REMOTE SENSING APPLICATIONS IN FORESTRY

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

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

REMOTE SENSING APPLICATIONS IN FORESTRY

QUARTERLY PROGRESS REPORT

for

NASA Contract No. ~~R-09-038-002~~ W-12,996

for the period

October 1, 1969 to December 31, 1969

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INTRODUCTION

This report is the fourteenth of a series of activity reports for research being performed under the auspices of the Forestry Remote Sensing Laboratory. The report summarizes the research activity of the current studies from October 1, 1969 to December 31, 1969.

The Forestry Remote Sensing Laboratory is responsible for the coordination and technical guidance of the NASA-sponsored forestry and range remote sensing research program. These tasks are carried out in cooperation with the Forest Service, U. S. Department of Agriculture. Technical guidance of this research program is provided by Dr. R. N. Colwell of the University of California.

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ANALYSIS OF REMOTE SENSING DATA FOR EVALUATING WILDLAND RESOURCES

by

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A. Work Performed During the Period Covered by this Report

1. Forestry and range remote sensing program coordination and support.

a. A meeting of all study leaders, nationwide, in the NASA sponsored forestry and range program was held in Berkeley on November 24 and 25, under auspices of the FRSL. Results of research were presented, and the present and future goals of the forestry and range program discussed. It was acknowledged that current and future research should attempt to utilize imagery having spatial resolution similar to that expected from ERTS-A in order that familiarization with this type of data might be accomplished before the launch of ERTS-A in early 1972.

b. The annual progress reports from the study leaders have been received and edited. These reports (unillustrated) will be sent to all the major forestry schools in the nation and most of the major remote sensing centers around the world.

c. The final draft of the study by Richard Wilson entitled, "Potentially Efficient Forestry and Range Applications of Remote Sensing Using Earth Orbital Spacecraft--Circa 1980" has been received. The preliminary draft was reviewed by over 20 individuals, both administrators and scientists, and their comments have been incorporated in the final draft.

2. Operational feasibility unit. The study entitled, "Applications of Remote Sensing in Multiple Use Wildland Management", was continued during this period. Sections which were completed include the following:

a. The development of mapping criteria for multiple use planning which is particularly amenable to the use of aerial photo interpretation techniques. This was necessary due to the fact that multiple use zones. as currently used, were not developed with aerial photography in mind and consequently do not lend themselves to photo interpretation.

b. The compilation of extensive photo interpretation keys and guides applicable to the mapping system described above. This material is intended as an example of the type of training material which can be developed for such applications, and as a practical test of the feasibility of performing multiple use mapping using the specifically developed criteria.

c. A discussion of the potential applicability to multiple use planning of advanced techniques presently being developed. Included in the discussion were such techniques as satellite photography, automated interpretation, color enhancement of multispectral imagery, and capabilities of sensors operating in other than the photographic portion of the spectrum.

3. Automatic image classification and data processing unit.

a. As shown in Figure 1, a modest capability was developed during this quarter to scan a photograph with a microdensitometer and record brightness values on magnetic tape. A printout could then be obtained from the tape at the University's Computer Center. With regard to spot size, the present state of development of the microdensitometer allows apertures of 0.06" (approximately) to be recorded. Figure 1 depicts the scan obtained from a black-and-white infrared photo of the NASA Bucks Lake Forestry Test Site, showing just two features isolated from the remaining optical densities (in this instance, water bodies and riparian vegetation). It is apparent from viewing the photo print which accompanies this figure that considerable greyscale integration is occurring with a spot size of 0.06".

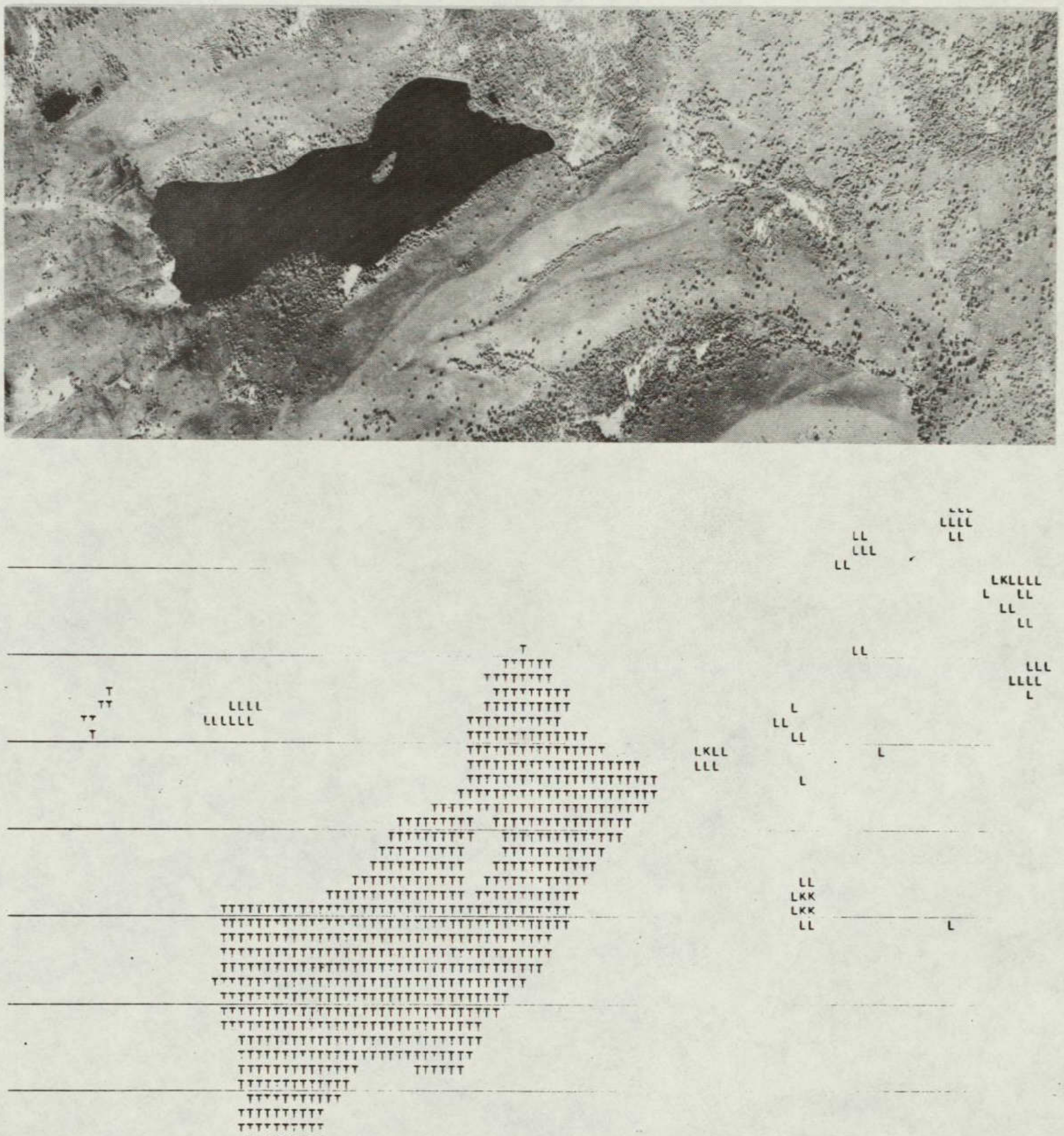

Figure 1. Photo print (top) and scanned display of optical densities (bottom). Twenty-six levels were recorded from the black-and-white infrared negative with only three symbols displayed. The relatively large aperture size (presently about 0.06") produces significant integration of grey levels; also, the display of every other line presently fails to take advantage of the microdensitometer's potential resolution capability.

