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# REMOTE SENSING APPLICATIONS IN FORESTRY

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OFFICE OF SPACE SCIENCE AND APPLICATIONS  
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# REMOTE SENSING APPLICATIONS IN FORESTRY

INVENTORY AND ANALYSIS OF NATURAL VEGETATION  
AND RELATED RESOURCES FROM SPACE AND  
HIGH ALTITUDE PHOTOGRAPHY

by

Charles E. Poulton

Range Management Program  
Agricultural Experiment Station  
Oregon State University

Final Report

30 September 1972

*A report of research performed under the auspices of the*

Forestry Remote Sensing Laboratory,  
School of Forestry and Conservation  
University of California  
Berkeley, California

*A Coordination Task Carried Out in Cooperation with  
The Forest Service, U. S. Department of Agriculture*

*For*

EARTH RESOURCES SURVEY PROGRAM  
OFFICE OF SPACE SCIENCES AND APPLICATIONS  
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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## PREFACE

On October 1, 1965, a cooperative agreement was signed between the National Aeronautics and Space Administration (NASA) and the U.S. Department of Agriculture (USDA) authorizing research to be undertaken in remote sensing as related to Agriculture, Forestry and Range Management under funding provided by the Supporting Research and Technology (SR&T) program of NASA, Contract No. R-09-038-002. USDA designated the Forest Service to monitor and provide grants to forestry and range management research workers. All such studies were administered by the Pacific Southwest Forest and Range Experiment Station in Berkeley, California in cooperation with the Forestry Remote Sensing Laboratory of the University of California at Berkeley. Professor Robert N. Colwell of the University of California at Berkeley was designated coordinator of these research studies.

Forest and range research studies were funded either directly with the Forest Service or by Memoranda of Agreement with cooperating universities. The following is a list of research organizations participating in the SR&T program from October 1, 1965, until December 31, 1972.

1. Forest Service, USDA, Pacific Southwest Forest and Range Experiment Station, Berkeley, California.
2. Forest Service, USDA, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.
3. School of Forestry and Conservation, University of California, Berkeley, California.
4. School of Forestry, University of Minnesota, St. Paul, Minnesota.

5. School of Natural Resources, University of Michigan, Ann Arbor, Michigan.

6. Department of Range Management, Oregon State University, Corvallis, Oregon.

This report summarizes the significant findings of this research and identifies research results which have been applied or are ready for application. In addition, the work carried on for the reporting period October 1, 1971, until December 31, 1972, is described in detail.

A listing of all research reports produced under NASA SR&T funding for forest and range studies can be found in the Appendix of this report.

## ABSTRACT

This final report covers accomplishments of a project supported by the National Aeronautics and Space Administration from 21 May 1968 through 30 April 1972. The work was carried out in southeastern Arizona on and in the vicinity of NASA Test Sites 29 and 220 and within the flight tracks of Apollo VI, VII, and IX. Earth Resources photographs from each of these missions, and photographs taken during Gemini IV, were used in the research along with high altitude and conventional aerial photography. A unified land use and resource analysis system was devised and used to develop a mapping legend for the above test areas. The natural vegetation, land use, macrorelief, and landforms of northern Maricopa County, Arizona, were analyzed and inventoried. This inventory was interpreted in relation to the critical problem of urban expansion and agricultural production in the study area. The central thrust of the research program has been to develop methods for use of space and small-scale, high-altitude aerial photography to develop information for land use planning and resource allocation decisions. The report describes accomplishments of the project in detail under the headings of Summary of Research Results, Major Significant Accomplishments, and Accomplishments in the Final Reporting Period. All reports and publications resulting from the project, together with some of the key references upon which the project drew for background and supporting information, are cited.

## ACKNOWLEDGMENTS

This research was performed under the sponsorship and financial assistance of the National Aeronautics and Space Administration for the Earth Resources Survey Program in agriculture/forestry/range, NASA Contract R-09-038-002.

The Oregon State University graduate students and research assistants involved with the author in this research program constituted an unusually diligent and dedicated team. They performed so effectively together that in many cases it is difficult to single out persons to credit them with individually unique contributions. As principal investigator, I have not been privileged previously to work with such a dedicated, unselfish group. They include David P. Faulkner, James R. Johnson, David A. Mouat, Edmundo Garcia-Moya, William T. Pyott, and Barry J. Schrupf. It is the work of these people that brought the noteworthy accomplishments of this project into fruition.

Acknowledgment is also due to Robert N. Colwell and Gene Thorley and their staff at the Forestry Remote Sensing Laboratory, University of California, for their support, direct collaboration, and encouragement in this project, as well as for skillful handling of many of the administrative details. The "every shoulder to the wheel, let's get the job done" philosophy that seems to guide and motivate the FRSL staff and its leadership is indeed commendable. Without it, many things that were accomplished would not have been possible.

Accomplishments on the project were also beneficially influenced by Arch B. Park and Robert H. Miller as USDA Remote Sensing Technical

Coordinators. Their involvement helped us arrange some opportunities for accomplishment that could not have been achieved without direct participation and assistance from their level.

During the course of the project, we also enjoyed excellent cooperation from numerous people from the University of Arizona and U.S. Geological Survey in Tucson and Phoenix, Arizona. Especially appropriate for recognition among this group are Herbert H. Schumann and Raymond M. Turner, USGS; and Thomas P. Harlan, Larry K. Lepley, Charles T. Mason, Walter S. Phillips, Ervin M. Schmutz, and P. N. Slater, all of the University of Arizona.

Without the cooperation of Lt. Col James A. Hamilton, Luke Air Force Base, and helicopter crews under his command, the accuracy checks of our Maricopa County land use and resource analysis could not have been made. Without the unique capability of these helicopters, the radiometric data could not have been taken over rangeland ecosystems.

Finally, thanks is also extended to Frank and Ariel Appleton, owners of The Research Ranch, Elgin, Arizona, for providing living quarters for our field crew during the 1971 season.

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INVENTORY AND ANALYSIS OF NATURAL VEGETATION  
AND RELATED RESOURCES FROM SPACE AND HIGH-ALTITUDE PHOTOGRAPHY

by

Charles E. Poulton

Rangeland Resources Program  
Agricultural Experiment Station  
Oregon State University

INTRODUCTION AND BACKGROUND

At the time of our initial involvement in the Earth Resources Survey Program of the National Aeronautics and Space Administration, late in 1966, little attention had been paid to the potentialities for vegetational interpretations from space photography. In December of that year, C. E. Poulton of Oregon State University and Ed Roberts of the Forestry Remote Sensing Laboratory, University of California, organized and conducted the first on-site evaluation of the potentiality for mapping and identification of natural vegetational features of the earth's surface from a frame of Gemini IV photography taken in the vicinity of Tucson, Arizona, (Carnegie, Poulton, and Roberts, 1967). These results were sufficiently encouraging that a research program was proposed through the Forestry Remote Sensing Laboratory to develop rangeland vegetational inventory and analysis capability through the use of space photography. In the following year, this program was modestly funded through the Pacific Southwest Forest and Range Experiment Station and the Forestry Remote Sensing Laboratory, and serious investigation and procedural development research was initiated. The new research was able to build on a background of some years of resource analysis research and

many years of range ecology research in diverse environments that had been carried out by Poulton and his graduate students at Oregon State University.

From this initial work by Roberts and Poulton, the following were evident:

1. Many kinds of vegetation-soil systems were uniquely imaged on the Gemini photography.

2. When rangeland resources are considered in the context of vegetation-soil systems, as the group at Oregon State University had traditionally been doing since the early 1960's, the more openly vegetated areas presented unique advantages over forested lands for investigating the potentials and limitations of space photography as a resource inventory and analysis tool. In these environments it is possible to see essentially the whole ecosystem, that is, usually to see all layers of the vegetation and, in arid environments, the amount of exposed soil surface that is normally expressed in each ecosystem.

3. While scale is small and resolution much reduced over the aerial photography with which we were accustomed, space photography presented some unique advantages through its synoptic coverage. The smaller scale also enhanced the economic feasibility of color and color infrared photography.

4. Depending on vegetation density, image characteristics were controlled on the one hand by vegetational features (in moderately dense to dense vegetations) and by soil surface features in the more sparsely vegetated areas. Because of our prior research on vegetation-soil

relationships that had repeatedly and successfully related phytosociological vegetation classes to soil taxonomic classes, we felt that there was tremendous potential interpretive power to be gained from an understanding of various vegetation-soil relationships.

5. Especially in the desert environment, relationships between landforms and vegetation were good. Thus, another important photo-identification technique became possible through reading the landforms and relating these to the ecosystems that comprise the landscape (vegetation-soil systems).

6. Comparisons of our initial mapping attempts with existing synoptic vegetational resource maps of the region showed very clearly that many highly meaningful corrections in vegetational resource maps could easily be made through the use of space photography.

7. Certain important vegetational features could not be discriminated or identified from the space photography. Therefore, in spite of the power of this new system, aircraft photography is still needed but in a new multistage sampling mode, ground work would still be important in operational surveys, and more sophisticated remote sensing systems should be investigated for their discriminating power in these instances.

