date than it was on the first. The value of the change factor ratio however would be positive and greater than one. Another location would have positive V.I. values on two dates with the second date greener (larger V.I.) than the first. Here again the value of the V.I. change factor ratio would be positive and greater than one. Thus, Vegetation Index change factors can be ambiguous.

The direction of change classification scheme failed largely because the grid fields showed a greater variety in patterns of change than did the class standards. There were therefore several grid fields that remained unclassified.

STRATIFICATION OF SANTA RITA--SONOITA TRANSECT

The most successful stratification strategy for stratifying grid fields was the MSS 5 + MSS 7 scheme used with Alternate standards. This strategy was used to classify every 25th resolution element on three adjacent scan lines of ERTS data. The three lines extended from points A to B in the previous Figure 4. They represented a transect of approximately 40 km (25 mi) which began at the west (point A) in desert grassland and near a drainage with Prosopis juliflora, crossed over the Santa Rita Mountains and extended eastward into the Sonoita grassland. The classification results are given in Figure 50. The eastward extension of the EVGN type was entirely possible due primarily to the evergreen oaks which occupy the northerly aspects along the larger drainages. This provides a satisfactory discrimination among the major EVGN and WISP components of the landscape along the transect.

	1	26	51	76	101	126	151	176	201	226	251	276	301	326	351	376	401	426	451	476	501	526	551	576	601
1	=	/	;	;	;	;	;	;	;	;	=	=	=	/	;	=	/	=	=	=	/	=	=	=	=
2	/	;	;	;	;	;	;	;	;	=	;	=	=	=	=	;	=	=	=	=	/	=	=	=	=
3	;	;	;	;	;	;	;	;	;	;	;	/	;	;	;	;	=	=	=	=	/	=	=	=	=

Figure 50. Stratification of the Santa Rita-Sonoita transect. Every 25th resolution element in three adjacent scan lines of ERTS data were classified with the MSS 5 ÷ MSS 7 scheme used with Alternate standards. The transect was approximately 40 km (25 mi) in length. The major vegetational components along the transect were EVGN (conifer forest and juniper/oak woodland) and WISP (perennial grassland).

CLASSIFICATION OF VEGETATION STANDS

The vegetation types of the study area that were identified for this and related studies were presented earlier in "Results and Discussion." There they were organized by phenological class: EVGN, WIND, and WISP. That assignment to class was based upon the phenological character of the more prominent species of each vegetation type.

A second approach for determining a phenological classification of several of the vegetation types was based on the multiseasonal radiance data acquired by ERTS. The types selected for this analysis are listed in Table 19 and organized in a manner taken directly from the earlier section. Six EVGN types were considered; the stands from two of the types characterized by Mortonia scabrella were grouped together. Three WIND and two WISP vegetation types were also considered. More EVGN types were included than for WIND and WISP because of the great diversity that existed between desert shrub and forested evergreens. The stands were classified with the MSS 5 + MSS 7 scheme with Alternate standards. This was the stratification strategy which produced the most acceptable results in the classification of grid fields. The phenological classification of specific vegetation stands (Table 20) produced four strata of vegetation types:

1. All stands classified as WIND:

    Latr-Prju
    Cemi-Cegi-Enfa
    Prju-Hate-Cholla

Table 19. Vegetation types selected for phenological classification with ERTS multiseasonal radiance data. The types are organized by phenological class (EVGN, WIND, and WISP) according to the phenological character of their more prominent species.

EVGN Larrea tridentata with Prosopis juliflora and/or Opuntia (cholla).
Abbreviation: Latr-Prju

Mortonia scabrella without Rhus choriophylla; Mortonia scabrella with Rhus choriophylla.
Abbreviation: Mosc; Mosc-Rhch

Quercus and Nolina microcarpa; without Cercocarpus breviflorus, Arctostaphylos pungens, and Mimosa biuncifera.
Abbreviation: Quercus-Nomi

Quercus, Arctostaphylos pungens, Pinus cembroides, Juniperus deppeana, without Mimosa biuncifera.
Abbreviation: Quercus-Arpu-Pice

Cercocarpus breviflorus with Juniperus deppeana and/or Pinus cembroides and usually with Quercus.
Abbreviation: Cebr

WIND Cercidium microphyllum and Cereus giganteus often with Encelia farinosa and Opuntia spp., and without Franseria deltoidea.
Abbreviation: Cemi-Cegi-Enfa

Prosopis juliflora and Haplopappus tenuisectus with Opuntia (cholla) and without Acacia constricta and Calliandra.
Abbreviation: Prju-Hate-Cholla

Acacia vernicosa, Flourensia cernua, Larrea tridentata, and Rhus microphylla.
Abbreviation: Acve-Latr-Rhmi

WISP Calliandra eriophylla and Bouteloua with any or all of Ephedra trifurca, Yucca baccata, Y. elata, Prosopis juliflora, and without Acacia constricta.
Abbreviation: Caer-Eptr-Yucca

Bouteloua and Aristida without large shrubs, Nolina microcarpa, Yucca, and Calliandra eriophylla.
Abbreviation: Bout-Arist

Table 20. Phenological classification of specific vegetation stands, EVGN (;), WIND (/), WISP (=), and TAIL(+). These results were achieved with the MSS 5 ÷ MSS 7 classification scheme utilizing Alternate standards adjusted for use with densitometrically derived 5/7 ratios. Two vegetation types were represented by nine rather than ten stands. This accounts for the two blanks present in the table.

Vegetation Type	Phenological classification by most prominent species	Phenological classification by ERTS multiseasonal, multispectral radiance									
		Stands									
		a	b	c	d	e	f	g	h	i	j
Latr-Prju	EVGN	/	/	/	/	/	/	/	/	/	/
Cemi-Cegi-Enfa	WIND	/	/	/	/	/	/	/	/	/	/
Prju-Hate-Cholla	WIND	/	/	/	/	/	/	/	/	/	/
Acve-Latr-Rhmi	WIND	/	/	/	/	=	=	=	=	=	=
Mosc; Mosc-Rhch	EVGN	/	/	/	/	/	=	=	=	=	
Caer-Eptr-Yucca	WISP	/	/	/	=	=	=	=	=	=	=
Bout-Arist	WISP	;	;	=	=	=	=	=	=	=	=
Quercus-Nomi	EVGN	;	;	;	;	;	;	/	/	=	+
Quercus-Arpu-Pice	EVGN	;	;	;	;	;	;	;	;	;	
Cebr	EVGN	;	;	;	;	;	;	;	;	;	/