Also, only every other line of scanned data is displayed, which visually restricts our recording sensitivity potential of measuring up to 1000 grey levels of optical density (between the range of 0.05 and 2.5). The intent, in developing this capability, is to permit interaction between the human and machine and thus develop an optimum procedure for data analysis.

b. Various software programs were written in order to record on digital tapes the densities of film emulsions.

c. Formats for the above-mentioned tapes were developed to facilitate analysis and display of data recorded on the tapes.

4. Spectral characteristics unit. Work was completed on a study of the feasibility of identifying several brush species from density measurements made on the film negatives for multiband photography acquired at the NASA Bucks Lake forestry test site. Spectral reflectance measurements were made in the field for those species under study, and these data were compared with film density measurements. A field portable spectroradiometer was used to obtain integrated spectral reflectance data from the plant canopy. The study is reported in Chapter 3 of the annual report of the Forestry Remote Sensing Laboratory.

5. Image interpretation and enhancement unit.

a. A report on the high flights made of the Phoenix area is nearing completion. This special report, entitled, "Analysis of Earth Resources on Sequential High Altitude Multiband Photography", is expected to be finished by February 1, 1970. It summarizes the various techniques used for analyzing resources in the Phoenix site (e.g., geology and wildland vegetation), and in the Bucks Lake (forestry) site.

b. The optical combiner is currently being modified to incorporate a means of regulating light intensity, facilitate image registration, and provide a shorter distance to the viewing screen.

6. Training unit.

a. In response to President Nixon's speech to the United Nations (in which he mentioned the willingness of the U. S. to provide remote sensing assistance for the solution of earth resource problems in foreign countries), a request was made to NASA by the government of India for assistance in assessing damage due to coconut blight (caused by a fungus *Phytophthora* spp.). On October 29, 1969, Dr. Pisharoty and Dr. Dakshinamurty, both from the government of India, visited the FRSL and tentative arrangements were made for a member of our staff to visit India in February, 1970, to help develop remote sensing techniques for early detection of this economically important disease.

b. Arrangements were made for the FRSL to give a one-day short course in remote sensing on August 27, 1970, in cooperation with the Association of American Geographers. This course will follow the annual meeting of the AAG which is to be held in San Francisco.

B. Work Currently in Progress

1. Forestry and range remote sensing program coordination and support.

a. Proposals for future NASA sponsored remote sensing research are being prepared by all study leaders, nationwide, in the forestry and range remote sensing program. These proposals are being received and coordinated by the FRSL for forwarding to the chairman of the NASA-USDA Research Management Group.

b. Annual reports are being typed and should be ready for distribution shortly after the first of the year.

2. Operational feasibility unit.

a. The multiple-use study discussed in A is being completed. All that remain on this study are the drafting of final conclusions and the preparation of the final report.

b. The bulk of the effort of the unit at the present time is being directed toward a determination of the user requirement for remote sensing data in the Phoenix, Arizona area where much of our remote sensing research is being conducted. As a follow-on to the S065 multispectral experiments, the Laboratory is involved in an integrated analysis of high altitude and space imagery in the Phoenix area; in that regard the duties of the Operational Feasibility Unit include a determination of data requirement priorities for agencies which make decisions relative to land use and land allocation. In addition, the unit will attempt to evaluate the degree to which these informational needs can be met by means of remote sensing techniques which have been developed (and evaluated as to technical feasibility)by the other units in the Forestry Remote Sensing Laboratory.

3. Automatic image classification and data processing unit.

a. Specifications are being prepared for the purchase of precision control hardware for our scanning microdensitometer to be delivered in early spring, 1970. The Computer Center has a simulated remote terminal arrangement to allow those planning such data handling configurations to start software programs for the system to be in operation by May, 1970. Modification and adaptation of the LARSYSAA program (Version II, Level 1) to the proposed system is underway and planned for operation by summer, shortly after the Computer Center has commenced its new processing system. Modification of the "X, Y scanning microdensitometer" is progressing with first attention being given to aperture size and refinement of the Y stage drive to 0.001".

b. Software programming for the data linkage and handling of optical density data is proceeding in order to facilitate the more difficult tasks which must follow: viz., the recording of more than one multispectral image with conjugate coordinate referencing, and the classification of wildland features.

c. A study currently is underway which uses our present microdensitometer equipment in the scanning and recording of agricultural data from the Imperial Valley, California and Mesa, Arizona test sites. The intent is to have these records analyzed at the LARS facility in Purdue in the near future. Some software is being developed to reduce registration problems associated with the scanning of multiple images.

d. Efforts are continuing that seek to develop improved capabilities for us to study various human-machine interactions of the type that eventually will be necessary in the analysis of ERTS data. Our present concept in this regard appears in the diagram in Figure 2. In this diagram, it is noted that after considerable specification review and discussion with the University Computer Center systems staff, a "mini-computer" system appears to offer, for our intended purposes, the greatest flexibility of control and analysis in terms of cost, reliability and ease of operation. Several reasons have caused the change in system configuration. The most important of these was a change in processing design by the Computer Center from a slow-turnaround "closed shop" system to a remote-terminal-oriented, "on-line" configuration. This will enable, for example, the adaptation of programs such as LARSYSAA to the FRSL system, which heretofore would have been too difficult and time-consuming to modify. Thus,

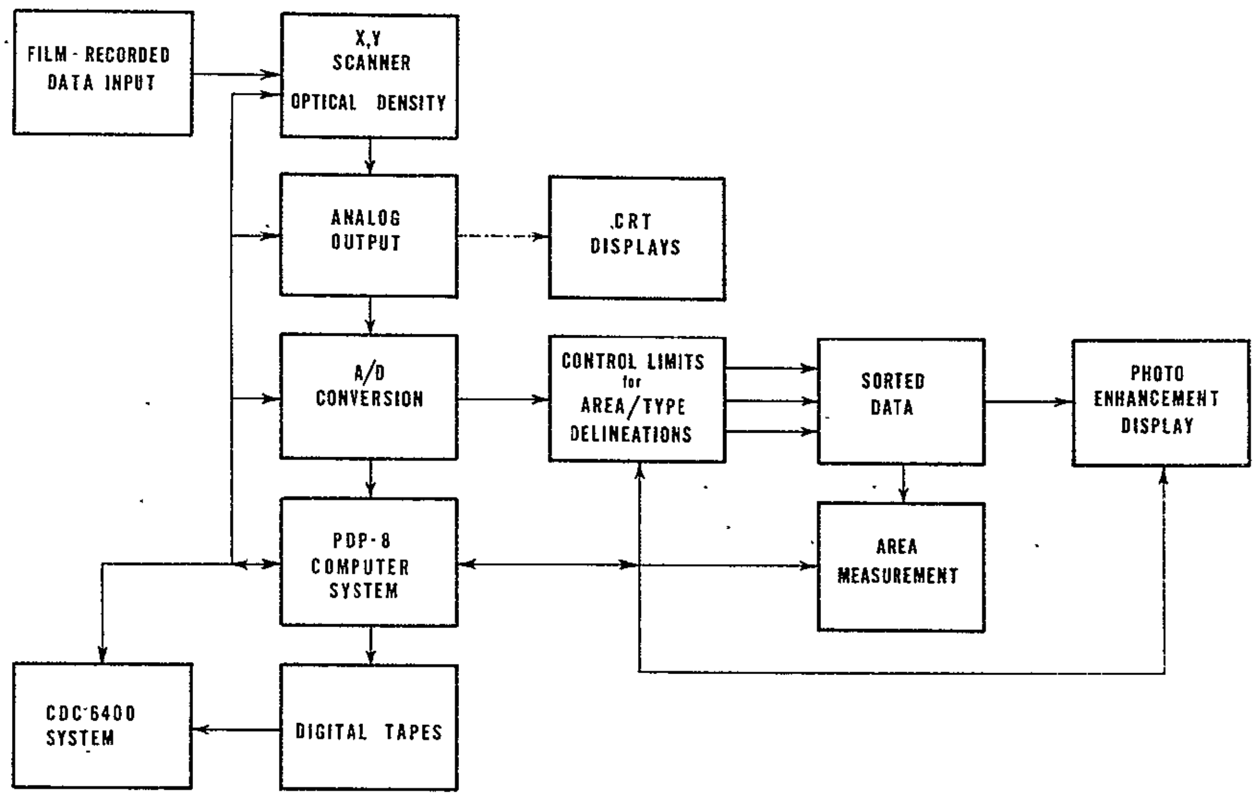

Figure 2. Activities are continuing toward the implementation of a data processing facility at the Forestry Remote Sensing Laboratory to complement some of our existing research efforts in photo interpretation analysis as well as enable the continued investigation of problems associated with "automatic" image classification of wildland resources. Figure 6.9 of the FRSL 1969 Annual Report has since been modified to the extent shown in this diagram.