SUMMARY OF RESEARCH RESULTS  
DURING THE PERIOD MAY, 1968-OCTOBER, 1971

This project had its origin in two cooperative activities between the author and colleagues at the Forestry Remote Sensing Laboratory, University of California, Berkeley. First was the development and

writing of a statement placing range management problems in a regional and world perspective and a summarization of the role remote sensing should play in the solution of range management problems (Carnegie, 1967). In this same publication, Poulton, with Roberts and Carnegie, reported on the "feasibility of analyzing range and related resources from Gemini color photography." This preliminary work with Gemini IV photography taken 5 June 1965 over southern Arizona clearly demonstrated the interpretability of certain rangeland ecosystems from space imagery and showed how vegetational resources maps could be improved by use of this imagery. This led to a proposal which was funded through the U.S. Department of Agriculture, Forest Service, beginning 21 May 1968. Following is a summary of the most significant accomplishments in the research program between this date and conclusion of the project on 30 April 1972.

1. Development and successful demonstration of a unified, hierarchical legend system for annotation of natural vegetation, land use, and important physical features of the environment in an ecologically meaningful context. These concepts were used to develop a specific legend for northern Maricopa County, Arizona, and a tentative legend for the Tucson-Willcox-Douglas area (NASA Test Site 220). The legends are now being updated under continuing ERTS-1 investigations.

2. Production of an integrated ecological resource and land use inventory of most of Maricopa County, Arizona, (Phoenix area). Both Apollo IX color infrared and high-altitude aircraft color and color infrared photographs were used. The inventory treated natural vegetation, macrorelief and landform with examples of descriptive and interpretive legends for selected ecosystems as mapped.

3. Interpretation of the above maps in terms of the urban-agriculture interface problem that is of critical importance in this area. This provided a demonstration of how ecological resource inventory can be used in land use planning. Some resource managers have recognized the vegetational mapping as an improvement over older available maps. Copies of the map were made available as uncontrolled photo mosaics to local agencies, and the interpretation was published as part of the 1971 Arizona Regional Ecological Test Site Symposium Proceedings. On the request and arrangement of a local citizen, Mr. Frank Appleton, a presentation of this work was made by Barry J. Schrupf and James R. Johnson of our staff to the Speaker of the Arizona House of Representatives and the President of the Senate. All this work collectively may have helped create a favorable environment for the coordinated ARETS (Arizona Regional Ecological Test Site) program that is now under way because it vividly demonstrated practical values in solving recognized problems.

4. A display prepared by the Range Club at Oregon State University based on the above Maricopa County work and entered in national competition at the American Society of Range Management meeting in 1971 was awarded first place. The display portrayed the use and relevance of the inventory data in land use planning.

5. Assisted the Bureau of Land Management to use our resource analysis techniques and legend in performing a successful pilot inventory of part of the California Desert. This was the starting point in a new desert land use planning and management program. With minor modification, our

our legend system and techniques were found applicable to the few additional vegetational types peculiar to the California Desert.

6. Our Maricopa County photo mosaic clearly demonstrated the superiority of high-altitude (1:120,000-1:250,000), metric quality photography for showing land uses and resources in clear perspective and for monitoring land use change.

7. Presented a suggested procedure to NASA for the quick-look evaluation of space imagery as an input to the ERTS catalog record. This included examples based on Apollo VII and IX photography from Tibet, Mississippi, and Southern California and made use of our broadest legend classes. While it was not possible to use this suggestion in the routine ERTS-1 program, we are finding the procedure most appropriate for quick-look analysis by our present multidiscipline ERTS-1 team at Oregon State University.

8. Completion of a hierarchical classification of natural vegetation in the vicinity of Tombstone, Arizona, by the application of numerical taxonomy concepts, discriminant function analysis and established plant sociological principles (Garcia-Moya, 1972). This provided a demonstration of how one should determine and characterize ecosystem units and develop the landscape legend classes. Recognition criteria and keys were provided. This work is currently being used in intensive vegetational resource mapping from large-scale aerial photography in preparation for an image characterization study and in final refinement of the southeastern Arizona legend. A unique feature of Dr. Garcia-Moya's work was the use of both high flight (USGS) and conventional scale color photography (NASA) to stratify his study area preliminary to the location of ground observation

points. Traditionally, students of vegetation-environment relationships have tended to locate study areas from ground examination only and to use conventional aerial photography for stratification after the localized study areas have been determined.

9. Developed computer software for generating plant symbol lists and prepared a plant symbol list for species found in Test Sites 29 and 220. The list was based on some previous work that was partially supported by a supplemental grant from the Pacific Northwest Forest and Range Experiment Station. The computer program organizes species lists, assigns plant symbols as a shorthand for field use, updates such listings, and handles some aspects of synonymy. The programs are operational at Oregon State University and could easily be used to add symbolization for all species in southwestern Arizona if such were deemed desirable (Garrison, et al, 1967).

10. Performed a macrorelief-landforms interpretation study in Test Site 220 with Apollo VI stereo photography and demonstrated some of the advantages of stereo interpretation from space.

11. Visited Test Site 29 on one occasion with Dr. C. T. Youngberg, Department of Soils, Oregon State University, and determined that some of the soils classes mapped in the Maricopa County Soil Association map could be related to our vegetational legend, and the two systems could have been effectively treated together. We then did a small test in part of Site 29 to determine the compatibility of the two delineations and the problems involved in combining these separate soil and vegetation inventories into a meaningful interpretation. The conclusion reached

was that it could have been done, but there was no urgent reason to complete the task because both maps were available to people who may have needed to consider the combined vegetation and soils information.

12. Provided on-site ground truth for use in interpreting Apollo imagery and numerous aircraft support missions. An attempt was made to get multidate aircraft coverage of Test Site 220 at all critical periods for a multidate interpretation experiment. We conceived and planned this experiment, but were unable to carry it out because at the conclusion of this project, we still had not received usable aircraft imagery from the critical August summer-green period. Fifteen ground locations were established as control in this experiment. These have been photographed and carefully documented at six dates through the phenological stages. They have been periodically rephotographed as an indication of variation in phenology. We were able to demonstrate the power of multidate imagery for mapping and recognition of natural vegetational features. This work set the stage for a thorough study of the concept under our ERTS-1 project.

13. Participated in the S-065 experiment aboard Apollo IX and contributed substantially to the development of ground truth and range resources support for that experiment. All ground truth and photo stations as well as the areas covered by low-elevation aerial obliques have been plotted on USGS topographic sheets at a scale of 1:250,000. This has provided record control, a mechanism for access to the data, and a way to relate such information to image locations in the space and high-altitude photography.



14. In collaboration with Richard S. Driscoll, Rocky Mountain Forest and Range Experiment Station, our project demonstrated one of two approaches to the use of space imagery for multistage inventory of range resources. We made use of Apollo VI, U.S. Geological Survey, 1:250,000, and NASA, 1:16,000, aircraft photography. These procedures are scheduled for further development by James R. Johnson in our continuing ERTS-1 study.

15. Performed work in cooperation with the Laboratory for the Application of Remote Sensing (LARS), at Purdue in the analysis of multi-spectral linescan data over an eastern Oregon test site. This was done in order to better understand the capability of multispectral scanner systems to detect important rangeland ecosystems, or features thereof, and to determine the multispectral signatures of selected vegetation-soil systems. For funding reasons, it was not possible to carry this work to a satisfactory conclusion, but results were encouraging in some respects. They were discouraging in that some sagebrush steppe ecosystems seemed inseparable by the single date (late May) of multispectral data.

#### MAJOR SIGNIFICANT ACCOMPLISHMENTS

During the life of this project, the five most definitive and important accomplishments from the rangeland resources point of view were:

1. Development of a unified ecological and land use legend system ideally suited to synoptic and multistage image analysis.

2. Application of such a system to demonstrate an ecological, resource, and land use analysis of northern Maricopa County, Arizona, with interpretations addressed specifically to the urban expansion problem.

3. Completion of a detailed plant sociological classification of desert vegetation in the Tombstone, Arizona, vicinity as an illustration of how the broad as well as detailed ecological legend unit should be developed by application of plant sociological principles and numerical taxonomy.

4. Successful use and application of the procedures by an independent agency.

5. Important contacts with key information users and legislators in the southeastern Arizona area in order to help create an environment for and a beneficial stimulatory impact on what has become a major multidisciplinary, multiagency space applications program in the Arizona Regional Ecological Test Site (ARETS).

#### A Unified Ecological and Land Use Legend System

Prior to the advent of space and small-scale, highflight aerial photography, the need did not really exist for a unified legend system applicable in the interpretation of synoptic imagery. History had created a situation where, working within the confines of their own responsibility, each agency or landowner could develop his own unique legend without great concern for coordination. In addition, most legend systems had evolved with a strong disciplinary or user-interest bias. None had really addressed itself to the question of a meaningful ecological legend that would permit an interpretation of landscapes useful in all areas of management.

Thus, in addition to providing a unified, integrated legend system, another objective in legend development was to provide a sound ecological framework based on the plant sociology of natural communities of plants as the index of unique kinds of environments. Since man has impacted the natural environment through land use changes, the need was also immediately obvious to incorporate some measure of land use assessment into the ecological legend system. This need also received attention throughout the life of the project. Finally, experience had already demonstrated that full exploitation of remote sensing capabilities -- especially in the context of an ecological resource analysis -- created such masses of data that any suitable legend system must be readily compatible with computerization in information management.

As we approached this problem, it was also apparent that the classification system used should be hierarchical and adapted to the growing concept of multistage remote sensing, since availability of space and high-flight as well as conventional aircraft photography to the civilian sector had created some entirely new opportunities for multistage sampling of natural resources. Thus, a facet of multistage compatibility was intentionally built into both the classification system and the legend symbology.