2. Stands classified as WIND and WISP:

   Acve-Latr-Rhmi
   Mosc; Mosc-Rhch
   Caer-Eptr-Yucca

3. Stands classified primarily as WISP:

   Bout-Arist

4. Stands classified primarily as EVGN:

   Quercus-Nomi
   Quercus-Arpu-Pice
   Cebr

The first five types listed in Table 20 had a shrub-scrub physiognomy. The three that classified exclusively as WIND were "microphyllous, non-thorny scrub, generally with succulents." Grasses generally had low prominence ratings in stands of these types. Even though Larrea tridentata is an evergreen the stands of the Latr-Prju group classified as WIND. Most likely, this was due to the low percent of vegetative cover which would have made the Latr-Prju stands "look like" WIND. The WIND grid fields of the Rincon grid, on which the classification standards were based, also had sparse vegetative ground cover. Cemi-Cegi-Enfa and Prju-Hate-Cholla both occur in that portion of the Rincon grid from which the Alternate WIND standards were derived. Radiance from these vegetation stands was, therefore, quite similar to the Alternate standards.

It was evident from the field data that perennial grasses frequently attained mid- to high prominence in the stands of Acve-Latr-Rhmi, Mosc, and Mosc-Rhch. Thus, WISP could be an acceptable classification for stands of these types. A review of the field descriptions for these specific stands, however, did not indicate any notable contrasts between those stands of the two groups which classified as WIND and those which classified as WISP. Although Mortonia scrabrella is an evergreen, none of the Mosc or Mosc-Rhch stands were classified as EVGN. There was no apparent relationship between the classification of each Mortonia stand and either the type it belonged to, the prominence of Mortonia in the stand, or the prominence of the grasses.

The physiognomy of Caer-Eptr-Yucca stands was either "herbaceous" or "scattered tall shrubs over herbs." The prominent herbaceous component both of this type and the Bout-Arist type apparently influenced the classification of several stands. The stands which were classified as WISP contained grasses which were given a prominence rating of five. Those which classified as WIND had grasses at lower prominence.

The field data provided no indication of why the two Bout-Arist stands classified as EVGN.

The last three vegetation types in Table 20 contained several evergreen species. The physiognomy of each type could vary as was indicated in their descriptions (preceeding Figures 14, 17, and 18). The classifications of Quercus-Nomi stands were quite varied. Of the last three groups, this group was the one which usually had a well developed herbaceous layer. Also, the stand which was classified as TAIL was the only stand not having oaks and/or junipers at a prominence of four or five. The Quercus-Nomi type appeared to have been the most varied of the eleven types that were sampled.

The physiognomy of the Quercus-Arpu-Pice and Cebr vegetation types varied between a forest or wood aspect to that of a shrub aspect. Evergreen species were prominent in both physiognomic forms, and there was consequently less variation in the classification results. Cebr stands usually were found to have evergreen oaks, junipers, and/or Pinus cembroides in mid- to high prominence. The stand which classified as WIND did not have this well developed evergreen tree layer.

CONCLUDING STATEMENTS

This study was designed to investigate data analysis techniques which would achieve an initial approximation of a vegetation classification and a vegetation map for a specified region. The investigative course capitalized on the expression of plant phenological development that could be documented in multiseasonal, multispectral radiance data acquired by an orbital satellite.

Two questions were initially posed: 1) Can vegetation types be characterized in terms of phenological patterns of change detected with multidate remote sensing? and 2) Can apparent phenological patterns be used for stratifying synoptic, multidate remotely sensed imagery?

The following were determined in relation to the first question:

1) Variations in phenological development among plant species was noted as well as the tendency for the seasonal appearance of some vegetation types to be dominated by the appearance of one or a few similarly developing species.

2) As evidenced from the ground, most of the common plants in the study area could be characterized by the temporal aspects of their phenological development. On that basis, they could be assigned to one of three classes: evergreen (EVGN); winter dormant (WIND); or winter-spring dormant (WISP). Generally speaking, plants belonging to EVGN had green foliage throughout the year (e.g., conifers, oaks, leaf succulents). Those belonging to WIND had green foliage in spring, summer, and early fall (e.g., many desert shrubs). WISP plants greened up in the summer and dried up or lost their leaves in early fall (e.g., many perennial grasses).

3) There was a strong similarity among the spectral signatures of vegetation types in which the spectral return was dominated by green plant material. This was true for vegetation types of entirely different physiognomic character. Radiant energy from EVGN, WIND, and WISP showed a similar pattern of spectral distribution among the ERTS MSS Bands. This spectral signature pattern was also evident in the radiance from EVGN during three seasons - summer, winter, and spring.

4) When the soil background dominated the spectral return from a vegetation stand, then the spectral radiance and the vegetation physiognomy were apparently related. A vegetation type having a uniform physiognomy also tended to have one phenological spectral signature; e.g., Larrea tridentata with Prosopis juliflora and/or Opuntia (cholla). In contrast, vegetation types which could be represented by a variety of physiognomic forms also tended to have a variety of phenological spectral signatures (e.g., Quercus and Nolina microcarpa; without Cercocarpus breviflorous, Arctostaphylos pungens, and Mimosa biuncifera).

5) When the deciduous shrubs (e.g., Prosopis juliflora) of the WIND group lost their leaves, their spectral signature altered with a slight decrease of radiance in the visible wavelengths and a strong decrease in the near infrared.

6) As the foliage of perennial grasses (primarily Hilaria mutica) cured from August to November, its apparent green radiance remained unchanged, red radiance increased over 50 percent, and near infrared radiance decreased approximately 30 percent. Radiance in all MSS bands increased between November and April, presumably with additional curring of the grass foliage.

7) A highly reflective mineral surface exhibited high radiance levels in all four bands, thus providing a marked contrast to the absorption characteristics of vegetation canopies. The contrast was especially dramatic in data of the green and red bands of the ERTS-1 MSS system.

8) The maximum dissimilarity among the phenological classes EVGN, WIND, and WISP was achieved with radiance in spectral bands 0.6-0.7μ (red) and 0.8-1.1μ (near infrared) from summer, winter, and spring.

9) More than one date of radiance data is necessary to achieve the best discrimination among phenological types.