agricultural resources can be automatically classified and readily compared with visual interpretation techniques for such areas as the Apollo 9 Phoenix Test Site. Techniques for developing programs for wildland classification can also be handled on such an analysis system.

e. On the X,Y scanning microdensitometer, those steps which remain to be perfected, and for which effort is currently being expended, are (1) the refinement of aperture spot size, (2) the refinement of the Y stage increment to 0.001" from its present 0.0025", and (3) the addition of a filtering "chopper wheel" to record up to seven channels of multispectral data from film emulsions (color and color infrared, included).

4. Spectral characteristics unit. Work is continuing on the development of techniques for the collection, analysis and interpretation of incident spectral illumination and spectral reflectance data to be recorded in the field for natural features. The current work is preparatory to expected spring delivery of a field portable recording spectroradiometer for spectral measurement of incident illumination. This instrument, when operated in conjunction with our present spectroradiometer used for obtaining spectral reflectance measurements will allow standardization of data obtained under a variety of illumination conditions.

5. Image interpretation and enhancement unit.

a. Data from the last two high altitude aircraft missions (September 30 and November 4, 1969) for the Phoenix, Tucson site have been received. Ground truth information for this area was collected and has been incorporated in calendars which document the phenological change for certain resources in the Phoenix test area. Studies have also been made on the evaluation of the geologic resource of the Phoenix site and forest resources of the Bucks Lake Test Site using sequential high altitude photographs.

b. Modifications to the optical combiner used to produce image enhancements at the University of California were considered. It appears that improvements can be made to the system which will virtually eliminate the registration and light fall-off problems which have been troublesome in the past.

6. Training unit.

a. Preparations for the trip to India are being carried out. This includes the rental of a 70mm Hasselblad camera and procurement of processing equipment and chemicals for the film.

b. A syllabus is being prepared for the AAG shortcourse. Also, a lengthy literature review of applications of remote sensing in resource planning is currently being updated for inclusion in the syllabus.

THE USE OF SPACE PHOTOGRAPHY FOR CLASSIFYING FOREST AND NON-FOREST LAND AND FOR DETECTING FOREST DISTURBANCES

by

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A. Work Performed During the Period Covered by this Report

1. 1:20,000 scale Agricultural Stabilization and Conservation Service photography was ordered for 10 randomly selected sample blocks within Apollo 9 photographic coverage. These blocks are 4-mile squares or 16 square miles in area. There are 5 blocks in the Mississippi Valley and 5 blocks in west central Georgia.

2. Sample strips have been located within these blocks and marked on the ASCS photographs. These strips coincide with 1:2,000 scale Anscochrome D/200 coverage obtained by the Forest Service remote sensing aircraft one month following the Apollo 9 mission. A 120-foot swath along the center line of the strips marked on the ASCS photographs will be interpreted for forest and land-use classes. This interpretation will form a base to compare with interpretation on the infrared color space photographs and the 1:20,000 scale infrared color. The 1:20,000 scale infrared color will provide the truth for both interpretation and microdensitometer forest classifications.

3. Both 10 diameter and 28 diameter photographic enlargements have been made of portions of the Apollo 9 photographs to facilitate location of sample strip center lines for photo interpretation and microdensitometry.

B. Work Currently in Progress

1. Sample strip center lines to be interpreted and scanned by the GAF

650 microdensitometer are being precisely located on all imagery.

2. Microdensitometer traces will be made for all strips on 1:20,000 IR color and on the Apollo 9 imagery (infrared color). The traces will be made with red, green, blue and visual filters. This will amount to a total of 80 traces; 40 on each film.

3. The analog charts will be digitized with a Bendix digitizer and the data stored on tapes for retrieval and computer analysis with photo interpretation and ground truth.

INVENTORY OF NATIVE VEGETATION AND RELATED RESOURCES FROM SPACE PHOTOGRAPHY

by

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A. Work Performed During the Period Covered by this Report

1. Research is continuing on the interpretation and use of space and supporting aircraft photography for rangeland resource applications in southern Arizona. Since the Apollo 9 and S065 photography was heavily cloud covered over the majority of our study area, we are continuing to use Apollo 6 photography for general studies and have concentrated most of our recent ground truth-image relationship work in a smaller Tombstone-Ft. Huachuca area where the Apollo 9 photography was cloud-free and in another cloud-free strip to the west of Tucson.

2. Work this quarter has concentrated on the analysis of ecological ground-truth records obtained during the summer in the Tombstone-Ft. Huachuca area. The ecological classification of data that results from these analyses provides a way to recognize the meaningful plant communities and the characteristics, potentials and limitations of each kind of rangeland. These plant communities define the specific ecosystems that are the basis of resource inventory and analysis. Once defined and mapped, these ecological classes (ecosystems) can be used to infer certain soils and resource use and management potentials of the land. Range resource managers need to know the kinds, areal extent, location and condition with respect to potential productivity and resource stability of each ecosystem found

within the areas for which they are responsible. This work is showing some close relationships between certain plant communities (specific ecosystems) and landforms that can be easily seen and identified from appropriate photography. Our legend system was found to fit this area very well and the work has added two new and more detailed units to the legend.

3. Our symbolic system has been tested for applicability in the annotation of interpretations from several scales of photography up to 1:20,000. It was found to be highly workable as a procedure for meaningfully labeling delineations on resource maps and thus will be useful in categorizing statistics about the landscapes. It should also provide useful classes for entering resource information into ADP systems. Limited work has been done on the generalization of the broader legend categories to fit native vegetation areas outside of the particular test area in southern Arizona. It appears that the legend concept can be made world-wide in application.

4. Ground-truth data with photographs have been collected at fifteen locations on six dates to provide a record of seasonal plant development in different desert-grassland ecosystems in support of the high-flight photography taken over our test area. This is for the primary purpose of studying the usefulness of multiseasonal photography in the identification and mapping of rangeland ecosystems. We have not yet obtained copies of the high-flight photography to begin analysis of these data.

5. The project leader participated in a principal investigators workshop called at the Forestry Remote Sensing Laboratory in November for program planning and coordination.

6. We are using macrorelief to denote the grossest of earth relief features that have ecological significance. We are using landform as a

subordinant classification representing the geomorphological nature of causes of macrorelief which in turn has a more local or restrictive influence on the ecology of landscapes. These features of macrorelief and landform are extremely useful as associated evidence. Awareness of them enables the analyst to read much more about the vegetation and soil resources as he interprets imagery of earth resources. Without considering macrorelief and landform, many photographic image characteristics do not in themselves permit essential vegetational discriminations. This is particularly true of Apollo 6 photography, not so much so of Apollo 9 color infrared or multispectral photography.

By first mapping macrorelief, one greatly reduces the number of alternative vegetational and soils identifications that are possible in each delineated area. As these broad classes can be further broken down by ecologically relevant landform features, the alternative choices are further restricted. The accuracy of photo interpretation may be significantly increased by following a procedure that considers image identification in the following order: (1) Broad geographical region or ecological province in which the imagery is taken, (2) Macrorelief class and the vegetations in the region that are normally associated with that class, (3) Ecologically relevant landforms and similarly vegetation and soils characteristics normally associated with each landform class, and (4) The specific image characteristics that are vegetation-soil related. This process can well narrow the alternative identification choices to less than a half dozen ecosystems and sometimes to only one or two.