Progress in the development of this legend system has involved changes and improvements each year during the life of the project. These have been previously reported in Annual Reports and special reports (Pettinger, et al., 1970; Poulton, Driscoll, and Schrupf, 1969; Poulton, Faulkner, and Schrupf, 1970; and Poulton, Schrupf, and Johnson, 1971).

Our most recent legend is presented in a subsequent section of this report.

Demonstration of an Ecological Resource and Land Use Analysis  
Maricopa County, Arizona

As these procedures and the legend system began to mature, we felt the need for a practical demonstration of their application in a reasonably large test area. We were scheduled and equipped to do this in connection with the early phases of the S-065 Experiment on Apollo IX as it passed over the Tucson-Willcox-Douglas, Arizona area, NASA Test Site 220. Even though it was extremely disappointing to a tremendously large team of scientists to have this mission essentially aborted by cloud cover, we fortunately were in a position to shift our demonstration area to northern Maricopa County as soon as it was learned that the Apollo IX mission obtained usable photography at this alternate latitude. Availability of similar high-altitude photography over NASA Test Site 29 created an ideal opportunity to perform a comparative demonstration with both space and high-altitude photography. One of our objectives was to determine how quickly a large area could be meaningfully analyzed by using these two kinds of imagery. While we hoped that the end product would be useful, our primary purpose was to demonstrate, test, and improve the techniques and legend at a broad vegetational resource and land use classification level. Our study area was all of northern Maricopa County included with the Apollo IX flight path as well as NASA Test Site 29 which encompassed most of northern Maricopa County.

We first applied the vegetation and land use legend in an inventory of northern Maricopa County, Arizona. This was accomplished by using one full Apollo IX frame and the portions of adjoining frames (Poulton, Johnson, and Mouat, 1970). We followed this with a similar map prepared from interpretations of high-altitude Ektachrome aerial photography. This treatment was at a much higher level of detail because of larger scale and increased resolution. The two mapping results were presented on uncontrolled mosaics prepared in color infrared from the Apollo IX imagery and in black-and-white from the color photography.

The high-altitude photomap was prepared by selecting one flight path out of the five available, delineating vegetation, land use, macrorelief and landform classes on that sample strip. The strip was then essentially 100% ground checked to develop the image-subject relationships and to confirm identifications. Most of the remainder of the area was then photo interpreted to complete the task. Map preparation was not intended to provide an entirely accurate nor necessarily a fully adequate detailed representation of the landscape. The activity definitely was to serve as a proving ground for the development of procedures incorporating satellite and high altitude aerial photography into integrated resource inventories. This objective was successfully accomplished.

Subsequent to completion of the inventory, we performed a random check of accuracy by use of helicopter transportation. In the photo interpreted area, this check showed 93% accuracy of delineations, based on the established legend units, through photo interpretation. This error level was arrived at by combining all error types that were judged

not to adversely impact an urban vs. agricultural land use decision. The zero error percentage was 65%. This experience led to further modification of the legend system to help minimize some of the more common sources of error in its application through photo interpretation and to increase the logic and consistency of the criteria used for legend class discrimination. These modifications are treated in a subsequent section of this report.

The map information content was found sufficient for some beneficial uses within Maricopa County. In some cases, the ecological resource delineations were sufficiently detailed to have high significance and relevance in land use planning and related decisions. In others, they represented extremely broad classes and/or complexes of subjects. This was the case where the ground detail was so intricate that it could not be practicably mapped at the working scale in anything except extremely broad generalizations.

#### Plant Sociological Classification of Desert Vegetation

When this work began in southern Arizona, we assumed that we would have large amounts of directly applicable "ground truth" information upon which to draw. Intensive vegetational studies, dating from some of the earliest research on plant ecology (Shreve, 1942, 1964; Nichol, 1952), have been conducted in this region. It soon became evident that comprehensive refinement of existing vegetation classification would be necessary for further legend development. Most of the work had involved an extremely broad-brush approach to vegetational classification. Because of the era in which it was done, the work was planned without particular thought to the suitability of classes for remote sensing interpretation.

We immediately saw the need also to demonstrate a vegetational classification approach that was hierarchical and that would produce classes that were sound from the plant sociological point of view as well as useful in remote sensing image interpretation under a multistage concept where both broad and highly specific vegetational classes would be required. With this objective in mind, Edmundo Garcia-Moya completed his doctoral dissertation on a plant sociological classification of the desert vegetation in the vicinity of Tombstone, Arizona (Garcia-Moya, 1972). He combined the application of plant sociological principles that have been well established by leading European phytosociologists, with a numerical taxonomic approach to develop an hierarchical classification suitable for both very broad and highly detailed resource analyses. In this work, he used classification models and computer programs developed by William T. Pyott of the Oregon State University Rangeland Resources Program on other independently funded research (Pyott, 1972).

Since this work was completed during the terminal reporting period of this project, it is reported in greater detail in the following section. This work does provide both a demonstration and a model that others can follow in refining vegetational classifications and in developing hierarchical groupings, especially for application in remote sensing interpretation of the ecology of natural landscapes.

#### Application by an Independent Agency

One of the most gratifying and significant developments during the life of this project was to be a party to, and see, an action agency take our procedure and legend system into an entirely new area and use

it successfully with minimum help from our project staff. In the southern California desert, the Bureau of Land Management is vitally concerned about the impact of new desert land uses on the environment and about the need for achieving acceptable levels of management control on these activities. They recognize that a superior approach to this problem would be to inventory the ecosystems of the desert and to gain knowledge about the land uses in relation to these systems. Upon learning what we had accomplished under this project in similar desert environments, the Bureau of Land Management asked for, and received, help in setting up a pilot program (Pettinger, et al., 1970).

In brief, the project was implemented as follows: Dillard H. Gates, while on sabbatical leave from Oregon State University to the Bureau of Land Management, Sacramento State Office, and being familiar with our program, organized and implemented a seminar on the potential of remote sensing applications to solution of California desert problems. This seminar was presented by Robert N. Colwell, University of California, and James R. Johnson and Charles E. Poulton, Oregon State University. It was attended by Bureau of Land Management state office and field staff representatives as well as a cross-section of involved agencies from California State government. Following this general familiarization session, the Bureau of Land Management sent two team members to our laboratory in Corvallis, to work out details and do preliminary photo interpretation preparatory to field work. They worked on their own photography in our laboratory for one week and returned to California to carry out field procedures according to our recommendations. After gaining field experience, David P. Faulkner and Poulton responded to a



request for on-the-ground assistance. Another brief seminar was held on details and specific problems in Sacramento, and the remainder of the week was spent working with the crews in the field. They were then testing applicability of the legend and working on subject-image relationships preparatory to doing some definitive photo interpretation and to writing legend descriptions. Our primary advisory role was to help them adapt our southern Arizona desert legend to their California pilot area. This required a surprisingly small amount of change. Following this, the Bureau of Land Management completed the pilot test in a 300,000 acre area at a cost of 3.3 cents per acre, including training, and 2.2 cents per acre exclusive of training costs. This seemed to them, and to us, an extremely reasonable figure for obtaining and mapping with high flight, small-scale photography, the vegetational systems of the pilot area, current land use where the natural vegetation had been replaced, as well as macrorelief, landform, surficial geology, and soil characteristics that were meaningful in and relevant to land use and resource management decisions. This effort led to an expanded program that eventually intends to inventory the entire southern California desert by comparable methods. This is perhaps the best single bit of evidence of the applicability of a workable ecological resource inventory and analysis procedure that can, in fact, be learned and used by others.

### Meaningful Local Contacts and Extension of Results

Intangible or indirect products of research are often derived because of what the investigators do peripherally to the actual research tasks. Such benefits often escape mention in reporting because they are the kinds of things dedicated research scientists tend to do on a contingency basis as opportunities arise and needs are identified. The motivation behind such responses is generally professional obligation. We feel that our work has helped to create a favorable atmosphere for the current and continuing Earth Resources Applications Program in the Arizona Regional Ecological Test Site.

Our contributions to and participation in local reviews and seminars, beginning with the one organized by Dr. Robert N. Colwell in the Phoenix area in March 17-19, 1970, as well as our contributions to both ARETS symposia (1970 and 1971), have helped to create a receptive and enthusiastic atmosphere for continuing work that has relevance to the land use problems of this area.

### Rangelands in the NASA Earth Resources Program

In the United States, North America, and the world, rangelands represent a unique kind of natural resource on a par with forests, water, and minerals (Carnegie, 1967). In addition to range resources being important in many areas primarily classed as forests, other rangeland areas are unique in their own right as economic resource features. This combined resource, forest and rangelands, constitutes one of the major reservoirs of fiber, carbohydrate, and meat production as well as being the land resource from which other more intensive land uses are carved.

When we began the program, there was only one funded project on rangeland resources applications under the leadership of David M. Carnegie, Forestry Remote Sensing Laboratory. This rather soon was expanded, in addition to the program herein reported, to include programs under the leadership of Richard S. Driscoll, U.S. Forest Service, and Paul T. Tueller, University of Nevada, under Department of Interior support. Obviously, no one group can claim all the credit in cases like these, but it should be pointed out that a conscious effort to change the initial recognition, agriculture/forestry, that prevailed at the beginning of this program to an agriculture/forestry/range recognition as it is now carried officially on the NASA Earth Resources Program discipline listing is a significant and noteworthy step ahead for rangeland resource recognition. It is, in large measure, the result of good work and definitive worthwhile results from the work of all those individuals who together pioneered remote sensing applications to rangeland resource problems in the 1960's and early 70's. We, the team from the Agricultural Experiment Station, Oregon State University, are privileged to have had a hand in all these stimulating and challenging developments.

