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REMOTE SENSING APPLICATIONS IN FORESTRY

A report of research performed under the auspices of the
FORESTRY REMOTE SENSING LABORATORY,
BERKELEY, CALIFORNIA—

A Coordination Facility Administered By
The School of Forestry and Conservation,
University of California in Cooperation with the
Forest Service, U.S. Department of Agriculture

For

EARTH RESOURCES SURVEY PROGRAM
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REMOTE SENSING APPLICATIONS IN FORESTRY

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FOREST SPECIES IDENTIFICATION AND TIMBER TYPE
DELINEATION ON MULTISPECTRAL PHOTOGRAPHY

By
Donald T. Lauer

School of Forestry and Conservation
University of California

Annual Progress Report

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A B S T R A C T

Research performed at the various NASA Forestry Test Sites is described and the results obtained are reported upon. Emphasis is placed on the expression of results in a quantitative fashion, wherever possible. Within the various test sites, it was found that a skilled photo interpreter can determine major vegetation type boundaries and identify the predominant forest species on high altitude-small scale aerial photography. However, the photography must be flown to optimum specifications in terms of film-filter combination, season of year and time of day. Analysis of photography taken over homogeneous pure stand cover types occurring within an extended study area, Flicker Ridge, indicates that (1) accurate vegetation surveys can be made without implementing expensive and time-consuming on-the-ground inventory techniques, (2) color infrared photography provides the interpreter with significantly more information on vegetative cover than panchromatic photography, and (3) color infrared photography requires approximately 25% fewer man hours of interpretation time than black-and-white photography. High resolution NASA photography was purposely degraded in one series of experiments until it exhibited only 100 foot GRD (Ground Resolved Distance), similar to the quality of existing Gemini and Apollo photography. It was found that even this degraded photography provided an interpreter with sufficient tone and color information to delineate and sometimes identify the primary cover types occurring in the San Pablo Reservoir Test Site. Results obtained at the Bucks Lake Test Site show that a low resolution photo-mosaic

(simulating a space photo) used in conjunction with a limited number of properly specified aerial photos and with the aid of double sampling techniques provides an improved means for obtaining inventory data, on a tree-by-tree basis, for a large heterogeneous mixed forest stand.

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 by personnel of the School of Forestry and Conservation, University of California.

Aerial photography and related imagery obtained of the various Forestry Test Sites with NASA's Houston-based aircraft proved to be of great value. Since the detailed interpretation and field checking of this imagery constituted the major effort herein reported upon, its importance to the study is hereby gratefully acknowledged.

Presentation of the materials contained in this report has been made possible through the cooperative efforts of several individuals and organizations. Lawrence R. Pettinger and Michael D. Rushton of the University of California rendered invaluable service in the collection of ground truth, interpretation of aerial photography and development of photo interpretation keys used in this study. Without their assistance, the organization and compilation of interpretation data would have been difficult, if not impossible.

Other members of the University staff who contributed time and effort to the work reported herein were D. M. Carneggie, W. C. Draeger, J. D. Lent, E. H. Roberts, J. W. Thomas, J. K. Berry, M. J. Gialdini, C. H. Tom and R. Ormondroyd.

In addition, personnel of the following organizations must be commended for timely assistance and cooperation: Barnes Engineering Co., Stamford, Conn.; Cartwright Aerial Surveys, Inc., Sacramento, Calif.; Pacific Southwest Forest and Range Experiment Station, Berkeley, Calif., Pacific Northwest Forest and Range Experiment Station, Portland Ore.,

**Mark Systems Co., Sunnyvale, Calif.; National Park Service, Yosemite,
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FOREST SPECIES IDENTIFICATION AND TIMBER TYPE DELINEATION ON
MULTISPECTRAL PHOTOGRAPHY

by

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INTRODUCTION

The research reported upon herein represents the most recent efforts on a continuing study designed to determine the feasibility of identifying forest species and delineating major timber type boundaries on remote sensing imagery obtained from earth orbital altitudes.

Phase I of this study, reported upon in the 1966 Annual Progress Report, involved selection of suitable test areas, procurement of remote sensing imagery--mainly by the Houston-based multisensor Convair aircraft, acquisition of ground truth information (i.e., stand composition, understory description, stand age, average tree height, range in tree height, average diameter at breast height, range in tree diameter at breast height, aspect, average percent slope and range in percent slope) and spectrometric analysis of leaf samples carefully taken from a variety of forest types.

The primary objective of Phase II, described in the 1967 Annual Progress Report, was to systematically analyze each of several factors governing the interpretability of the remote sensing imagery taken of the forested test sites. An attempt was made to determine, when possible, the optimum combination of factors, with an emphasis on their relation to spaceborne imagery, for identifying the major tree species and timber types in selected parts of the world. The worthiness of certain

advanced techniques used for identifying forest species was investigated, such as: (1) comparative study of sequential imagery, (2) tone signature analysis of spectrozonal imagery, and (3) false color image enhancement. In addition, a comparison was made to determine the ease with which tree species composition, timber type boundaries and cultural patterns can be interpreted on a Gemini VII photograph and on 3,200 conventional aerial photographs reduced in scale to a 10' x 15' mosaic.

A generalized conclusion derived from the intensive research reported upon in 1966 and 1967 can be summarized as follows: Within the various forestry test sites, it is feasible to delineate major vegetation type boundaries and to identify the predominant forest species on high altitude, small scale aerial photography when optimum photographic specifications are utilized. In particular, homogeneous stands of timber (e.g., even-aged plantations of Eucalyptus or Monterey pine) can be distinguished from adjacent homogeneous or heterogeneous stands on high altitude photography. However, estimates of species composition within heterogeneous mixed stands are much more difficult.

This year, an attempt has been made to define the simplest conceivable observational and analysis techniques necessary for extracting valuable forest inventory data from imagery, obtained from high flying aircraft, taken over areas containing either homogeneous (pure type) or complex heterogeneous (mixed type) forest stands. The imagery obtained from the NASA aircraft has been analyzed in the context of (1) spacecraft capabilities (i.e., periodicity and stability) and (2) quality of imagery procured from earth orbital altitudes (i.e., synoptic view and resolution). Lastly, for each case examined, user objectives have been

explicitly defined and the ultimate benefits derivable from these data by the forest land manager have been discussed.

JUSTIFICATION FOR CURRENT RESEARCH

If populations, incomes, tastes, technologies and prices change in the future in the manner that recently was predicted by the Sixth World Forestry Congress, the world will require by 1975 approximately 1,500 million cubic meters of wood a year for industrial purposes alone. This is some 450 million cubic meters more than was used in 1961. In addition, the world will require roughly 1,200 million cubic meters of fuelwood.

In order to meet these anticipated levels of wood consumption, the human race must implement maximum efficiency in managing the earth's forest resources both regionally and globally. Intelligent resource management entails three phases: inventory, analysis and operation. The logical first step in management intensification is the development of rapid accurate, economical inventory procedures. It is in this respect that remote sensing, specifically aerial photography, is proving to be extremely useful to forest land managers.

If one considers the magnitude of data required to review the resource potential of a large forested region, it becomes apparent that conventional "on the ground observations" create overwhelming manpower and logistic problems. However, aerial observations have proven to be an excellent source of information. Rarely would the analysis of a forest resource not capitalize on the use of conventional vertical aerial photographs having scales of from 1/15,000 to 1/50,000.

A major problem confronts an image analyst when evaluating the

timber resource by means of remote sensing--that of making an accurate determination of timber types through identification of the species of individual trees comprising the various timber stands. Current inventory procedure is to "stratify" timber stands directly on aerial photographs by age class, crown density and broad vegetation type. Information on volume by species for representative sample plots is generally obtained on the ground by an experienced field crew. In many instances, however, timber volume estimates based on photogrammetric determinations of tree heights, crown diameters and stand densities can be made directly from aerial photos through the use of appropriate volume tables. If species identifications could also be made from photo images, then the costly field operations essential to current survey practices could be totally (or partially) eliminated.

In the next few years, as huge tracts of unexplored forest land in interior Alaska, Canada and Latin America need inventory and evaluation, data may be obtained by means of remote sensing from earth orbiting vehicles. These vehicles, travelling at approximately 18,000 miles per hour and imaging a swath over one hundred miles wide, are certain to have a major effect on forest inventory procedures. By utilizing simulated spaceborne imagery (i.e., high altitude, small scale aerial photography) an attempt is being made to determine the extent to which major timber types can be delineated and forest species composition can be identified. In relation to the definition of the manned earth-orbital experiment program, this research is needed as one of the first steps toward determining the feasibility of making timber surveys from data obtained from manned earth-orbital vehicles.

The discussion of descriptive photo interpretation keys, image procurement specifications, sequential imagery, spectrozonal imagery, false color image enhancement, sampling designs, interpretation of Gemini photography, interpretation techniques and advanced remote sensing systems presented in this series of Annual Progress Reports would be useful information to forest land managers throughout the world. No matter what objective is desired, such guides for determining tree species accurately on high altitude, vertical aerial photography would prove valuable.

LITERATURE REVIEW

Over 20 publications dealing with forest species identification by means of remote sensing have been summarized in the two preceding Annual Progress Reports. The objective here is to supplement these materials with a summarization of four papers most recently published on this subject. In addition, at the rear of this report is a bibliography listing all research efforts that relate to this problem, known to the author at the time of this writing.

Stellingwerf (1968), realizing the importance of forest species identification for volume estimation and damage assessment, describes in detail his own work, and work done by others, on what actually can be achieved on certain scale/film-filter combinations. He reports that black-and-white infrared film taken at a scale of 1/15,000 is the preferred photography for forestry purposes in Austria. Similar results were obtained in the Netherlands. The accuracy of species interpretation (three conifers and two broad-leaved species) on scales of 1/20,000 and 1/10,000 showed different results for the species involved and showed

no difference between the two scales involved. In Finland, panchromatic photographs taken at a scale of 1/30,000 allowed about 75% of the pure and mixed stands of pine, spruce and birch to be correctly interpreted. In a study area in Belgium, Ektachrome Infrared Aero flown at a scale of 1/10,000 proved to be superior to black-and-white infrared film for species recognition. The advantage of color infrared film exists mainly in the differentiation of conifers, and to a lesser extent of broad-leaved species.

Hegg (1966) recently developed an aerial photo identification guide for land and forest types of interior Alaska. Because of the very large area involved--229 million acres, normal inventory procedures using complete photo coverage with a large ground sample proved to be too costly. Instead, continuous strips of conventional aerial photos were obtained at 30 mile intervals intersecting the major drainages necessitating a complex "triple sampling" design of photo interpretation/photo measurement, proportional air check and a small ground sample. Either small-scale photography (that which existed was of poor quality) or space photography (non-existent) would have greatly facilitated the extraction of survey data. Three film types--panchromatic, modified infrared and color--were tested for ease and accuracy of interpretation. Although each type had its merits, modified infrared was chosen because of a small gain in accuracy and the greater ease in differentiating hardwoods from softwoods--an important consideration in the region. The author presents a detailed dichotomous elimination key, supported by ground and air stereograms, leading to the identification of the various land and

forest types of interior Alaska.

Draeger and Lauer (1967) discuss in some detail present and future forestry applications from space. This paper suggests that a number of direct forestry applications for remote sensing from earth orbital vehicles soon will be possible, such as timber volume estimation, forest species identification, determination of water yield and quality, and evaluation of rangeland and wildlife habitat carrying capacity. The majority of their results were based on the analysis of simulated space photography (i.e., high altitude, small-scale aerial photography) of a quality that will be feasible in the near future. In particular, the authors point out certain advantages of orbital vehicles as sensor platforms that are of interest to the wildland resource manager: (1) the synoptic view, (2) opportunity for sequential coverage, (3) rapidity of obtaining data, (4) uniformity of the image and (5) economy.

Doyle (1968) discusses the prospects of mapping the earth's surface from satellite photography. He points out in the table following that map coverage of the world is woefully incomplete.

Of primary concern is the fact that the rate of obsolescence of existing maps nearly equals the rate of production of new maps, so that with present techniques the job will never be completed. Furthermore, the map production cycle is about three years from photography to printing so that the new map is three years out of date on the day it is published. In his discussion of the applicability of space photography to this problem, the author lists several useful products that can be made from such photography which are totally impossible from conventional aerial photography. These include: (1) synoptic mosaics of continental

Table I. World Wide and U. S. Map Coverage

Quality	Small Scale 1/600,000 and smaller	Medium Scale 1/75,000 to 1/600,000	Large Scale 1/75,000 and larger
World Coverage			
Adequate	0%	15%	5%
Require Revision	30%	5%	5%
Inadequate	70%	40%	10%
Nonexistent	0%	40%	80%
United States Coverage			
Adequate	100%	96%	64%
Inadequate	0%	4%	4%
Nonexistent	0%	0%	32%

(Data compiled by Army Map Service; Antartica is excluded).

areas at scale of 1/1,000,000 or 1/500,000, (2) photogrammetric control data for maps at a scale of 1/35,000 anywhere in the world (obtainable from a proposed 12 inch focal length camera system), (3) compiled maps at a scale of 1/250,000 for any part of the world, and (4) large scale, rapid response, mosaics and revised maps for any selected area in the world (obtainable from a proposed 24 inch focal length camera system).

METHODS AND PROCEDURES

I. Preparation of Training Aids

a. Several large (16" x 20") translucent display materials were prepared. Upon completion, each display board was delivered to the Office

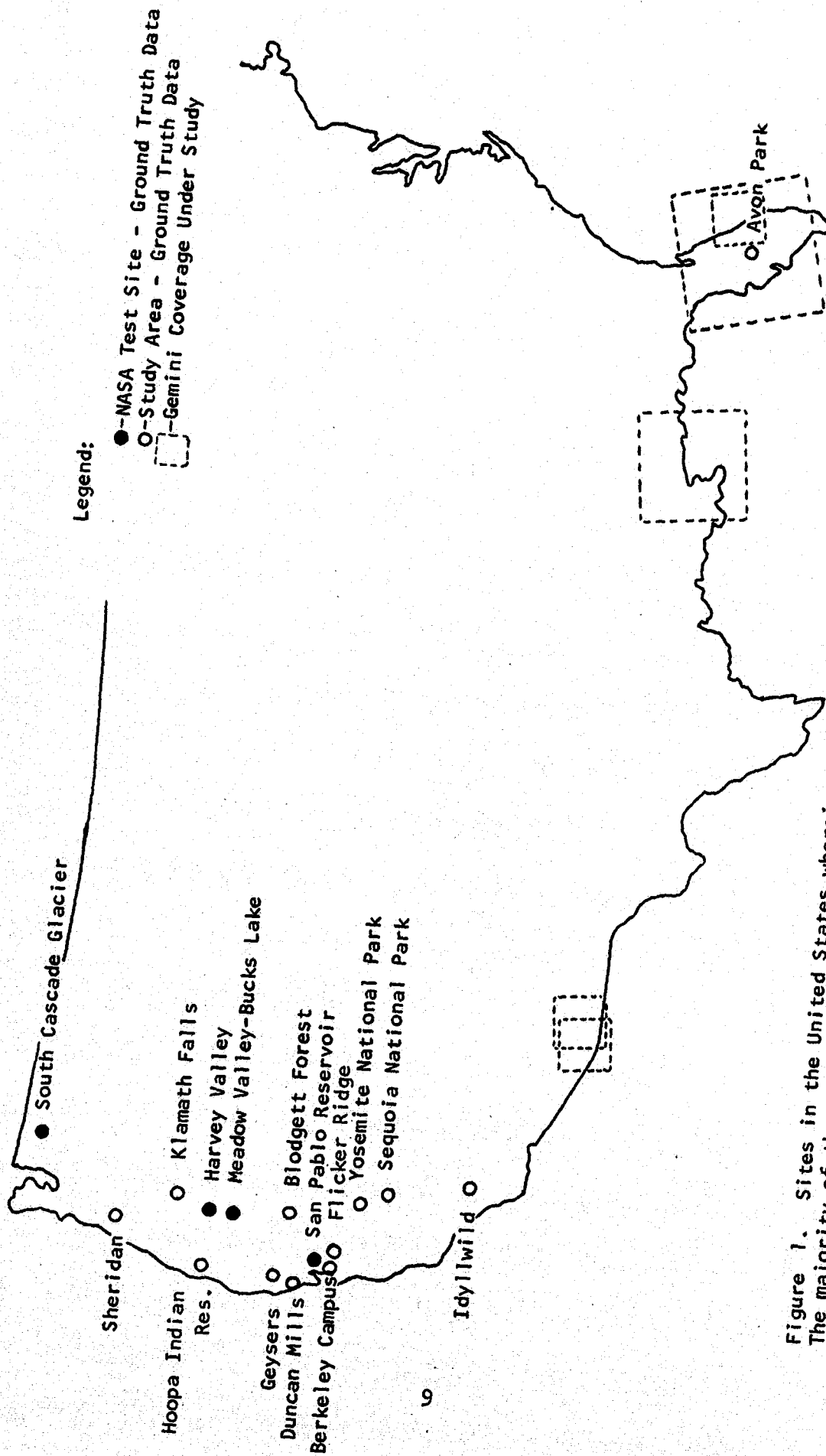


Figure 1. Sites in the United States wherein various aspects of the present investigation were conducted. The majority of the study areas occur in the Sierra Nevada (mixed conifer forest type) or in the California Coast Range (chaparral-woodland forest type).

of Agricultural Research Service, USDA, Washington, D.C. The boards illustrate the relative accuracy with which forest species identifications, typing delineations and stand density estimations can be made on four different types of aerial photography (i.e., panchromatic, black-and-white near infrared, aerial Ektachrome and Ekta Aero Infrared). They also demonstrated the usefulness of multispectral imagery and sequential imagery in forest tree species identification.

b. Several different types of photo interpretation keys were prepared and illustrated in the 1966 and 1967 Annual Progress Reports. These keys combined various techniques of key preparation and were quite general in nature. A more specific operational type of photo interpretation key was constructed to aid in the identification of the major tree types found to occur within the San Pablo Reservoir/Flicker Ridge Test Area. This latter key utilizes Ekta Aero Infrared transparencies flown by the Houston-based Convair aircraft and taken to optimum photographic specifications.

c. The scenario for a 35mm film strip was made which summarizes with illustrations the research findings reported upon in the 1966 and 1967 Annual Progress Reports. Briefly stated, the training film attempts to show that (1) individual tree species and stand types may exhibit unique tonal and/or morphological characteristics when remote sensing imagery is taken to the proper specifications, and (2) these characteristics often are identifiable when a sound interpretation process is utilized.

d. A short (15 min.) 16mm movie film was prepared and presented at the Earth Resources Program--NASA Aircraft Mission Results meeting

held in Houston, September 16, 17 and 18. The film emphasized four aspects of research: (1) acquisition of ground truth, (2) defining image procurement specifications, (3) development of image interpretation techniques, and (4) interpretation of Gemini photography.