Considering the importance of these relief features, we conducted a simple, preliminary test of the macrorelief component of our legend system. It enabled us to determine some of the specific problems and training needs associated with accurate macrorelief identification from space photography.

We mapped the macrorelief on the entire Apollo 6 strip from the Gulf of Baja California to Willcox playa and have compared the mapping by two interpreters on one frame. Using a 4-class system to define Flat, Undulating and Rolling, Hilly, and Mountainous lands, we assumed that these classes could probably be detected accurately with minimum pre-training by working from written descriptions of the classes and with no previous interplay between the two interpreters. This minimum training, minimum contact approach was used intentionally to better bring out the problems, training, and supervision needs. From this work a list of problem areas was developed for further attention and examples were selected for putting together a set of macrorelief training aids.

The two primary problems encountered were: (1) in discrimination between the "Flat" and "Undulating-Rolling" macrorelief classes and (2) in variation between men in the way each person grouped classes when delineating complex areas of such size and intricacy that it became cartographically ridiculous to map individual classes into separate delineations. The need for specific guidelines on how to group features into meaningful, mixed-class delineations was made clearly evident.

7. Some preliminary plans were made for possible participation in NASA high-flights over our Oregon test site. If this comes about, it will provide essential backup in preparation for ERTS-A evaluation in the Oregon area. This planning included continuing participation in the use and evaluation of high-flight photography over our southern Arizona test site.

B. Work Currently in Progress

1. Continue work with the high-flight and space photography from Apollo 9 to study the influence of seasonal development of the vegetation on image interpretability and develop the criteria for making important vegetation discriminations from multiseasonal color infrared photography.

2. Continue ecological classification of ground truth data and expansion of the symbolic mapping legend to fit valid vegetational classes in the literature and the refined classes being developed from our ground-truth research in the area. We are improving on the legend system and its description with the expectation that it will be usable by others involved with native vegetation analysis in the Earth Resources Program and especially in range resource analysis by the multistage or subsampling technique.

3. Begin quantitative studies of image characteristics and the consistency with which presently available space and supporting aerial photography may be interpreted and prepare photo interpretation aids for those images that can be consistently identified.

4. Continue efforts to demonstrate the refinement of existing vegetation maps by the use of space or supporting high-flight photography.

5. Develop plans for high-flight coverage and data analysis in our proposed Oregon ERTS test area. This is for the purpose of providing improved ground-truth records and maps of sample areas for more rapid and effective evaluation of ERTS-A data when it becomes available.

6. Develop plans for computerization of ground-truth records to facilitate manipulation and access to data and to increase efficiency of its use in the study of ground truth-image relationships and eventually in automatic signature recognition.

THE IDENTIFICATION AND QUANTIFICATION OF HERBLAND AND SHRUBLAND VEGETATION RESOURCES FROM AERIAL AND SPACE PHOTOGRAPHY

by

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A. Work Performed During the Period Covered by this Report

1. Data Reduction and Analyses. Major plant communities and other generalized earth surface features can be discriminated well on small-scale (1:139,000) color aerial photographs using a GAF scanning microdensitometer. Color infrared positive transparencies were found in our studies to be superior for separating a body of water from bare soil, aspen forest, big sagebrush stands, and spruce-fir forest. This is due to the relatively high absorption of near-infrared energy by water as compared to the other land features. This film type also provided better separation between aspen stands and big sagebrush stands. Contrariwise, color film provided better separations between bare soil and aspen, sagebrush and spruce-fir; aspen and spruce-fir; and big sagebrush and spruce-fir.

Variations within generalized vegetation types could not be significantly separated with the microdensitometer on 1:135,000 scale color infrared transparencies. For example, the mean density difference between uncut and selectively cut ponderosa pine forests was only 2 percent. Density differences between the grasslands and timberlands were significantly different, however. Imagery of these features on color film was not available for film comparisons.

Film density differences between cultural treatment images of native rangeland in 1:2,700 scale color infrared transparencies were variable.

Cultural treatment combination, including nitrogen fertilization, provided greater image density differences as compared to those treatments where no fertilizer was used. Areas treated with herbicides could not be differentiated from untreated areas. Color film imagery of these features, likewise, was not available for film comparisons.

The following Matrix tables illustrate mean image density differences among the items discussed.

Film Scale - 1:139,000

Film Type - Ektachrome Aero Infrared

Microdensitometer Effective Aperture - $416\mu^2$

Item	Mean Density	Item: Aspen Forest	Sagebrush	Spruce-Fir Forest	Lake
		- - - - Percent Density Difference - - - -			
Bare Soil	3.16	-2.0	5.4	9.2	28.5
Aspen Forest	3.11		5.5	10.9	30.5
Big Sagebrush	3.33			3.6	21.9
Spruce-Fir Forest	3.45				17.7
Lake	4.06				

Table 1. Percent density differences between various vegetation and terrain features on color-infrared film.

Film Scale - 1:139,000

Film Type - Anscochrome D/200

Microdensitometer Effective Aperture - $416\mu^2$

Item	Mean Density	Item: Aspen Forest	Sagebrush	Spruce-Fir Forest	Lake
		- - - - Percent Density Difference- - - - - -			
Bare Soil	1.81	8.3	10.5	21.5	23.8
Aspen Forest	1.96		2.0	12.2	14.3
Big Sagebrush	2.00			10.0	12.0
Spruce-Fir Forest	2.20				2.0
Lake	2.24				

Table 2. Percent density differences between various vegetation and terrain features on Anscochrome D/200 film.

Film Scale - 1:135,000

Film Type - Ektachrome Aero Infrared

Microdensitometer Effective Aperture - $416\mu^2$

Item	Mean Density	Item: Bluegrass Seeding	Uncut Forest	Selective Cut Forest
Native Grassland	3.09	5.2	18.4	20.7
Bluegrass Seeding	3.25		12.5	14.8
Uncut Forest	3.66			2.0
Selective Cut Forest	3.73			

Table 3. Percent density differences between generalized vegetation types on Color Infrared film.

Film Scale - 1:2,7000

Film Type - Ektachrome Aero Infrared

Microdensitometer Effective Aperture - $104\mu^2$

Item	Mean Density	Item: Untreated	Item: Fertilized	Item: Fertilizer & Herbicide
		- - - Percent Density Difference- - -		
Herbicide	2.70	0.4	3.3	4.4
Untreated	2.71		3.0	4.1
Fertilizer	2.79			1.1
Fertilizer & Herbicide	2.82			

Table 4. Percent density differences between rangeland cultural treatments on Color Infrared Film.

Preliminary investigations have been initiated to determine the usefulness of an Isodensitracer to discriminate between shrub species and grassland communities treated with herbicides and/or fertilizers.

Basically the IDT automatically scans and measures the optical density of all points in a film transparency and plots the measured density values as a 4-color coded display with a potential of 64 density modes.

Results were poor for shrub species differentiation. The scanning aperture used was too large to obtain enough detail for species identification. The transparency should be rescanned with a smaller scanning aperture and various filter combinations before further evaluation is made. Results were fair for grassland community differentiation. Some patterning was apparent between fertilized and unfertilized areas. Additional work needs to be done with various varying aperture sizes and film-filter combinations before specific recommendations can be made.

