REMOTE SENSING APPLICATIONS IN FORESTRY

A report of research performed under the auspices of the

FORESTRY REMOTE SENSING LABORATORY,
SCHOOL OF FORESTRY AND CONSERVATION
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA

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

For

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

FACILITY FORM 602

N70-41217
(ACCESSION NUMBER)
62
(PAGES)
CR-113895
(NASA CR OR TMX OR AD NUMBER)
(THRU)
1
(CODE)
13
(CATEGORY)

Reproduced by
NATIONAL TECHNICAL INFORMATION SERVICE
Springfield, Va. 22151

REMOTE SENSING APPLICATIONS IN FORESTRY

THE DEVELOPMENT OF SPECTRO-SIGNATURE
INDICATORS OF ROOT DISEASE IMPACTS
ON FOREST STANDS

by W-12-996

John F. Wear
F. P. Weber

(Pacific Southwest Forest and Range Experiment Station)
Forest Service, U. S. Department of Agriculture

Annual Progress Report 30 September, 1969

A report of research performed under the auspices of the

FORESTRY REMOTE SENSING LABORATORY,
SCHOOL OF FORESTRY AND CONSERVATION
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA

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

OCT 1970

For

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

Frontispiece--Forester inspecting portion of broken stump that has been disintegrated by Poria weirii root rot disease. This disease destroys annually about 170 million board feet of valuable Douglas-fir. As disease advances upward into tree trunk no economic salvage is possible. Airborne techniques for early detection of distressed timber would minimize such losses.

ABSTRACT

Remote sensing research to identify parameters that best discriminate healthy Douglas-fir trees from those infected with *Poria weirii* root-rot was continued in 1969. Biophysiological investigations were emphasized to gather data on emitted radiation from the two types of tree crowns (healthy and diseased).

Remote sensing in the thermal infrared region shows great promise for the early detection of root-rot infected trees. More substantiating data are needed, however, on the period of the day and season of the year for using thermal infrared to detect such trees.

An aerial tramway system was designed and installed for use as a remote sensing platform from which to record continuous data. Two trams were needed because of the difficulties involved in aligning trees in the natural second-growth stand over which environmental data would be taken. The design and installation procedures for establishing the tramway system and the wide array of instrumentation needed in this phase of the study are described and illustrated.

A secondary phase of the study was to determine possible effects of helicopter rotor wash on surface temperatures at various elevations above water surfaces. Techniques for determining "ground truth" temperatures of leaf surfaces in coniferous forest canopies are being investigated.

A major objective of this remote sensing research is to investigate the possibilities of detecting stress trees on satellite imagery. Such a study was conducted with Apollo 9 photography and is described in this report.

ACKNOWLEDGMENTS

This research was performed under the Earth Resources Survey Program in Agriculture/Forestry under the sponsorship and financial assistance of the National Aeronautics and Space Administration, Contract ~~No. R-09-038-002~~.

The cooperation and assistance of various members of the following organizations have facilitated the implementation of this remote sensing project during the past year:

Pacific Northwest Regional Office, U. S. Forest Service, Portland, Oregon.

Pacific Southwest Forest and Range Experiment Station, U. S. Forest Service, Berkeley, California.

Pacific Northwest Forest and Range Experiment Station, U. S. Forest Service, Portland, Oregon.

Wind River Nursery, Gifford Pinchot National Forest, Carson, Washington.

Agricultural Engineering, Agricultural Research Services, Forest Grove, Oregon.

Bonneville Power Administration, U. S. Department of Interior, Vancouver, Washington.

NASA-USDA Forestry Remote Sensing Laboratory, University of California, Berkeley, California.

Oregon Audio Video Systems, Portland, Oregon.

United Radio Company, Portland, Oregon.

Special thanks is given to the Wind River Nursery and the Wind River Ranger District for the use of their land, storage facilities, vehicles, metal shop and equipment.

We would like to acknowledge the excellent ground photography provided

by Wally Guy, James Hughes and Richard Myhre for this report. High praise is also extend to the summer field assistant, James von Mosch, for his diligent and conscientious efforts in collecting the many types of remote sensing data required in this study.

The time and experience of many technical and professional scientists were willingly provided at no cost in the development of sound techniques and methods to solve the root rot disease problem that so vitally affects one of our major natural resources.

TABLE OF CONTENTS

FRONTISPIECE	i
ABSTRACT	ii
ACKNOWLEDGMENTS	iii
INTRODUCTION	1
LITERATURE REVIEW	4
JUSTIFICATION	4
METHODS AND PROCEDURES	5
Development of Ground Truth System	6
Aerial Tramway System	7
Tower Construction	8
Tramway Construction	10
Tramway Control System	15
Biophysiological Data Collection	17
Environmental Factors	19
Tree Physiological Factors	26
Aerial Procedures	30
Multispectral Imagery	30
Aerial Thermal Infrared Tests	32
RESULTS	34
Environmental Effects Versus Physiologic Variables	34
Calibration of PRT-5 Video Scan System	39
ESTIMATING TREE MORTALITY FROM APOLLO 9 IMAGERY	43
LITERATURE CITATIONS	56
APPENDIX	57

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

by

John F. Wear
F. P. Weber

INTRODUCTION

Investigations were continued to determine the extent to which multispectral remote sensing techniques can provide information on certain critical forestry problems that have a serious impact on our world timber supply. Forest diseases reduce tree growth and each year destroy or degrade millions of board feet of valuable timber. In the United States each year approximately 170 million board feet of valuable timber are destroyed by the root rot disease, Poria weirii (Murr.). Extensive stands of Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco), a major commercial timber species of the Pacific Northwest, suffer heavy losses because of this disease (see frontispiece). Disintegration of a tree's root system subjects the tree to both "rot throw" and "wind throw" (Fig. 1).