#### ACCOMPLISHMENTS IN FINAL REPORTING PERIOD

During the terminal reporting period under this project (October 1, 1971-April 30, 1972), there were three particularly noteworthy accomplishments. These were the completion, submission, and acceptance of Dr. Edmundo Garcia-Moya's dissertation on a hierarchical plant community classification in the Tombstone, Arizona, area; a major updating and revision of the broad

classes in our legend system; and participation in numerous training sessions and conferences that contributed significantly to information transfer and preparation of the user community for technological advances growing out of the Earth Resources Program.

The dissertation by Dr. Edmundo Garcia-Moya, "A Preliminary Vegetation Classification of the Tombstone, Arizona, Vicinity," exemplifies the application of phytosociological principles and numerical taxonomy in the development of a plant community classification in hierarchical arrangement that is suitable to the interpretation of vegetation from both small-scale and large-scale imagery. Some of his classes segregate vegetational units at subassociation levels which cannot be separated or identified even on very large-scale photography. His association and alliance groups are, however, appropriate and useful in vegetational inventories. Using these groups, he interpreted and mapped a mosaic of the Tombstone study area which is still being used in continuing investigations.

#### Preliminary Vegetation Classification In the Tombstone, Arizona Vicinity

As pointed out by Garcia-Moya (1972), the need for classifying vegetation in a more precise way is evident. Also, there is a need to provide a hierarchical classification scheme that will match changes in image characteristics as one moves through the scales from space to conventional aerial photography. Such refined classifications of vegetation are the first steps toward a better understanding of the potentialities and limitations of a specified area which help in the

detection of analogous environmental conditions for resource allocation and management purposes. These needs become more urgent as use and competition for natural resources and land increases. The first approximation of a classification scheme may meet these needs for a test site in the Tombstone, Arizona, vicinity. This classification task was accomplished by the use of a "hierarchical-polythetic-agglomerative" package using presence-absence data and standardized cover estimates (Pyott, 1972).

The following tentative associations and a variant were found, upon division of the original data into groups of convenient size, to meet the limitations of the computer programs:

- Association A (Panicum hirticaule/Tidestromia lanuginosa-Boerhaavia coulteri)  
                   la (a variant of Association A)
- Association B (Rhus microphylla-Dalea formosa)
- Association C (Gutierrezia sarothrae/Eriogonum abertianum)
- Association D (Menodora scabra/Tridens grandiflorus)
- Association E (Hilaria belangeri)
- Association F (Gilia rigidula-Rhynchosia texana)
- Association G (Hilaria mutica/Eriochloa gracilis/Crotalaria pumila)
- Association H (Haplopappus tenuisectus/Eragrostis lehmanniana)
- Association I (Ayenia pusilla/Eragrostis intermedia)
- Association J (Cnidoscolus angustidens)
- Association K (Typical Association lacking character species) of Alliance III (Fouquieria splendens-Acacia constricta-Aloysia wrightii)

Association L (Agave palmeri-Agave parryi/Haplopappus  
laricifolius)

Association M (Mortonia scabrella)

These were grouped by the classification into units of higher rank. Associations (A), (B), and the variant (1a) were grouped into an alliance with the character species, Acacia vernicosa-Larrea tridentata-Flourensia cernua. Associations (A), (B), and the variant (1a) were grouped into an alliance with the character species, Acacia vernicosa-Larrea tridentata-Flourensia cernua. Associations (C), (D), (E), and (F) were grouped into the Yucca elata/Bouteloua eriopoda Alliance; and Associations (I), (J), and (K) were held together in an Alliance by the character species, Fouquieria splendens-Acacia constricta-Aloysia wrightii.

Validity of the character and differential species as association and subassociation "identifiers" was tested by the use of stepwise discriminant analysis. Two hierarchical levels and two runs per group were carried out using this analysis. A perfect discrimination between or among the groups was found at all levels except one. Species identified as differential or character species in the classification process were found to be the best discriminants. This suggests that the vegetation units identified by these species are valid.

The "hierarchical-polythetic-agglomerative" approach to vegetation classification, as used by Garcia-Moya, provides the kind of framework which is compatible with the classical phytosociological techniques of vegetation study. It eliminates, however, the cumbersome task of hand

sorting and tabulation and increases the capacity of complex operations as well as introduction of more systematic and thorough evaluation into the analysis. This approach of classifying vegetation appears to be suited for survey-type studies in areas where vegetation information is limited and the need exists for an initial classification in order to begin more comprehensive quantitative studies. This does not preclude using the method for other purposes. Because it is a hierarchical method, one can go into as much classification detail as is dictated by the purpose of the vegetation study. This last feature is well suited to the use of the results in interpretation of multiscale photography so important in the field of resource analysis.

Research needs to be done to answer the very fundamental question of why Euclidean distance (as a measure of similarity) and Ward's method (as a sorting strategy) provided a more adequate hierarchical classification scheme when presence and absence data are used rather than standardized cover data. Research is needed on the most effective criteria to divide large data sets into groups of the appropriate size.

Results of this classification now need to be tested by practical field use in the recognition of ecosystems and their mapping on appropriate scales of remote sensing imagery. To aid the practical user of this information, a dichotomous key to the phytosociological classes was developed by Garcia-Moya. This requires the recognition of 8 species to make classifications at alliance level and 32 species to achieve the association separations. A key for subassociation level was not prepared because the practical value of this level is somewhat in doubt.

To aid the field application of these results, Dr. Garcia-Moya also developed a dichotomous key to his associations (Table 1).

We feel that the user of this information will benefit from having concise summaries of the character and differential species that have indicator value in the recognition of these vegetational units. Of the 440 species identified by Dr. Garcia-Moya in the study area, only those shown in Tables 2 and 7 have definitive indicator value. His key to associations and alliances can be effectively used by knowing only 32 species for the former and 8 for the latter. This is certainly in the realm of feasibility even for managers without botanical training.

Table 2 presents the character and differential species for the Alliance level classification. It is extremely helpful for the field user of results from plant sociological classification studies to have unique lists of indicator species in an abbreviated form for ready reference. Because of the impact of resource use and disturbance on certain species, it is sometimes difficult to accurately recognize a plant sociological taxon if only a few species are used as indicators. This problem can practically always be solved if one looks upon the indicator group as the meaningful criterion rather than individual selected species from within the group. It is also important to recognize that the indicator group may be adequately and reliably represented when any reasonable combination of the indicator species is found on the site. Not all species have to be present for the group to be represented and, thus, to indicate the group's appropriate alliance. In



TABLE I. KEY TO THE VEGETATIONAL UNITS OF THE TOMBSTONE,  
ARIZONA, VICINITY

- 1a Grasses prominent, with or without scattered shrubs 2
- 2a Yucca elata and Bouteloua eriopoda are the most prominent species  
Alliance II (YUCCA ELATA/BOUTELOUA ERIPODA) 3
- 3a With Menodora scabra and Tridens grandiflorus--  
Association D (MENODORA SCABRA/TRIDENS GRANDIFLORUS)
- 3b Without Menodora scabra and Tridens grandiflorus 4
- 4a With Hilaria belangeri in relative dense uniform stands--  
Association E (HILARIA BELANGERI)
- 4b Without Hilaria belangeri or if present in small patches 5
- 5a With Gilia rigidula and Rhynchosia texana--Association F  
(GILIA RIGIDULA-RHYNCHOSIA TEXANA)
- 5b Without Gilia rigidula and Rhynchosia texana but with Gutierrezia  
sarthrae and Eriogonum abertianum--Association C  
(GUTIERREZIA SAROTHRAE/ERIOGONUM ABERTIANUM)
- 2b Yucca elata and Bouteloua eriopoda are not the most prominent species.  
If present, very scattered. 6
- 6a With Agave palmeri, Agave parryi and Haplopappus laricifolius--  
Association L (AGAVE PALMERI-AGAVE PARRYI/HAPLOPAPPUS  
LARICIFOLIUS)
- 6b Without Agave palmeri, A. parryi and Haplopappus laricifolius 7
- 7a With Hilaria mutica, Eriochloa gracilis, and Crotalaria pumila--  
Association G (HILARIA MUTICA/ERIOCHLOA GRACILIS/  
CROTALARIA PUMILA)
- 7b Without Hilaria mutica, Eriochloa gracilis, and Crotalaria  
pumila but with Haplopappus tenuisectus and Eragrostis  
lehmanniana--Association H (HAPLOPAPPUS TENUISECTUS/  
ERAGROSTIS LEHMANNIANA)
- 1b Grasses not prominent, shrubs the most prominent. 8
- 8a Acacia vernicosa, Larrea tridentata, and Flourensia cernua are  
the most prominent species. Low grass cover--Alliance I  
(ACACIA VERNICOSA-LARREA TRIDENTATA-FLOURENSIA CERNUA) 9
- 9a With Rhus microphylla and Dalea formosa. In addition, Yucca  
baccata and Nolina microcarpa--Association B (RHUS  
MICROPHYLLA-DALEA FORMOSA)
- 9b Without the above species, or if present scattered, but with  
the annuals Panicum hirticaule, Tidestromia lanuginosa and  
Boerhaavia coulteri--Association A (PANICUM HIRTICAULE/  
TIDESTROMIA LANUGINOSA-BOERHAAVIA COULTERI)