2. Plant Anatomical and Morphological Effects on Near Infrared Energy. Anatomical and spectrophotometric analyses have been made of four western browse plants. These were big sagebrush (*Artemisia tridentata*), mountain mahogany (*Cercocarpus montanus*), greasewood (*Sarcobatus vermiculatus*), and cottonwood (*Populus sargentii*). In addition, spectrophotometric curves were generated for bitterbrush (*Purshia tridentata*), and creosote bush (*Larrea divaricata*). The spectrophotometric work was done by C. E. Olson, University of Michigan. Due to the time lapse between leaf excision in Fort Collins and the development of reflectance curves at Ann Arbor, the curves are not entirely representative.

At least three plant leaf structural arrangements appeared to be important in the determining the nature of light energy reflectance in the photographic portion of the spectrum, including the near-infrared. These were all related to differences in structure and arrangement within the plant leaf, the absence of presence and character of leaf cuticle, and relative hairiness of the leaf. For example, with big sagebrush, no cuticle is present on the leaf surface and the mesophyll tissue is made-up entirely of palisade parenchyma with no spongy mesophyll tissue present. These cells appear tightly packed when viewed in cross-section but paradermally show a loose arrangement with a rather well developed system of intercellular spaces. This should allow for a high rate of near infrared reflectance. However, the presence of a relatively dense, thick (200 microns) covering of epidermal hairs apparently "traps" some of this light energy so it may not reach a sensor system. This is confirmed by the reflectance curves which show approximately 40 percent of the light energy is reflected within the 0.5-0.9 micron region. This is a major reason why the species is imaged in a light pink color on color infrared film. Peak reflectance for the species, approximately 65 percent, occurs between 1.0 and 1.3 microns.

On the other hand, mountain mahogany leaves have a thick, conspicuous cuticle over the upper epidermis and is very sparsely pilose, becoming hairless with age. Cross-section and paradermal views of the leaf show very closely packed palisade cells filled with amorphous material immediately under the epidermis and very few small intercellular spaces under the palisades. The chemical nature of the amorphous material is unknown but is believed to be resinous. The reflectance curves of this species show a peak at approximately 0.8 microns with approximately 55 percent of the light energy in this region reflected.

The image color of mountain mahogany is bright red on color infrared photographs. The exact reason for this is unknown, but it is probably related to the thick cuticle and dense, closely packed epidermal and palisade cells and not necessarily to the spongy mesophyll and intercellular spaces.

These kinds of data are important to decide where in the spectral region a multispectral sensor might best be programmed to provide discrimination between the individual species or between plant communities dominated by the individual species. In the case discussed, single wide-band photography would be satisfactory for separation of the two species or communities dominated by them. However, maximum discrimination might be achieved by a multiband system with one band programmed at 0.8-0.9 micron for mountain mahogany communities and another band programmed at 1.0-1.1 micron wavelength for big sagebrush communities.

3. Photo Interpretation and Keys. Statistical analysis using factorial design has been completed of a photo interpretation test designed to compare large-scale (1:800) color and color infrared aerial photos for shrub identification. Image characteristics were defined for 11 shrubs, these characteristics arranged into a dichotomous photo interpretation key, and the test given to four image analysts. Results of this test were as follows:

1. Identification of individual shrubs was significantly higher (P=.01) using color infrared positive transparencies regardless of interpreter experience or shrub species.

2. There was a significant difference (P=.01) among interpreters for identifying the species, depending on photo interpretation experience and knowledge of the area imaged in the photos. The analyst with the most interpretation experience and knowledge of the area scored highest. The analyst with no knowledge of the area and with minimum interpretation experience scored lowest.

3. Identification of some species was significantly greater (P=.01) regardless of film type or interpreter.

Eight of the 11 shrubs were identified at acceptable levels of accuracy (>80 percent correct) using the color infrared photos; two of them were identified 100 percent correctly by all interpreters. Six species were identified with accuracies greater than 80 percent using color photos and none of them identified 100 percent correctly by all interpreters.

Preliminary descriptive photo interpretation keys have been developed for the identification of herbaceous species at our Manitou test location. Plant image descriptors include color, shape, texture, shadow and relative size. Two film types, color and color infrared, at large scales, 1:600-1:1,000, have been procured 4 times during the growing season.

Initial results indicate that early June photography might be the best single date for herbaceous species identification for this area. At the largest scale, individual plants less than 2 inches in diameter are detectable in the photography, but may not be identifiable. No significant conclusions can yet be made as to which film/plant phenology combination or combinations would provide the most reliable information for species identification purposes.

B. Work Currently in Progress

1. Data Reduction and Analysis. A detailed study will continue on use of the scanning microdensitometer by varying the effective aperture area to the geometry of vegetation on the ground. Included will be a determination of the relations between ground estimates of herbage production and removal determined remotely by an electronic herbage meter to scan data using various scale color and color infrared aerial photography. Plans are developing to work with Technical

Operations, Inc., in more detail on use of the isodensitracer for image interpretation.

2. Plant Anatomical and Morphological Effects on Near Infrared Energy. Limited additional work is immediately planned on this phase of the project until data in hand are completely analyzed. We hope to expand this effort to investigate effects of induced stress as a factor in near-infrared reflectance and transmittance as well as leaf age, position and orientation on the plant. Results of this kind of research will provide insight for programming specific remote sensors to detect shrubland areas stressed by some physiological abnormalities.

3. Photo Interpretation and Keys. Primary effort is being devoted to refining the photo interpretation key for herbaceous species using both types of color photographs. The threshold aerial and/or space photo scale at which specific plant species and communities can be detected and identified is also being investigated.

4. Space Photography and Shrubland-Herbland Inventory. Refined multistaged sampling techniques will be investigated to determine kind and extent of shrubland and herbland communities utilizing space and supporting aircraft photographs.

COMPARATIVE MERITS OF MULTISPECTRAL, LINE-SCAN DATA AND AERIAL PHOTOGRAPHY FOR THE ANALYSIS AND MAPPING OF RANGE RESOURCES FEATURES IN SELECTED SHRUB STEPPE AND PINYON/JUNIPER WOODLAND ECOSYSTEMS

by

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A. Work Performed During the Period Covered by this Report

1. With the employment of a Graduate Research Assistant, James R. Johnson, on 28 July 1969 and completion of our part of the S065 90-day report, work on this project was resumed in this quarter.

2. In the period August and September '69, Johnson became familiar with the test site at Squaw Butte, with the ground truth record and maps, and did extensive reading to familiarize himself with previous work and the general research procedures used in LARSYSAA. In the process he checked out the initially selected training samples used by LARS to produce the first iteration of histograms and multispectral plots. These initial training samples were selected from half-scale printouts, and it was found that a number of them did not represent pure examples of range resource ecosystems (vegetation-soil units). Because of the intricate patterns in which plant communities often occur on shrub steppe- and juniper-dominated landscapes, full scale computer printouts must be used for the accurate location of training samples. In the half-scale printouts, inclusions of atypical conditions often go unnoticed and thus the spectral signature is erroneously characterized. This problem is thought to be much more important in rangeland applications than in agricultural and most forestry applications because of the more intricate vegetational patterns and

irregular type boundaries. In our project, this is particularly important because we are attempting to carry automatic recognition and mapping down to specific ecosystems where the integrated signature of definable combinations of plant species and soil surface conditions is the basis for discrimination of one specific ecosystem from another. In other words, we are going as far as we can beyond the mere recognition of broad classes such as brushland, grassland, forest, etc.

3. The initial histograms and multispectral plots prepared by LARS were generally based on combinations of a number of separate areas to make up the total training sample by which the spectral signature of individual subjects was to be characterized. Since individual histograms and spectral plots were also produced for each of these separate training areas, it was possible to set aside those that did not provide the required "pure" representation of the subject. This was done and the remaining spectral plots were compared manually to get a better estimate of the likelihood of discrimination at the individual ecosystem and rangeland feature level. The results are much more encouraging than indicated in our report for the first calendar quarter of 1969.