10) Classification schemes which successfully distinguished the phenological classes were:

A. A maximum likelihood, discriminant analysis classifier (CALSCAN);

B. MSS 5 ÷ MSS 7;

C. August to November, November to April, and August to April MSS 5 ÷ MSS 7 change factors; and

D. (MSS 7 - MSS 5) ÷ (MSS 7 + MSS 5), the Vegetation Index.

11) Classification of training field elements representing EVGN, WIND, and WISP had an overall performance of 99.8 percent correct. In the EVGN class, one of 546 resolution elements was misclassified as WISP. Of the 64 elements in the WIND class, one was also misclassified as WISP. All elements in the WISP and TAIL classes were correctly classified. This merely served to indicate that the four classes, as represented by the ERTS-1 MSS data, were distinct, and that the resolution elements were good representatives of their respective classes.

12) Classifications of training fields with MSS 5 ÷ MSS 7 and the Vegetation Index achieved 100 percent accuracy.

13) Change Factor classifications achieved 82 percent accuracy.

The following were determined in relation to question two:

1) Phenological patterns of change may not be useful for classifying vegetation having a high percentage of bare ground.

2) Multiseasonal spectral signatures for vegetation types having high percentages of bare ground could be successfully used to distinguish vegetation types which belonged to the three phenological classes.

3) A stratification of an ERTS scene could be achieved which distinguished phenologically dissimilar areas.

4) The stratification provided a fairly good approximation of "ground truth."

5) The stratification was accomplished by analyzing only 0.2 percent of the available ERTS data points.

6) A constant, "no change" reference surface occurring within the scene was used to correct radiance data for subjects which were subject to temporal variation.

Several areas of interest for further investigation were recognized from these results. Of particular interest would be:

1) Further clarification of the relationships of the MSS 5 ÷ MSS 7 and Vegetation Index to such characteristics of natural vegetation as stand structure, floral composition, ground cover, and plant phenology.

2) The determination of detection thresholds pertaining to phenological change.

3) Further experimentation with the classification of vegetation with multiseasonal spectral radiance in comparison to single date

classification.

4) Further theoretical development of the concept of subject recognition through the identification of unique and repeated patterns of temporal variation.

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APPENDICES

APPENDIX A

PROMINENCE RATINGS: CONCEPT AND DEFINITIONS
(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 of Symbol
5	The most prominent species in the stand; the most obvious species in terms of amount present. Impression on the observer is that there is clearly more of the subject species than any other. Some stands may not have a species that clearly rates "5" and the class would be omitted. A stand can have only one species with this prominence level.
4	Clearly the second most prominent species in the stand or one of a group of species that share about equally in being most prominent (in such a 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".

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.