TABLE 1. (CONTINUED)

- 8b Acacia vernicosa, Larrea tridentata, and Flourensia cernua are not the prominent species. Grass cover abundant. 10
- 10a With Fouquieria splendens, Acacia constricta and Aloysia wrightii--Alliance III (FOUQUIERIA SPLENDENS-ACACIA CONSTRICTA-ALOYZIA WRIGHTII) 11
- 11a With Cnidoscolus angustidens or Avenia pusilla and Eragrostis intermedia
- 12a With Cnidoscolus angustidens--Association J (CNIDOSCOLUS ANGUSTIDENS)
- 12b Without Cnidoscolus angustidens but with Avenia pusilla and Eragrostis intermedia--Association I (AYENIA PUSILLA/ERAGROSTIS INTERMEDIA)
- 11b Without Cnidoscolus angustidens or Avenia pusilla and Eragrostis intermedia--Association K (TYPICAL ASSOCIATION)
- 10b Without Fouquieria splendens, Acacia constricta, and Aloysia wrightii but with Mortonia scabrella--Association M (MORTONIA SCARRELLA)

using indicator species groups, one also has to learn to overlook some of the highly ubiquitous species that have no plant sociological meaning. Sometimes species in this latter group have high economic significance, and if one approaches the landscape with a strong economic bias, he may misread or overlook the site indicators that are there. Table 2 lists only those species that have indicator significance for Alliances I, II, and III. It is particularly meaningful (in terms of the validity of these alliances) that Alliances I and II have only one out of 48 indicator species in common; Alliances II and III have only two species out of 53 in common; and there is no overlap among the indicator species for Alliances I and III. One has little grounds to doubt the validity of these plant sociological taxa for which repeated examples can be found across the landscape and which are as floristically unique as these three.

Similarly, the character and differential species for associations within each of these alliances are presented in Tables 3 through 5. In these tables, the most reliable differential species are underlined, but again the entire group should be used as described above in making field identifications or in confirming such identifications after having used the key from Table 1.

This classification developed four valid associations (Table 6) that had no affinity for a higher hierarchical class or alliance. They each stood alone as unique plant sociological taxa in the study area. In addition to identification by the key, the list in Table 6 will enable field confirmation and recognition of each of these associations. It may be that, as studies are extended beyond this locality, other flora

TABLE 2. CHARACTER AND DIFFERENTIAL SPECIES FOR ALLIANCES<sup>1</sup>

Alliance I	Alliance II	Alliance III
<u>Acacia vernicosa-</u> <u>Larrea tridentata-</u> <u>Flourencia tridentata</u> Alliance	<u>Yucca elata/</u> <u>Boutelous eriopoda</u> Alliance	<u>Fouqueria splendens-</u> <u>Acacia constricta-</u> <u>Aloysia wrightii</u> Alliance
<i>Acacia vernicosa</i> <i>Larrea tridentata</i> <i>Flourencia cernua</i> <i>Muhlenbergia porteri</i> <i>Zinnia pumila</i> <i>Erioneuron pulchellum</i> <i>Panicum hirticaule</i> <i>Tidestroma lanuginosa</i> <i>Boerhaavia coulteri</i> <i>Euphorbia micromera</i> <i>Scleropogon brevifolius</i> <i>Prosopis juliflora</i> <i>Parthenium incanum</i> <i>Rhus microphylla</i> <i>Dalea formosa</i> <i>Aristida divaricata</i> <i>Aristida purpurea</i> <i>Abutilon incanum</i> <i>Euphorbia serpyllifolia</i> <i>Dasyliirion wheeleri</i> <i>Thamnosia texana</i> <i>Melampodium leucanthum</i>	<i>Yucca elata</i> <i>Bouteloua eriopoda</i> <i>Muhlenbergia arenicola</i> <i>Aristida longiseta</i> <i>Panicum hallii</i> <i>Croton corymbulosus</i> <i>Gutierrezia sarothrae</i> <i>Eriogonum abertianum</i> <i>Haplopappus gracilis</i> <i>Boerhaavia coulteri</i> <i>Menodora scabra</i> <i>Tridens grandiflorus</i> <i>Aristida wrightii</i> <i>Aristida sp.</i> <i>Penstemon dasyphyllus</i> <i>Polygala racemosa</i> <i>Hilaria belangeri</i> <i>Oxytropis lambertii</i> <i>Cyperus rusbyi</i> <i>Eriogonum wrightii</i> <i>Gomphrena caespitosa</i> <i>Convolvulus incanum</i> <i>Hoffmanseggia drepanocarpa</i> <i>Gilia rigidula</i> <i>Rhynchosia texana</i> <i>Hoffmanseggia densiflora</i>	<i>Fouqueria splendens</i> <i>Acacia constricta</i> <i>Aloysia wrightii</i> <i>Ayenia pusilla</i> <i>Eragrostis intermedia</i> <i>Bouteloua eludens</i> <i>Sisymbrium linearifolium</i> <i>Salvia parryi</i> <i>Froelichia arizonica</i> <i>Verbesina rothrockii</i> <i>Eysenhardtia polystachya</i> <i>Acacia angustissima</i> <i>Cnidocolus angustidens</i> <i>Schistophragma intermedia</i> <i>Tridens grandiflorus</i> <i>Ayenia microphylla</i> <i>Haplophyton crooksii</i> <i>Brickellia sp.</i> <i>Muhlenbergia pauciflora</i> <i>Stipa eminens</i> <i>Tecoma stans angustata</i> <i>Hibiscus coulteri</i> <i>Calliandra eriophylla</i> <i>Jatropha macrorrhiza</i> <i>Muhlenbergia emersleyi</i> <i>Bouteloua radicata</i> <i>Yucca elata</i>

1

In the analysis performed by Dr. Garcia-Moya, the species which were so ubiquitous that they lacked plant sociological significance were deleted. Notice the small number of species common to more than one alliance, Boerhaavia coulteri between Alliances I and II, and Yucca elata and Tridens grandiflorus between Alliances II and III, and none between Alliances I and III. The overlapping species also differ greatly in prominence.

TABLE 3. CHARACTER AND DIFFERENTIAL SPECIES FOR ASSOCIATIONS WITHIN ALLIANCE I

Association A

*Acacia vermicosa*  
*Larrea tridentata*  
*Flourenzia cernua*  
*Muhlenbergia porteri*  
*Zinnia pumila*  
*Erioneuron pulchellum*  
*Panicum hirticaule*  
*Tidestroma lanuginosa*  
*Boerhaavia coulteri*  
*Euphorbia micromera*  
*Scleropogon brevifolius*  
*Prosopis juliflora*  
*Parthenium incanum*

Association B

*Acacia vermicosa*  
*Larrea tridentata*  
*Flourenzia cernua*  
*Muhlenbergia porteri*  
*Zinnia pumila*  
*Erioneuron pulchellum*  
*Rhus microphylla*  
*Dalea formosa*  
*Aristida divaricata*  
*Aristida purpurea*  
*Abutilon incanum*  
*Euphorbia serpyllifolia*  
*Dasyliirion wheeleri*  
*Thamnosia texana*  
*Melampodium leucanthum*

1

The underlined species are the differential species used to name the associations.

may be encountered to which one or more of these associations will be related at alliance level. Nonetheless, each of these associations is a valid indicator of a unique kind of environment, and one would expect most of these associations to reflect some consistency in the kinds of soils found with each.

Finally, Table 7 presents a one-page summary of the entire classification and indicates the number of subassociations identified by the taxonomic analytical procedures. For detailed information on subassociations, one should consult the dissertation which accompanies this report (Garcia-Moya, 1972). It is our untested opinion that the classifications at alliance level will be highly relevant to the interpretation of remote sensing imagery and that many of the associations should be uniquely identifiable from their images, although some may not. It is extremely unlikely, on the other hand, that the subassociation classification level will be at all relevant to the interpretation of even moderately large-scale photographic imagery. While these were segregated by the classification procedures, it remains to be seen if subassociation has practical relevance. It is likely that if they are relevant classes, it will be in indicating subtle differences in soils or other local environmental conditions. This classification was generated on the basis of existing vegetation in an area that is known to have been subjected, in part, to a history of heavy grazing. As a result, some of these classes may reflect disturbance conditions rather than areas of equivalent climax or vegetational potential. Nonetheless, the study did not include enough field sample locations so that it is certain

TABLE 4. CHARACTER AND DIFFERENTIAL SPECIES FOR ASSOCIATIONS WITHIN ALLIANCE II.