4. Based on these manual comparisons of individual spectral signatures, for example, it appears that heavy and light grazing use on crested wheatgrass seedings may be discriminated and that three different kinds of rangeland dominated by the same species of sagebrush may be identified by their spectral signatures. If this proves out on the next iteration it will demonstrate a far more useful application than merely discriminating the broad vegetational growth forms. This higher level of detail represents the kind of information that the land manager needs. Out of a

total of 231 comparisons, discrimination potential exists for 116, may be possible for an additional 24, and appears unlikely for 91 without refinement or adaptation of classification and recognition techniques.

5. In some cases it has been possible to relate individual RSU's as registered on full-scale printouts to actual ground location and thus to specific components of variation within the individual ecosystem areas; but in many instances, it is extremely difficult to be sure of a pinpoint ground location on the computer printouts. This makes it very difficult to locate training samples that would permit one to study causes of variation in spectral signature for those land areas that, in the first iteration, displayed highly variable or bimodal signatures. We are following up on three approaches to solution of this problem.

6. LARS has prepared a full-scale printout for one of our concentrated study areas that will help greatly in cleaning up training samples for the second iteration and classifications to be made with LARSYSAA.

B. Work Currently in Progress

1. Working from full-scale computer printouts, selecting new training samples for the second iteration of multispectral signature plots and run the complete LARSYSAA classification of range resource ecosystems using the 1,000 foot data from our Squaw Butte test site.

2. Cooperation is continuing with Jerry Lent of the Forestry Remote Sensing Laboratory in this work.

3. Comparisons of photographic printouts and ground truth mapping are being made between the 1,000 foot and 3,500 foot data preparatory to studies with the latter to determine the effect of increasing size of ground resolution unit on results obtainable in range resource survey by

multispectral linescan systems and LARSYSAA programs.

4. Plans are being made for experiments subsequent to completion of the work in 1) above to determine the accuracy with which specific range resource features may be classified with training samples distantly removed from the test location and to compare results with photo interpretation.

5. Plans are being made for densitometer studies of selected subjects on photographic printouts to determine possible spectral signature crossovers in bands outside 0.40 to 1.0 microns that would improve interpretability of range resource features if the appropriate ones among these additional bands could be added to the analytical system.

VIGOR LOSS IN CONIFERS DUE TO DWARF MISTLETOE

by

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A. Work Performed During Period Covered by this Report

Initial funding of this project occurred during the present quarterly reporting period in time to permit the following activities to be performed:

1. A Ph.D. candidate has been assigned to the project. He will devote approximately 1/4-time to the project during winter and spring quarters, full-time in summer, and 1/2-time during fall quarter. He is a veteran pilot and well-experienced in aerial photography and photo interpretation. He has begun to gather materials and plan the first stages of the project.

2. Three possible locations for the taking of tramway-photography have been selected for field inspection in March. Two locations for the taking of aerial photography of a more extensive nature also have been selected.

3. Components for the tramway system have been decided upon and a materials supplier contacted.

B. Work Currently in Progress

1. All previous aerial photography and field data on the test sites are in the process of being collected and evaluated.

2. Professor David W. French is currently doing a reconnaissance survey of dwarf mistletoe problems in the coniferous forests of Chile -- so when he gets back, we'll have "foreign expertise" on our project!

THE DEVELOPMENT OF SPECTRO-SIGNATURE INDICATORS OF ROOT DISEASE ON LARGE FOREST AREAS

by

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A. Work Performed During the Period Covered by this Report

Preprocessing, screening and analysis was begun on the airborne data that had been collected over the Wind River test site in July, 1969, by the University of Michigan multispectral aircraft. Analysis criteria were established for the identification of forest classes in the Douglas-fir community surrounding the Wind River study area.

1. Spectrometer processing

Airborne spectrometer data from ten registered channels, between 0.40 to 1.00 micrometers, were analyzed on the analog computer/processor at IROL to identify the following four Douglas-fir community classes: (1) healthy second growth Douglas-fir, (2) *Poria weirii* root rot-infested second growth Douglas-fir, (3) hardwood (*Alnus* sp.) fir complex, and (4) bare soil/fir regeneration background. Multiple color mosaics were produced of the composite target recognitions from both the maximum likelihood ratio analysis and the Euclidian distance analysis output from the analog computer. Processing was completed from one aircraft run at one altitude, selected because of the nominal midday thermal conditions monitored on the ground.

Analog computer processing with two channels of reflective IR registered with one channel of thermal IR (1.0 to 1.4 micrometers, 2.0 to 2.6 micrometers, and 4.5 to 5.5 micrometers) was begun using the same discrimination functions as for spectrometer data.

2. Thermal processing

Airborne thermal infrared data (8.0 to 13.8 micrometers) from one run over the intensively instrumented test site were subjected to several thermal processing routines. Thermal slicing with amplitude gating according to preset thermal reference levels was tried resulting in color coded output at 0.1° and $0.2^{\circ}C$ intervals. Color-coded slicing levels were selected by their correlation with thermally related target energy regimes on the ground.

Thermal contouring was tried, with the individual display of about 700 consecutive scan lines, which adequately covered the area of intensive ground instrumentation. These data were displayed as "A" scope trace photographs, with amplitude related to target irradiance. Individual scan lines were digitized on magnetic tape for computer analysis.

3. Photographic evaluation

Duplicate copies of all 70 mm. photographic imagery taken over the Wind River test site in July were received from MSC, Houston. Cursory examination of all emulsion types indicated that the photography was generally of acceptable quality in terms of exposure and area of coverage. The color (type 2448) and color infrared (type 8443) photographs were used for selection of training samples to be used on the analog processor and for identifying any visual manifestation of infection centers. Although nothing has been identified on the photography as yet which relates to visual stress in living infested trees, many of the photographs already have been very useful for pinpointing openings in the forest stand which resulted from random "rot-throw" and "wind-throw" of diseased timber.

4. Field Work

During this reporting period, much of the field work was oriented toward winterizing equipment that is to remain on the test site, protecting the instrumented trailer from the normal heavy snows (by moving the unit under permanent type shelter at the Wind River Nursery), and transfering all electronic and chart recording equipment and instruments to Berkeley for routine maintenance, modification, and storage. The dual tramway platforms with attendant instruments, the electrical automatic switching system, and wiring that might be damaged by wind and snow have been taken down and stored. The stainless steel tramway cables were left attached (without tension) to the three towers.

The biophysiological evaluation system for measuring forest parameters will be reinstalled at the Wind River test site by mid May 1970 with an efficient and more sophisticated computer data gathering system than was used in 1969.

B. Work Currently in Progress

1. Analog computer processing of spectrometer data is continuing for information collected at other diurnal sampling periods.

2. Processing of the three channel IR data will soon be resumed.

3. The digitized thermal infrared data are being used to make detailed profile analyses over the instrumented ground site. The purpose is to correlate scanner data to the thermal profiles of individually instrumented trees on the ground.

REMOTE SENSING OF CHANGES IN MORPHOLOGY
AND PHYSIOLOGY OF TREES UNDER STRESS

by

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A. Work Performed During the Period Covered by this Report

1. Anatomical Studies

The study of foliar reflectance from sugar maple (Acer saccharum) seedlings subjected to drought and salinity was terminated at the end of the 1969 growing season. Results of this study were presented at the Sixth Symposium on Remote Sensing, in Ann Arbor, in October. A copy of that report was appended to our annual report (Olson, et. al, 1969)

At the end of the study, one pair of opposite leaves on each seedling was chosen for the final set of reflectance measurements. Each pair of leaves was photographed on Kodachrome II film to record the extent of visible symptoms of treatment. Immediately after the photographs were taken, a reflectance curve (0.5 to 2.6 um) was obtained for each leaf. The pair of leaves was then removed from the plant and treated as follows:

a. The outline of one leaf was traced on paper and any visible abnormalities marked on the tracing. Samples were then cut from selected areas of the leaf and placed in CRAF A and B killing and fixing solution. These samples will be sectioned and examined microscopically for differences in internal structure.

b. The second leaf from each pair was weighed immediately after removal from the plant and its xylem sap pressure then determined in a Scholander pressure cell. The leaf was then oven-dried for three days at 100°C and the fresh and dry weights were used to calculate the moisture content of the leaf when picked. Difficulty was experienced in obtaining accurate measures of xylem sap pressure because of frothing, possibly caused by the sugar in the sap.