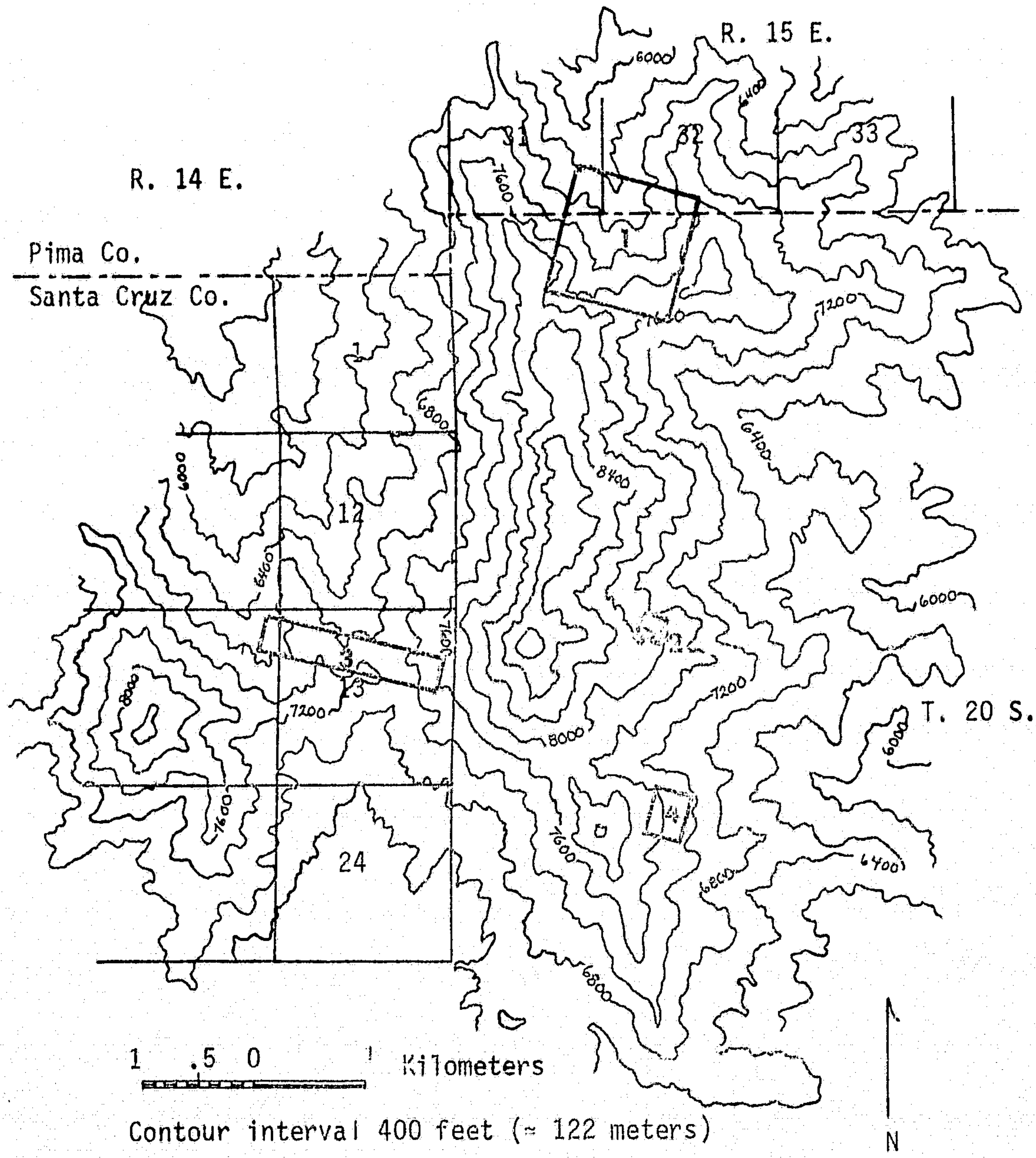
APPENDIX B

APPROXIMATE GROUND AREAS SELECTED TO REPRESENT THE PLANT PHENOLOGICAL AND "NO CHANGE" CLASSES

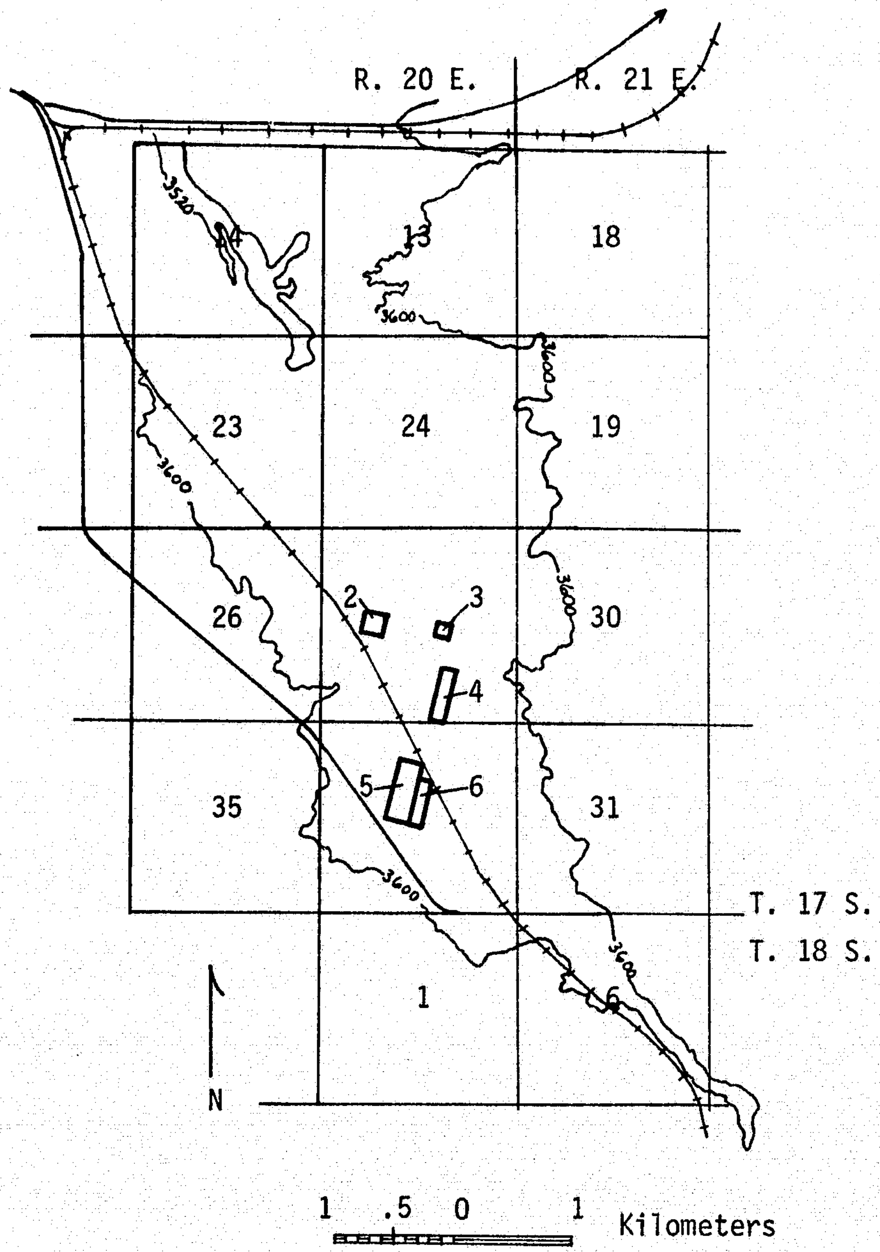
The Evergreen (EVGN) phenological class was represented by four ground areas. Areas One, Two, and Three were composites of several facets, most facing in a northerly direction. Area Four was located on a uniform east facing slope (slope azimuth = 90°).

The Winter-dormant (WIND) and Winter-spring dormant (WISP) classes were represented by five ground areas each. All areas were on nearly horizontal surfaces.

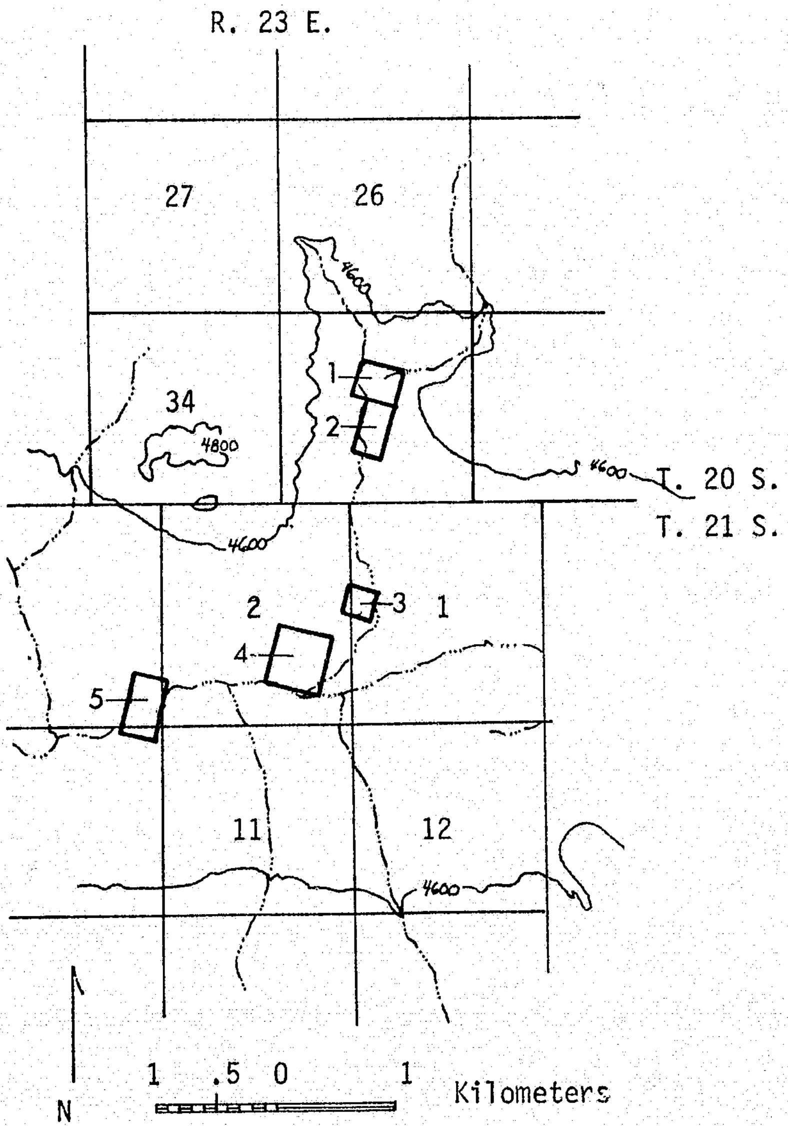
The TAIL class representatives were located in Section 32, of T. 16 S., R. 13 E., and in T. 17 S., R. 13 E., Section 5, NW1/4 (Twin Buttes Quadrangle, Arizona; 15 minute series).