Spectral signature indicators of tree-killing diseases may help identify and locate centers of distressed timber that need to be salvaged promptly. If the timber in such a center is not removed quickly the size of the infested area will continue to expand and the economic loss will soon be tremendous. New remote sensing survey techniques may permit forest managers to protect forest resources more effectively and maximize the use of diseased timber. The research program conducted this year and described herein is a continuation and expansion of research started under NASA contract R-09-038-002 and reported under NASA-CR-78-781. By locating the

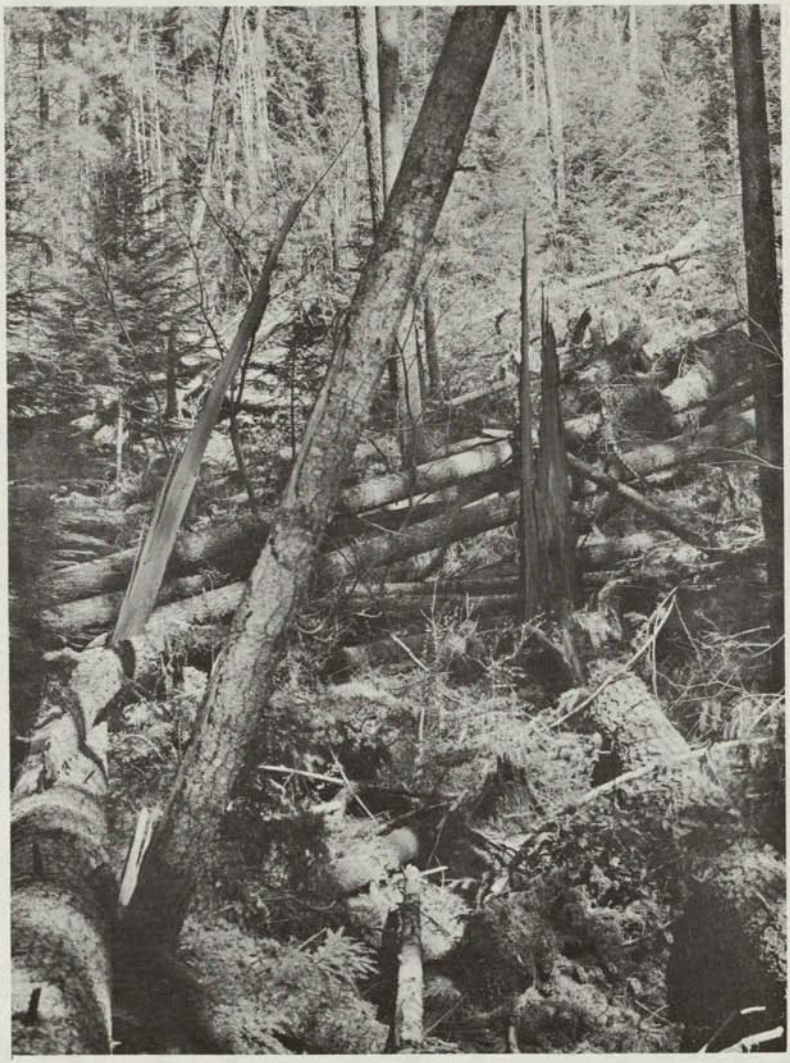

Figure 1--A large pocket of 50-year-old Douglas-fir "rot thrown" by the fungus Poria weirii. Splintered stump at center of picture shows typical decay pattern in advanced stage. Losses of this magnitude create serious impact on our earth resources.

many root-rot centers that occur sporadically over extensive areas, forest managers would be able to develop logging plans to economically remove all stages of diseased timber and minimize spread of the disease.

The value of developing a satisfactory remote sensing survey technique to replace laborious and costly ground survey methods has been recognized since the beginning of this research. With an adequate remote sensing survey technique for root-rot disease a 640-acre forested area could be surveyed by one man in less than an hour compared with 40 days of effort by a 2-man ground crew. The principal objective of this research is to develop more efficient survey methods for locating and evaluating the incidence of root-rot disease centers in forested areas by exploiting new remote sensing technology.

During this report period remote sensing research on Poria weirii root-rot disease was continued in the visible, reflective infrared and thermal infrared spectral zones of the electromagnetic spectrum. Major consideration was given to the biophysical assessment of trees under stress from root-rot disease compared with healthy trees to establish whether thermal differences exist between these two condition classes. A three-tower (100') aerial tramway system was installed in the second-growth Douglas-fir plot at Wind River, Washington, to provide data on various biophysical parameters of both healthy and diseased trees. We wanted to know if, as environmental stress increases during the summer months, significant physiological differences occur between healthy and diseased trees. Overflights were made by The University of Michigan 19-channel multispectral aircraft (under contract to NASA) in mid-July and again in September. Intensive effort was made to collate airborne data with

"ground truth" at the Wind River test site.