2. Differences between ring-porous and diffuse-porous species

Active data collection on this study was terminated and reduction of the data begun. Time required to complete the data reduction will be considerably greater than was originally anticipated. Analysis of the data has been begun and should be completed late in the next quarter.

3. Aerial detection of Fomes annosus in pine plantations

Spectral reflectance data have been obtained for foliage on healthy and infected red pine seedlings grown in the greenhouse and for healthy and infected trees at the Ann Arbor Test Site. Reduction and analysis of these data are nearly complete.

An overflight of the Ann Arbor Test Site by the University of Michigan C 47 aircraft was completed on November 26. Flight parameters were the same as in earlier flights and have been described in our previous reports. No additional flights were scheduled for 1969.

Analysis of the imagery from the two August flights, and the November flight, has been delayed by the lack of imagery. Analysis of the imagery from the October 1968 overflight is continuing.

B. Work Currently in Progress

1. Anatomical Studies

Material preserved for anatomical studies is now being sectioned, stained, and photographed through the microscope and a system for measuring anatomical characters is being devised. The results of the anatomical analyses will be compared with the reflectance and moisture data to determine the extent of correlation between:

a. moisture content and drought or salinity treatment

b. xylem sap pressure and moisture content

c. xylem sap pressure and drought or salinity treatment

d. moisture content and foliar reflectance

e. foliar reflectance and anatomical properties

2. Difference between ring-porous and diffuse-porous species

Analysis of the data from this study has been begun. Some differences between ring- and diffuse-porous species seem consistent and will be described more fully in our next quarterly report.

3. Aerial detection of Fomes annosus in pine plantations

Analysis of the imagery from the imagery from the August and November 1969 overflights will begin as soon as the imagery has been received from NASA Houston. Tree characteristics of infected and healthy trees will be compared with the reflectance data, and tonal signatures evolved if possible. The 1968 and 1969 imagery will be compared to determine the extent to which spread of the fungus can be monitored from the air.

c. Literature Cited

Olson, C.E., Jr., J. M. Ward and W. G. Rohde, 1969. Remote Sensing of Changes in Morphology and Physiology of Trees Under Stress. Annual Progress Report, School of Natural Resources, University of Michigan for Earth Resources Survey Program, OSSA, NASA.

THE USE OF MULTISPECTRAL SENSING TECHNIQUES TO DETECT PONDEROSA PINE TREES UNDER STRESS FROM INSECT OR PATHOGENIC ORGANISMS

by

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A. Work Performed During the Period Covered by this Report

1. Bell Aerosystems undertook a subcontract to investigate the possibilities of using spatial frequency distribution analysis to seperate healthy trees from insect-infested pines. They were successful in finding military targets under trees using similar processing methods. They used tapes produced from the IROL (Infrared and Optics Laboratory) multispectral scanner. They found:

a. Too much information was lost in using the digitized magnetic tapes produced at Purdue by LARS. Alternate scan lines and resolution elements were skipped. No frequency spectrum could be produced from the digitized tapes.

b. The analog magnetic tapes duplicated from the Michigan scanner lacked adequate frequency data to perform spatial frequency computations.

c. By analyzing spirally generated microdensitometer traces of color transparencies taken over the Black Hills test site, a frequency spectrum of healthy pines was found to be different from that of discolored pines.

d. Similarly, analysis of scanner traces from a military scanner over discolored trees near Reno, Nevada, showed that temperatures were warmer over the discolored trees and that the spatial frequency was distinctly different as compared with the healthy trees.

e. These techniques show promise for rapid automatic access, but will require a greater amount of investigation than has been undertaken to date. Bell is interested in continuing on a time and materials basis.

2. Airborne data collected over the Black Hills Study Area II during July, 1969, by the Michigan multispectral aircraft was subjected to preprocessing screening and to the initial analysis routines.

a. Processing of spectrometer data

Airborne spectrometer data from ten registered channels, below 0.40 to 1.00 micrometers, were analyzed on the analog computer/processor to identify four forest condition classes: (1) healthy, (2) old-killed trees with few needles, (3) faded (discolored) infested trees, and (4) nonfaded infested trees. Multiple color mosaics were produced of the composite target recognitions from both the maximum liklihood ratio analysis and the Euclidian distance analysis. Processing was completed for one aircraft run at one altitude chosen because of the favorable ground-measured conditions during the flight.

Analog computer processing was begun using the same discrimination functions as for spectrometer data, with two registered channels of reflective IR registered with one channel of thermal IR (1.0 to 1.4 micrometers, and 4.5 to 5.5 micrometers).

b. Processing of thermal data

Airborne thermal infrared data (8.0 to 13.8 micrometers) from the best run at one flight altitude were subjected to several intensive thermal processing routines. Thermal slicing techniques were tried, resulting in color-coded output at 0.2°C intervals. Color-coded slicing levels were correlated to thermally related target strata on the ground.

Thermal contouring was attempted, with the individual display of about 1,200 consecutive scan lines, which more than covered the area of ground truth data. These data were displayed as "A" scope trace photographs, with amplitude related to target irradiance, and the individual scan lines were digitized on magnetic tape for computer analysis.

Although considerable progress was made during this reporting period on the initial phases of processing airborne data, results will not be forthcoming until the end of the next reporting period.

B. Work Currently in Progress

1. Analog computer processing of spectrometer data is continuing for airborne information collected at two higher flight altitudes, 11,000 feet above MSL and 13,500 feet above MSL.

2. A continuation of three-channel IR data processing is anticipated to take advantage of the first good data available to us which will combine two channels of reflective IR with one channel of thermal IR, all in registration.

3. A continuing effort is anticipated using computer analysis on the individually digitized thermal scan lines. A computer routine is needed to stratify and identify the energy regime of the infested trees, which were indicated as being warmer than the healthy trees from radiometer measurements taken at the time of the airborne flight. It appears now that spectral radiance data between 2.0 and 12.0 micrometers would be most helpful for interpretation of airborne data by computer analysis. We will attempt to collect this important support information in future field studies.

4. On December 29, 1969, we received the RB-57 imagery taken over the Black Hills test site (149) on August 3 and 8. We have examined all photography and plotted the coverage on 1:250,000 maps. We expect to compare

one selected strip (1 by 3 miles) of the RB-57 photo combinations with large-scale coverage (1:8,000) taken August 11 of this strip with a Zeiss RMK 21/23 camera. We know the location of over 200 infestation centers as reported in the September 1969 annual progress report.

5. After determination of the best film filter-scale combination, we shall compare six 1-by 10-mile strips for which we have precision photo coverage (Ansco D/200, 1:8,000) and "ground truth."

THE DEVELOPMENT OF AN EARTH RESOURCES INFORMATION SYSTEM USING AERIAL PHOTOGRAPHS AND DIGITAL COMPUTERS

by

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A. Work Performed During Period Covered by this Report

The study to develop techniques for the automatic discrimination of forest types from digitized pictorial data was continued.

Five new independent samples were drawn at random from the scanner data. Each sample contained 50 observations from each of 5 forest types. The forest types sampled were open conifer, conifer, conifer-hardwood, hardwood-conifer, and open areas. These samples were used to test the behavior of the LDF and the non-parametric density estimation technique and to compare the two methods.* The same set of variables was used to obtain all of the results described here. These were the first, second, and fourth moments, the first and second moment squared, position on the picture squared and sun angle. Each of the five samples was used as a training sample to classify the other four samples.