II. Extended area studies in the San Pablo Reservoir Test Site

a. Previous findings derived in the San Pablo Reservoir Test Site relating to the objectives of this project were tested in an adjacent similar area, henceforth called the Flicker Ridge area.

b. Photo interpretation keys to the major tree species found to occur within the Flicker Ridge area were prepared.

c. A photo interpreter attempted to identify the major timber types, delineate stand boundaries and estimate timber stand density using the prepared keys first on conventional panchromatic aerial photography, then on Ekta Aero Infrared photography.

d. A 100% "ground truth" survey of the timber resources (providing information of timber type boundaries, stand composition and stand density) was made with the aid of large scale, NASA photography for a continuous strip, one-half mile wide and four miles long.

e. The data obtained by photo interpretation were compiled in the form of planimetric maps illustrated in color. Each annotated map represents a summation of the information derived from photo interpretation of each of the two film-filter combinations and from the ground truth survey.

f. Using a dot-grid overlay system, each color map was compared with the ground truth map for the same area, thereby enabling a quantitative analysis to be made. Among the factors quantified were the use-

fulness of photo interpretation keys, and the relative accuracy of timber stratifications and individual tree species identifications on each film-filter combination.

III. Development of an Operational Survey Procedure at the Meadow Valley-Bucks Lake Test Site

a. A survey technique was developed that incorporates (1) stratified homogeneous forest types delineated on a simulated spaceborne photograph (i.e., photo reduction of a photo-mosaic), (2) sample multi-spectral aerial photography taken to optimum specifications from a conventional aircraft and (3) ground truth estimate data obtained from large scale aerial photography.

b. An aerial photo-mosaic of the Bucks Lake Test Site was constructed at a scale of 1/200,000, simulating spaceborne photography. A method was developed that allows homogeneous land use cover types to be identified and delineated on such photography.

c. A relatively homogeneous area, 5,000 acres in size, was delineated on the photo-mosaic. On July 20, 1968, sample (and subsample) small and large scale aerial photographic coverage was procured for the 5,000 acre study area.

d. A two-man field crew cruised the 5,000 acre area on the ground, collecting pertinent forest survey data utilizing a common survey procedure called variable plot/wedge prism cruising.

e. A photo interpreter, using only the small and large scale photography and a carefully prepared photo interpretation key, attempted to determine the species composition within the 5,000 acre area.

f. These data obtained by means of remote sensing were then com-

pared with ground truth inventory data obtained by means of the conventional ground survey.

IV. Stationary Platform Multispectral Studies

a. The Davis water tower study area was utilized during the 1968 growing season for the purpose of obtaining multispectral imagery of various tree types.

b. A target array comprised of small trees and shrubs of various species was constructed at the base of the water tower. The array consisted chiefly of 4' x 4' pallets of potted trees (i.e., Melaleuca armillaris, drooping melaleuca; Eucalyptus rudis, desert gum; Baccharis pilularis, coyote brush; Photinia arbutifolia, toyon; Pinus radiata, Monterey pine; Eucalyptus globulus, blue gum eucalyptus). In addition, five grey scale masonite panels and three primary color cloth panels were included.

c. A portable field spectroradiometer was used to measure irradiance in nanowatts per square centimeter per millimicron from each of the targets within the array. The unit can measure light reflectance from 350 millimicrons to 1200 millimicrons in band widths as narrow as a few millimicrons.

d. As spectroradiometric measurements were being made on the ground, multispectral photography was obtained with a 4" x 5" frame camera from the catwalk of the tower 150 feet above the target array. Each photo was taken from precisely the same camera station with precisely the same camera orientation. In this manner many film-filter combinations were procured rapidly, accurately and inexpensively.

e. Optical negative density measurements were made for each

target on each multispectral photograph using a Welsh densitometer. Each negative density value was normalized by referencing it to the negative density values obtained from the grey scale panel array.

f. Attempts were made to correlate tone densities of each target as derived from multispectral imagery with spectroradiometer data derived from the same target. From these correlations, one can predict which regions of the spectrum might provide maximum tonal discrimination between targets of interest on properly specified multispectral imagery.

V. Coordination with the International Participation Program

a. Brazilian representatives Arnaldo S. Coelho and Luiz G. Carvalho and Mexican representatives Ramon Solis and Alfonso De LaTorre were cordially invited to observe and participate in forest remote sensing activities for a combined period of one month (May 12 through June 8, 1968).

b. The principal investigator and others discussed with these men various NASA financed remote sensing projects and research techniques applicable to forestry problems found to occur within their respective countries.

c. In addition, our guests were given a guided tour of each of the forestry test sites (i.e., Bucks Lake, San Pablo Reservoir, Davis Campus and Yosemite Valley). Aerial photography, flown May 26-27, 1968, by the Houston-based Convair aircraft was quickly processed at the MSC photo lab and immediately returned to the principal investigator in the field. Six days after the photo mission, the principal investigator and foreign visitors were on site evaluating the usefulness of aerial photography for forestry purposes, as shown in Figure 2.



Figure 2. Brazilian and Mexican representatives participated in forest remote sensing activities for a combined period of one month (May 12 through June 8). Aerial photography, flown May 26-27, by the Houston-based Convair aircraft, was quickly processed at the MSC photo lab and immediately returned to the principal investigator in the field. Six days after the photo mission, the principal investigator and foreign visitors were on site evaluating the usefulness of aerial photography for forestry purposes.

TIMBER TYPING - HOMOGENEOUS FOREST STANDS

San Pablo Reservoir Study

During the latter part of 1966, a preliminary study was performed in the San Pablo Reservoir Test Site to determine the extent to which the species composition of timber stands and other types of vegetative cover could be ascertained from an interpretation of high altitude-small scale aerial photography. The results of this first investigation were reported in Appendix I of the 1967 Annual Progress Report.

Briefly stated, those results indicated that through the use of a suitably-prepared photo interpretation key the major types could be adequately identified and mapped within the study area. These results also indicated that, for purposes of species identification, color photography (both Ektachrome and Infrared Ektachrome) is more interpretable than black-and-white photography. More specifically, the interpreter's finest performance was registered when interpreting Aerial Ektachrome photos while his poorest results were produced using conventional panchromatic minus-blue photos.

The photography used in this test was flown by the NASA Houston-based Convair aircraft on August 28, 1966. The following four film-filter combinations were procured at a scale of 1/33,500: Panchromatic film with a Wratten 12 (minus-blue) filter; (2) Infrared Aerographic film with a Wratten 89B filter, (3) Aerial Ektachrome film with an HF-5 (haze-cutting) filter, and (4) Ekta Aero Infrared film with a Wratten 12 + EF 2200 filter. Interpretation of the photography was performed by

a skilled forest photo interpreter. The interpreter received training for this particular task solely through the use of a dichotomous photo interpretation key (fully illustrated in the 1966 Annual Progress Report).

Results obtained from the San Pablo Reservoir study were encouraging but not conclusive. It was difficult for the principal investigator to accept the fact that relatively little differences in interpretation accuracy existed between results obtained from the four-film combinations, even though color photography proved to be slightly superior to the black-and-white photography. One would expect, based on previous tests and past experience, far superior results from the interpretation of tri-emulsion layer color photography. Consequently, during the period covered by the present report, a similar study was conducted with very stringent constraints on methodology within an adjacent and analogous area, known as the Flicker Ridge Study Area.

Flicker Ridge Study

The Flicker Ridge Area (see Figure 3) is a woodland-chaparral-grassland forest type occurring within the California Coast Range in close proximity to the San Pablo Reservoir Test Site. Predominant homogeneous "pure stand" types are: (1) Sequoia sempervirens (coast redwood), (2) Pinus attenuata (knobcone pine), (3) Pinus radiata (Monterey pine), (4) Eucalyptus globulus (blue gum eucalyptus), (5) mixed hardwood (big leaf maple, madrone, buckeye, coast live oak and California bay), (6) chaparral (coyote brush and chamise), and (7) annual grasslands. Consistent with the objectives of this report, it

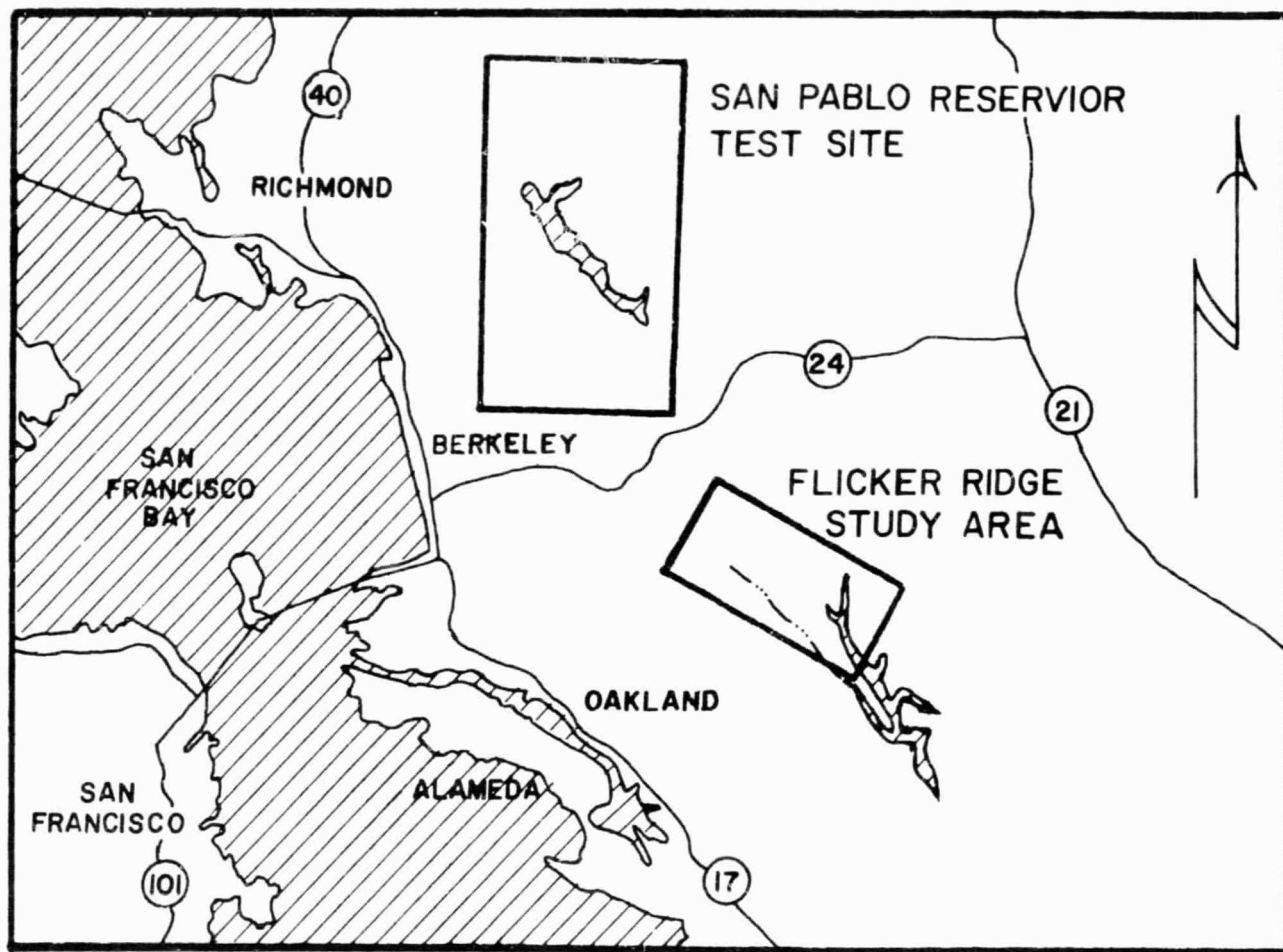


Figure 3. Location map showing the proximity of the Flicker Ridge study area to the San Pablo Reservoir Test Site. Photo interpretation keys were made, interpretation techniques were developed, and photographic specifications were determined using photography taken over the San Pablo Test Site. These findings were then tested in the analogous, adjacent Flicker Ridge area.

was possible through on-the-ground observation to accurately map the areal distribution and species composition for each of these types.

Lumber derived from coast redwood and produced in the north-coast counties of California is the mainstay to the economy of that region. Valuable stands of redwood grow in large pure stands principally on the alluvial flats and lower side slopes of the drainage networks. A primary concern of the timber producers within the area is to obtain accurate inventory data pertaining to location, distribution and frequency of occurrence of these important timber stands. The study reported upon herein may very well lead to a rapid and accurate means of inventorying redwood in this region of California.

Monterey pine, knobcone pine and eucalyptus have a lesser commercial importance than redwood, but serve as valuable forest cover types, enhancing the water retention capabilities of watershed lands throughout the arid western United States. Similarly, range managers and cattle ranchers are continually seeking accurate survey data on the location and areal extent of major vegetation cover types (i.e., grassland, brushland and timberland) for the areas they must manage.

The Flicker Ridge study was designed to determine how accurately a vegetation cover type survey could be made of an area approximately one-half mile by four miles in size using high altitude, small scale aerial photography. Utilizing methods discussed in the 1967 Annual Progress Report, optimum photographic specifications were determined for this region. The NASA Convair aircraft then obtained photography of the study area as specified: (1) fall seasonal state--allowing for

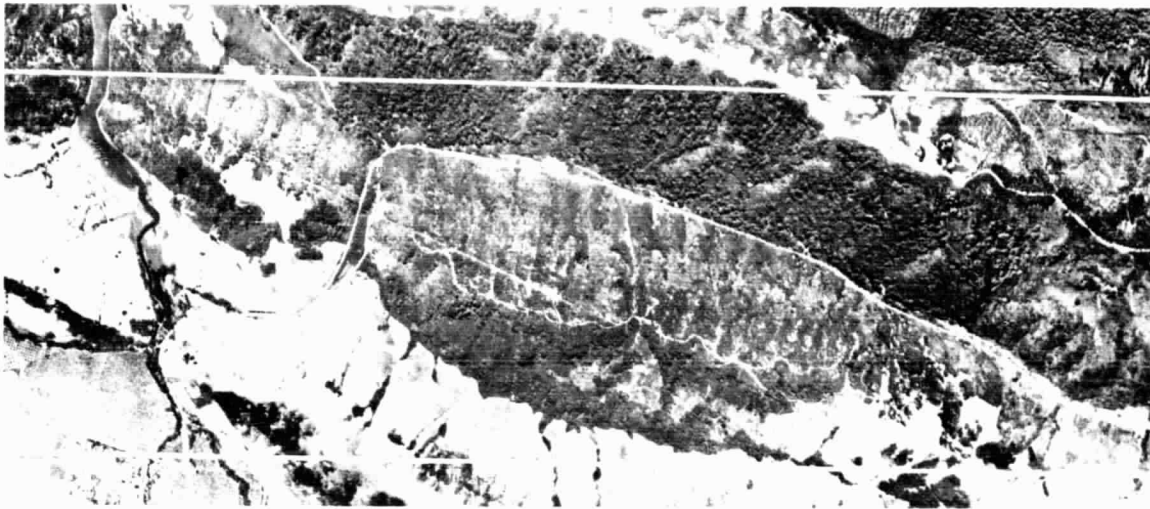
maximum foliage coloration differences between species, (2) midday time, high sun angle--assuring minimum shadow density, (3) six-inch focal length Wild RC 8 metric cameras--providing maximum image resolution, (4) maximum flying altitude (scale 1/32,000)--simulating, insofar as possible, spaceborne photography, (5) no stereo overlap--stereo parallax will have negligible influence on satellite photography taken of forested areas, and (6) Plus X Aerographic film with a Wratten 12 filter and Ekta Aero Infrared film with a Wratten 15--the two film-filter combinations being tested (see Figure 4).

On the ground a 100% "ground truth" survey of the timber resource was made, with the aid of large scale NASA photography. In this survey, timber type boundaries were accurately delineated based on stand composition and stand density. The individual who performed the photo interpretation showed proper motivation, patience, good judgment, a capability for deductive reasoning and high acuity for the perception of tone, color and image sharpness. Since he had no experience in forestry, was not familiar with the Flicker Ridge area and was not involved in the field checking, possibilities for interpreter bias were largely eliminated. The interpreter received training for the particular task solely through the use of a dichotomous photo interpretation key (see Table II, III and IV; Figures 5 and 6).

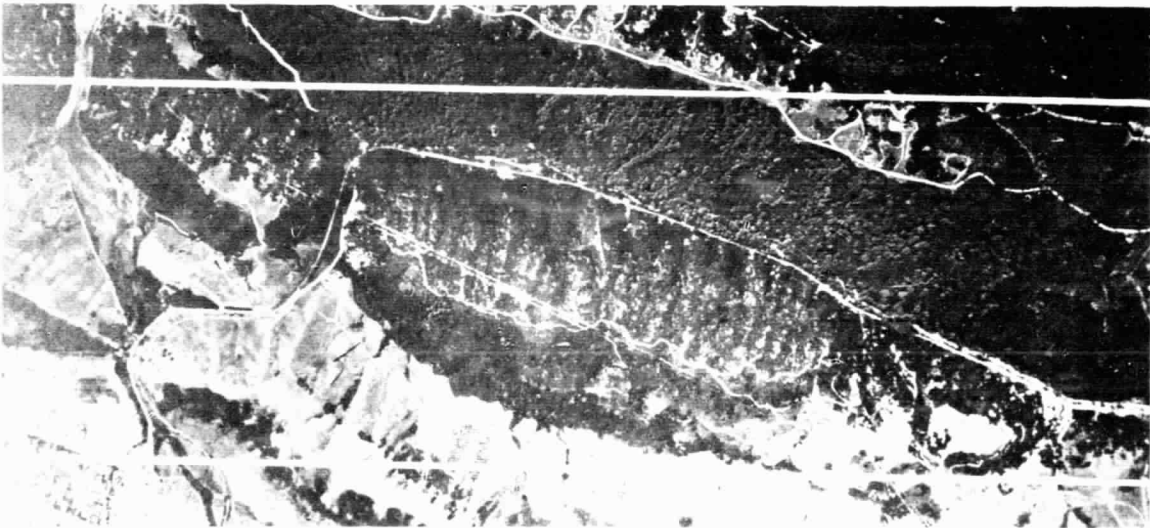
The interpreter followed the procedures prescribed in the following instructions and recorded the time spent during each training period and during each interpretation period:

I. Training Period #1 (panchromatic photography)

- A. Study each stand description in the photo interpretation key.