Limited helicopter operations were conducted with the integrated videoscan-infrared heat sensing system to determine the effect of rotor "downwash" on the surface temperatures of water at various hovering altitudes and on the response time of the thermal radiometer to the video tape readout. Thermal infrared readings were also made of test trees on the Wind River test site.

The Wind River, Washington test site obviously was too far north to be photographed by Apollo spacecraft. However, satellite photography from Apollo 9 covering areas of lower latitude was interpreted and analyzed for timber under stress. One test site near Ruidoso, New Mexico, revealed considerable group mortality. Extensive cloud cover along the Apollo 9 flightpath negated several potential sites for analyzing tree mortality from satellite photography.

LITERATURE REVIEW

A search of the literature on *Poria weirii* root rot revealed no pertinent basic research data that would improve our remote sensing research effort. With more emphasis on biophysiological parameters of distressed trees, several additional references are cited in Literature Citations.

JUSTIFICATION

More forest resources are destroyed each year by forest diseases than by any other damaging agents. Forty-five percent of the total growth loss in forested areas of the United States is also caused by tree diseases. In one recent year, 300 million board feet of sawtimber were lost to root diseases alone in the United States. Losses of this magnitude create a

serious impact on our decreasing supply of timber and are of great concern to forest managers and earth resource analysts.

This research is needed to develop remote sensing techniques that can rapidly detect and locate disease centers which cause such tremendous worldwide damage to forests. Foresters and land managers must have adequate detection techniques to minimize the impact of tree diseases and to maintain healthy forests.

Poria weirii root rot is by far the most destructive disease of Douglas-fir in Washington and Oregon (Fig. 1). Douglas-fir is the most important timber species in the Pacific Northwest, representing 57 percent of the total sawtimber volume in that region. An adequate root rot disease survey technique would provide tangible benefits to the forest economy of the United States.

METHODS AND PROCEDURES

The aerial remote sensing techniques initiated during the past few years have indicated great promise for use of the thermal infrared portion of the electromagnetic spectrum in certain kinds of earth resource surveys including the early detection of plant stress. In addition, the visible and near infrared portions of the spectrum are continuing to be investigated in various modes in an effort to learn whether multispectral analysis will enhance the recognition of specific characteristics of healthy and diseased trees. Much basic tree physiology data must be collected, as was done in the Black Hills, to understand which specific parameters are meaningful in detecting stressed trees with airborne sensors.

The remote sensing research covered in this progress report concerns the testing and developing of airborne sensors that might be effective in discriminating root rot infected trees from healthy trees, and the developing

of a "ground truth" system to analyze the biophysiological responses of trees under stress. Data from the multichannel sensors flown by The University of Michigan DC-3 aircraft will not be available for inclusion in this report, although arrangements have just been completed for obtaining such data in the near future. Major emphasis of this report will be on the systems development for obtaining reliable "ground truth" data with appropriate illustrations and preliminary results of various physiological measurements.

DEVELOPMENT OF "GROUND TRUTH" SYSTEMS

The feasibility of applying remote sensing techniques to assess root rot infection centers in forest areas from orbital or suborbital altitudes is largely dependent upon the ability to discriminate differences between healthy and diseased trees. Except in the most advanced stages of decline, trees infected with root rot do not generally show visual symptoms or tone signatures significantly different from healthy trees. Interpretation of photography with color and false color films (Ektachrome and Ektachrome IR) has not been effective in discriminating healthy Douglas-fir trees from those recently infested with root rot. More intensive and comprehensive "ground truth" is required, therefore, to determine whether, in the absence of reflectance differences, detectable thermal differences occur.

The biophysiological parameters and internal physiological processes of Douglas-fir trees and the influence of forest pests on tree growth and tree decline need to be ascertained. This is a prerequisite for determining the ideal airborne remote sensor(s).

Significant temperature differences between healthy and root rot

infected Douglas-fir trees were first discovered in our 1967 studies(3) which employed helicopter overflights with a PRT-5 thermal radiometer. These differences occurred in all age classes of Douglas-fir (young growth, second growth and old growth) at certain times of the day and periods of the year in 1967. Evidence of these thermal differences was not as clear-cut in 1968(4). Measurement of physiological factors affecting tree temperatures was therefore considered important. Biophysical research was oriented to measuring energy balance of the forest canopy, leaf moisture tension[1/] foliage temperatures, soil moisture tension, rate of sap flow, and various types of meterological data (wind speed, relative humidity, ambient air temperatures, vapor pressure deficit and rainfall.)