Approximate ground areas representing the Evergreen phenological class. Map is from the Mount Wrightson Quadrangle, Arizona; fifteen minute series.



Approximate ground areas representing the Winter dormant phenological class. Map is from the Happy Valley and St. David Quadrangles, Arizona; fifteen minute series.



Approximate ground areas representing the Winter-spring dormant phenological class. Map is from the Gleeson Quadrangle, Arizona; fifteen minute series.

APPENDIX C

SOURCES AND EVIDENCE OF TEMPORAL VARIATION IN ERTS-I MSS DATA

Several variables may contribute to the temporal variations evident in the electromagnetic data recorded by the satellite's detectors. The variables may include: sensitivity of the detectors, earth-sun distance, angle of incidence, atmospheric attenuation, bi-directional reflectance, and spectral reflectance characteristics.

DETECTOR SENSITIVITY

Long term changes in detector sensitivity were monitored by using an internal calibration source lamp on board the satellite. During every other retrace movement of the MSS scanning mirror, the emitted energy of the calibration lamp was reflected into the detectors. This provided the means for revealing changes in the response characteristics of the individual detectors. Variations in the energy output of the calibration lamp were monitored by reflecting direct solar radiation onto the MSS detectors at a specific point in the satellite's orbit. The calibration data were transmitted with accompanying measurements of reflected energy from the earth. The latter were calibrated prior to distribution of the data to investigators (NASA, 1972).

EARTH-SUN DISTANCE

The earth's orbit around the sun is an ellipsoid. The mean distance of the earth from the sun is half the sum of the longest and shortest distances (Robinson, 1966). The energy received by the earth from the sun is defined as the solar constant: the total solar radiation at normal incidence outside the atmosphere at the mean solar distance (List, 1949). It follows, that the total solar radiation will vary with changes in the earth-sun distance; the variation is approximately 6.8 percent annually. The irradiance by the direct solar beam of a surface normal to that beam can be calculated from the solar constant and the radius vector of the earth[4/]:

$$I = I_o \div R^2$$

where

I is the irradiancy by the solar beam at normal incidence

I_o is the solar constant [1.94 langleys $min.^{-1}$ One langley (ly) = one gram-calorie per square centimeter (cal cm^{-2})]

R is the radius vector of the earth

The values of the radius vector of the earth for the dates of imagery selected for analysis were: 22 Aug 72 (1.01141); 2 Nov 72 (0.9924); 13 Apr 73 (1.00276). These values were linearly interpolated from List (1949, Table 169). Values for "I" on those dates were: 1.896, 1.970, and 1.929 ly min^{-1}, respectively.

[4/] The radius vector of the earth is the distance from the center of the earth to the center of the sun divided by the mean earth-sun distance (List, 1949). The mean earth-sun distance is also known as the semi-major axis of the earth's orbit, the numerical value of which is called the astronomical unit (Robinson, 1966).

ANGLE OF INCIDENCE

This angle is defined by the direct solar beam and the normal to the surface of interest. For a horizontal surface, this angle is determined by several variables referenced to the time and place of observation. Those variables are: latitude, solar declination, and time from solar noon. For inclined surfaces, slope and aspect must also be considered. Surfaces remained fixed with respect to latitude, slope, and aspect. The local standard time of satellite overpass remained relatively constant from date to date. However, both the declination of the sun and the time from solar noon at the moment of observation did vary among dates. The latter was accounted for by the ephemeris of the sun (Robinson, 1966). The variation of these two factors resulted in date to date changes in the solar altitude and azimuth (see Table 3). It followed that with changes in the sun's position in the sky, the incidence of the direct solar beam on a specified surface and the instantaneous irradiation of that surface also varied.

An example is provided in Appendix E showing the calculation of the instantaneous irradiation of selected surfaces in the study area.

ATMOSPHERIC ATTENUATION

The transmission of e-m radiation by the earth's atmosphere may vary with changes in concentrations of the atmospheric constituents. The length of the pathway through the atmosphere, which is a function of the sun's elevation above the horizon, may vary with time of day and year; increases in that length provide more opportunity for the atmospheric constituents to interact with the penetrating wavelengths (see Review of Literature, Atmospheric Effects and Irradiation of the Earth's Surface).

The length of the atmospheric pathway, as indicated by the optical air mass, did vary among the dates for which ERTS-1 imagery was selected for analysis.

	Solar		
Date	Elevation	Zenith angle	Optical air mass
22 Aug 72	56^o	34^o	1.21
2 Nov 72	37^o	53^o	1.66
13 Apr 73	55^o	35^o	1.22

Atmospheric attenuation can exhibit wavelength dependence. The extent to which the radiance data recorded by the ERTS-1 MSS system may have undergone wavelength dependent attenuation can be approximated from data provided by Robinson (1966, Chapter 5). The following indicates the magnitude of change in spectral energy distribution of the direct solar beam which could accompany the solar elevation variation given above. The atmosphere is assumed to be clean and dry (Rayleigh atmosphere).

Spectral band	% of total energy elev. = 55^o	35^o	% Change
0.425 - 0.535μ	11.05	10.75	-2.71
0.535 - 0.644μ	14.30	14.15	-1.05
0.644 - 0.764μ	13.35	13.60	+1.87
0.764 - 1.050μ	19.40	20.05	+3.35

The change in solar elevation from a high on 22 Aug 72 to a low on 2 Nov 72 was theoretically accompanied by a relative reduction of direct solar beam energy in the blue and green wavelengths and a relative increase in the red and near infrared wavelengths (a portion of the blue and green energy subtracted from the direct beam will still impinge on the earth's surface as sky radiation). It would appear that data gathered by the ERTS-1 MSS system would indicate that relatively more energy was being reflected in longer wavelengths with respect to the shorter wavelengths than was really the case. Also, this condition would be magnified on dates of lower solar elevation in comparison to dates of higher solar elevation. However; due to sky radiation, the spectral distribution of global radiation may be quite similar to that of extra-terrestrial solar radiation, although they differ markedly in magnitude due to atmospheric attenuation.