Panchromatic Film, Wratten 12 Filter
Photographic Scale (shown here) 1/32,000



Ekta Aero Infrared Film, Wratten 15 Filter
Photographic Scale (shown here) 1/32,000

Figure 4. The Flicker Ridge Study Area is outlined above on the two film-filter combinations used in the interpretation test. The 1,460 acre area is covered with the following vegetative cover types: Monterey pine (15.5 acres), knobcone pine (33 acres) redwood (199.5 acres), eucalyptus (87 acres), mixed hardwood (653 acres), chaparral (185 acres) and grassland (287 acres).

Table II. SUMMARY OF IDENTIFYING CHARACTERISTICS OF SEVEN VEGETATION COVER TYPES FOUND TO OCCUR IN THE FLICKER RIDGE STUDY AREA

<u>SPECIES</u> <u>OR TYPE</u>	<u>TOPE ON PANCHRO-</u> <u>MATIC PHOTOS</u>	<u>COLOR ON</u> <u>EKTA IR PHOTOS</u>	<u>CROWN</u> <u>APEX</u>	<u>CROWN</u> <u>MARGIN</u>	<u>AVERAGE HEIGHT</u> [*]
<u>Pinus</u> <u>radiata</u>	very dark grey	dark red	obtuse	denticulate	40-100'
<u>Pinus</u> <u>attenuata</u>	medium grey	dark red	obtuse	denticulate	10-40' (may reach 80')
<u>Eucalyptus</u> <u>globulus</u>	dark grey	brownish red	rounded	denticulate	70-140'
<u>Sequoia</u> <u>sempervirens</u>	medium grey	pinkish red	acute	dentate	70-200'
mixed hardwood	shades of medium grey	bright red	rounded	lobed sinuate	10-70'
chaparral	light to medium grey	bright red to brownish red	not generally visible	not generally visible	3-10'
annual grassland	very light grey	light tan to olive tan	not applicable	not applicable	less than 3'

* On non-stereo photography, an experienced photo interpreter can estimate relative average plant or stand height primarily by observing shadow length.

Table III. DICHOTOMOUS PHOTO INTERPRETATION KEY FOR SEVEN VEGETATION COVER TYPES FOUND TO OCCUR IN THE FLICKER RIDGE STUDY AREA, BASED ON PANCHROMATIC PHOTOGRAPHY, FALL SEASONAL STATE

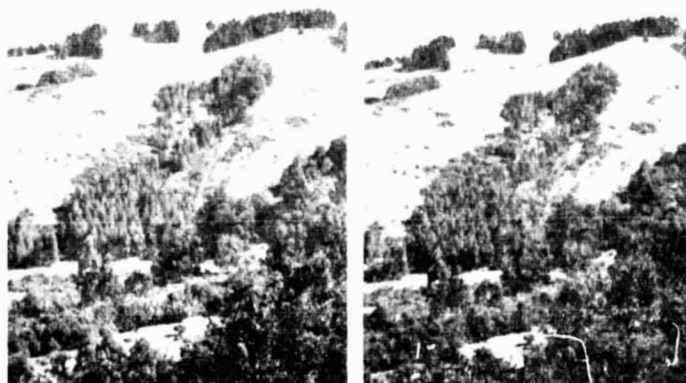
1. Low ground cover, no height apparent. Very light grey tone.
Annual grassland
1. Vegetation in shrub or tree form, height distinctly apparent. Medium to dark grey tone. 2.
 2. Vegetation even-textured, plants less than 10 feet tall. Crown detail not apparent. Chaparral
 2. Vegetation uneven-textured, tall and tree-like (generally greater than 40 feet tall). Crown detail usually apparent. 3.
 3. Trees medium tall (less than 70 feet) with deeply rounded (lobed) or wavy (sinuate) crown margins. Having shades of medium grey tones due to species mixture. Mixed hardwood
 3. Trees tall (greater than 70 feet) with sawtoothed (dentate or denticulate) crown margins. Medium to dark grey tone. 4.
 4. Mature stands dark grey to very dark grey in tone 5.
 4. Mature stands medium grey in tone. 6.
 5. Mature stands dark grey, crown apexes broadly rounded. Stands homogeneous, individual crowns infrequently distinct. Eucalyptus globulus
 5. Mature stands very dark tone, crown apexes bluntly rounded. Individual crowns uniformly spaced, of approximately the same diameter. Pinus radiata
 6. Trees small (rarely greater than 80 feet tall). Crowns small, often indistinct, with denticulate margins. Pinus attenuata
 6. Trees large (generally greater than 80 feet tall). Crown large, usually distinct with dentate margins. Sequoia sempervirens

Table IV. DICHOTOMOUS PHOTO INTERPRETATION KEY FOR SEVEN VEGETATION COVER TYPES FOUND TO OCCUR IN THE FLICKER RIDGE STUDY AREA, BASED ON EKTA AERO INFRARED PHOTOGRAPHY, FALL SEASONAL STATE

1. Low ground cover, no height apparent. Light tan to olive tan color.
Annual grassland
1. Vegetation in shrub or tree form, height distinctly apparent. Light or dark red color. 2.
 2. Vegetation even textured, plants less than 10 feet tall. Crown detail not apparent. Chaparral
 2. Vegetation uneven-textured, tall and tree-like (generally greater than 40 feet tall) 3.
 3. Trees medium tall (less than 70 feet) with deeply rounded (lobed) or wavy (sinuate) crown margins. Bright red to pink color. Mixed Hardwood
 3. Trees tall (greater than 70 feet) with sawtoothed (dentate or denticulate) crown margins. Bright to dark red color. 4.
 4. Mature stands brownish red, crown apices broadly rounded. Stands homogeneous, individual crowns infrequently distinct. Eucalyptus globulus
 4. Mature stands are bright to dark red, crown apices bluntly rounded. 5.
 5. Mature stands are bright pinkish red. Crown margins have shaggy appearance (dentate crown margin). Sequoia sempervirens
 5. Mature stands dark red. Crown margins finely sawtoothed. 6.
 6. Mature stands homogeneous, individual crowns infrequently discernible. Dark red color. Pinus attenuata
 6. Individual crowns distinct, uniformly spaced, of nearly the same diameter. Very dark red color. Pinus radiata

Pinus radiata
(Monterey pine)

Flicker Ridge Study Area



Distribution: Native in San Mateo, Monterey, and northern San Luis Obispo Counties where the species is found on gentle to moderate slopes, from sea level to a maximum near 1000 feet, and from the coast line to about six miles inland. Planted in parks and gardens and, especially in coastal California, for reforestation.

Soils: Grows on a variety of soils developed from different parent materials. The soils are characteristically coarse-textured sandy loams, strongly acid, and at least moderately permeable. On the best sites, the soil is well-drained, moderately deep sandy loam. The characteristic patterns of fog movement inland seem to explain the distribution of the Monterey pine forest where other factors are not limiting.

Assoc. Species: Coast live oak, valley oak, California bay, blue gum eucalyptus, willow, buckeye, bigleaf maple.

Crown apex:

obtuse



Crown margin:

denticulate

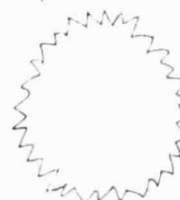
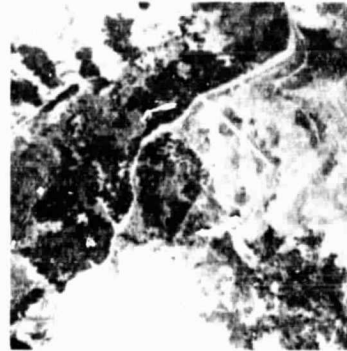


Figure 5. A selective photo interpretation key to the seven major vegetation cover types in the Flicker Ridge area was prepared that supplements the dichotomous system shown in Tables III and IV. A terrestrial stereogram, description of distribution, soils and associate species and a schematic drawing of the crown characteristics for Monterey pine are shown here.

Pinus radiata



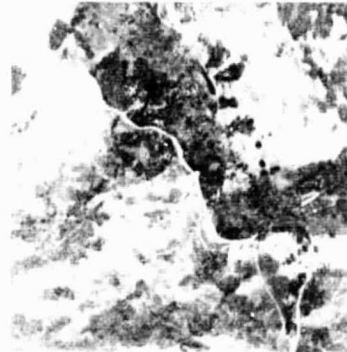
Film: Panchromatic
Filter: Wratten 12
Scale: 1/5,000



Film: Panchromatic
Filter: Wratten 12
Scale: 1/30,000



Film: Ekta Aero Infrared
Filter: Wratten 15
Scale: 1/5,000



Film: Ekta Aero Infrared
Filter: Wratten 15
Scale: 1/30,000

Aerial Description: A 40 to 100 foot evergreen tree with a straight trunk. Stout spreading branches form a compact, often irregular, round to obtuse crown apex. The finely sawtoothed crown margin becomes obscured at scales of 1/5,000 or smaller. The tree appears dark red on Ekta Aero Infrared film. On panchromatic photography, the tree is generally darker in tone than ponderosa pine, digger pine and white fir, but appears very similar to Douglas fir. The species is easily identified as a coniferous species but specific species identification is difficult.

Figure 6. In addition to the information presented in Figure 5, a selective photo interpretation key should also contain representative aerial photo examples and a comprehensive word description for each species being presented (Monterey pine is illustrated in this example).

B. Analyze each of the stand types as shown in the photo illustrations.

C. Classify example forest stands with reference to the dichotomous key, tree description and photo illustrations.

1. Identify species composition (numerator)

<u>Symbol</u>	<u>Species</u>
R	Redwood
MP	Monterey pine
KP	Knobcone pine
E	Eucalyptus
MH	Mixed hardwood
C	Chaparral
G	Annual grassland

2. Estimate timber density (denominator)

<u>Symbol</u>	<u>Density</u>	<u>Percent of total ground space covered by crowns</u>
1	Dense	80 (+)
2	Semidense	50-80
3	Open	20-50
4	Very Open	5-20
5	Apparently unstocked	5 (-)

D. Check results and review.

II. Interpretation Period #1 (panchromatic photography)

A. Review each stand description in the photo interpretation key.

B. Review example forest stands.

C. Classify forest types within the outlined area

1. Delineate each type (minimum area = 1 acre)
2. Identify species composition (numerator)
3. Estimate timber density (denominator)

III. Training Period #2 (same as #1, but with Ekta Aero Infrared photography). (Allow at least four weeks time to elapse between Steps II and III when working with a single photo interpreter).

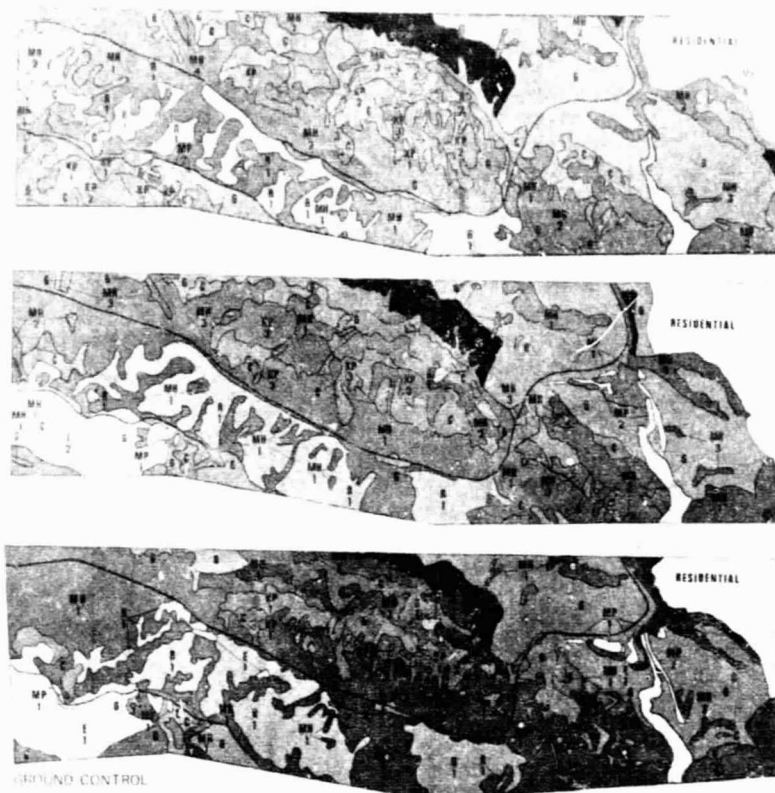
IV. Interpretation Period #2 (same as #1, but with Ekta Aero Infrared photography).

The information obtained by photo interpretation was compiled in the form of planimetric maps illustrated in color (see Figure 7). In order to eliminate map compilation errors, a photogrammetric instrument called the Kail plotter was used to plot planimetric detail. Each annotated map represents a summation of the information derived from photo interpretation of each of the two film-filter combinations used in this test.

With the aid of a dot-grid overlay system, each color map was compared with the ground truth map for the same area, thereby enabling a quantitative analysis to be made (see Tables V and VI, Figure 8).

Probably the most satisfying conclusion drawn from the Flicker Ridge study pertains to the usefulness of a photo interpretation key. The key, used as the sole source of training and reference material, provided the interpreter with a means of mapping vegetation in an area completely unfamiliar to him. For the 1,460 acres analyzed, he misinterpreted the identity of the predominant vegetative cover type on only 332 acres on panchromatic photography and only 151 acres on Ekta Aero Infrared photography. Thus, if an interpreter exhibits the proper motivation and skill, if photography is flown to proper specifications, and if an adequate photo interpretation key is made available, accurate vegetation surveys can be made without implementing exorbitantly expensive and time consuming conventional on the ground survey techniques.

These results show that Ekta Aero Infrared photography provided the interpreter with significantly more information for this purpose than panchromatic photography, especially when attempting to locate and identify those forest types having similar image characteristics



Key to Vegetation Types:

- Yellow = Sequoia sempervirens (redwood)
- Orange = Pinus attenuata (nobcone pine)
- Blue = Pinus radiata (Monterey pine)
- Violet = Eucalyptus globulus (blue gum eucalyptus)
- Dark Green = Mixed hardwood (maple, madrone, buckeye, bay, oak)
- Grey = Chaparral (chamise, coyote brush)
- Light Green = Grassland
- Red = Orchards

Figure 7. The top two annotated maps shown in this figure represent a summation of the information derived from photo interpretation of each of the two film-filter combinations used in this test (i.e., panchromatic-Wratten 12 and Ektar Aero Infrared-Wratten 15). Each map was compared with a third map (the ground truth map shown at the bottom of this figure) in order to determine the relative accuracy of timber stratifications and individual tree species identifications on each film-filter combination. A quantitative expression of the results of this test will be found in Tables V and VI and in Figure 8.

Table V. TIMBER TYPING ON SMALL SCALE NASA PHOTOGRAPHY - FLICKER RIDGE STUDY AREA

Panchromatic Film; Wratten 12 Filter; Scale 1/30,000. Figures in darkest rectangles indicate accuracies achieved, as expressed in both acreages (numerator) and percentages (denominator). Figures in other rectangles indicate errors made. In the total area of 1,460 acres, 1,128 acres were correctly identified, giving an overall accuracy of 77%.

COVER TYPE	TOTAL AREA	IDENTIFIED AS:						
		MH	MP	E	KP	C	R	G
MIXED HDWD.	653	547.5 85%	0 0%	0 0%	11 1%	47.5 7%	30 5%	17 2%
MONT. PINE	15.5	9 58%	1.5 10%	0 0%	3 19%	0 0%	0 0%	2 13%
EUCALYPTUS	87	0 0%	0 0%	0 0%	85 98%	0 0%	2 2%	0 0%
KNOB. PINE	33	1 3%	0 0%	0 0%	26 79%	6 18%	0 0%	0 0%
CHAPARRAL	185	24.5 13%	0 0%	0 0%	5 3%	143 77%	0 0%	12.5 7%
REDWOOD	199.5	64.5 32%	0 0%	0 0%	0 0%	0 0%	135 68%	0 0%
GRASSLAND	287	8.5 3%	0 0%	0 0%	0 0%	3 1%	0 0%	275.5 96%

Table VI. TIMBER TYPING ON SMALL SCALE NASA PHOTOGRAPHY - FLICKER RIDGE STUDY AREA

Ekta Aero Infrared Film; Wratten 15 Filter; Scale 1/30,000. Figures in darkest rectangles indicate accuracies achieved, as expressed in both acreages (numerator) and percentages (denominator). Figures in other rectangles indicate errors made. In the total area of 1,460 acres, 1,309 acres were correctly identified, giving an overall accuracy of 89%.