Aerial tramway system

To gather data continuously from above the forest canopy for a long period of time, we decided to establish an aerial tramway system that would permit remote sensing devices to be suspended above both healthy and root rot-infected trees. Factors of logistics and administration were considered first. A young-growth stand located near Eatonville, Washington, on the University of Washington's Pack Forest was first considered because of available electric power and other research activity in progress. Tree mortality and *Poria weirii* root rot infection centers were so extensive, however, that only a few healthy trees could be found. Also in this area, the cloud cover could be expected to prevail during two-thirds of the summer days, thereby seriously interfering with data collection. The second-growth stand of Douglas-fir on the Wind River test site proved more acceptable

1/ It is currently argued that a hydrostatic pressure bomb actually measures xylem sap pressure rather than leaf moisture tension in softwoods. For now, we consider the terms to be synonymous.

because of (1) a better distribution of healthy and diseased trees for a tramway system, (2) closer proximity to research headquarters at Portland for travel and maintenance, and (3) more favorable weather for sensing because this area is located on the east crest of the Cascades where only one-fourth of the days would normally be cloudy. Electrical power could be provided from a 1500 foot distance.

A dual tower system to include both diseased and healthy trees was abandoned because of the distance involved (over 250 feet), and the lack of sufficient numbers of desired trees located in a straight line. The tri-tower system evolved with the central tower serving as the focal point for two tramways (Fig. 2). One tramway operated over healthy trees, the second over diseased trees. Towers were located approximately 120 feet apart to equalize travel time for each tram and to have an adequate number of tree crowns exactly in line. Extensive scouting and field engineering were required to align the tram over tree tops in the natural stand. Three trees in each condition class were finally selected in respective lines for biophysical analysis. Two of the selected trees are part of the previously established second-growth study trees on the Wind River test site.

Increment borings were made on four sides of approximately 35 trees to determine the presence or absence of *Poria weirii* root rot. Pathological cultures of each selected boring proved the presence or absence of *Poria weirii*.

Tower Construction

Many problems can be expected in erecting towers under forest conditions especially when natural vegetation is to remain relatively undisturbed. The logistics of working through heavy vegetative cover, over downed logs

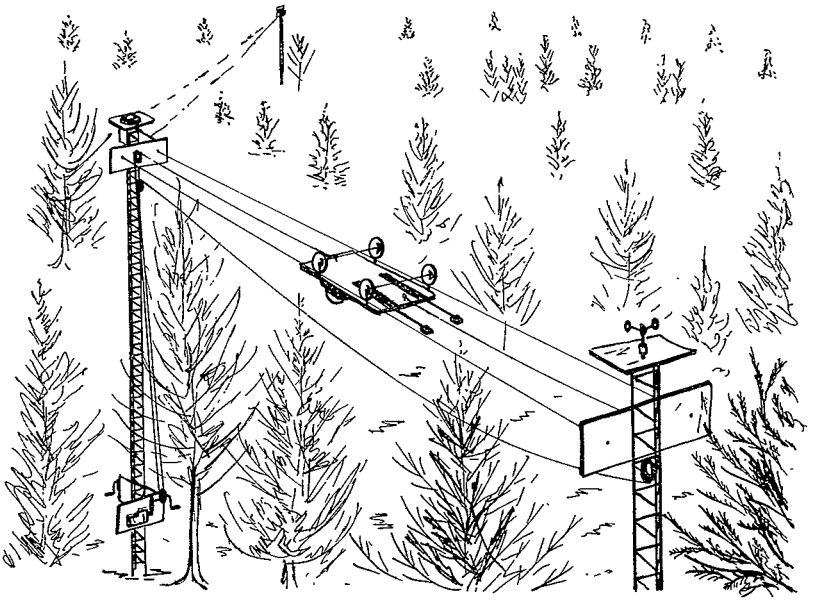

Figure 2--Diagram of dual aerial tramway system needed to estimate solar and emitted energy budgets from healthy and diseased Douglas-fir trees. This automated system provides important data for biophysical analysis of several forest parameters. These data can be collected continually and are essential to identify thermal differences for separating healthy from diseased trees at different times of the day and seasons of the year. Information of this type is essential to scheduling of suborbital overflights and providing accurate "ground truth".

and uneven terrain, across soft spots, and manipulating cables through trees with dead branches in the lower two-thirds of the crown were problems solved in sequence.

Construction of the three towers and securing the guy wires were carried out according to the tower manufacturer's instructions. Each tower was built separately and guyed as the tower was erected. Turnbuckles for the four guys on each side of a tower (Fig. 3) were attached to the long anchor rods. Tower sections were hoisted into position (Fig. 4) using a pole erector attached to the last tower section. Each section was bolted in place (Fig. 5) before adding the next section. Guys were strung and secured at 25-foot intervals up the tower. A light rope with a heavy flag hoist hitch on the end was first thrown from the tower toward an anchor base. The ground crew attached the 3/8" guy cable to the rope and the tower climber attached the cable to the tower. The guy cable was tightened at the turnbuckle using a cable puller on a block and tackle. Final adjustments for plumbing the tower and obtaining adequate tension were made with the turnbuckles at the three anchor points. A plumb bob on a string attached to the top of each 25-foot tower section provided the vertical orientation for the tower. Small adjustments were made during the field season. Figure 6 is a ground view of the central 100-foot tower.

Tramway Construction

The tram lines were attached to heavy backing boards by eye bolts with turnbuckles. Each backing board (two laminated pieces of 3/4" exterior grade plywood) was bolted to the top of a tower by 4 U-bolts. Steel aircraft cable (3/32") was used for all running and standing rigging. Lines were started across the 120-foot distance between towers using a bow and

Figure 3--Concrete slabs (2' x 2' x 18") located on three sides of each tower, are adequate anchors for attaching 4 guys at 25-foot intervals to stabilize the 100-foot towers.