Association C

*Yucca elata*  
*Bouteloua eriopoda*  
*Muhlenbergia arenicola*  
*Aristida longiseta*  
*Panicum hallii*  
*Croton corymbulosus*  
*Gutierrezia sarothrae*<sup>1/</sup>  
*Eriogonum abertianum*  
*Eriopappus gracilis*  
*Boerhaavia coulteri*

Association D

*Yucca elata*  
*Bouteloua eriopoda*  
*Muhlenbergia arenicola*  
*Aristida longiseta*  
*Panicum hallii*  
*Croton corymbulosus*  
*Menodora scabra*  
*Tridens grandiflorus*  
*Aristida wrightii*  
*Aristida sp.*  
*Penstemon dasyphyllus*  
*Polygala racemosa*

Association E

*Yucca elata*  
*Bouteloua eriopoda*  
*Muhlenbergia arenicola*  
*Aristida longiseta*  
*Panicum hallii*  
*Croton corymbulosus*  
*Hilaria belangeri*  
*Oxytropis lambertii*  
*Cyperus rusbyi*  
*Eriogonum wrightii*  
*Gomphrena caespitosa*  
*Convolvulus incanum*

Association F

*Yucca elata*  
*Bouteloua eriopoda*  
*Muhlenbergia arenicola*  
*Aristida longiseta*  
*Panicum hallii*  
*Croton corymbulosus*  
*Hoffmanseggia drepanocarpa*  
*Gilia rigidula*  
*Rhynchosia texana*  
*Hoffmanseggia densiflora*

<sup>1</sup> The underlined species are the differential species used to name the associations.

TABLE 5. CHARACTER AND DIFFERENTIAL SPECIES FOR ASSOCIATION WITHIN ALLIANCE III.

Association I

*Fouqueria splendens*  
*Acacia constricta*  
*Aloysia wrightii*  
*Ayenia pusilla*<sup>1</sup>  
*Eragrostis intermedia*  
*Bouteloua eludens*  
*Sisymbrium linearifolium*  
*Salvia parryi*  
*Froelichia arizonica*  
*Verbesina rothrockii*  
*Eysenhardtia polystachya*  
*Acacia angustissima*

Association J

*Fouqueria splendens*  
*Acacia constricta*  
*Aloysia wrightii*  
*Cnidocolus angustidens*  
*Schistophragma intermedia*  
*Tridens grandiflorus*  
*Ayenia microphylla*  
*Haplophyton crooksii*  
*Brickellia sp.*  
*Muhlenbergia pauciflora*  
*Stipa eminens*  
*Tecoma stans angustata*  
*Hibiscus coulteri*  
*Calliandra eriophylla*  
*Jatropha macrorrhiza*

Association K

*Fouqueria splendens*  
*Acacia constricta*  
*Aloysia wrightii*  
*Muhlenbergia emersleyii*  
*Bouteloua radicata*  
*Yucca elata*

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<sup>1</sup> The underlined species are the differential species used to name the associations.



TABLE 6. CHARACTER AND DIFFERENTIAL SPECIES FOR UNALLIED ASSOCIATIONS. THESE PLANT SOCIOLOGICAL TAXA ARE NOT RELATED TO THE THREE ESTABLISHED ALLIANCES WITHIN THE STUDY AREAS ALTHOUGH THEY COULD BE RELATED TO OTHER ALLIANCES WITHIN THE REGION.

Association G

Hilaria mutica<sup>1</sup>  
Eriochloa gracilis  
Crotalaria pumila  
*Talinum aurantiacum*  
*Aristida adscensionis*  
*Erioneuron pulchellum*  
*Acacia vernicosa*  
*Allionia incarnata*  
*Aristida longiseta*  
*Bahia absinthifolia*  
*Baccharis pteroniodes*  
*Bouteloua eriopoda*  
*Cassia bauhinioides*  
*Croton corymbulosus*  
*Dalea lemmonii*  
*Eriogonum abertianum*  
*Erneapogon desvauxii*  
*Euphorbia serpyllifolia*  
*Opuntia violaceae macrocentra*  
*Parthenium incarnum*  
*Portulaca parvula*  
*Sida procumbens*

Association L

Agave palmeri  
Agave parryi  
Haplopappus laricifolius  
Sphaeralcea grossulariaefolia  
*Desmanthus cooleyi*  
*Hilaria belangeri*  
*Dalea lemmonii*  
*Haplopappus tenuisectus*  
*Andropogon cirratus*  
*Trachypogon montufari*  
*Mollugo verticillata*  
*Krameria parrifolia*  
*Elyonurus barbiculmis*  
*Brickellia venosa*  
*Heteropogon contortus*

Association H

Haplopappus tenuisectus  
Eragrostis lehmanniana  
*Evolvulus ariaonicus*  
*Chloris virgata*  
*Bouteloua aristidoides*  
*Acacia greggii*  
*Proboscidea arenaria*  
*Mollugo verticillata*  
*Evolvulus sericeus*  
*Zinnia grandiflora*  
*Bouteloua gracilis*  
*Desmanthus cooleyi*  
*Ipomoea costellata*

Association M

Mortonia scabrella  
*Aristida adscensionis*  
*Quercus pungens*  
*Stipa eminens*  
*Acacia constricta*  
*Eysenhardtia polystachya*  
*Muhlenbergia emersleyi*  
*Leptochloa dubia*  
*Cercocarpus breviflorus*  
*Rhus choriophlla*  
*Muhlenbergia pauciflora*  
*Heterosperma pinnatum*  
*Pteria scoparia*  
*Polansia trachysperma*  
*Notholaena sinuata cochisensis*  
*Condalia spathulata*  
*Acacia vernicosa*  
*Larrea tridentata*  
*Koeberlinia spinosa*  
*Opuntia leptocaulis*  
*Setaria macrostachya*  
*Coldenia canescens*

<sup>1</sup> The underlined species are the differential species used to name the associations.

TABLE 7. SUMMARY OF ALLIANCES, ASSOCIATIONS, AND SUBASSOCIATIONS IN THE TOMBSTONE STUDY AREA.

Alliance I (*Acacia vernicosa-Larrea tridentata-Flourenola tridentata*)

Association A (*Panicum hirticaule/Tidestroma lanuginosa-Boerhaavia coulteri*)  
with 3 subassociations based on one or more high fidelity, differential species. Also one variant with high prominence of *Prosopis juliflora*.

Association B (*Rhus microphylla-Dalea formosa*)  
5 subassociations

Alliance II (*Yucca elata/Bouteloua eriopoda*)

Association C (*Gutierrezia sarothrae/Eriogonum abertianum*)  
2 subassociations

Association D (*Menodora scabra/Tridens grandiflorus*)  
2 subassociations

Association E (*Hilaria belangeri*)  
2 subassociations

Association F (*Gila rigidula-Rhynchosia texana*)  
2 subassociations

Alliance III (*Fouquieria splendens-Acacia constricta-Aloysia wrightii*)

Association I (*Ayenia pusilla/Eragrostis intermedia*)  
2 subassociations

Association J (*Cnidoscolus angustidens*)  
2 subassociations

Association K (Typical of the alliance)  
3 subassociations

Individual Associations:

Association G (*Hilaria mutica/Eriochloa gracilis/Crotalaria pumila*)  
2 subassociations

Association H (*Haplopappus tenuisectus/Eragrostis lehmanniana*)  
2 subassociations

Association L (*Agave palmeri-Agave parryi/Haplopappus laricifolius*)  
2 subassociations

Association M (*Mortonia scabrella*)  
2 subassociations

that these classes are repeated in space and that they are identifiable entities, at least down to association level.

#### Short Courses and Training Sessions

During the last reporting period, we participated in a number of short courses and training sessions that helped to make potential users aware of this research program. We provided specific training in some of the techniques developed by the Project and by others who have contributed to the overall effort in Earth Resources remote sensing technology. Members of the project staff contributed to the following:

1. 20-21 October 1971, Barry Schrupf participated in the training session for U.S. Department of Interior personnel put on in Phoenix, Arizona, by the Forestry Remote Sensing Laboratory, University of California, Berkeley.

2. 24-28 January 1972, all of the staff was involved in a comprehensive remote sensing short course offered by the Rangeland Resources Program at Oregon State University. The course was attended by 54 professionals, most of them from the Northwest, but including people from Texas to British Columbia, Canada.

3. 15 March 1972, David Faulkner conducted a training session for the Bureau of Land Management, Vale, Oregon, District Staff, in some photogrammetric applications to range improvement evaluation using conventional black-and-white aerial photography.

4. 15 March 1972, Poulton presented one segment of the Forestry Remote Sensing Short Course covering some of the results of this project and explaining the then projected ERTS-A experiment.

### Legend Revisions

While our legend system, as previously reported, is highly workable and has been proven successful as a means of ecologically characterizing landscapes and conveying information to users, our use and application efforts have drawn attention to certain inconsistencies and problem areas. During the last reporting period, substantial amounts of team effort went into a reassessment of the legend classes, the consistency of criteria by which they were differentiated, and the logic of the complete system. In doing this work, we in effect went through the entire legend and critically challenged all classes, both broad and highly specific. Out of this evaluation, some significant improvements were developed, especially in the higher hierarchical levels.

This activity also strengthened our growing feeling that the higher hierarchical levels in the vegetational legend must be based on physiognomic and structural criteria. The intermediate levels should distinguish broad floristic differences. The detailed portion of the legend, dealing with specific ecosystems, will have to be regionalized in its development and the classification units based on plant sociological criteria and diagnostic (character and differential) species. These concepts have been incorporated into the new legend.

The macrorelief legend has remained unchanged and is highly workable. The "landforms" legend has undergone some revision, and we are not yet completely satisfied with it. We have been unable to give attention to further development of the surficial geology and soils legends because these disciplines were not represented on our team.