COVER TYPE	TOTAL AREA	IDENTIFIED AS:						
		MH	MP	E	KP	C	R	G
MIXED HDWD.	653	577.5 88%	0 0%	1 0%	11 2%	29.5 5%	29 5%	5 0%
MONT. PINE	15.5	5 32%	7 45%	2.5 16%	0 0%	0 0%	0 0%	1 7%
EUCALYPTUS	87	0 0%	0 0%	83 95%	0 0%	1.5 2%	2.5 3%	0 0%
KNOB. PINE	33	5 1%	0 0%	0 0%	31 94%	1.5 5%	0 0%	0 0%
CHAPARRAL	185	20.5 11%	0 0%	1 0%	9.5 5%	147 79%	0 0%	8 4%
REDWOOD	199.5	11.5 6%	0 0%	0 0%	0 0%	0 0%	188 94%	0 0%
GRASSLAND	287	6 2%	1 0%	0 0%	0 0%	4.5 2%	0 0%	275.5 96%

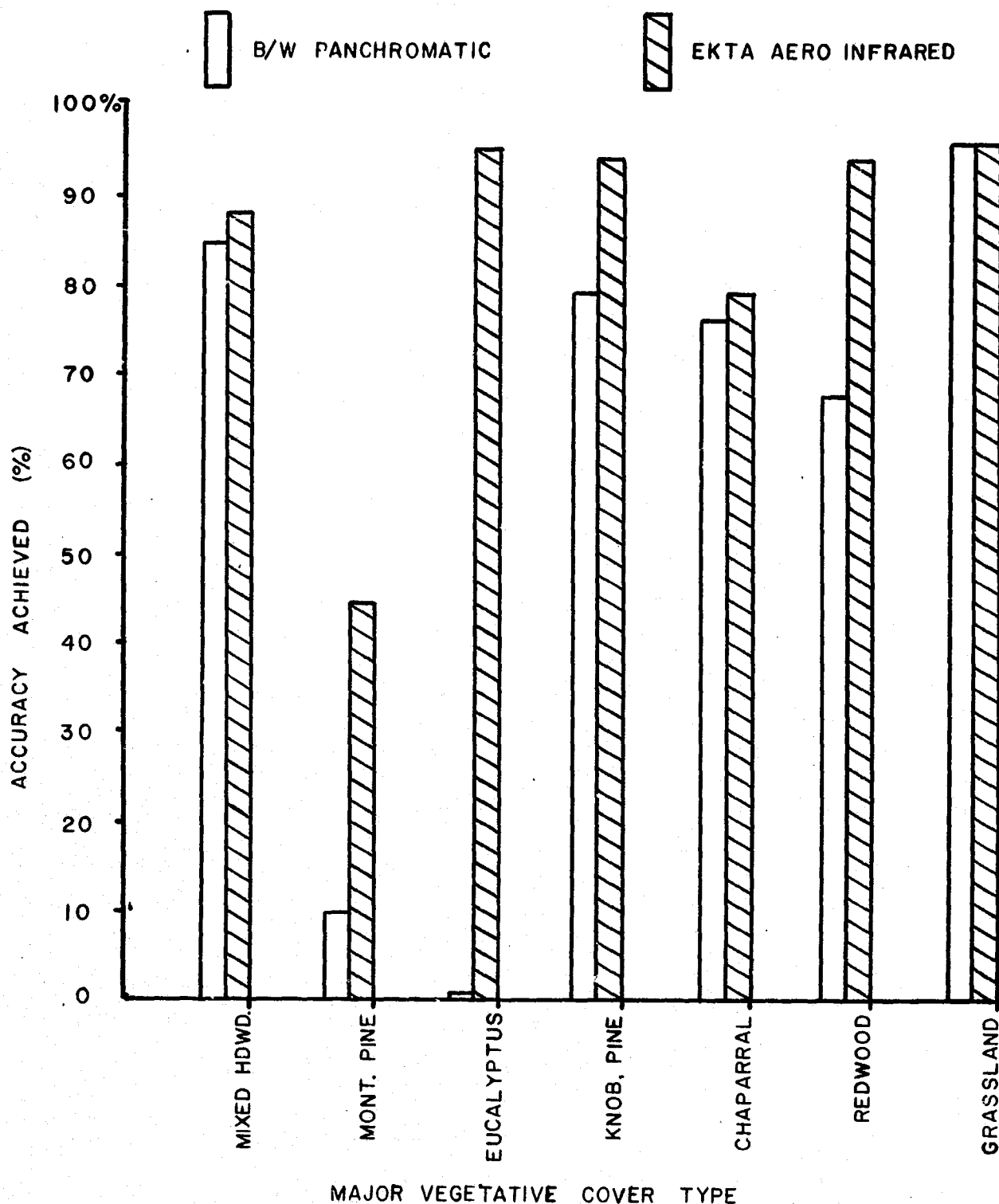


Figure 8. The interpretation results presented in this histogram show that, in terms of accuracies achieved, Ekta Aero Infrared photography provides the interpreter with more information for species identification than black-and-white panchromatic photography. The false color infrared photography was vastly superior to the black-and-white photography for differentiating those species with similar identifying characteristics (i.e., Monterey pine, knob-cone pine, eucalyptus and redwood).

(i.e., Monterey pine, knobcone pine, eucalyptus and redwood).

From the results of this study, one might prematurely conclude that although color photography permits slightly superior results to be obtained, (compared with black-and-white photography) the slight increase in interpretation accuracy would not offset the added cost of obtaining the color photography. However, Table VIII shows that, in addition to providing more accurate results, the analysis of color infrared photography required approximately 25% fewer man-hours of interpretation time than black-and-white photography. Considering high labor costs, this factor is extremely important, especially when salaries dominate the costs of large survey jobs. When interpreting color photos, the interpreter more quickly recognizes image characteristics and more rapidly identifies the species composition. Consequently, much less time is spent in pondering over difficult decisions. With this combination of advantages, the interpreter is far less likely to experience fatigue when studying color photography. Since the accuracy of interpretation decreases rapidly as fatigue increases, the total gain resulting from the use of color photography, particularly on large projects, may be far greater than is indicated from a casual inspection of Figure 8.

Feasibility Ratings for 100-Foot Ground Resolved Distance (GRD)

The Flicker Ridge Study proved that timber type delineation and species identification can be done on small scale, high altitude aerial photography. However, the question remains--can forest surveys be made on photographs obtained from earth orbital altitudes?

Photography procured at a scale of 1/30,000 with the metric cameras

Table VII. COST OF INTERPRETATION: BLACK AND WHITE PANCHROMATIC VERSUS EKTA AERO INFRARED PHOTOGRAPHY

	<u>Panchromatic Photography</u>	<u>Ekta Aero Infrared Photography</u>
Time required to study key	2.5 hrs.	2.0 hrs.
Time required to interpret test plots	1.5 hrs.	2.0 hrs.
Time required to interpret 1,460 acre study area	10.0 hrs.	6.5 hrs.
Total time required	14.0 hrs.	10.5 hrs.
Hourly wage	\$ 3.06/hr.	\$ 3.06/hr.
Interpretation cost (time)	\$42.80	\$32.20
Total acreage of study area	1,460 acres	1,460 acres
Total cost per acre	2.93¢/acre	2.21¢/acre
Cost ratio	100%	75.5%

aboard the NASA aircraft provide data on which the minimum Ground Resolved Distance (GRD) is equal to approximately three feet. In addition to photographic tone or color, these data provide useful information on tree morphology such as tree height and shape of the crown margin and crown apex. However, recognition of timber stand form and structure from earth orbit is sometimes considered an unattainable goal. Katz (1960), discussing the theoretical resolving power obtainable from a reconnaissance satellite at an altitude of 142 miles, showed how a conventional twelve inch focal length metric camera stationed in space, capable of resolving 40 line pairs per millimeter, could not image objects smaller than 60 feet in diameter. Theoretically, an efficient system (i.e., long focal length, high resolution) mounted in orbiting satellites could resolve ground objects a few inches in size; however, primarily because certain foreign governments will not condone ultra-high resolution sensors over their countries, the assumption is made that spaceborne systems in the near future will provide only moderate ground resolution. The question now reads--can forest surveys be made on 100 foot resolution photography whereby image analysis will be based primarily on tone or color contrast (i.e., the difference in tone or brightness between an image and its background)?

Analysis of low resolution space photography has been limited to the few existing photos taken from several Gemini missions and the Apollo 6 mission. An Ekta Aero Infrared photo taken from Gemini VII over the southeastern United States was analyzed and reported upon in the 1967 Annual Progress Report. This photo provided a GRD (Ground

Resolved Distance) of approximately 300 feet, yet, even with this inherent limitation, a trained photo interpreter was able to delineate and identify, with the aid of a photo interpretation key, certain vegetation types and culturally induced vegetation patterns. They were: (1) coastal tidal marshes or prairies, (2) coastal beaches or sand dunes, (3) bottom-land hardwoods, (4) conifer forests with varying concentrations of hardwoods, (5) grassland areas, (6) areas of general farming and (7) sugar cane fields. In this case, photographic tone and color was the primary criterion used for image analysis.

Due to a lack of spaceborne photography of forested areas in the United States, an attempt was made to simulate a condition of 100 foot GRD by degrading high altitude-small scale NASA photography taken of the San Pablo Reservoir Test Site (see Figure 9). The technique entails reproducing the original transparency with a flat plate of frosted acetate placed at various positions between the original photo and the copy camera. In this manner, image sharpness can be manipulated while image color or tone remains nearly unaltered. (The two photos at the top of Figure 9 show that, despite obvious differences in resolution, tone values of specific areas as seen on photos taken at orbital and conventional altitudes are nearly the same). Natural terrain features 100 feet or less in size can be made to disappear or reappear on the copy photograph depending upon the degree of degradation.

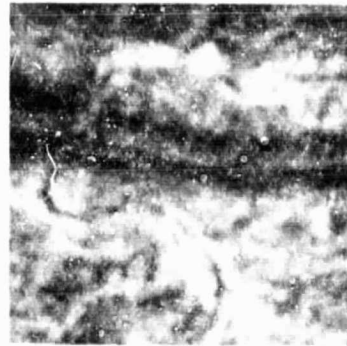
Table VIII on the succeeding page indicates the feasibility of detecting and identifying on simulated space photography the identifying characteristics of the five major vegetation types found to occur within the San Pablo Reservoir Test Site. The symbols appearing in the various

Gemini Photography:



Scale: 1/500,000; 100 ft. GRD

Aircraft Photography (Degraded)



Scale: 1/500,000; 100 ft. GRD



Gemini Photography:



Scale: 1/500,000; 100 ft. GRD

Gemini Photography:



Scale: 1/50,000; 100 ft. GRD

A portion
enlarged 10X

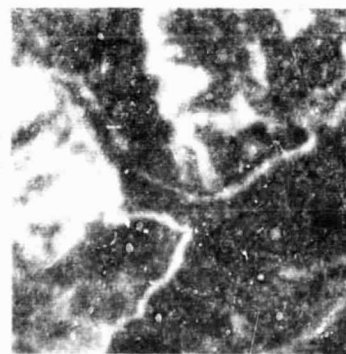


NASA Aircraft Photography:



Scale: 1/50,000; 3 ft. GRD

NASA Aircraft Photography:



Scale: 1/50,000; 100 ft. GRD

Reproduced through
a diffusing screen

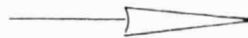


Figure 9. In order to provide a means for arriving at the feasibility ratings shown in Table VIII, NASA photography taken over the San Pablo Reservoir Test Site was reproduced through a diffusing screen. By degrading image sharpness without grossly affecting image tone or color, photography can be analyzed that exhibits 100 foot GRD, similar to the quality of existing Gemini photography and photography expected from satellites in the near future.

Table VIII. FEASIBILITY OF INTERPRETING, ON LOW RESOLUTION PHOTOGRAPHY, THE IDENTIFYING CHARACTERISTICS OF THE FIVE MAJOR VEGETATIVE COVER TYPES FOUND TO OCCUR WITHIN THE SAN PABLO RESERVOIR
TEST SITE (BASED ON ANALYSIS OF PHOTOGRAPHY SHOWN IN FIGURES 10, 11 and 12)

Vegetation Type	Identifying Characteristic	Sensor Specification				GRD = 3'				GRD = 30'				GRD = 100'			
		B & W Plus X		Color Infrared		B & W Plus X		Color Infrared		B & W Plus X		Color Infrared		B & W Plus X		Color Infrared	
		Single Season	Two Seasons	Single Season	Two Seasons	Single Season	Two Seasons	Single Season	Two Seasons	Single Season	Two Seasons	Single Season	Two Seasons	Single Season	Two Seasons	Single Season	Two Seasons
Monterey Pine	Tone or Color	+	++	++	++	-	+	+	++	-	++	-	++	-	+	-	+
	Crown Detail	-	+	+	+	-	-	-	+	-	-	-	-	-	-	-	-
	Height/Density	+	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-
	Physiography	+	+	+	++	-	-	-	+	-	-	-	-	-	-	-	-
Eucalyptus	Tone or Color	+	++	++	++	-	+	+	++	-	++	-	++	-	+	-	+
	Crown Detail	-	+	+	+	-	-	-	+	-	-	-	-	-	-	-	-
	Height/Density	+	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-
	Physiography	+	+	+	++	-	-	-	+	-	-	-	-	-	-	-	-
Mixed Hardwood	Tone or Color	+	++	++	++	-	+	+	++	-	++	-	++	-	+	-	+
	Crown Detail	-	+	+	+	-	-	-	+	-	-	-	-	-	-	-	-
	Height/Density	+	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-
	Physiography	+	+	+	++	-	-	-	+	-	-	-	-	-	-	-	-
Chaparral	Tone or Color	+	++	++	++	-	+	+	++	-	++	-	++	-	+	-	+
	Crown Detail	-	+	+	+	-	-	-	+	-	-	-	-	-	-	-	-
	Height/Density	-	+	+	++	-	-	-	+	-	-	-	-	-	-	-	-
	Physiography	-	+	+	++	-	-	-	+	-	-	-	-	-	-	-	-
Grassland	Tone or Color	++	++	++	++	+	+	+	++	+	++	+	++	+	+	+	++
	Crown Detail	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Height/Density	+	+	+	++	-	-	-	+	-	-	-	-	-	-	-	-
	Physiography	+	++	++	++	-	-	-	+	-	-	-	-	-	-	-	-

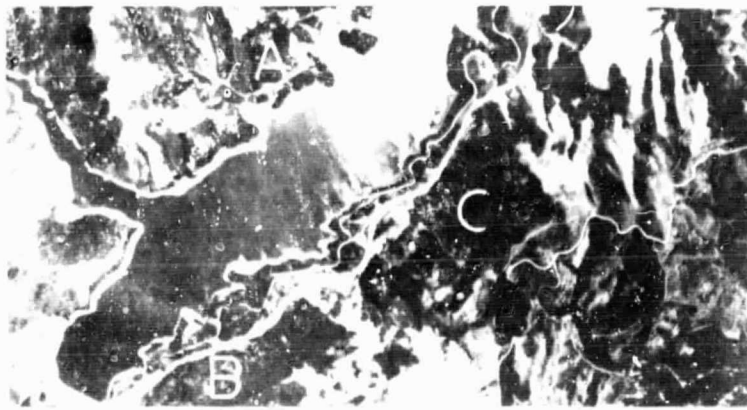
Legend: ++ consistently detected and identified
+ occasionally detected and identified
- rarely detected and identified
-- not detected and identified

squares of this table have the meanings indicated in the legend. The ratings represent the consensus of the principal investigator and several photo interpreters who were actively engaged in this research, each of whom independently assigned feasibility ratings for each square of the table. The ratings are all based on the examination of the photography appearing in Figures 10, 11 and 12. In the past, it was often necessary to extrapolate from aerial photographic examples that had been flown to specifications that were similar to but not identical with those called for in some particular square of the table. Here conclusions are drawn from specific photographic examples taken to the specifications indicated and covering a particular forested region where accurate ground truth had been obtained either at the instant of aerial photography, or very shortly thereafter.

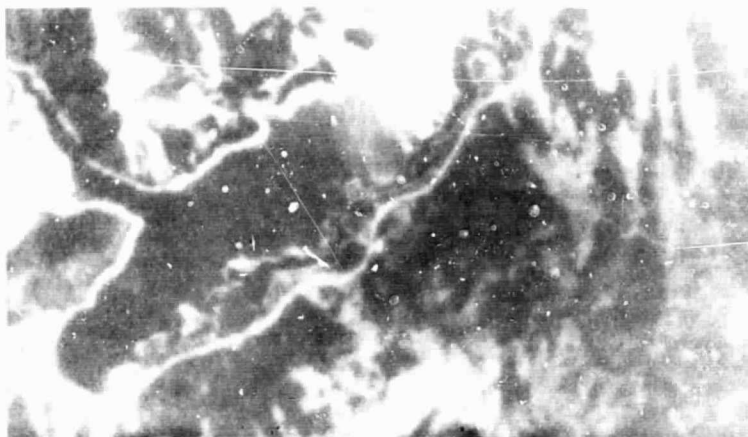
It is believed that, until actual orbital photography is made available of the NASA-USDA Forestry Test Sites, the question of whether timber surveys can be made on satellite photography is best examined in the manner that has been employed in this study.

Sequential Coverage

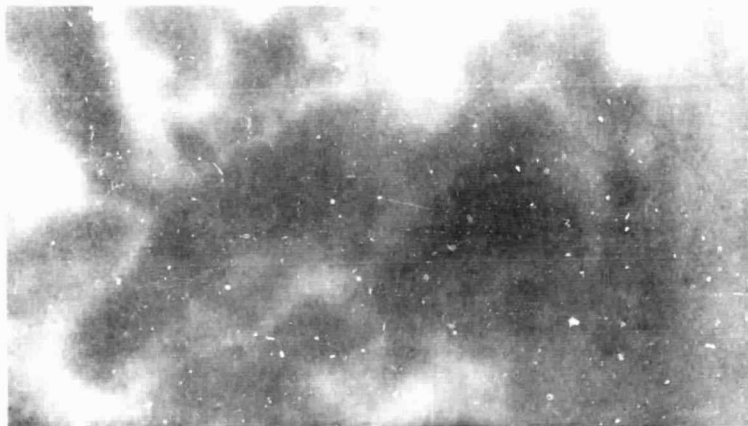
By studying the feasibility ratings in Table VIII and examining the degraded photographic illustrations shown in Figures 10, 11 and 12, one can clearly see that photographic tone or color is the primary criterion on which species identifications are based when shackled with low resolution photography. Note also that additional information can be gained when seasonal color changes can be evaluated on sequential photography.



Panchromatic Film; Wratten 12 Filter; Fall Seasonal State
GRD = 3 feet; Scale 1/50,000

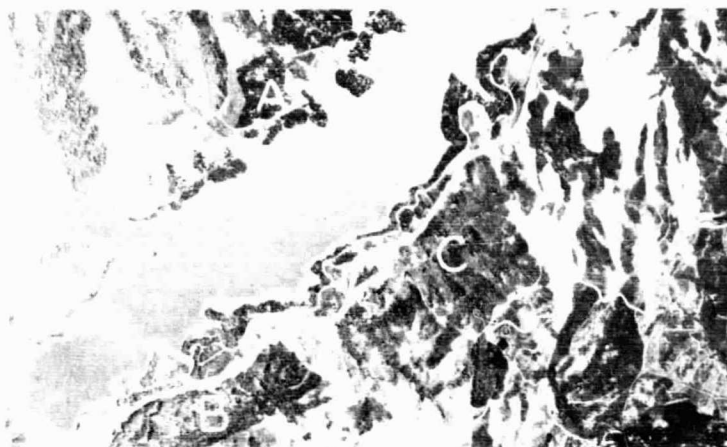


Panchromatic Film; Wratten 12 Filter; Fall Seasonal State
GRD = 30 feet; Scale 1/50,000



Panchromatic Film; Wratten 12 Filter; Fall Seasonal State
GRD = 100 feet; Scale 1/50,000

Figure 10. The feasibility ratings shown on Table VIII were arrived at through an analysis of the photographic illustrations shown above and in Figures 11 and 12. The five major cover types shown here are (1) Monterey pine at A, (2) eucalyptus at B, (3) mixed hardwoods at C, (4) chaparral at D, and (5) annual grassland at E.