Figure 4--Tower sections are hoisted into position using a portable tower pole erector pole, pully and rope. The erector pole is clamped to the top of the highest section.

Figure 5--Each additional section is bolted in place with two one-fourth inch bolts per leg. Note safety belt being worn as required while operator works on the tower.

Figure 6--Upward view from base of 100-foot tower showing four guys on three sides. Dynamic strength of tower is ample to support 300-pound load at top of tower in 100 mph wind. Counterweights (visible to left of tower) offset weight of multistrand electrical wires leading from instruments on tramway to the central tower.

arrow (attached to monofilament line on a fishing spinning reel). The steel cable was then pulled across and secured to the backing boards. The two tram lines were secured to turnbuckles using thimbles and cable clamps. Sag deflection in these lines is minimal.

The instrument tram is constructed of exterior plywood, aluminum strips and 4 aircraft pulleys. Pegs in the aluminum strips (under the pulleys) prevent tram wires from slipping out. Pulleys ride above the tram platform (Fig. 2).

The operating cable is attached to both ends of the tram and feeds through fiber pulleys (two at the top of each tower) and the main 6-inch drive pulley (double wrapped to prevent slipping) at the power switching position (base of central tower).

Tramway Control System

A control system was needed that could operate the tramway in different modes as necessary to collect short-term or long-term data, either manually or automatically, and by continuous line scan or stationary readings over selected trees. An electronic system of relays, reversing mechanisms, and micro limit-switches to control the geared motor of each tramway was designed and engineered by electronic specialists of United Radio Co., and the U. S. Forest Service. The electronics unit (Fig. 7) was mounted in a waterproof box.

When the tramway control system is being operated, microswitches to reverse polarity and direction of travel are tripped by cable clamps on the running cable. The clamps are located at appropriate distances to control the total travel of the instrumented tram between towers. A double microswitch system is installed at both ends of the cable to prevent overrun of

Figure 7--The electronic switching system (A) controls the automatic operation of each tramway. The integrated drive components consist of: (a) geared motor with 12 rpm output, (b) chain drive (sprocket ratio 1:4) which turns 6-inch pulley (moves tramway both ways), (c) microswitch system which reverses geared motor, and (d) hand crank for manual operation of tramway system, the chain drive being easily disengaged from the pulley.

the tram in case of microswitch malfunction. The rate of instrument tram travel is about 6 feet per minute with the present gear ratio (12 rpm gear motor reduced 1 to 4 rpm with sprocketed chain drive to 6" pulley). Rate of tram travel can be controlled by changing sprocketed gear ratios.

Manual operation of the 6" pulley to move the instrumented tram is achieved by disengaging the sprocketed gear from the pulley shaft and turning the handcrank. The control system for each tramway is mounted on 3/4" waterproof plywood. The two control systems are U-bolted to the central tower for easy maintenance and operation. A rain shield covers the motor and chain to minimize corrosion. In normal use, data can be collected automatically.

The problem of keeping the bundle of electrical instrument wires free and clear of the tree tops as the tram travels back and forth is solved by a weighted pulley system. A 6-foot accessory yardarm is attached to the top of the tower from which the electrical wire from the tram is fed downward over a pulley in a looping manner. A 6-pound weight on a pulley in this loop takes the slack out of the bundle of wires so that the tram can move freely in either direction. (If undue slippage occurs, a similar counterweight system can be installed on the opposite tower).

The density of the forest canopy in the 50-year old Douglas-fir stand on the Wind River site is shown in Figure 8. The relative positions of the three 100-foot towers can be observed in the oblique view.

Biophysiological Data Collection

It is essential to understand the differential tree responses to environmental and induced stresses caused by such things as *Poria weirii* root rot in Douglas-fir or moisture stress from drought. Only by knowing the effect of these stresses on the plant community compared with a healthy

Figure 8--Aerial view of 100-foot towers above forest canopy. Tramway wires between the two towers may be visible in foreground.

or normal situation is it possible to develop satisfactory techniques for maximizing these differences. Remote sensing techniques have been tested with encouraging results for discriminating healthy from root rot diseased Douglas-fir trees. However, more definitive answers are needed to establish "ground truth" and remote sensing research confidence levels for applying airborne sensors.

Several meteorological instruments were installed at the Wind River study site to gather data on the environmental and tree physiological processes. From these data, tree response differences between healthy and diseased trees can be accurately ascertained for specific periods of time.

Among the instruments installed at the Wind River study site in the summer of 1969 were three types of radiant energy measuring instruments, four types of weather data collecting instruments, a soil moisture measuring instrument, needle temperature measuring devices, a leaf water potential device, and several sap flow measuring instruments. A special instrument to record emitted radiant energy of healthy and diseased trees was not available for this field season. A description of the various instruments and their application for collecting environmental and physiological tree data follows:

Environmental Factors

1. Solar Radiation (0.35 to 4.0 microns). The total incoming solar radiation was obtained from a Star pyranometer stationed at the top of the center 30.5 m instrument tower. This Eppley type instrument had an electrical output calibration of 4.43 mv ly^{-1}, which was recorded in analog form on a multi-point recorder which sampled incoming energy four times each minute.