We have not altered the land use, agricultural, urban, industrial, or transportation portions of the unified legend presented earlier (Pettinger, et al., 1970). Nearly adequate classifications developed by experts concerned with these subjects (Department of Transportation, 1969; C. W. Johnson, 1969) were incorporated directly into that legend with only slight modification. Further appropriate modification of these categories requires attention by scientists not directly available to us. The new land use legend being developed by an Inter-Agency Committee under sponsorship of the U.S. Geological Survey is a step in this direction, but this new work (U.S. Geological Survey, 1972) needs to be further developed to make it compatible with our comprehensive ecological resource analysis legend. The two are potentially highly compatible, and it is hoped that future developments will make a close collaborative effort possible. Steps have been taken in this direction.

Legend development has reached a sufficient level of stability that we felt an official paper on the subject would be appropriate. Such was given at the 8th International Symposium on Remote Sensing of Environment at Ann Arbor, Michigan, October 2-6, 1972 (Poulton, 1972). This paper explains the legend and the kinds of revisions that were made.

The following six legend categories meet the needs for a first-order delineation of space and highlight imagery.

#### PRIMARY SURFACE FEATURE CLASSES

- 100 - Barren Lands (other than crop fallow)
- 200 - Water Resources (free water surfaces)
- 300 - Natural Vegetation
- 400 - Agricultural Crop and Idle Land
- 500 - Urban and Industrial Land (including transportation features)
- 600 - Obscured Surface (not visible, atmospheric obstruction)

The logic of arrangement is from essentially nonvegetated, to naturally vegetated, to altered landscapes, and finally to a class accounting for features obscured by clouds, smoke, haze, etc. Each of these primary classes is subdivided into one or more subordinate levels. The secondary legend classes for Barren Land are as follows:

#### SECONDARY BARREN LAND CLASSES

##### 100 - BARREN LAND

- 110 - Playas (dry or intermittent lake basins)
- 120 - Aeolian Barrens (dunes and sandplains, exclusive of beaches)
- 130 - Rocklands
- 140 - Shore-lines (beaches, tidal mud flats, sand and gravel banks)
- 150 - Badlands (barren silts, clays, and related easily weathered rock types)
- 160 - Slicks (saline, alkaline, soil structural non-playa barrens)
- 170 - Mass Movement (barrens associated with slumps and mud flows)
- 180 - Man-made Barrens (mine dumps, excavations, fills and settling ponds)
- 190 - Undifferentiated complexes of barren lands

We have found that when the breakdown of barren land types is carried too far, it becomes redundant with some landform classes or with surficial geology. The above parenthetical statements indicate some of the kinds of subordinant barren land types that have been numerically designated by a "units digit" in the complete legend.

The subcategories for the Water Resources class are as follows:

#### SECONDARY WATER RESOURCE CLASSES

##### 200 - WATER RESOURCES

- 210 - Ponds, Lakes, and Reservoirs
- 220 - Water Courses, Permanent Flowing
- 230 - Springs, Seeps, and Wells
- 240 - Bays, Coves, and Estuaries
- 250 - Lagoons and Bayous

- 260 - Oceans, Seas, and Gulfs
- 270 - (Unused Class)
- 280 - Snow and Ice
- 290 - Undifferentiated Complexes of Water Resources

We have suggested two subclasses under 210, Ponds, Lakes, and Reservoirs, and 220, Water Courses. These are --1, Natural, and --2, Man-made, in each instance. Under class 280, Snow and Ice, we have suggested 281, Ephemeral, and 282, Permanent, subclasses. Beyond this we are hopeful that water resources specialists will pick up this thread and further develop the details for maximum relevance to the information user.

The secondary and tertiary subclasses of natural vegetation are based on physiognomic and structural or growth form characteristics of the plant communities. These classes are presented in Table 8.

In developing this vegetational legend, the savanna-like vegetation gave us the greatest difficulty. We believe that there is a real need for a broad hierarchical level to span the intergrading situations between the woody (forest and tall shrub) and the non-woody vegetations. The term savanna has some very specific meanings that do not fully describe this situation in both temperate and tropical environments.

After much thought, we decided to physiognomically and structurally define this intermediate vegetation as a very scattered or open, tall, woody layer over a relatively homogeneous and closed layer of subordinate vegetation that may be prominently herbaceous, low-growing woody, or a combination thereof. Some people will say that such a statement describes a savanna, but others will not agree. We have attempted to resolve the dilemma by referring to class 330 as "Savanna-like Intergrade Types."

Some will note that we have eliminated three secondary vegetational classes from our initial legend. These are Desert, Tundra, and Vegetation of Aquatic Environments. Each of these is environmentally, not physiognomically and structurally, determined. Thus, they were inconsistent with the classification criteria. In addition, each can be fully accounted for within the framework of the four secondary classes in Table 8.

Based on floristic and phytosociological criteria, the legend system can be carried all the way to specific ecosystem level. Floristics comes into play at the decimal point in the symbolic legend. Depending on the complexity of the ecological region, up to the second decimal (1/100ds) position may be required to handle these broad floristic similarities, usually at the generic level of plant identification. Beyond this, the criteria become phytosociologic, and highly specific kinds of plant communities may be symbolized. The following example illustrates the symbolic legend carried to this level of detail (Martin, 1970; Poulton, Faulkner, and Martin, 1971):

#### VEGETATION CLASSIFICATION TO ECOSYSTEM LEVEL

##### 300 - NATURAL VEGETATION

##### 320 - Shrub-scrub vegetation

##### 324 - Microphyllous salt tolerant vegetation

##### 324.1 - Saltsage (Atriplex) prominent vegetation

##### 324.11 - Shadscale/Budsage (Atco/Arsp) communities

324.111 - Atco(4-5) - Arsp(3-4/Sihy(3-5) -  
Brte(0-3)<sup>1</sup>

324.112 - Atco(4-5) - Arsp(3-5)-Grsp(2-3)/  
Sihy(1-5)-Brte(0-

324.113 - Atco(4-5) - Arsp(3-4)-Save(2),  
Chvi, Chna(2)/Sihy(3-5)-  
Pose(2-3)-Brte(0-5)

<sup>1</sup>These symbols are derived from the scientific plant name, and the numerals express relative prominence of the species in the community



TABLE 8. SYMBOLIC VEGETATIONAL LEGEND TO TERTIARY LEVEL ON PHYSIOGNOMIC AND STRUCTURAL CHARACTERISTICS OF THE VEGETATIONAL COMMUNITIES OR PLANT SOCIOLOGICAL TAXA.

300 - NATURAL VEGETATION Subclasses

310 - Herbaceous types (w/ or w/o platyphyllous succulents or low shrubs)

- 311 - Lichén, cryptogam & related communities
- 312 - Prominently annuals (grass-forb-succulents; usually grass aspect)
- 313 - Forb types (broad-leaved forb aspect)
- 314 - Bunchgrass steppe (tussock grass)
- 315 - Sodgrass and mixed sodgrass-bunchgrass steppe and prairie
- 316 - Meadows (Graminaceous/Cyperaceous)
- 317 - Graminaceous Marshes (Panicums, Settaria, etc.)
- 318 - Tule Marshes (Cyperaceae, Juncaginaceae, Typhaceae, etc.)
- 319 - Undifferentiated complexes of herbaceous types

320 - Shrub-scrub types

- 321 - Microphyllous, non-thorny scrub, generally with succulents
- 322 - Microphyllous thorn scrub
- 323 - Succulent scrub
- 324 - Microphyllous saltsage and related scrub types
- 325 - Shrub steppe (single species or simple mixtures of shrubs)
- 326 - Evergreen sclerophyll shrub
- 327 - Deciduous macrophyllous shrub
- 328 -
- 329 - Undifferentiated complexes of shrub-scrub types

330 - Savanna-like Intergrade types

- 331 - Scattered tall shrub )
- 332 - Scattered broad-leaved tree )--- over herbs
- 333 - Scattered needle-leaved tree )
- 334 - Scattered needle-leaved tree )
- 335 - Broad-leaved tree )--- over low shrubs
- 336 -
- 337 -
- 338 -
- 339 - Undifferentiated complexes of savanna-like types

340 - Forest and Woods types

- 341 - Needleleaf
- 342 - Broadleaf
- 343 - Mixed forests of needleleaf-broadleaf
- 344 -
- 345 -
- 346 -
- 347 -
- 348 -
- 349 - Undifferentiated complexes of forest and woodland types

One example will suffice of how we adapted the Coding Manual classes for Agriculture, Urban, Industrial, and Transportation.

ADAPTATION OF EXISTING AGRICULTURAL AND  
URBAN-INDUSTRIAL CLASSIFICATION

- 400 - AGRICULTURAL LANDS
  - 410 - Field and Seed Crops
    - 412 - Legumes for Seed
      - 412.2 - Peas, field
- 500 - URBAN AND INDUSTRIAL (including transportation)
  - 510 - Residential Housing
    - 511 - Household units
    - 512 - Group quarters
      - 512.3 - Residence halls and dormitories
  - 540 - Transportation, Communication, and Utilities
    - 543 - Aircraft transportation
      - 543.1 - Airports and flying fields

Those familiar with the Coding Manual and the work of Johnson (1969) will immediately see that our agricultural crop symbols are derived by dropping the initial 81 ... designator in the Coding Manual and replacing it with a 4 in the hundreds position. To generate a symbol in the Urban, Industrial, and Transportation categories, we merely added the digit 5 in front of the Coding Manual symbol and placed a decimal after the third digit. Even though many of the legend classes in the Coding Manual cannot be photo identified, it is a comprehensive list, and most of the intermediate units are photo identifiable.