Incoming solar radiation was measured at the time of satellite overpass by two instruments located on the University of Arizona campus. One instrument (a pyreheliometer) measured the direct solar radiation at normal incidence; the other (a pyranometer) measured global radiation (total incoming radiation received by a horizontal surface). Global radiation is solar radiation (usually not at normal incidence) plus sky radiation. Those measurements were as follows:

	Direct solar radiation	Global radiation	units
22 Aug 72	1.44	1.28	langleys/min.
2 Nov 72	1.39	0.91	"
13 Apr 73	1.49	1.33	"

Direct solar irradiation at normal incidence above the atmosphere on the dates of interest was 1.90, 1.97, and 1.93 langley/min., respectively. From the values for normal incidence above and below the atmosphere, the atmospheric attenuation factor of the direct solar beam can be calculated to have been:

22 Aug 72	:	.24
2 Nov 72	:	.29
13 Apr 73	:	.23

The variation may be attributable to changes in the actual optical air mass through which the radiation was transmitted.

Determination of the atmospheric attenuation of the direct beam may not be the most meaningful for remote sensing purposes. A portion of that energy removed from the direct beam still may irradiate the subject of interest in the form of sky radiation. An assessment may be made of effective attenuation by calculating the instantaneous irradiation of a horizontal surface (a pyranometer receiver), assuming no stmosphere, and comparing that calculated figure to the actual pyranometer measurement. From Appendix E, Surface One, the calculated value of the instantaneous irradiation of the pyranometer receiver, assuming no atmosphere, at the time of the satellite overpass would have been:

22 Aug 72	:	1.569 ly/min
2 Nov 72	:	1.201 ly/min
13 Apr 73	:	1.568 ly/min

Corresponding pyranometer measurements were: 1.28, 0.91, and 1.33 ly/min. The effective atmospheric attenuation factor for the three dates of data was, therefore:

22 Aug 72	:	.18
2 Nov 72	:	.24
13 Apr 73	:	.15

BIDIRECTIONAL REFLECTANCE

Some variation may have been introduced into the data from this source, but it was reasonable to expect that it was relatively small. Bidirectional reflectance may vary with both the look angle and the angle of irradiation. For nearly horizontal surfaces in the study area, the angle of irradiation varied with the solar elevation which varied a maximum of 19°. The variation in look angle of the MSS scanning mirror was quite small.

SPECTRAL REFLECTANCE

Actual reflectance measurements could not be determined from ERTS-MSS data alone. However, variations in the apparent spectral radiance of several target areas indicated that reflectance characteristics of some subjects did change between the dates of successive data acquisitions. Those changes were evident from a review of three dates of ERTS-1 MSS reconstituted color composite photographs and of radiance data extracted from the ERTS-1 MSS computer compatible tapes.

APPENDIX D

ADJUSTMENTS OF ERTS-I MSS DATA

Energy recording instruments such as those employed in remote sensing data acquisition and analysis systems record energy as it is received at the sensor. This provides an approximation of the actual spectral radiance being reflected and/or emitted by ground subjects. For this reason, soils and plants, which are frequently subjects of interest and therefore targets for remote sensors, are represented by "apparent" radiance values differing from "actual" radiance primarily due to atmospheric effects and bidirectional reflectance. Signal modulations imposed by the sensors may contribute to further decay of the actual radiance prior to presentation as an apparent radiance value on computer tape or photographic product; these modulations may be corrected by sensor calibration.

Radiance data collected on several dates for a specific subject may be adjusted for among date differences in angle of incidence and atmospheric attenuation. Data adjusted in this manner may then be compared and differences in that data attributed to factors other than changing solar elevation and atmospheric attenuation.

Adjustments for solar elevation are based solely on geometric considerations. As presented in Appendix E, the instantaneous irradiation, I_s, of a horizontal surface, ignoring atmospheric effects, is given by:

$$I_s = \frac{I_o}{R^2} \sin \gamma, \text{ where } \gamma = \text{solar elevation, or}$$

$$I_s = \frac{I_o}{R^2} \cos z, \text{ where } z = \text{solar zenith angle } (90^{\circ} - \gamma)$$

The adjustment for solar elevation is therefore made by dividing the actual radiance or irradiance measurement by sin γ.

Adjustment for atmospheric effects may be made if measurements of actual incoming radiation at the moments of interest are available. Comparison of the instantaneous irradiation of a horizontal surface above the atmosphere (calculated) with the instantaneous irradiation of a horizontal surface at ground level (pyranometer measurement) reveals the effective atmospheric attenuation factor of e-m radiation on one traverse of the atmosphere (calculated - actual) ÷ calculated. Once the factor is known, the actual radiance or irradiance measurement may be divided by (1.00 - the attenuation factor), to adjust for atmospheric attenuation. This would approximate a correction applicable to horizontal or nearly horizontal surfaces.

Adjustment of ERTS-1 MSS data for atmospheric effects in this manner involves at least two assumptions. First, that the effective attenuation based on global radiation is similar to the attenuation of the wavelengths to which the MSS detectors were sensitive. Second, that spectral shifts in energy distribution with changing optical air mass were minimal. The magnitude of attenuation by the atmosphere is wavelength dependent. The shorter wavelengths are more susceptible to scattering, for example, than are the longer on a clear, dry day.

The ERTS-1 MSS detects energy in the green, red, and near infrared wavelengths, not those which contain the highest levels of energy and which are most susceptible to scattering namely the blue. An attenuation factor calculated on the basis of the attenuation of the direct beam would show the impact of the atmospheric selectivity for the shorter wavelengths and therefore suggest a stronger attenuation than was probably the case of the wavelengths that the MSS sensors detected. Calculation of the effective atmospheric attenuation utilizing measurements of global irradiance is subject to the ameliorating effect of the partial restoration of energy in the shorter wavelengths. This may be more representative of the attenuation of the MSS detected wavelengths. Still this is only an approximation of the impact of the atmosphere, which is largely the reason why the adjustment is called an adjustment rather than a correction.

Spectral shifts of energy are also known to accompany changes in the optical air mass being traversed. However, these shifts are most noticeable when the solar zenith angle is approaching 80 degrees or more (optical air mass = 5.6 or higher). Spectral shifts accompanying the variation of optical air mass actually encountered in this study were probably quite small.

These adjustments for multidate data (comparable data acquired over more than one date) adjust for only one passage of the e-m radiation through the atmosphere. The data recorded by the ERTS-1 MSS system pertained to energy which passed through the atmosphere twice, except for that component which was scattered upward by the atmosphere.