2. Reflected Radiation (0.35 to 4.0 microns). The reflective short-wave radiation component was measured for both healthy and diseased trees using two inverted Star pyranometers. These instruments traveled independently on separate tramway systems which positioned one pyranometer directly over three separate healthy fir trees and the other over three disease infected firs. These instruments had electrical output calibrations of 8.00 mv ly^{-1} and 5.75 mv ly^{-1} respectively. Their continuous output was recorded on an analog point recorder once each minute.

3. Net All-Wave Radiation. Net radiation was measured for both healthy and diseased trees using two high-output all-wave net radiometers. These two instruments were placed on the tram system running over the tops of the healthy and the diseased trees. Each tram, which carried a pyranometer and a net radiometer, was in effect a vehicle for positioning transducers over the tops of the tree crowns to be able to record an energy exchange profile for healthy and diseased trees within the study area. The continuous output of the net radiometers was recorded on a strip-chart recorder (Fig. 11).

4. Wind Speed. Air movement within the study area was recorded from an anemometer located at the top of one of the instrument towers. This light-chopping type instrument has an accurate starting speed of 0.23 m sec^{-1}. The wind velocity transmitter input was wired to a standard strip-chart recorder which ran during two 15-minute periods each hour during the day and one 15-minute period each hour at night.

5. Air Temperature. Ambient air temperatures were measured with shielded thermocouples located 3.7 m below the top and above the base of the center instrument tower. All thermocouple data were recorded on a

Figure 9--Instrumented trailer in timber close to the towers provides all-weather protection for a series of recording instruments. Space inside trailer adequate for small workshop needed in equipment maintenance. Note "miles" of wire feeding into trailer from tramway instruments and various parts of study trees.

Figure 10--Interior of trailer shows two Honeywell-Brown "Electronik" analog recorders, a third Honeywell multipoint recorder(under fluorescent light), and a cabinet of 8 Rustrak recorders. Details of these recorders are shown in Figures 11, 12 and 13. Not shown is an Esterline angus millivolt recorder that records weather data.

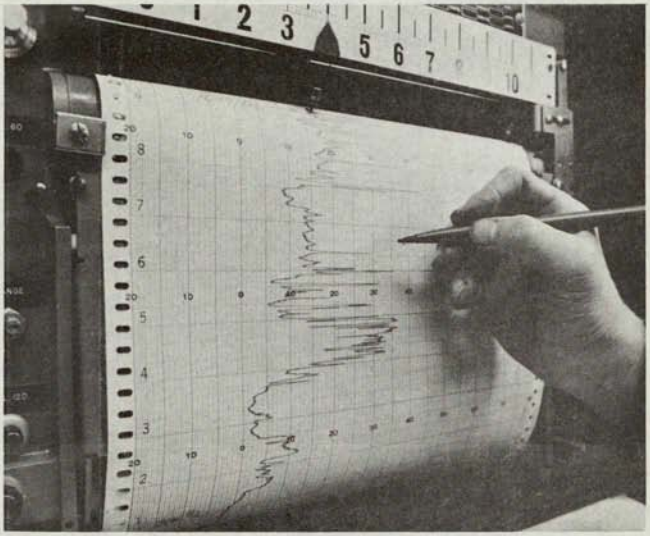

Figure 11--Honeywell analog recorder collecting data from net radiometers on a continuous basis from each of the tramways. Note profile over various types of vegetative materials.

multiple point temperature recorder (Fig. 12). An additional set of temperature data was collected continuously in a thermograph situated 1.3 m above the base of one of the outside instrument towers.

6. Humidity. Relative humidity was recorded on a standard clock-driven hygrograph. One such device was located near the ground and a second instrument was situated within the crown level of the study trees. The recorded relative humidity values were used to calculate actual vapor pressure and vapor pressure deficits.

7. Precipitation. Precipitation data were taken from an official ESSA Weather Bureau site located at the Wind River Ranger Station, less than one-fourth mile from the study area. Because of the general nature of rainfall distribution in the area, there seemed no reason to question the validity of the precipitation data even though not collected within the study area.

8. Soil Water. Soil water content and soil water potential were used as measures of the availability of soil water to the study trees. A reliable measure of soil water was important to understanding differential thermal responses of foliage to other environmental variables. It was of further interest to relate soil water to relative transpiration rates and to leaf water potentials.

Soil moisture was routinely measured with a P-19 neutron probe (Fig. 13). At the beginning of the field season, four sets of access tubes were placed at the base of study trees in the soil profile to monitor soil moisture vertically through the entire root horizon. Two sets of eight access tubes were placed around healthy trees and the same number were located around the diseased study trees.

Figure 12--Soil moisture at various levels is determined by use of a Nuclear Chicago gauge scaler and neutron probe. Timed differences between neutrons emitted and those recovered indicate the soil moisture availability. Electronic readings of neutron inputs are recorded for intervals of two minutes. Neutron probe is in foreground in shielded case. Separate readings are made into the ground at 6-inch intervals to bedrock.