Symbolization of the environmental feature, macrorelief, is handled as follows:

PRIMARY PHYSICAL ENVIRONMENT CLASSES

- 1.0 - Flat Lands (slopes < 10 percent)
  - 1.1 - Nondissected
  - 1.2 - Dissected
- 2.0 - Moderately Undulating to Rolling Lands (slopes 10-25 percent)
  - 2.1 - Nondissected
  - 2.2 - Dissected
- 3.0 - Hilly Lands
- 4.0 - Mountainous Lands

These classes define the macroscale relief and contour features of the earth's surface in a way that is ecologically relevant. They can be used with high consistency to interpret space and highlight imagery. They have been defined and illustrated in earlier reports (Pettinger, 1970).

The legend for detailed relief and landform features is still changing. This part of the legend has gone through a more radical evolution than any other section. We are best satisfied with the first-order classes which we have chosen to call Secondary Physical Feature Classes as follows:

#### PHYSICAL FEATURE CLASSES

- 1.0 - Depressional or Wet Lands, Non-Riparian
- 2.0 - Bottomlands, Riparian
- 3.0 - Planar Surfaces
  - 3.1 - Fans and Bajadas
  - 3.2 - Terraces
  - 3.3 - Pediments
- 4.0 - Aeolian Featured Landscapes
- 5.0 - Slope Systems
- 6.0 - Gravity and Mass Movement Landscapes

Some of these classes can be logically broken down by well-accepted landform names. Others pose difficulties in identifying subclasses that follow geomorphological nomenclature and which are relevant to the ecology of landscapes or to resource management.

We have found a legend based on rock types to be quite workable as a surficial geology legend leading into soils notations. This was first developed in another project under Western Regional Research support (W-25, Ecology of Brush Infested Ranges) by Poulton, Fosberg and Pyott (1968). As an applications "spinoff" from the project herein reported, the Bureau of Land Management arrived at the identical first-

order classes as part of a California Desert Project (California State Office, Bureau of Land Management, 1971). The first-order categories for surficial geology are as follows:

PHYSICAL ENVIRONMENT CLASSES  
SURFICIAL GEOLOGY

- 10 - Coarse Grained Igneous
- 20 - Fine Grained Igneous
- 30 - Sedimentary
- 40 - Metamorphic
- 50 - Unconsolidated Material
- 90 - Undifferentiated soil forming material

We have not developed a soils legend in this research, but we suggest two basic systems for handling this feature of the physical environment: (1) Symbolize the soils taxa according to the National Standard Survey System, or (2) Symbolize soils characteristics that are ecologically or managerially relevant. Such features as solum depth, texture, stoniness, degree of development, presence of restrictive layers or pans, etc., are examples of the kinds of notations required. We have had some experience with this latter system in areas where soils are little known and have not been classified. It was found useful and workable. In most instances, both approaches can be translated into a numerical symbology that is computer compatible (Poulton, Fosberg, and Pyott, 1968).

We are quite certain that some of the above classes will be subject to some change. They can be improved upon. All the present classes are workable and they do express features that are generally relevant to the interpretation of space and aerial photography and of other systems sensitive to vegetational signatures. All the classes are

consistently based on the selected criteria for differentiation and similarity. Based on our experience, we believe the vegetation legend to tertiary level has continent-wide and possibly global application. It is ideally suited to interpretation of space and high altitude imagery. At the quaternary level, first decimal position, we believe the regionalization of the legend is the only feasible way to go. These regional boundaries should, however, be determined by ecological provinces, not by political or ownership boundaries. This step enables one to hold the digits in the symbolic legend to a reasonable number and still maintain the logic of the system.

We have given the legend system sufficient publicity to get a very good cross-section of reaction. Nearly all has been encouraging because reviewers see direct value and applicability in the unified, computer-compatible system. Specifically, personnel of the Mt. Hood and Siuslaw National Forests in Oregon are interested in trying the system for some of their multidisciplinary resource analysis work. We are using the legend in two ERTS-1 participation projects at Oregon State University. In addition, we have actually used the system in other resource inventory projects from salt desert to forest types. The writer had an opportunity in the fall of 1971 to adapt the legend to very broad levels of vegetational resource inventory in the Brazilian Amazon and some of the drier types to the south. Although the Brazilians were already using another entirely workable system, it is interesting that our legend system, developed initially for an arid environment, was rather easily adapted to accommodate the vegetational legend classes which the Brazilian scientists had devised. These experiences, plus

the increasing attention being paid to the need for a nation-wide rangeland resources inventory and the movement of Federal and State land management agencies toward interdisciplinary inventory and team management of natural resources, compel us to strongly urge that this legend system be given serious consideration for nation-wide adoption as a uniform ecological resource analysis legend. It truly has multi-disciplinary applicability and results in the recognition of landscape units that are ecologically unique and that will serve as a base on which all the individual disciplines can accumulate most of the additional detail required for their individual decisions and action programs.

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APPENDIX A

NASA-USDA FORESTRY AND RANGE REMOTE SENSING RESEARCH PROGRAM  
 "REMOTE SENSING APPLICATIONS IN FORESTRY" SERIES

1966 Annual Reports

<u>STAR* No.</u>	<u>Title</u>
N67-19905	Carnegie, D. M., W. C. Draeger and D. T. Lauer. The use of high altitude, color and spectrozonal imagery for the Inventory of wildland resources. Vol. I: The timber resource. School of Forestry and Conservation, University of California, Berkeley. 75 pages.
N66-39698	Carnegie, D. M., E. H. Roberts and R. N. Colwell. The use of high altitude, color and spectrozonal imagery for the inventory of wildland resources. Vol. II: The range resource. School of Forestry and Conservation, University of California, Berkeley. 22 pages.
N67-19939	Carnegie, D. M. and R. N. Colwell. The use of high altitude, color and spectrozonal imagery for the inventory of wildland resources. Vol. III: The soil, water, wildlife and recreation resource. School of Forestry and Conservation, University of California, Berkeley. 42 pages.
N66-39304	Heller, R. C. et al. The use of multispectral sensing techniques to detect ponderosa pine trees under stress from insect or pathogenic organisms. Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, USDA. 60 pages.
N66-39386	Lauer, D. T. The feasibility of identifying forest species and delineating major timber types in California by means of high altitude small scale aerial photography. School of Forestry and Conservation, University of California, Berkeley. 130 pages.
N66-39700	Wear, J. F. The development of spectro-signature indicators of root disease on large forest areas. Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, USDA. 24 pages.

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<u>STAR No.</u>	<u>Title</u>
N66-39303	Lent, J. D. Cloud cover interference with remote sensing of forested areas from earth-orbital and lower altitudes. School of Forestry and Conservation, University of California, Berkeley. 47 pages.
N66-39405	Weber, F. P. Multispectral imagery for species identification. Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, USDA. 37 pages.
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N68-17671	Carneggie, D. M., C. E. Poulton and E. H. Roberts. The evaluation of rangeland resources by means of multispectral imagery. School of Forestry and Conservation, University of California, Berkeley. 76 pages.
N68-17378	Wear, J. F. The development of spectro-signature indicators of root disease on large forest areas. Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, USDA. 22 pages.
N68-17408	Heller, R. C., R. C. Aldrich, W. F. McCambridge and F. P. Weber. The use of multispectral sensing techniques to detect ponderosa pine trees under stress from insect or pathogenic organisms. Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, USDA. 65 pages.
N68-17247	Weber, F. P. and C. E. Olson. Remote sensing implications of changes in physiologic structure and function of tree seedlings under moisture stress. School of Natural Resources, University of Michigan. 61 pages.

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Title

1968 Annual Reports

- N69-16461      Lent, J. D. The feasibility of identifying wildland resources through the analysis of digitally recorded remote sensing data. School of Forestry and Conservation, University of California, Berkeley. 130 pages.
- N69-25632      Carnegie, D. M. Analysis of remote sensing data for range resource management. School of Forestry and Conservation, University of California, Berkeley. 62 pages.
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- N72-74472 Langley, P. G. and D. A. Sharpnack. The development of an earth resources information system using aerial photographs and digital computers. Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, USDA. 26 pages.
- N69-15856 Olson, C. E. and J. M. Ward. Remote sensing of changes in morphology and physiology of trees under stress. School of Natural Resources, University of Michigan. 43 pages.
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- N70-41282 Colwell, R. N. et al. Analysis of remote sensing data for evaluating forest and range resources. School of Forestry and Conservation, University of California, Berkeley. 207 pages.
- N70-41063 Poulton, C. E., E. Garcia-Moya, J. R. Johnson and B. J. Schrupf. Inventory of native vegetation and related resources from space photography. Department of Range Management, Agricultural Experiment Station, Oregon State University. 66 pages.

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N71-32815	Dana, R. W. Calibration of color aerial photography. Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, USDA. 14 pages.
N72-28327	Driscoll, R. S. and R. E. Francis. Multistage, multi-band and sequential imagery to identify and quantify non-forest vegetation resources. Rocky Mountain Forest and Range Experiment Station, U.S. Forest Service, USDA. 75 pages.
N72-28328	Amidon, E. L., D. A. Sharpnack and R. M. Russell. The development of an earth resources information system using aerial photographs and digital computers. Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, USDA. 7 pages.
N72-28324	Personnel of the Remote Sensing Research Work Unit. Monitoring forest land from high altitude and from space. Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, USDA. 179 pages.
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