Ekta Aero Infrared Film; Wratten 15 Filter; Fall Seasonal State
GRD = 3 feet; Scale 1/50,000

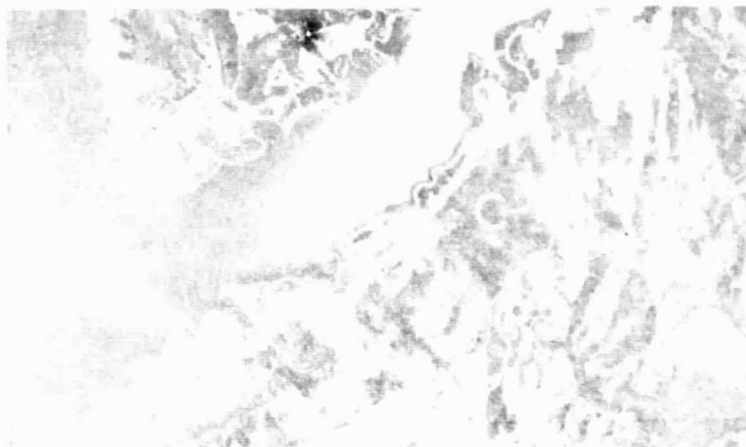


Ekta Aero Infrared Film; Wratten 15 Filter; Fall Seasonal state
GRD = 30 feet; Scale 1/50,000

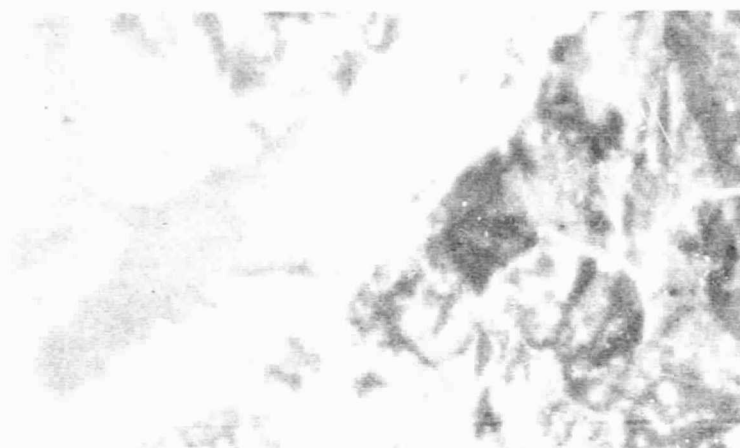


Ekta Aero Infrared Film; Wratten 15 Filter; Fall Seasonal State
GRD = 100 feet; Scale 1/50,000

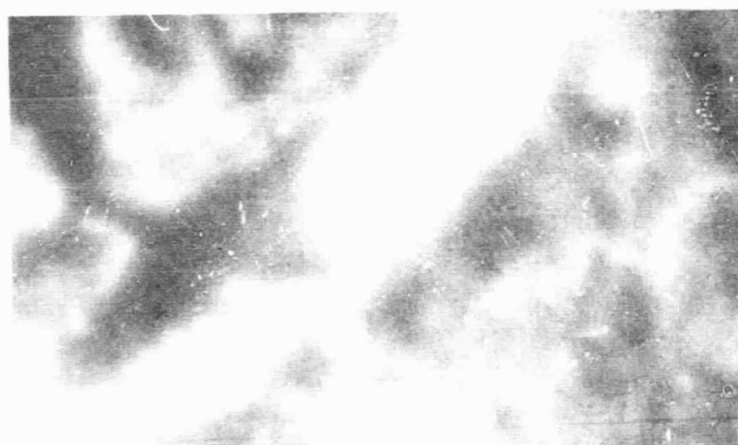
Figure 11. The feasibility ratings shown on Table VIII were arrived at through an analysis of the photographic illustrations shown above and in Figures 10 and 12. The five major cover types shown here are (1) Monterey pine at A, (2) eucalyptus at B, (3) mixed hardwoods at C, (4) chaparral at D, and (5) annual grassland at E.



Ekta Aero Infrared Film; Wratten 15 Filter; Spring Seasonal State
GRD = 3 feet; Scale 1/50,000



Ekta Aero Infrared Film; Wratten 15 Filter; Spring Seasonal State
GRD = 30 feet; Scale 1/50,000



Ekta Aero Infrared Film; Wratten 15 Filter; Spring Seasonal State
GRD = 100 feet; Scale 1/50,000

Figure 12. The feasibility ratings shown on Table VIII were arrived at through an analysis of the photographic illustrations shown above and in Figures 10 and 11. The five major cover types shown here are (1) Monterey pine at A, (2) eucalyptus at B, (3) mixed hardwoods at C, (4) chaparral at D, and (5) annual grassland at E.

The reflectance characteristics of individual tree species or timber types change with time--season of year having a definite influence on image tone or color. Therefore, an "optimum season or seasons of year" for image acquisition should be determined for each particular region that is being studied. Eventually, it will be highly feasible to obtain from earth orbiting satellites sequential coverage, similar to the examples shown in Figure 13, taken either every few hours or at somewhat longer time intervals. Thus, even on 100 foot GRD photography, a high degree of interpretation accuracy can be obtained when certain physiological variations occurring between species are recorded such as: coloration at specific times, the rate of change in coloration and the duration of coloration.

TIMBER TYPING - HETEROGENEOUS FOREST STANDS

The inventory of timber by species is much more difficult within mixed forest stands than within pure homogeneous forest types. In mixed stands one cannot rely on integrated photographic tones or colors as the primary criterion for determining tree species composition. In mixed stands, especially, there tends to be an extreme variability of tree tone or color within a particular species, which is often greater than the tone or color difference between different species. Consequently, tree morphology or, in some cases, certain physiographic characteristics must be the primary means of identification; image tone or color is only of secondary importance.

When trees and timber stands are observed from progressively higher altitudes, they exhibit progressively fewer morphological features.



Ekta Aero Infrared Film
Wratten 15 Filter
Scale 1/50,000; GRD = 100 feet
Fall Seasonal State



Ekta Aero Infrared Film
Wratten 15 Filter
Scale 1/50,000; GRD = 100 feet
Spring Seasonal State

Figure 13. There is good prospect of obtaining high quality sequential photography over long periods of time from future earth orbital reconnaissance satellites. To determine whether seasonal variations in the reflectance characteristics of different vegetation types could be exploited in this way, studies such as the one shown above were conducted. In this example, the annual grasslands at A are most easily detected, delineated and identified on fall photography. However, on spring photography separations can be made between Monterey pine at B and chaparral at C; between eucalyptus at D and mixed hardwood at E; and between chaparral at F and mixed hardwood at G. Thus, increased accuracy of interpretation can be obtained when photography is procured at several seasons of year.

Since satellite photography, even in the future, most likely will provide rather poor ground resolution, one might erroneously conclude that such photography will be of no use to the forester for the purpose of species identification within a mixed forest type. Most of the difficulties are overcome, however, when these low resolution space photos covering the entire area of interest are used in conjunction with a limited number of properly specified aerial photos procured from low flying aircraft. Such a combination of photography makes possible the use of double (or triple) sampling techniques which show great promise for providing a rapid and accurate means of obtaining inventory data on a tree-by-tree basis for large heterogeneous mixed forest stands.

Bucks Lake Study

The west side of the Sierra Nevada Mountains in California consists of several broad land use cover types (i.e., timber, brush, grass, etc.) each of which is associated with a complex admixture of topographic, biotic and edaphic conditions. It is of the utmost importance to forest land managers in this region to be able to stratify the wildlands they manage into several broad classes. By so doing, they are able to determine exactly where the making of more expensive and time consuming timber inventories will be justified. In an attempt to determine whether this first step of land use classification might be done on space photography, an aerial photo-mosaic of the entire Bucks Lake Test Site (approximately 120 square miles) was constructed from 1/30,000 scale infrared ektachrome aerial photos and then reduced to one-tenth its original size, thus simulating small scale spaceborne photography. Then a method was

developed, using a photo interpretation key, which would reveal the extent to which broad cover types could be identified and delineated on the mosaic (see Figure 14).

Results obtained in this study were consistent with the findings reported upon in an earlier section of this report. Specifically, it was found that, even in the heterogeneous stand conditions encountered at the Bucks Lake Test Site, a photo interpreter who is properly trained and given adequate reference materials, can delineate and identify on simulated space photography most of the homogeneous cover types using photographic tone or color as the means of identification. In this case, the interpreter could recognize consistently the following types: (1) brush-hardwood, (2) merchantable conifer forest, (3) non-merchantable (understocked) conifer forest, (4) rock-bare ground, (5) water and (6) meadow-riparian hardwood.

Given information on the areal extent and distribution of major cover types, the land manager is then in a position to concentrate his efforts on obtaining detailed inventory data within those areas considered most important, in this example--merchantable conifer forest. In this region of California, Plumas County, timber resources provide the primary means of economic stability (recreation resources are rapidly becoming equally important). Timber is sold on the stump on a volume-by-species basis. For example, in 1960, pine on the stump generally sold at \$22.50 per 1000 board feet, Douglas fir at \$6.50 per 1000 board feet, white fir and incense cedar at \$3.00 per 1000 board feet. Up to the present time, species composition has been determined in this area



Legend :

- Type #1 = chaparral-oak
- Type #2 = merchantable conifer forest
- Type #3 = non-merchantable conifer forest (understocked)
- Type #4 = rock-bare ground
- Type #5 = water
- Type #6 = meadow-riparian hardwoods

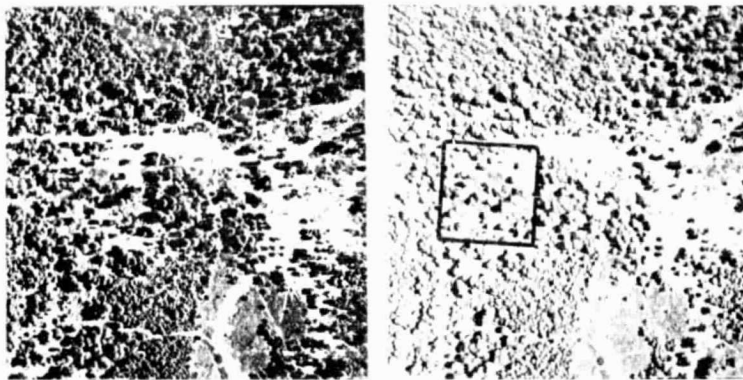
Figure 14. A simulated spaceborne photograph (in this example, enlarged 3X to a scale of 1/100,000) of the Bucks Lake Test Site. A method was developed that allowed a photo interpreter to delineate and identify the six land use cover types appearing in the above legend. Sample and sub-sample large scale aerial photography was procured of a 5300-acre study area (white square) within the merchantable conifer forest type. A double sampling scheme was developed whereby species composition, on a tree-by-tree basis, was determined for this valuable cover type.

primarily through the use of costly ground survey techniques.

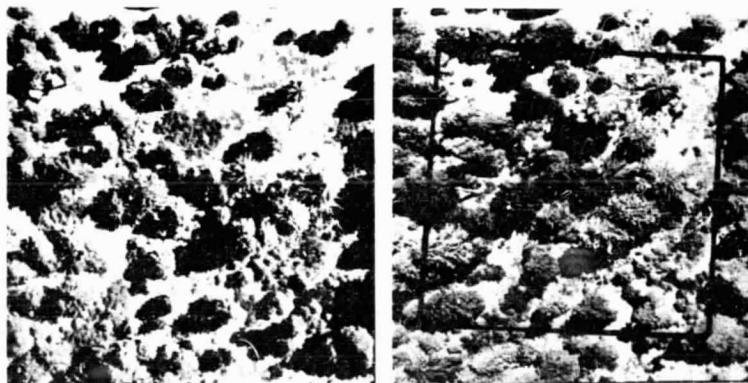
The study reported upon herein attempts to show that, given a stratified land use map prepared from space photography, an interpreter then can obtain inventory data on species composition within a merchantable conifer forest type by utilizing a limited number of sample and subsample aerial photographs.

A 5,300 acre study area was chosen that occurred within cover type #2 on the photo mosaic (see squared area in Figure 14). The entire study area was flown (under operational conditions sample coverage would be sufficient) utilizing predetermined optimum photographic specifications: Aerial Ektachrome film, HF-2 filter, 12 inch focal length camera, scale-1/7,000 and 60% forward overlap for stereo viewing. From these photos a planimetric base map was made using the radial line plot technique. The base map was gridded into 5-acre sections and 100 5-acre plots were randomly selected for interpretation. Each of the 100 5-acre plots was then transferred onto the aerial photos. The interpreter located and identified by species each merchantable tree (Dunning crown class 1, 2, 3, 4 and 5) on each 5-acre plot (see Figure 15).

In addition, 10 of the 5-acre plots were photographed in stereo at very large scale (1/2,000) using Aerial Ektachrome film, thus providing the structure for a double sampling scheme. Each of the 100 5-acre plots were re-interpreted on the large scale photos. By calculating regression estimators from the double sample data, a prediction equation was determined for total number of trees per acre and for total number of trees of each species per acre. The interpretation results are shown in Table IX.



Aerial Ektachrome Film
 HF-2 Filter
 Scale = 1/7,000



Aerial Ektachrome Film
 HF-2 Filter
 Scale = 1/2,000

Figure 15. The aerial stereograms shown here are representative of the photography used in the Meadow Valley Study. 100 5-acre plots (black square) were interpreted on the 1/7,000 scale photos and 10 of those 100 plots were re-interpreted on the 1/2,000 scale photos. For further information, see text.

Ground truth was provided by an experienced two-man field crew. Using an established cruising technique called Variable Plot/Wedge Prism Cruising, the field crew determined species composition for the 5,300 acre study area. This field work entailed 6 man weeks of work, but provided information essential to the study that could not otherwise have been obtained.

Upon examining the interpretation results in Table IX, certain facts concerning this study become evident. First, the interpreter did very poorly on the 1/7,000 photography. Not only did he have a difficult time identifying the five major tree species, but he could consistently locate only about one-third of all merchantable trees on each of the 100 5-acre plots. The remaining two-thirds of the total went unnoticed, probably because (1) some trees were partially obscured by surrounding trees, (2) some trees were closely grouped and therefore were counted as single trees and (3) the majority of the trees in the study area were in lower diameter classes near the cutoff point between merchantable and non-merchantable.

In order to increase the accuracy of the estimate of average number of trees per acre obtained from the 1/7,000 photography, regression estimators were computed, making use of supplementary interpretation data obtained from the 1/2,000 scale photography. The relationship between tree counts on large and small scale photography helped improve the estimate of average number of trees per acre. The plot of several pairs of values on coordinate paper suggested that the variability of y was nearly the same at all levels of x and that the relationship of y to x was linear, as would be expected. The prediction formula selected on

Table IX. PHOTO INTERPRETATION RESULTS OBTAINED BY DOUBLE SAMPLING USING REGRESSION ESTIMATORS

Species or Type	Ground Truth From Field Survey	Interpretation From 100 5-Acre Plots on 1/7,000 Photography		Interpretation From 10 5-Acre Double Sample Plots on 1/2,000 Photography Using Linear Regression			
	Av. No. of Trees/Acre	Av. No. of Trees/Acre	Std. Error of Mean	Av. No. of Trees/Acre	Std. Error of Mean (R)	Correl. Coef. (r)	Signif. 5% Level
Total No. Trees	38.41	12.84	2.95	39.01	15.33	0.56	No
Total No. Trees w/o White Fir	17.20	7.10	1.84	8.86	4.42	0.80	Yes
Total No. White Fir	21.20	5.74	2.17	14.38	31.25	0.81	Yes
Total No. Douglas fir	9.24	5.34	1.55	5.93	2.22	0.91	Yes
Total No. Sugar Pine	3.36	0.78	0.40	5.82	1.22	0.21	No
Total No. Incense Cedar	2.25	0.74	0.37	3.26	1.92	0.20	No
Total No. Ponderosa Pine	2.36	0.24	0.24	0.28	0.16	0.24	No

* Correlation coefficient (r) represents a measure of the linear association between interpretation data obtained from 10 5-acre plots as seen on 1/2,000 photography and data obtained from those same 10 5-acre plots as seen on 1/7,000 photography. For a discussion of how these data relate to ground truth, see text.

the basis of this information was the linear regression $y = a + bx$.

The sampling technique appeared successful after calculating the average number of all species per acre by regression to be 39.01, compared to a ground truth value of 38.41. However, in this case there is not a strong linear association ($r = 0.56$) between interpretation data on the large and small scale photography and, therefore, the sample correlation coefficient is not significant when tested at the 5% level. In other words, r could equal 0.56 just by chance when actually there is no linear association between the sampled variables. The estimates of the average number of trees per acre for each of the five coniferous species were slightly improved by the prediction equation; however, these values fell far short of the corresponding ground truth data. For example, the interpreter found it nearly impossible to distinguish between incense cedar and ponderosa pine on both large and small scale photos; in addition, he often confused Douglas fir with sugar pine. He was most successful in identifying the white fir. Again, the problem of missing many of the smaller trees regardless of species was the primary factor accounting for the underestimated results.

Sampling Procedures

In this study, the valid assumption is made that the 100% timber cruise which was made on the ground by two professionally trained foresters constitutes, for all practical purposes, completely accurate "ground truth". Based on this assumption, the double sampling scheme used in the Bucks Lake Study did not provide reliable inventory data on species composition. Basically, the statistical procedures used were sound; photo

interpretation difficulties created most of the problems. A number of sampling procedures could be employed when attempting to inventory species composition within heterogeneous mixed stands, each of which might reduce the interpretation difficulties encountered in the Bucks Lake Study. Briefly stated, these alternate methods are:

Method #1. Stratify predominant vegetation cover types into homogeneous groups as seen on low resolution space photography. Estimate the average number of merchantable trees per acre by species on a large number of sample plots as seen on 1/7,000 scale aerial photography. Rather than use a sub-sample of 1/2,000 aerial photography, obtain double sample data directly on the ground with a limited amount of field work. This method would be more costly than the method used in the Bucks Lake Study, but it would provide more accurate results.

Method #2. Stratify predominant vegetation cover types into homogeneous groups as seen on low resolution space photography. Estimate the average number of merchantable trees per acre by species on a large number of sample plots as seen on 1/2,000 scale aerial photography. Obtain double sample data directly on the ground with a limited amount of field work. Because of the employment of very large scale aerial coverage, this method would be more costly than either of the previously mentioned schemes but, again, it would provide more accurate results.

Method #3. Stratify predominant vegetation cover types into homogeneous groups as seen on low resolution space photography. Estimate the average number of all trees per acre regardless of species (both merchantable and non-merchantable) on a large number of sample plots as seen on 1/7,000 scale aerial photography. Obtain an improved estimate of average

number of all trees per acre by double sampling on 1/2,000 scale aerial photography. In addition, determine from a large number of plots on the 1/2,000 photography (independently of the previous estimate) the proportion of merchantable versus non-merchantable trees and the proportion of each species among the merchantable trees. Then, by applying these proportionate values to the estimate of total number of trees per acre, improved by regression, an accurate inventory of species composition could be obtained.

SUMMARY AND CONCLUSIONS

Phases I and II (1966 and 1967) of this research project indicated that within the various NASA Forestry Test Sites, it is feasible to delineate major vegetation type boundaries and to identify the predominant forest species on high altitude, small scale aerial photography when optimum photographic specifications are utilized. This year, an effort has been made to define the simplest conceivable observational and analysis techniques necessary for extracting valuable forest inventory data from imagery obtained from high-flying aircraft, taken over areas containing either homogeneous (pure type) or complex heterogeneous (mixed type) forest stands.