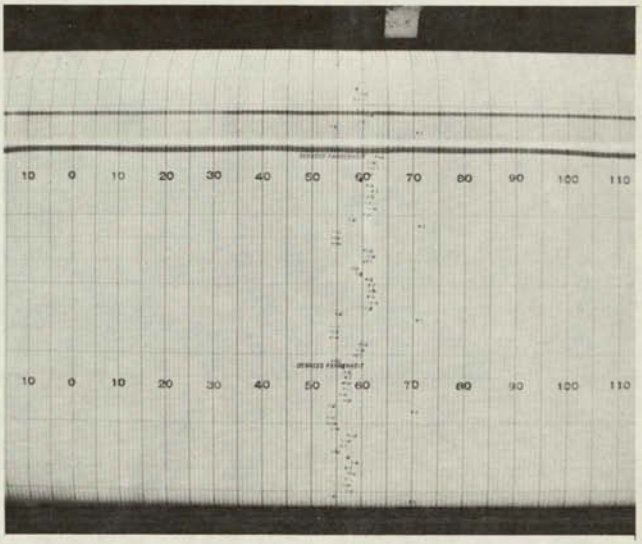

Figure 13--Honeywell 16-point recorder showing individual tree needle temperatures from healthy and diseased trees as well as soil and ambient air temperatures from thermocouples.

Tree Physiological Factors

1. Needle Temperature Measurements. Trees are exposed to radiant energy from the sun, from surrounding surfaces and from the atmosphere. Leaf temperature is an important indicator of the response of the tree to environmental factors such as solar and thermal radiation, air temperature, vapor pressure deficit, wind movement and soil water availability. The temperature of a leaf (e.g., a Douglas-fir needle) is an indication of its response and adjustment to the heat load imposed upon it by the surrounding environment.

Foliage temperatures were measured by inserting microthermocouples of copper constantan into living cell tissue of individual needles. Foliage temperatures were sampled at two locations within the upper crown of three healthy and three diseased trees. Copper constantan transmission wires joined the thermocouples to a recording station on the ground where the needle temperatures were recorded on the multipoint recorder shown in Figure 13. Foliage temperatures were recorded during two 15-minute intervals each hour during the day and one 15-minute interval at night.

2. Apparent Emitted Temperature Measurements. The crown of a Douglas-fir tree, like other natural objects on the surface of the earth, radiates thermal energy according to the fourth power of its absolute temperature, and the efficiency with which it radiates is determined by its surface characteristics defined by an emissivity constant. The primary emphasis for this phase of the biophysical study is to determine conclusively whether or not diseased firs emit energy at specific times, that is measurably different from that emitted by healthy firs.

The research plan required the measurement of apparent temperatures

by two different techniques, one direct and the other inferred. A special and unique black body radiometric plate was designed within the body of a Kahl net radiometer. The temperature of the upper and lower radiometric plates was measured with a microthermocouple of copper constantan. The upper plate in effect measured the hemispherical incoming longwave infrared radiation and the lower plate measured the apparent emission temperature of objects below. The downward facing surface of the radiometer housing is fitted with cones of various sizes which effectively narrow the field of view of the instrument. It was unfortunate that these instruments were not delivered until the end of the field season. They are now being thoroughly tested and calibrated for the next field season.

Apparent emitted temperatures, however, can be inferred from other data. This requires solution of the radiation flux density formula using foliage temperature values and a constant emissivity of 0.93. Atmospheric attenuation of emitted energy is assumed to be zero because of the small distance to the sensing instrument. Strong indications of emitted energy levels will be determined from analysis of these data.

3. Leaf Water Potential. Water potential of the foliage on study trees is a variable measured to assess the internal water relations of trees under different environmental conditions. The technique, first reported over fifty years ago and in wide use with biological material the last five years, derives a measure of a leaf's water potential with a hydrostatic pressure chamber (Fig. 14).

Leaf water potential values were recorded within one-half hour after branch samples were taken from the study trees. An effort was made to obtain water potential data at least once each week, weather permitting.

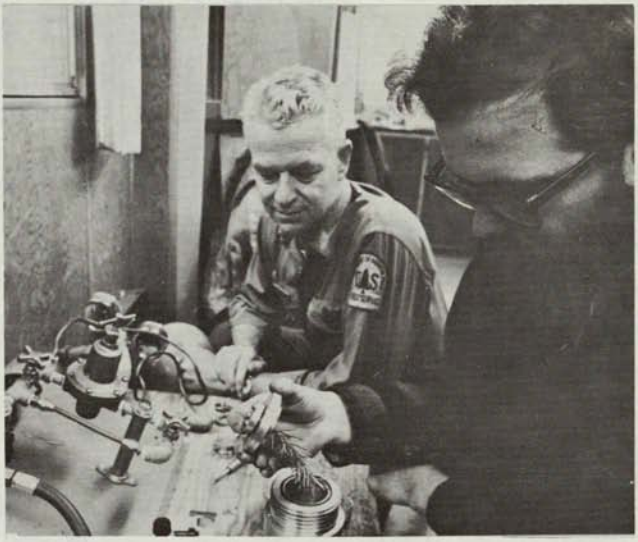

Figure 14--The needle moisture tension (or the hydrostatic pressure required to transpire moisture to the atmosphere) is measured through the hydrostatic bomb. Nitrogen pressure is applied against the inverted twiglet inside the bomb until moisture exudes from the cut surface of the twiglet. This pressure is related to amount of available moisture, weather factors, and demands of the tree at various times of the day and seasons of the year.