The first traverse was along a slant path with optical air mass greater than one. The second was directly upward from ground to satellite with the optical air mass equal to one. The first traverse varied from date to date, the second was constant. Adjustments for the first traverse are probably more critical than adjustments for the second traverse.

Adjustment for differences in the response characteristics among the MSS detectors may also be made. There were different values of maximum radiance required to raise each detector response to its highest level of response. The value for Band 6 was the lowest; that for Band 7 was highest. Values for Bands 5 and 4 fell in between. That meant that Band 6 response was strongest, followed by Bands 5 and 4, and Band 7 response was weakest. In order to achieve a maximum count of 63, Band 4 detectors had to receive a radiance in front of the lens of 2.48 mw/cm^2 - steradian. Similar values for Bands 5, 6, and 7 were 2.00, 1.76, and 4.60 mw/cm^2 steradian. If, for example, the detector if Band 4 recorded a sensor count of 50, this would indicate an apparent scene radiance of $50 \times 2.48 \div 63 = 1.97$ mw/cm^2 - steradian. Rather than to convert the counts to units of energy, the detector outputs can be normalized by multiplying Band 4 counts by 2.48/1.76, Band 5 by 2.00/1.76, and Band 7 by 4.60/1.76. This put all counts on a par with those of Band 6.

Radiance received by the MSS sensors was recorded by the scanning system as sensor "counts." A "count" could fall within the range of zero to 63. The maximum count would be achieved by the "maximum radiance" for each band. For reasons dealing with signal to noise ratios (NASA, 1972) the data in MSS Bands 4, 5, and 6 were logarithmically compressed prior to satellite to earth transmission. Band 7 data were transmitted linearly. The compressed data were decompressed prior to calibration and writing on computer compatible tapes. The decompression formula expanded the zero to 63 scale of compressed data to a zero to 127 scale.

From the compression and decompression curves (NASA, 1972), it is possible to see how a sensor count was converted to a CCT count in MSS Bands 4, 5, and 6. For example:

Sensor count (satellite)	Compressed count (transmitted)	Decompressed count (CCT)
6 (ca. 10% max)	13	12
9 (ca. 15% max)	18	18
16 (ca. 25% max)	27	32
32 (ca. 50% max)	42	63
47 (ca. 75% max)	53	95

The logarithmic compression expanded the lower levels and compressed the higher levels of sensor counts. The decompression function in effect was nearly linear for the lower levels and greatly expanded in the higher levels of compressed data. Prior to calibration, the decompressed data could only occupy specific levels of the zero to 127 scale. After slight adjustments were made in the data to calibrate for drift in detector sensitivity the data could occupy some of the unused levels of the scale (Thomas, 1973). The decompressed values were linear, ranged from zero to 127, and were approximately double the original sensor count. Data on the two scales can be reconciled by matching the end points of the scales, either halving one or doubling the other.

Radiance values presented in Table 13 of "Results and Discussion" had been adjusted in the manner described in this appendix. Those values had also been adjusted for what I have chosen to call the November anomaly. Data in the following table are directly comparable to that of Table 13; they are not, however, adjusted for the anomaly. An unexpected variation in the data of the following table cast doubt on the validity of the magnitude of the November data. Note the values for TAIL-3. The study of the chronological sequence of aerial photography led to the conclusion that TAIL-3 probably retained constant reflectivity characteristics throughout the sampling period. Instantaneous solar irradiation values calculated for TAIL-3 and adjusted for angle of incidence showed date to date change factors of : Nov/Aug = 1.06, Apr/Nov = 0.96, and Apr/Aug = 1.01. These two considerations led to the belief that the adjusted November values for TAIL-3 should have been more in line with its August and April values. A new November value was calculated as the average of: (Aug value)(1.06) = Nov value and (Apr value) ÷ 0.96 = Nov value, from the change factors above. The TAIL-3 November values thus calculated were: MSS 4 = 166, MSS 5 = 166, MSS 6 = 132, and MSS 7 = 292. Reduction of the TAIL-3 November values made little sense unless those of the other subjects were also reduced. The other subjects may well have undergone reflectance changes between samplings, therefore, ERTS-1 MSS computer compatible tape counts adjusted for count scale, detector response, angle of incidence, and effective atmospheric attenuation.

		CCT Counts			
Subject	Month	MSS 5	MSS 5	MSS 6	MSS 7
EVGN-4	Aug	49	34	52	151
	Nov	58	38	68	204
	Apr	34	18	35	104
WIND	Aug	56	37	63	187
	Nov	65	39	41	102
	Apr	66	51	54	142
WISP	Aug	60	40	71	211
	Nov	80	70	60	158
	Apr	86	76	65	160
TAIL-3	Aug	157	157	127	272
	Nov	185	172	140	304
	Apr	160	159	125	284

their reduction had to be guided by that of the TAIL-3 reduction. If the November anomaly was significantly correlated with the magnitude of the count, then the reduction of the November values for the other subjects should be in the same proportion as that for TAIL-3. If such a correlation did not occur, but all the November values were simply high by a constant amount for each band then the values could be reduced by the amount of those constants. The decision was arbitrary, the latter adjustment was chosen.

APPENDIX E

CALCULATION OF INSTANTANEOUS IRRADIATION OF SELECTED SURFACES AT THE TIME OF ERTS-1 DATA ACQUISITION

The following calculations did not consider the interaction of the atmosphere with electromagnetic radiation. The calcualtions pertained, therefore, to an equivalent surface above the atmosphere or to the case of no atmosphere. The calculations followed those of Frank and Lee (1966); explanation of the equation of time (ephemeris of the sun) was given by Robinson (1966); data for solar declination, equation of time, and the radius vector of the earth were from List (1949); latitude, slope, and aspect for surfaces of interest were determined from USGS topographic maps (scale = 1:62,500) for the study area; and Greenwich Mean Time at the moment of ERTS data acquisition was from the ERTS-1 scene annotation blocks.

$$I_s = \frac{I_o}{R^2} (\sin \theta \cdot \sin \delta + \cos \theta \cdot \cos \delta \cdot \cos \omega t)$$

where:

I_o = solar constant {1.94 ly min^{-1} (List, 1949)}

R^2 = radius vector

Θ = terrestrial latitude

δ = solar declination (+, north of the equator; –, south)

ω = angular velocity of the earth's rotation, 15 degrees per hour ($360^o \div 24$ hrs)

t = number of hours before (–) or after (+) true solar noon – the moment the geometric center of the sun crosses the meridian (longitude) of the observer.