The conclusions drawn from a study of photography taken over homogeneous vegetation types found to occur within the extended test area (Flicker Ridge) support those findings derived from an analysis of photography taken over the San Pablo Reservoir Test Site. First, if an interpreter exhibits the proper motivation and skill, if photography is flown to proper specifications, and if an adequate photo interpretation

key is made available, accurate vegetation surveys can be made without implementing expensive and time consuming conventional on-the-ground survey techniques. Second, Ekta Aero Infrared photography provides the interpreter with significantly more information on vegetative cover than panchromatic photography, especially when he is attempting to locate and identify those forest types having similar image characteristics. And lastly, in addition to providing more accurate results, the analysis of color infrared photography requires approximately 25% fewer man-hours of interpretation time than the black-and-white photography.

By degrading image sharpness without affecting image tone or color, NASA photography was analyzed that exhibited 100 foot GRD (Ground Resolved Distance) similar to the quality of existing Gemini photography and photography expected from satellites in the near future. The results indicate that when shackled with low resolution photography tone or color is the primary criterion on which species identifications must be based. Even on 100 foot GRD photography, however, a high degree of interpretation accuracy is obtainable when certain seasonal physiological variations occurring between species are recorded on sequential photography.

The Bucks Lake Study showed that the making of suitably accurate estimates of species composition by means of remote sensing within heterogeneous mixed stands is much more difficult, but not necessarily impossible. In this case, a low resolution photo-mosaic (simulating a space photo) used in conjunction with a limited number of properly specified aerial photos procured from low altitude and with the aid of double

sampling techniques provided a means for obtaining inventory data on a tree-by-tree basis for a large heterogeneous mixed forest stand. In addition, several sampling procedures were considered. These utilize low resolution spaceborne photography, a limited number of large scale aerial photographs obtained from conventional aircraft, and a minimum of "ground truth" field data.

The research reported upon herein was done in the context of spacecraft capabilities and ultimate image quality of spaceborne photography taken over forested areas. Among the advantages of orbital vehicles as sensor platforms for species identification and general forest inventory purposes stressed in this report are (1) the synoptic view, (2) opportunity for sequential coverage, (3) rapidity of obtaining data, (4) uniformity of the image and (5) economy.

RECOMMENDATIONS

Studies on the feasibility of identifying forest species and delineating major timber types by means of high altitude multispectral imagery should be continued because:

1. The studies conducted in the San Pablo Reservoir Test Site and Flicker Ridge Study Area have shown that homogeneous timber stands can be distinguished on high altitude-small scale (1/30,000) NASA photography. In an attempt to fill an obvious void in these investigations, the worthiness of ultra-high-altitude small scale photography (1/30,000 to 1/100,000) obtained with short focal length high flying aircraft should be examined. Preliminary investigation in south central Oregon has been initiated where valuable forests of ponderosa

pine, lodgepole pine and mixed coniferous species are found to occur.

2. The usefulness of existing spaceborne imagery should be more fully investigated. Several high quality photographs taken from Gemini IV and V and from Apollo VI and VII over the arid southwestern United States are available. Among the kinds of information obtainable from such a study are (1) degree of photographic detail on space photos, (2) reproducibility of photographic tone or color on photos taken from progressively higher altitudes, (3) effect of sun angle (i.e., time of day) on the interpretability of forested areas, (4) the usefulness of the synoptic view for evaluating entire mountainous regions (i.e., Chiricahua Mountains and/or Huachuca Mountains) and (5) interpretability of physiologically induced variability between vegetation cover types as seen on space photos obtained sequentially.

3. The applicability of various alternative sampling procedures mentioned earlier in this report should be tested in order to determine the extent to which species composition within heterogeneous mixed forest stands can be determined, on a tree-by-tree basis.

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APPENDIX I - STATIONARY PLATFORM MULTISPECTRAL STUDIES

Generally speaking, the higher the altitude from which photography is taken, the greater the reliance which a forest photo interpreter must place on a forest's tone signature when attempting to identify species composition, and less reliance he can place on tree or forest configuration. Since the multispectral tone signature of a vegetation type often is indicative of the species composition, tone signatures assume considerable importance for the interpretation of forest cover types as seen on photography obtained from earth orbiting vehicles.

It follows that, with a better understanding of the reflectance characteristics of different forest types, one can make a more accurate interpretation of tree species composition from a study of plant tone signatures as seen on multispectral photography. Theoretically, it should be quite feasible to (1) measure plant spectral reflectance in the field, (2) determine from an analysis of the resulting spectral reflectance data the film-filter combinations that would allow maximum tonal differentiation among the plant types that are to be identified and (3) predict the tone signature of each plant type as it would appear on multispectral photography, by combining curves of solar illumination, plant reflectance, filter transmission and film sensitivity.

The study reported upon herein does not rigorously examine each of the points stated above. Rather, a preliminary attempt was made to correlate tone densities of each of several plant types as derived from multispectral photography with spectral reflectance data derived from the same plants with a newly acquired portable field spectroradiometer.

A target array comprised of small trees and shrubs of various species was constructed at the base of the Davis water tower. The array consisted chiefly of 4' x 4' pallets of potted trees, a five-step grey scale made of masonite panels, and three primary color cloth panels. Most of the plant types were selected on the basis that they also occur within one or more of the NASA Forestry Test Sites (e.g., San Pablo Reservoir, Bucks Lake). The justifications for using a stationary platform and target array for this experiment rather than utilize the existing test sites, are that (1) an experiment can be rapidly and accurately performed, (2) vertical photography and ground truth can be obtained simultaneously, (3) natural terrain features can be simulated within the target array, (4) troublesome variables can be measured and controlled, (5) replications easily can be made, and (6) experimental costs are low.

A portable field spectroradiometer (the E.G.&G. Model 580/585) was used to measure irradiance falling on the detector head in nanowatts per square centimeter per nanometer from each of the targets within the array. Within a narrow field of view, the unit measures light reflectance at wavelengths ranging from 350 to 1200 nanometers in band widths as narrow as five nanometers.

While spectroradiometric measurements were being made on the ground, multispectral photography also was being obtained with a 4"x5" frame camera from the catwalk of the tower, 150 feet above the target array. In this manner, photographs of many different film-filter combinations were taken from precisely the same camera station with precisely the same camera orientation. For each target, as seen on each multispectral photograph, optical negative density measurements were

made using a Welsh densitometer. Then, to allow comparisons to be made of tone values as seen on different film-filter combinations, each negative density value was normalized by referencing it to the negative density values obtained from the white and black panels in the grey scale panel array. In this manner, variability in tone between film-filter combinations caused by different exposure times can be eliminated; however, one must assume that each photograph was exposed such that the negative density values for both the black panel and the white panel fall on the linear portion of the gamma curve.

Comparisons of spectral reflectance for the various plant types are shown on the following pages. Note that the trend of values for each species measured by one particular method can be compared and that the general trend between the two methods can be compared. For example, spectroradiometer data indicate that a cross-over in the spectral reflectance of Pinus radiata as compared with Melaleuca armillaris occurs somewhere between 500 and 600 nanometers. This same relationship is apparent in data obtained from the multispectral photography, although it is impossible to specify by this means exactly where the cross-over occurs because broad band pass Wratten gelatin filters were used. Similarly, both methods indicate that at shorter wavelengths (i.e., 400-450 nanometers) Baccharis pilularis and Pinus radiata have higher reflectances than either Melaleuca armillaris or Photinia arbutifolia.

The results from this preliminary test indicate that reliable reflectance data can be obtained in the field with a portable spectroradiometer, and that these data would allow for the determination of

the optimum film-filter combination for maximum tone discrimination between targets of interest. A logical "next step" will be to assess the variability of reflectance associated with each vegetative type by replicating measurements from each species under a variety of conditions. Then one can apply statistical testing procedures to the data to determine the range in reflectance from each species at various wavelengths and predict the part or parts of the spectrum wherein significant reflectance differences exist between species.

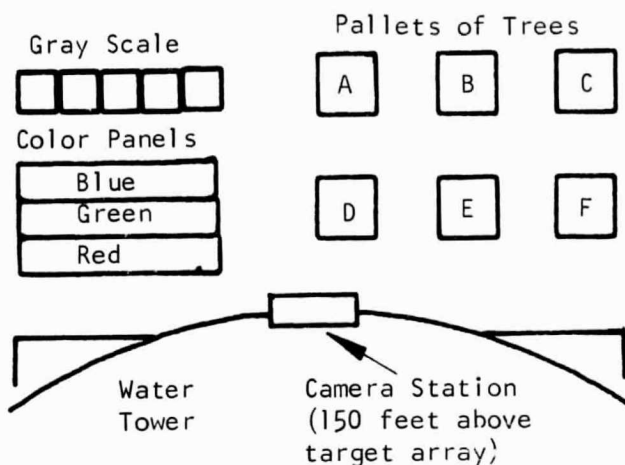


Nursery stock provided by the California Division of Forestry was used for the target array in this multispectral experiment. Four foot square pallets are shown being emplaced beneath the Davis water tower. From the tower catwalk, 150 feet above the target array, a photographer obtained near vertical multispectral photography with a 4" x 5" frame camera.



Immediately before and after the multispectral photographs were being made, a two-man crew obtained light reflectance data from each species using a portable field spectroradiometer. In order to control certain troublesome variables, the axis of measurement of the spectroradiometer was identical to the optical axis of the camera atop the tower.

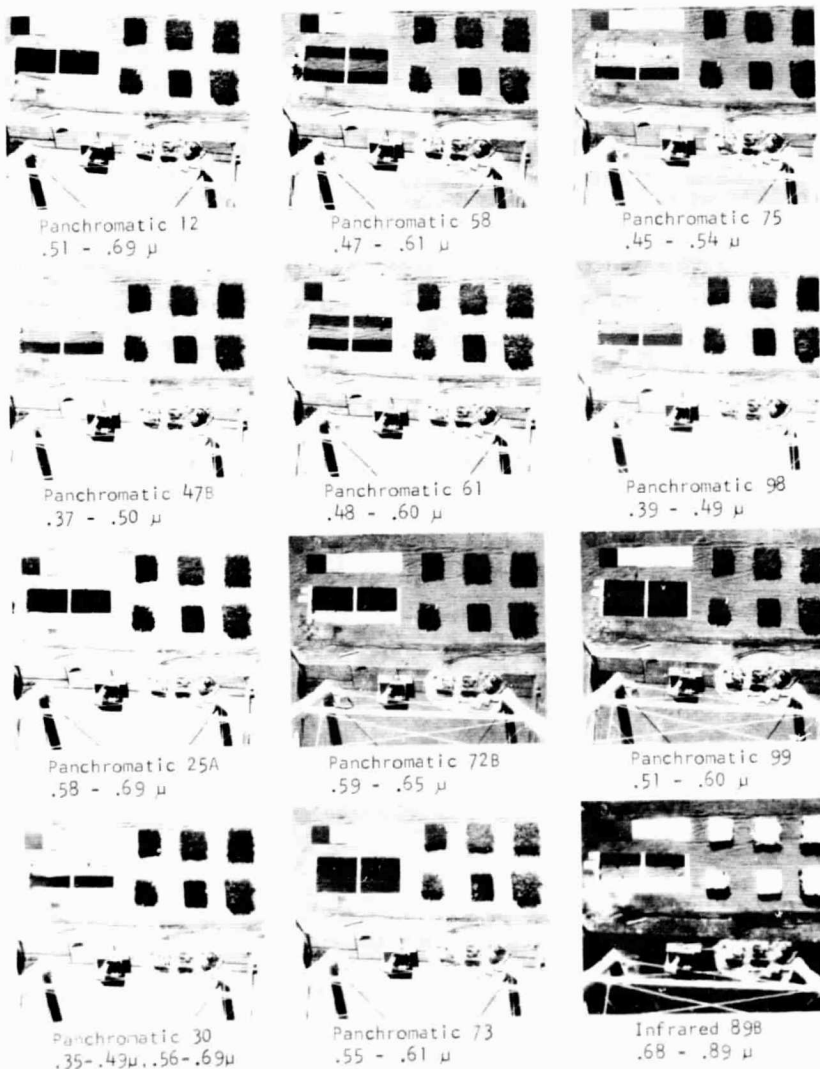
Plan View of the Target Array:



Legend:

- A. Pinus radiata
- B. Baccharis pilularis
- C. Melaleuca armillaris
- D. Eucalyptus globulus
- E. Photinia arbutifolia
- F. Eucalyptus rudis

Multispectral Photography:



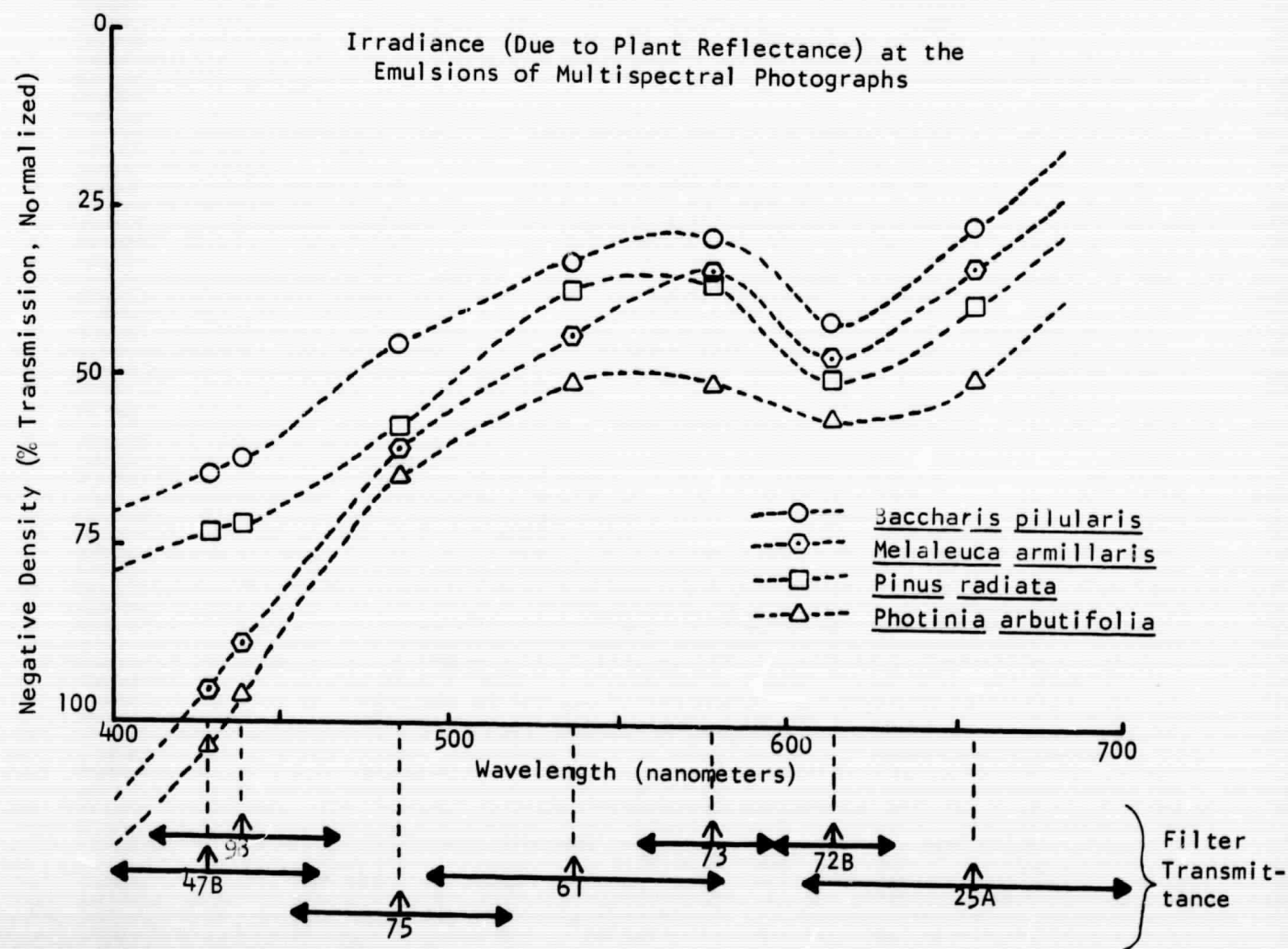
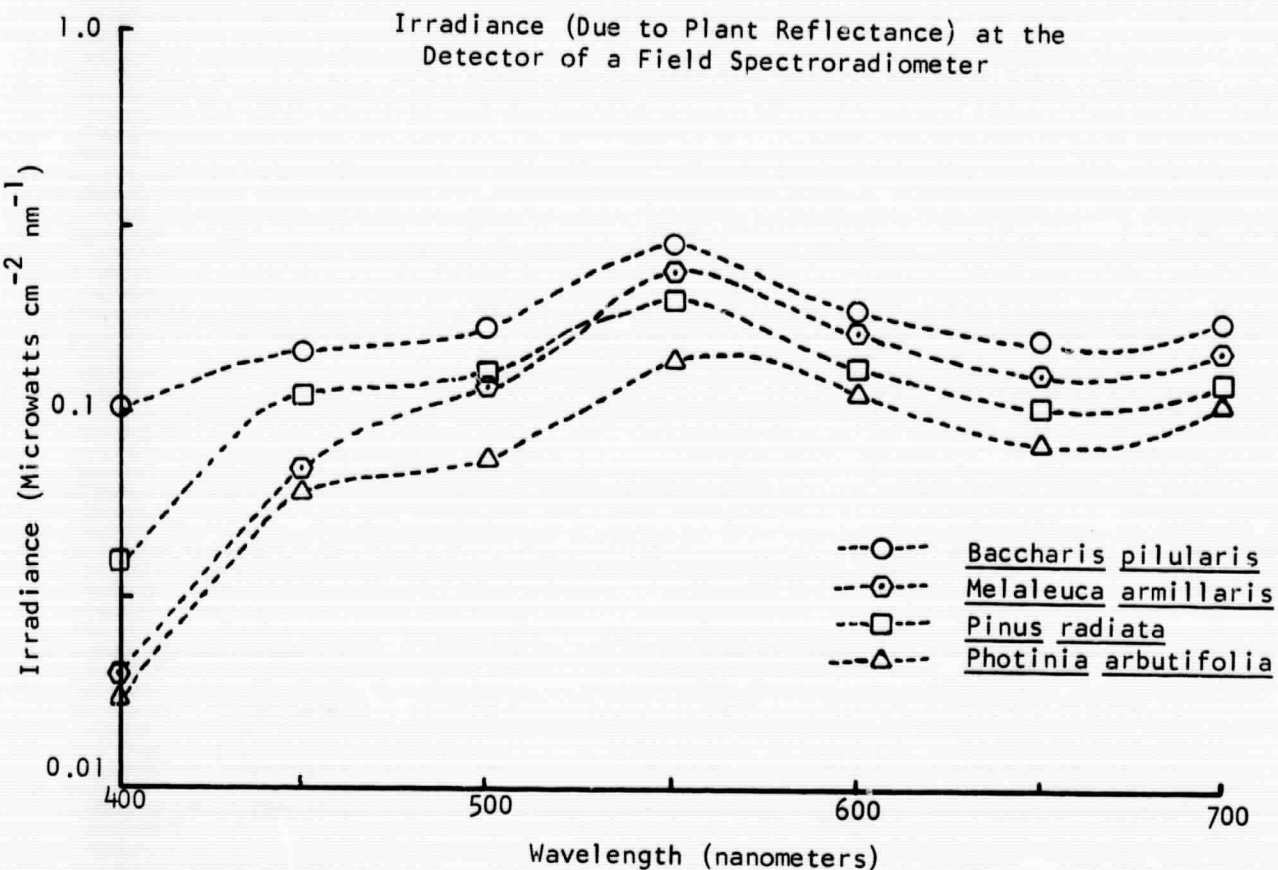
MEASUREMENTS OF OPTICAL DENSITY ON MULTISPECTRAL PHOTOGRAPHIC NEGATIVES
(Percent Transmission - Absolute)
OBTAINED BY USING PANCHROMATIC FILM AND THE FILTERS INDICATED