Table 1 shows the error rate in classifying 1,000 test cases for both the LDF and the Density Estimation method.

*The term "LDF" (Linear Discriminant Function) pertains to a multivariate classification scheme which assumes that all variables have the normal distribution pattern, whereas the "non-parametric density estimation" is not based on this assumption. For further explanation see our Sept. 30, 1969 Progress Report.

Training Sample	LDF	Density Est.
1	.424	.478
2	.426	.421
3	.426	.492
4	.434	.554
5	.425	.512
Mean	.427	.491

Table 1

In addition to a lower error rate, the LDF provides more consistent results when different training samples are used. An indication of the kind of errors that were made is given by the error tally for the LDF (Table 2). The tally is similar for the density estimation method.

		Predicted Type				
		OC	C	CH	HC	O
True Type	OC	854	86	14	12	34
	C	171	438	76	238	77
	CH	163	199	201	389	48
	HC	58	165	129	615	33
	O	116	59	49	19	757

Each row contains 1,000 test cases

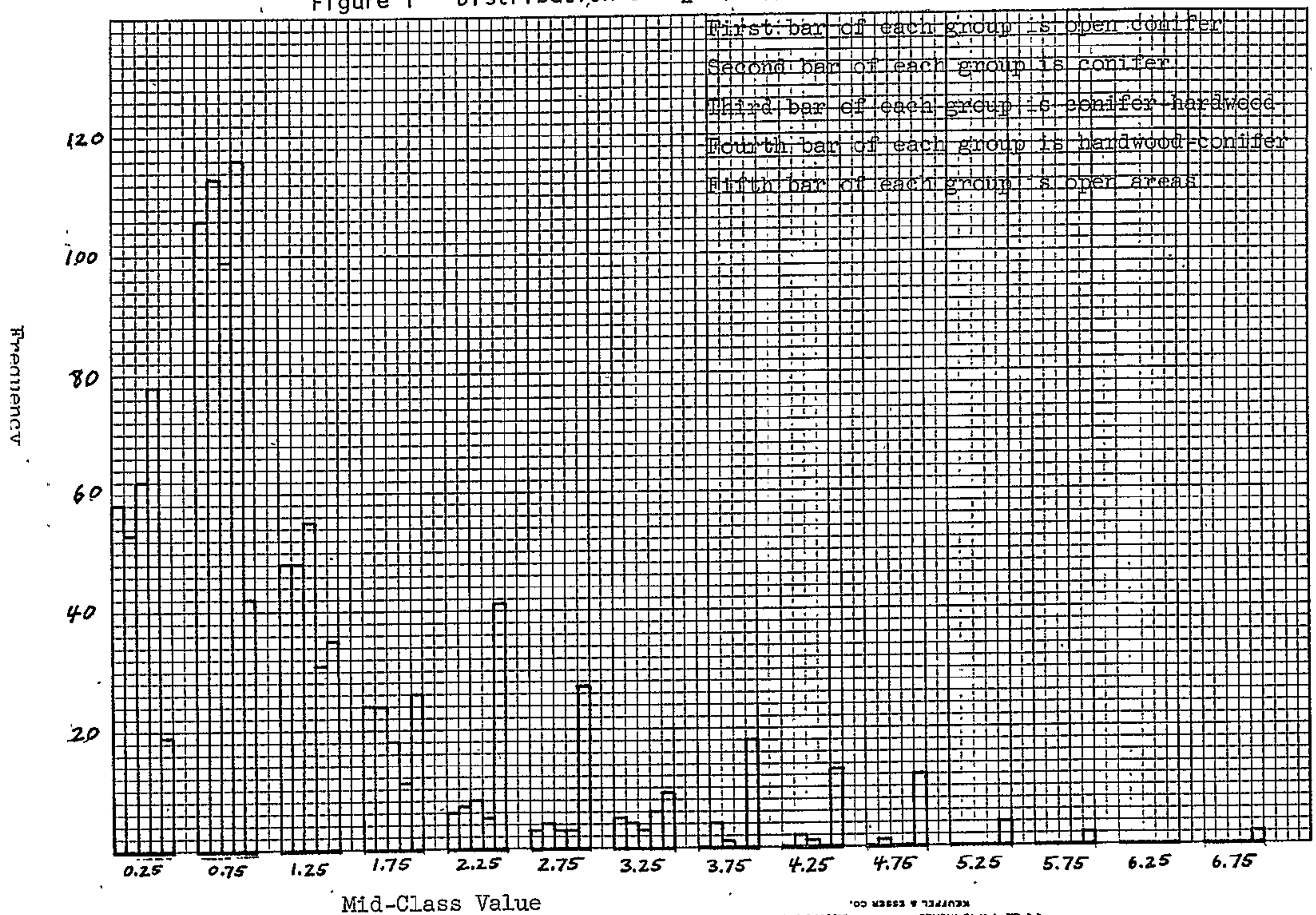
Table 2 - LDF Error Tally

The results of the discrimination among all five forest types are not satisfactory. In looking for the reasons for this performance the distribution of each variable by type was plotted. A typical histogram (Figure 1) shows that the distributions for the first four forest types are very similar. In using these particular variables, we cannot expect much better results regardless of the technique used. The exception to this conclusion is the distribution of the fifth type--open areas. It is distinctly different from the distribution of the other four forest types and we can expect that adequate discrimination can be obtained.

By examining the distribution of errors using the LDF model (Table 2) we can see another division of the ground cover into populations which will be useful. Table 2 shows that about 76% of the open areas and 85% of the open-conifer areas are identified correctly. Of the 3,000 observations belonging to the other three forest types, only 18% are identified as coming from either open-conifer or open type. Thus, it should be possible to separate the total forest area into categories by canopy density.

By examining the error tallys from both discrimination techniques we can see why some of the other classification errors may have occurred For example, the 116 open areas classified as open-conifer by the LDF model could arise from two possible sources. First, it is difficult in such a broad category to define a precise line between what is an open area and what is just a slightly wider spacing within a low density forest area. Second, the random placement of the cells on the open-conifer areas and the open areas may mean that a cell falls exactly on a small opening in an open conifer type or it contains one tree in an otherwise large open area. This would tend to confuse any

Figure 1 Distribution of M_2 by types



classification scheme. Another similar case appears in the tally for the density estimation technique for those cells known to be conifer-hardwood type. A cell known to be a conifer-hardwood cell is almost equally likely to be classified as a conifer-hardwood or hardwood-conifer. It is possible that this is a function of the cell size and of the clumpiness of the hardwoods within the conifers or the conifers within the hardwoods

In comparing the results of the two methods (Table 1), we found that in almost every case the LDF performs better than the non-parametric density estimation technique. This, despite the fact that some of the variables, particularly the moments, are not normally distributed. When we look at the tally of errors we found that in all cases, except the classification of conifer-hardwood, the LDF has significantly more correct classifications.

The LDF was found to have four advantages over the Density estimation technique:

1. The error rate was lower,
2. the results are more consistent when different training sets are used,
3. it is faster to classify a new point with the LDF,
4. less computer storage is required for the LDF.

The study on the automatic mapping of forest types from digitized stereo-pairs of aerial photos was continued also. The computer program for generating terrain functions from equally spaced elevation data, using orthogonal polynomials, has been extended to generate a terrain function from unequally spaced data. This was necessary to accomodate distortions in the scanner data matrices caused by the rotations introduced in the rectification algorithms.

B. Work Currently in Progress

1. Continuing the development of storage and retrieval functions of the earth resources information system.

2. Continuing the development of techniques to automatically map forest types from digitized stereo pairs of aerial photographs.

3. Continuing the development of techniques to automatically discriminate between forest types from digitized aerial photographs using NASA RB-57 photography, Mission 193.

4. Continuing the development of multi-stage sampling theory for resource surveys employing space and aerial imagery and ground data.