Local standard time (zone time) is the mean solar time of the time zone in question. Time zones basically are 15° longitudinal zones; Mountain Standard Time, for example, is 105th Meridian time (the study area was in this zone). The mean solar time for a specific location in the zone is earlier or later than the local standard time; add four minutes to the local standard time for each degree of longitude the location is east of the standard meridian, or subtract four minutes for each degree west of the standard meridian. True solar time at the specified location differs from its mean solar time by varying amounts through the year as given by the Equation of Time. The value for the Equation of Time is added algebraically to the location's mean solar time to obtain the true solar time.

Three dates of ERTS-1 data were selected for analysis; pertinent specifications for those data are as follows:

Date	22 Aug 72	2 Nov 72	13 Apr 73
Time (MST)	10.45 hrs	10.47 hrs	10.48 hrs
Equation of Time	-0.051 hrs	0.273 hrs	-0.013 hrs
Solar Delineation	12.05°	-14.50°	8.77°

Surface One: A level surface on the campus of the University of Arizona, Tucson (latitude = 32.23°N, Longitude = 110.95°W, aspect and slope = 0°).

Calculation of "t" for 22 Aug 72:

Subtract four minutes for each degree west of the standard meridian to determine mean solar time for this location:

110.95° - 105° = 5.95°
5.95° x 4 min/1° = 23.80 min = 0.40 hrs.
10.45 hrs (MST) - 0.40 hrs = 10.05 hrs (mean solar time).

Add algebraically the value for the Equation of Time:

10.05 hrs + (-0.05 hrs) = 10.00 hrs (true solar time)

Subtract from 12:00 noon:

12.00 hrs - 10.00 hrs = 2 hrs

t = -2 hrs (the sign is minus because the time preceeded noon.

In a similar manner, "t" for 2 Nov 72 and 13 Apr 73 are calculated to be -1.66 hrs and -1.93 hrs respectively.

Calculation of I_s for 22 Aug 72:

I_s = 1.896 ly/min {sin 32.23° · sin 12.05° + cos 32.23° · cos 12.05° · cos (15°/hr · -2 hrs)} = 1.569 ly/min

Similarly, I_s for 2 Nov 72 = 1.201 ly/min
I_s for 13 Apr 73 = 1.568 ly/min

<u>Surface Two:</u> An east facing mountain slope having slope inclination (k) = 21.8°, slope azimuth (h) = 90°, latitude = 31.7°N, and longitude = 110.8°W (EVGN - 4, see Appendix B)

In the case of an inclined surface, an "equivalent" horizontal surface (Lee, 1962) is calculated having an adjusted latitude and longitude. The new values are used in the calculation of I_s.

$$\theta' = \sin^{-1} (\sin k \cdot \cos h \cdot \cos \Theta + \cos k \cdot \sin \Theta)$$ 5/

$$\omega t' = \omega t + \propto$$

$$\propto = \tan^{-1} \{(\sin h \cdot \sin k) \div (\cos k \cdot \cos \Theta - \cos h \cdot \sin k \cdot \sin \Theta)\}$$

Substituting Θ' and $\omega t'$ for Θ and ωt, I_s for this slope on 22 Aug 72, 2 Nov 72, and 13 Apr 73 was respectively: 1.807, 1.424, and 1.804 ly/min.

5/ "$\sin^{-1}$" notation is read: "The arc (angle) whose sin is . . .," also called "arcsin," "inversesin," and "inverse function."

APPENDIX F

STANDARD DEVIATIONS ASSOCIATED WITH THE MEAN RADIANCE OF PLANT PHENOLOGICAL AND "NO CHANGE" CLASSES (Table 13)

		MSS 4	MSS 5	MSS 6	MSS 7
EVGN-4 (n=35)	Aug	6.79	5.51	3.56	8.04
	Nov	4.02	4.64	7.48	18.07
	Apr	3.55	4.18	5.87	18.58
WIND (n=65)	Aug	7.11	9.08	7.52	14.76
	Nov	8.07	9.37	7.63	20.69
	Apr	7.77	9.79	7.17	15.39
WISP (n=170)	Aug	5.22	7.47	7.49	27.14
	Nov	5.73	8.05	7.26	17.83
	Apr	4.21	4.85	5.40	17.34
TAIL-3 (n=56)	Aug	6.16	6.37	6.71	14.84
	Nov	7.61	8.45	6.89	16.11
	Apr	6.37	9.25	7.83	19.59

APPENDIX G

ERTS-1 MSS COMPUTER COMPATIBLE TAPE COUNTS FOR TRAINING FIELDS AND CLASSES

		22 Aug 73		2 Nov 72		13 Apr 73	
Subject	Samples	0.6-0.7μ	0.8-1.1μ	0.6-0.7μ	0.8-1.1μ	0.6-0.7μ	0.8-1.1μ
EVGN-1	361	13.98	16.14	7.87	9.42	17.81	15.90
EVGN-2	16	19.12	21.81	12.31	17.06	22.12	22.44
EVGN-3	135	18.97	19.91	15.44	20.59	9.01	11.72
EVGN-4	35	23.26	22.46	18.46	21.34	12.43	15.86
EVGN		15.96	17.64	10.55	13.16	15.42	15.06
WIND-2	9	18.44	22.78	13.78	8.22	30.78	18.56
WIND-3	6	24.00	24.17	17.83	9.17	26.50	19.83
WIND-4	14	21.14	24.86	13.86	7.79	29.57	19.00
WIND-5	24	21.67	23.87	15.50	8.75	30.17	17.83
WIND-6	12	27.58	25.67	19.58	10.83	37.50	20.67
WIND		22.42	24.29	15.88	8.89	31.14	18.89
WISP-1	30	21.30	31.83	25.97	13.43	46.97	23.10
WISP-2	28	23.21	30.11	22.07	12.50	46.29	22.79
WISP-3	16	23.13	26.81	23.81	14.50	45.44	20.12
WISP-4	56	26.91	25.14	24.91	14.14	45.91	20.30
WISP-5	40	23.70	25.47	23.02	14.38	47.85	20.87
WISP		24.20	27.38	24.08	13.84	46.57	21.32
TAIL-2	85	90.60	43.16	67.74	25.58	95.60	37.29
TAIL-3	56	93.87	35.41	69.38	26.57	97.12	37.84
TAIL-4	12	113.25	38.17	60.42	26.00	106.25	38.00
TAIL		93.58	34.93	67.76	25.97	96.99	37.55