Object	Filter Used						
	25A	47B	61	72B	73	75	98
Black Panel	69.0	46.0	85.0	100	57.5	87.0	49.0
White Panel	3.5	2.8	3.9	12.0	2.8	5.4	3.3
<u>Pinus radiata</u>	31.0	34.8	33.0	57.5	23.0	51.0	36.3
<u>Baccharis pilularis</u>	21.5	31.0	29.0	50.0	19.2	42.6	32.5
<u>Melaleuca armillaris</u>	26.5	44.8	34.8	55.5	21.7	53.8	45.8
<u>Eucalyptus globulus</u>	29.0	38.0	34.0	56.2	23.0	49.0	41.0
<u>Photinia arbutifolia</u>	38.0	49.0	44.8	60.2	31.6	59.5	51.0
<u>Eucalyptus rudis</u>	28.0	39.0	35.5	55.0	23.0	48.0	37.0

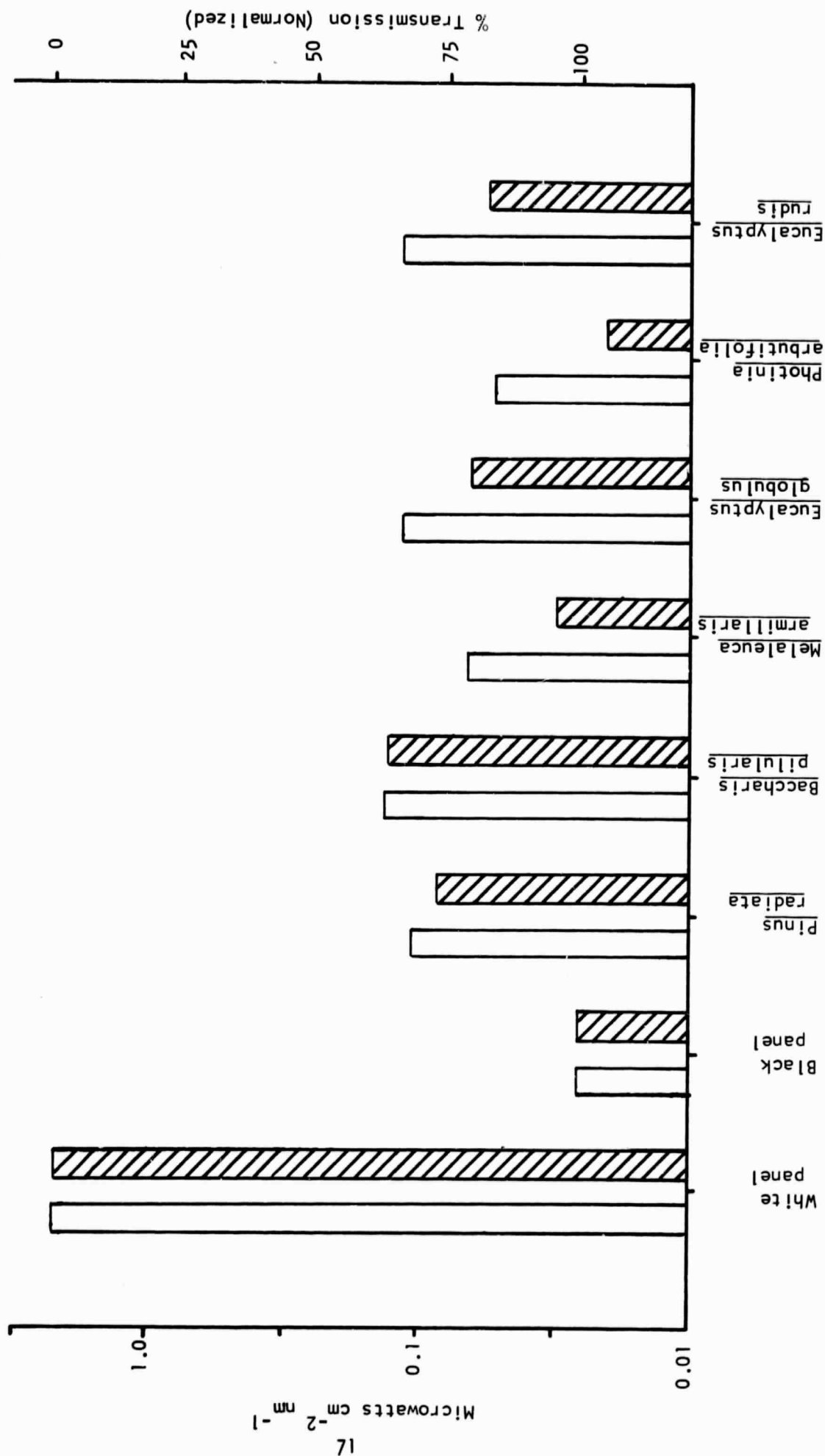
Normalization Equation: $\frac{\text{object} - \text{white panel}}{\text{black panel} - \text{white panel}} \times 100$

MEASUREMENTS OF OPTICAL DENSITY ON MULTISPECTRAL PHOTOGRAPHIC NEGATIVES
(Percent Transmission - Normalized)
OBTAINED BY USING PANCHROMATIC FILM AND THE FILTERS INDICATED

Object	Filter Used						
	25A	47B	61	72B	73	75	98
Black Panel	100	100	100	100	100	100	100
White Panel	0	0	0	0	0	0	0
<u>Pinus radiata</u>	41.0	74.0	35.0	51.0	36.0	55.0	72.0
<u>Baccharis pilularis</u>	27.0	65.0	30.0	43.0	29.0	45.0	63.0
<u>Melaleuca armillaris</u>	35.0	97.0	38.0	48.0	34.0	59.0	92.0
<u>Eucalyptus globulus</u>	38.0	81.0	37.0	50.0	36.0	53.0	82.0
<u>Photinia arbutifolia</u>	52.0	106	50.0	54.0	52.0	63.0	104
<u>Eucalyptus rudis</u>	37.0	83.0	38.0	48.0	36.0	52.0	73.0



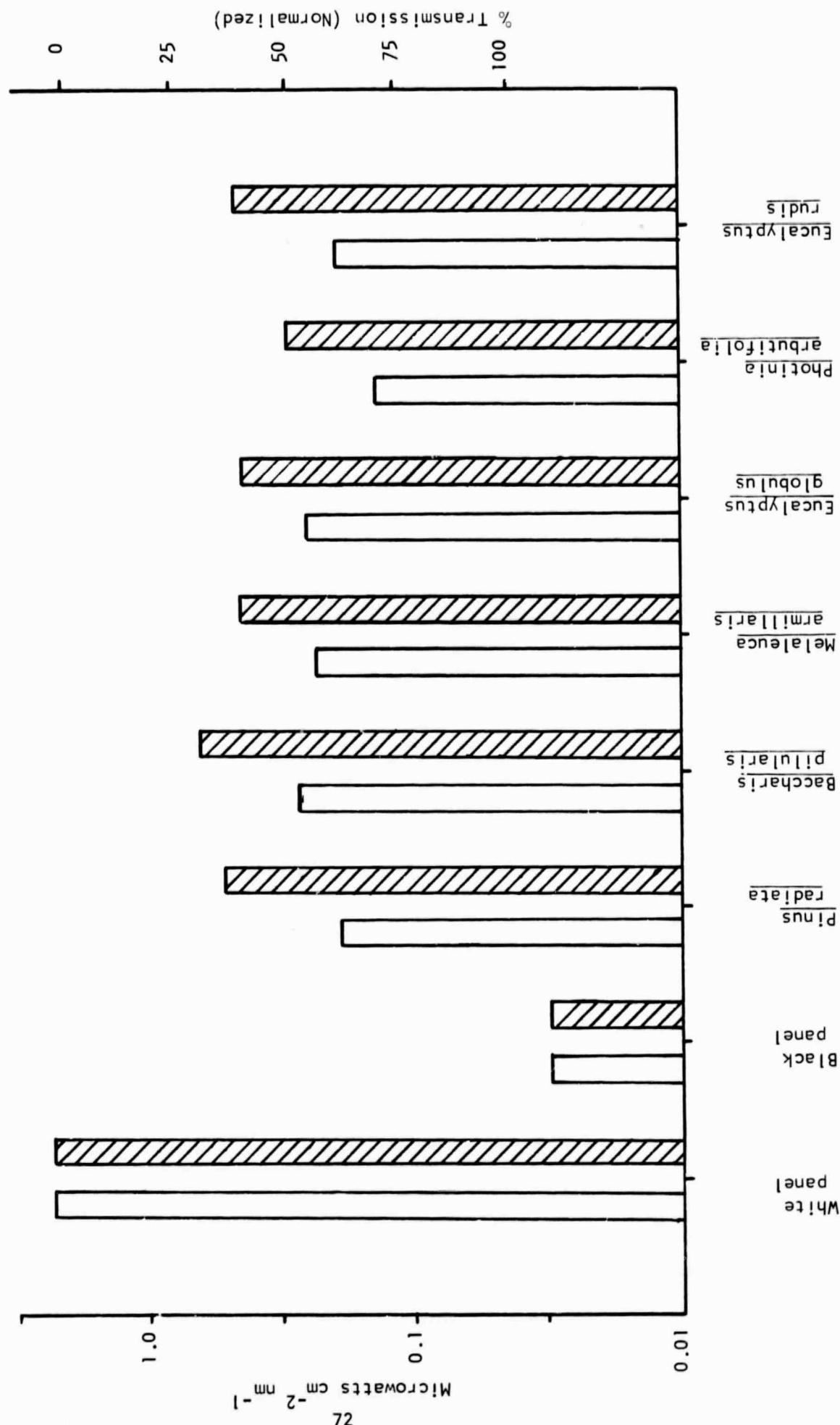
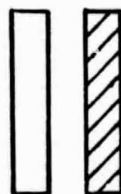
Spectroradiometer data measured at 450 nm (microwatts $\text{cm}^{-2} \text{nm}^{-1}$).
Spectral tone signature on panchromatic film with a Wratten 47B filter, sensitive to 400-470 nm (% transmission, normalized).



WAVELENGTH BANDPASS: GREEN

Spectroradiometer data measured at 550 nm (microwatts $\text{cm}^{-2} \text{nm}^{-1}$).

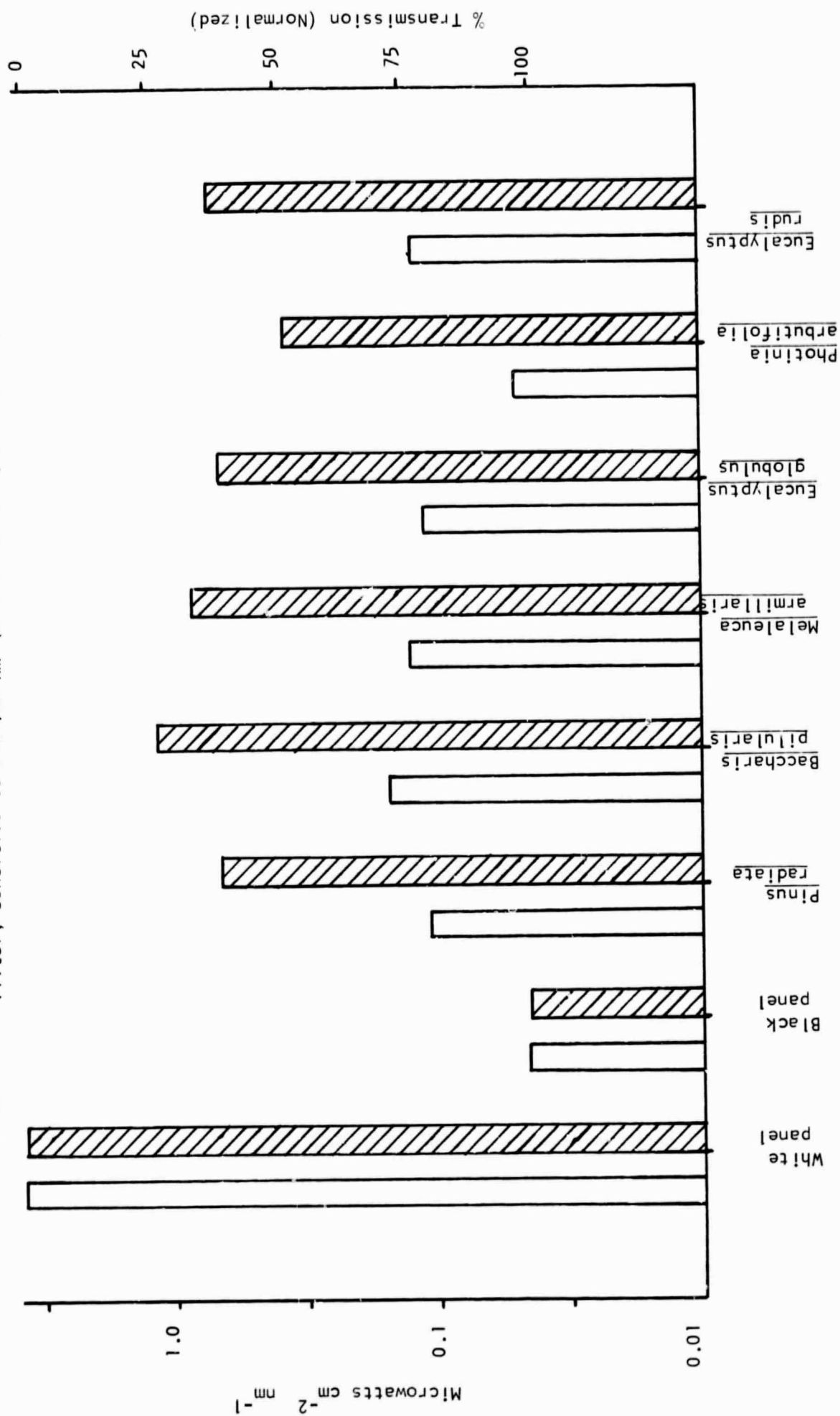
Spectral tone signature on panchromatic film with a Wratten 61 filter sensitive to 490-580 nm (% transmission, normalized).



WAVELENGTH BANDPASS: RED

Spectroradiometer data measured at 650 nm (microwatts $\text{cm}^{-2} \text{nm}^{-1}$).

Spectral tone signature on panchromatic film with a Wratten 25A filter, sensitive to 610-700 nm (% transmission, normalized).



APPENDIX II - COLOR COMPENSATED EKTA AERO INFRARED PHOTOGRAPHY

The use of Ekta Aero Infrared photography in wildland resource studies has been recognized as one of the more significant recent developments in the field of remote sensing. This emulsion type, when exposed through a Wratten 12 or 15 filter, has been used to detect insect and pathogenic attacks on forest trees and agricultural crops, to identify forest species, and to study soil, geologic and moisture conditions. The "state of the art" relating to this film type has been well documented in terms of such applications as these. Consequently, one might be content to use the film as recommended by its producers, obtaining color signatures of the resultant images, as controlled by (1) basic sensitivity characteristics of the film and (2) transmission characteristics of the recommended Wratten 12 or 15 filter.

Recently, however, proponents of multiband sensing systems have pointed out that certain inherent limitations of tri-emulsion layer color films cause troublesome variability in the quality of images and thus complicate an interpretation of them. Furthermore, they have shown how multiband systems can overcome certain of these limitations, through wider selection of band passes, higher image resolution and ease of reconstitution of selected bands in innumerable false color combinations. In addition, current research on the expanded usefulness of color infrared film through selective color compensating filtration is attempting to reduce certain of these limitations previously ascribed to tri-layer color film. It has been shown that the color balance of color infrared photography can be shifted through the use of color compensating filters

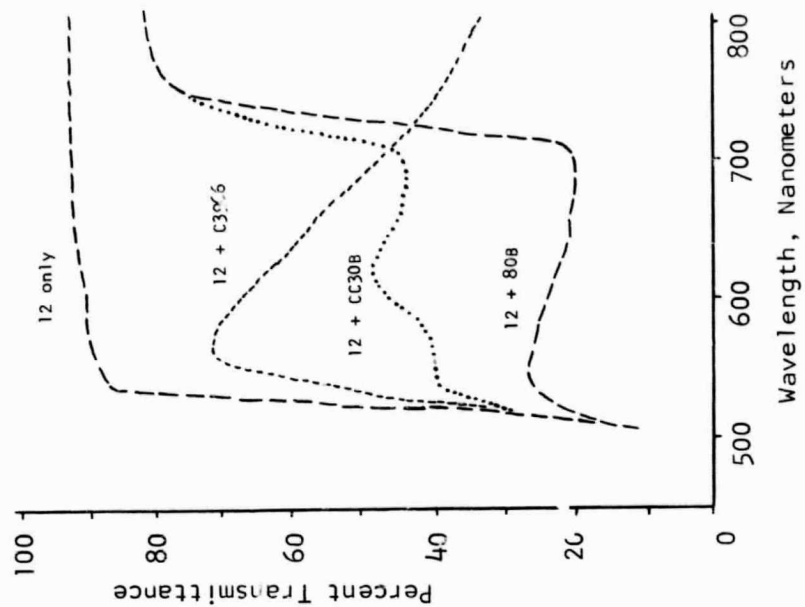
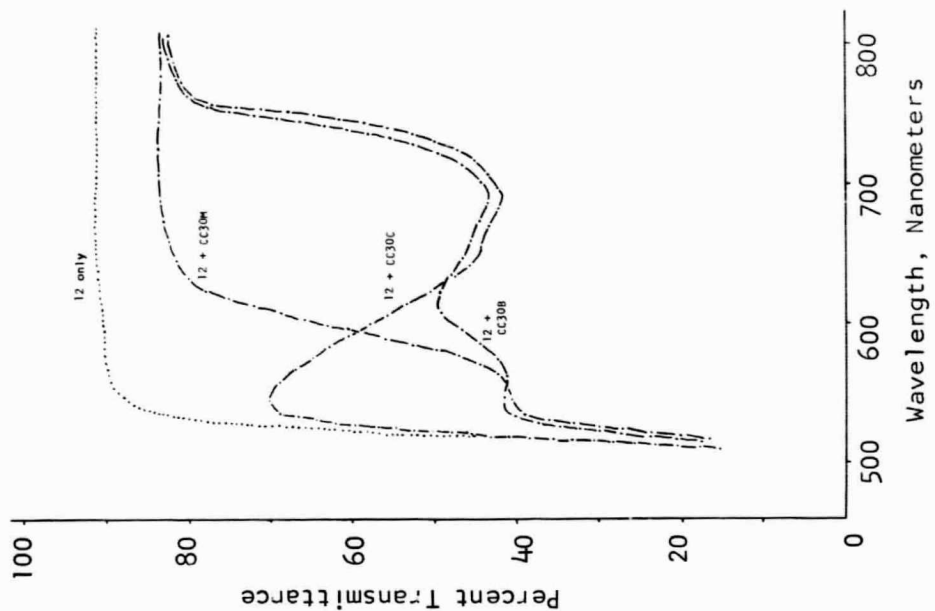
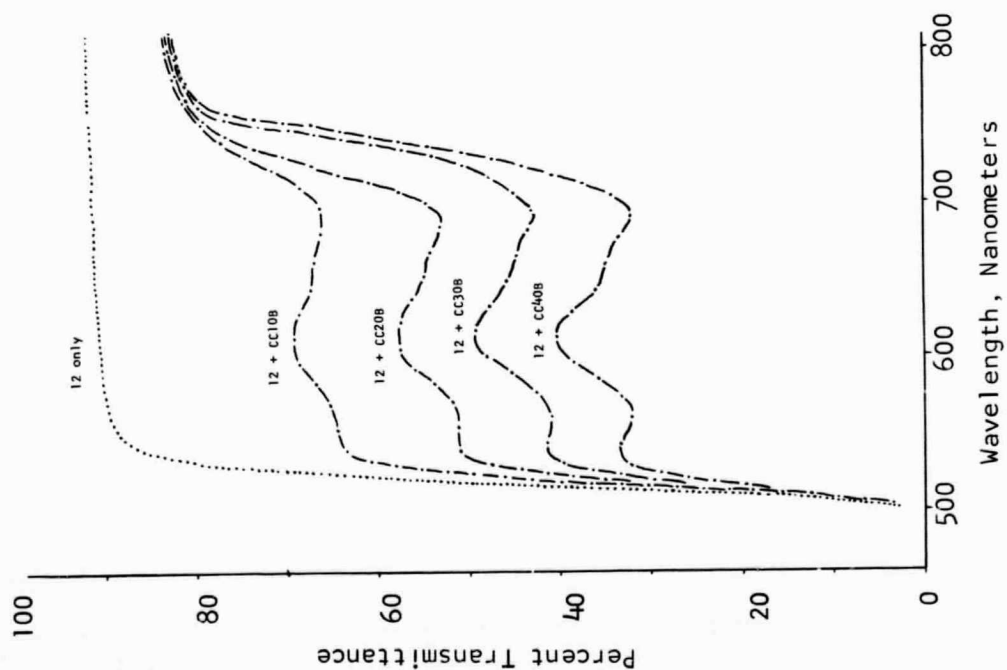
which alter the relative transmission of visible and near infrared radiation. Since most of these filters do not affect longer wavelength near infrared radiation, but have different absorption and transmission characteristics in the visible regions, a wide variety of color shifts can be created. An exposure series using these filters (each available in several densities) will produce an array of photographs which can be studied to select those filter combinations which provide optimum target discrimination for a particular set of conditions.

The task of making color infrared film a more valuable emulsion for use at high altitudes is being studied by Robert Pease and Leonard Bowden. They claim that the Wratten 80B filter holds particular promise for high altitude remote sensing because it, coupled with color infrared film and a minus-blue filter, is successful in recording infrared reflectance through great thicknesses of atmosphere. In particular, this film-filter combination will detect vegetation, rendered in subtle reds, with a low infrared reflectance where other filters fail. Also, the 80B is reported to have the best haze penetrating ability of the filters tested. Pease and Bowden report that Ekta Aero Infrared film with a Wratten 12 + CC30B filter combination is considered better for imaging objects colored red and orange, although the overall infrared record from these objects is not as great. Other filters are recommended, depending upon whether moderate or drastic enhancement is desired.

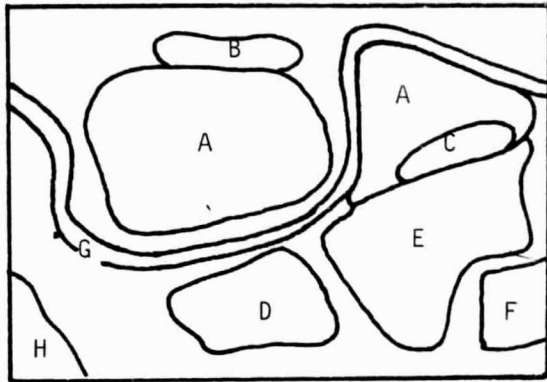
The photo illustrations shown on the following pages provide a few examples of color compensated Ekta Aero Infrared photography taken of forested areas. By studying such images, as well as the transmission curves of the corresponding filters, one begins to recognize how great

the possibilities are for more critical specifications to be made when color infrared film is used to solve a particular problem. The outlook in the future is promising for work of this nature, and the principal investigator and his associates plan to examine techniques for specifying criteria for selecting the appropriate filters for solving the particular problem of forest species identification.

FILTER TRANSMISSION CURVES

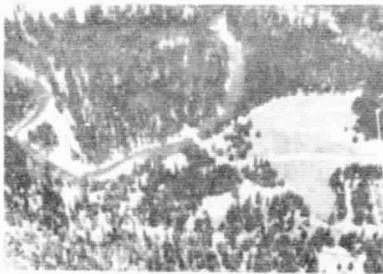


Yosemite Study Area:
July 26, 1968



Legend:

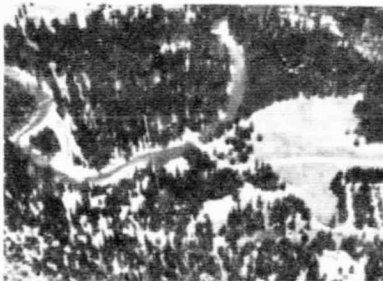
- A. Mixed conifer forest
- B. Quercus kelloggii (Calif. black oak)
- C. Populus trichocarpa (black cottonwood)
- D. Mixed hardwood and conifers
- E. Meadow
- F. Apple orchard
- G. Merced River
- H. Granitic talus slope



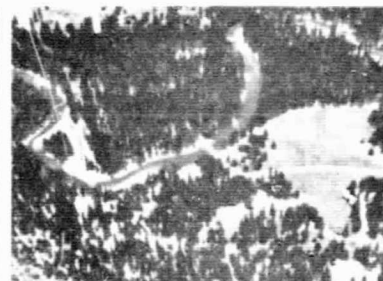
Extra Aero Infrared Film
Whittier 12 Filter



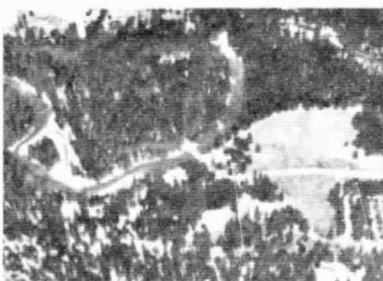
Extra Aero Infrared Film
Whittier 12 + CC30M Filter



Extra Aero Infrared Film
Whittier 12 + CC30M Filter



Extra Aero Infrared Film
Whittier 12 + CC30M Filter

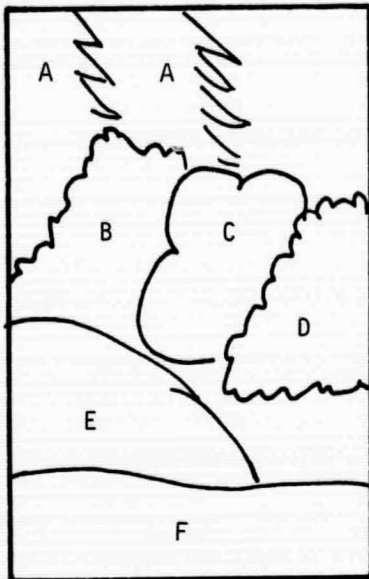


Extra Aero Infrared Film
Whittier 12 + CC30M Filter
1287 115



Extra Aero Infrared Film
Whittier 12 + CC30M Filter
1287 115

Berkeley Campus Study Area:
July 5, 1968



Legend:

- A. Sequoia sempervirens (coast redwood)
- B. Umbellularia californica (Calif. bay)
- C. Quercus agrifolia (coast live oak)
- D. Aesculus californica (Calif. buckeye)
- E. Rhododendron sp.
- F. Lawn



Ekta Aero Infrared
Wratten 12 +
CC10M Filter



Ekta Aero Infrared
Wratten 12 +
CC30M Filter



Ekta Aero Infrared
Wratten 12 +
CC30C Filter



Ekta Aero Infrared
Wratten 12 +
CC40B + CC30M Filter

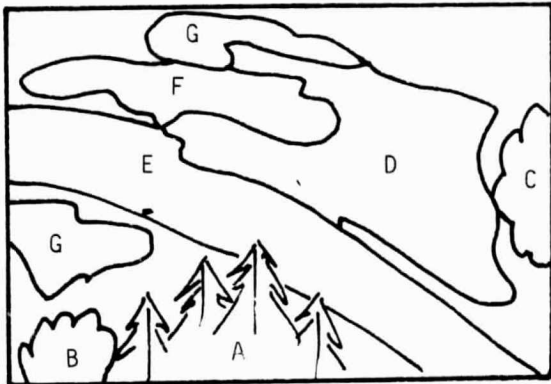


Ekta Aero Infrared
Wratten 12 +
Corning 3966 Filter



Ekta Aero Infrared
Wratten 12 + CC30M
Corning 3966 Filte

Yosemite Study Area:
July 26, 1968



Legend:

- A. Pinus ponderosa (ponderosa pine)
- B. Quercus kelloggii (black oak)
- C. Populus trichocarpa (black cottonwood)
- D. Lush sedges and rushes
- E. Merced River
- F. Stagnant pond
- G. Sand bar



Ekta Aero 111-
no filter



Ekta Aero 111-
Wratten 15 Filter



Ekta Aero Infrared 111-
Kodak 12 + CC108 + CC40M Filter



Ekta Aero 111-
Wratten 15 + 50 Filter



APPENDIX III - FALSE-COLOR IMAGE ENHANCEMENT

Depending upon the complexity of information desired, accurate interpretation of a single photo image can be a tedious and difficult task. Conscientious attempts at the interpretation of multispectral imagery, taken by sensing in several different spectral bands and acquired on several different dates of a large forested area, would boggle the human mind. As the complexity of tone signatures increases and the volume of data accumulates, conventional interpretation processes soon break down. However, certain advanced interpretation techniques have been developed and are being perfected that may alleviate the problem. False color image enhancement is a relatively new and useful data reduction technique that often facilitates the interpretation of forest species on multispectral photography. For the technique to be successful, however, it is essential that each frame of imagery taken of the same area have identical orientation and geometry. This requirement easily can be fulfilled when imagery is obtained with either bore-sighted multilens cameras or certain optical mechanical scanners.

The procedure used in obtaining the examples shown on the next few pages can be summarized as follows: (1) black-and-white multiband photos of an area are obtained simultaneously in each of several spectral bands, (2) a lantern slide is made from each of these photos, (3) by means of a multiple projector system, the multiband photos are optically combined in common register onto a reflecting screen, and (4) by inserting a colored filter into the optical path of each projected image, a single false color composite image is created.

By such means any number of images (two, three or four usually

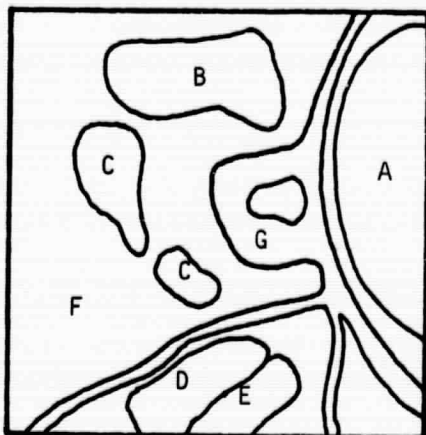
being the optimum) can be viewed simultaneously, and minute tone differences between objects of interest can be enhanced and presented to the image analyst as unique color differences in the composite image. The latter aspect of this technique exploits the ability of the human eye to perceive a tremendous number of variations in color as compared to relatively few variations in black-and-white tones. And, by proper filter selection, each "tone signature" that has been registered in a variety of grey scale values on the multiband imagery will appear as a very distinct color on the composite image. Theoretically, by projecting the correct spectral bands through the correct filters, an exact replica of either an Aerial Ektachrome image or an Ekta Aero Infrared image can be produced. Also, with perfect registration of all images, the projected color composite image may provide higher spatial resolution than is obtainable on conventional color films. This possibility is increased through (1) the use of high resolution black-and-white film emulsions, and (2) the minimizing of back scattering or "noise" such as occurs in tri-color film emulsions. In addition, the system can create nearly any false color image desired.

Of course, the photo reproductions shown here do not exhibit the high quality originally produced on the reflecting screen. Nevertheless, a thorough examination of these examples will allow the reader to grasp the potential of the technique, especially when interpreting complex vegetative cover types. It is also important to realize that only an interpretation technique is being demonstrated in these few examples. Recommendations on which film-filter combinations or projection filters will provide maximum color discrimination between targets of interest

must await tests currently in progress at our laboratory and elsewhere. To avoid confusion on this point, a description purposely has been omitted of multiband photography and projection filter combinations used to make the color composite images shown here.

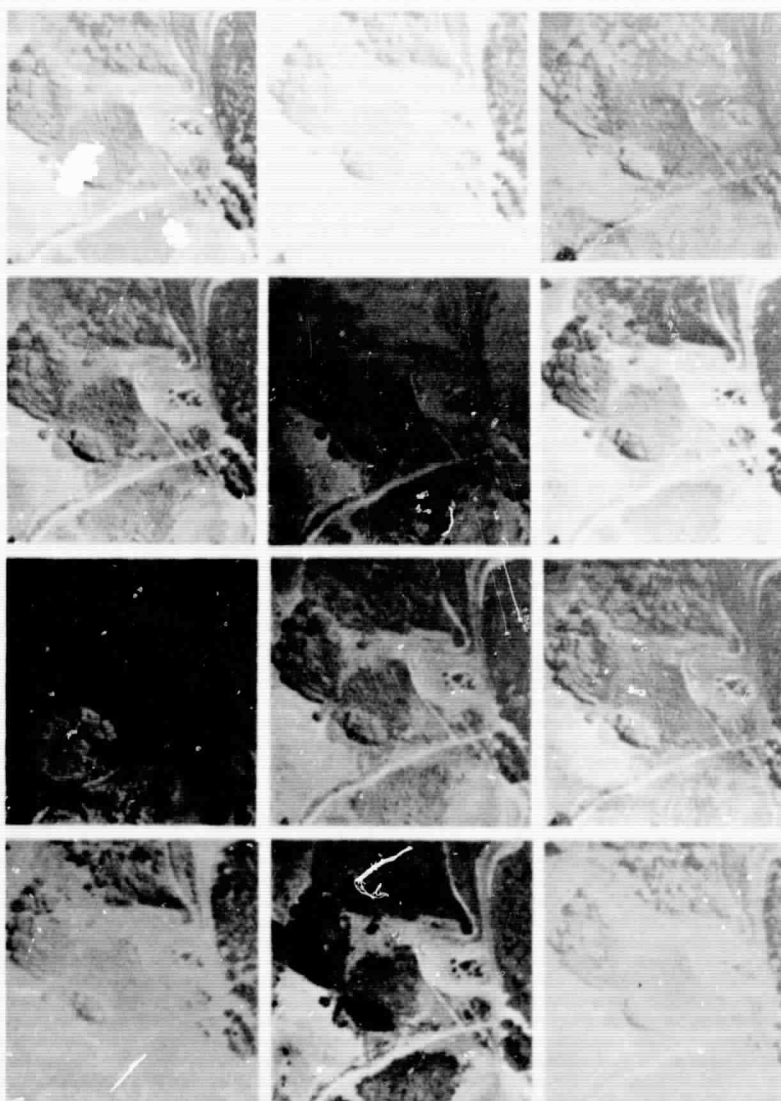
The usefulness of multicolor projection image enhancement on multiband photography obtained from a reconnaissance satellite is easily recognized considering that spaceborne imagery probably will be returned to earth either in recoverable cassettes, containing high resolution black-and-white emulsions, or by black-and-white line scan television transmission.

San Pablo Reservoir Test Site:

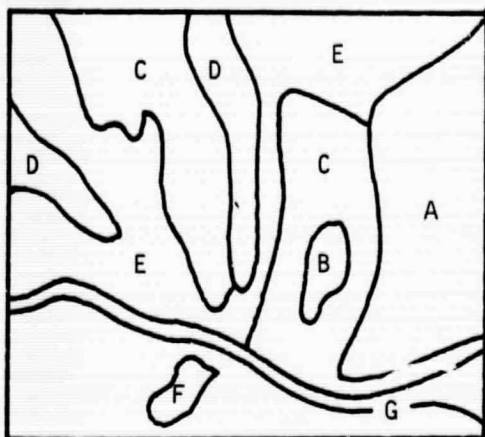


Legend:

- A. Pinus radiata (Monterey pine)
- B. Quercus agrifolia (coast live oak)
- C. Umbellularia californica (Calif. bay)
- D. Baccharis pilularis (coyote brush)
- E. Rhus diversiloba (poison oak)
- F. Annual grassland
- G. Asphalt



San Pablo Reservoir Test Site:



Legend:

- A. Pinus radiata (Monterey pine)
- B. Rhus diversiloba (poison oak)
- C. Baccharis pilularis (coyote brush)
- D. Quercus agrifolia (coast live oak)
- E. Annual grassland
- F. Watering pond
- G. Dirt road