Figure 15--Sap flow detector attached to tree consists of two thermistors and a heat impulse needle. Timed thermal differences after heat impulse indicate rate of sap flow.

Collection and measurement usually lasted throughout the day and provided data for evaluating the effect of daily variations due to radiation load, soil moisture tension, rate of water transport in the main stem and relative state of tree vigor.

4. Sap Flow Determination. The rate of sap flow is one of the important parameters providing data on the translocation of available moisture from the tree's root system to the canopy. A special sap flow detector, consisting of two thermistors and a heat impulse probe, have been designed by Weber to determine flow rates (Fig. 15). The heat impulse is imparted in the xylem through a No. 16 hypo needle that is attached to nichrome wire from the electrical heat source. The timed differential travel of the sap sensed by the thermistors following heat impulse is an indicator of sap flow rates. Two detectors are attached at d.b.h. on each study tree. These data were to be recorded on the 8 Rustrak recorders (Fig. 16) that are located in the trailer.

AERIAL PROCEDURES

Multispectral Imagery

NASA made available the University of Michigan's Infrared and Optics Laboratory (IROL) airborne multispectral scanner system twice during the field season. The IROL system incorporates two highly modified AAS/5 optical-mechanical scanners. One of the scanners has a unique 12-channel spectrometer as one-half the collecting optics. The spectrometer has real-time registration for each of 12 discrete bandwidth samples between 0.40 and 1.00 micron. In addition, the thermal infrared channels on the second scanner have internal thermal calibration of gray-scale density. The

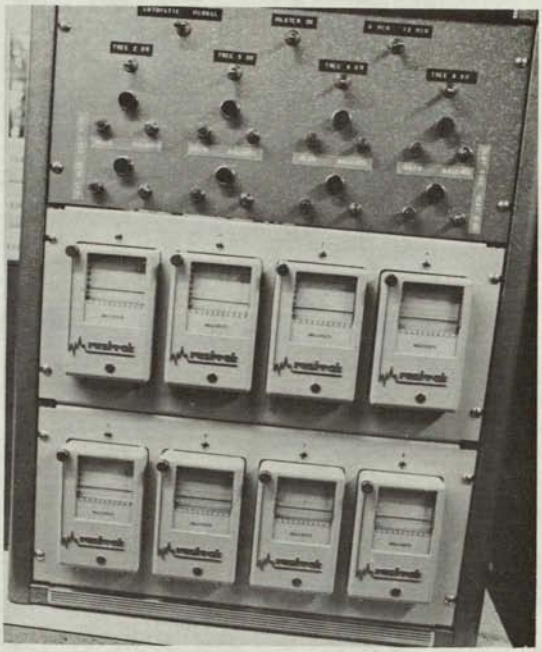

Figure 16 -- A cabinet of 8 Rustrak recorders designed to collect sap flow data from healthy and diseased trees in the study. This parameter may be highly significant in establishing biophysical differences.

The upper and lower limits of gray-scale density can be controlled by a hot and cold plate thermal reference.

Seventeen flight passes were made over the study site with the IROL multispectral system during a two-day period, July 14 and 15, and eleven more were made on September 26. Diurnal spacing of the flights enabled collection of information at the following time periods: (1) early morning, (2) midmorning, (3) midday, and (4) midafternoon. Although the system has a potential capability of 19 data channels, only 15 will be utilized for this research (Table 1).

An intensive program for analysis of these multispectral data is underway at the University of Michigan. Analyses will be grouped into two categories, thermal processing and multispectral processing. Application will be made of the image interpretation techniques developed under the Black Hills study for the purpose of defining target signatures for healthy and disease-infected firs. The necessary manipulation of background signatures will also be covered. Previous data seem to resolve this research problem to one of thermal detection; consequently, great use will be made of several applicable thermal processing techniques. Thermal slicing with amplitude gating and thermal contouring will likely provide the most useful information for thermal discrimination of tree vigor.

AERIAL THERMAL INFRARED TESTS

Considerable concern has been expressed by remote sensing technicians that the rotor blast from a hovering helicopter could materially alter the temperature of any surface affected by such breezes.

The thermal infrared video scanning system, developed this past year to provide in-place information and thermal profiles over forested areas,

Table 1. Michigan multispectral scanner system--wavelengths sampled.

Scanner No.	Detector Location	Wavelength Band	Spectral Response	Tape Channel
1	End A	8.0-13.5	Far Infrared	6
1	End B	4.5-5.5	Far Infrared	5
2	End A	.80-1.00	Photo Infrared	14
2	End A	.72-.80	Photo Infrared	13
2	End A	.66-.72	Deep Red	12
2	End A	.62-.66	Light Red	11
2	End A	.58-.62	Yellow Red	10
2	End A	.55-.58	Yellow	9
2	End A	.52-.55	Yellow Green	8
2	End A	.50-.52	Green	6
2	End A	.46-.48	Blue	4
2	End A	.40-.44	Violet	2
2	End B	2.0-2.6	Middle Infrared	5
2	End B	1.5-1.8	Middle Infrared	3
2	End B	1.0-1.4	Near Infrared	1

was mounted in a Hiller SL-4 to conduct calibration tests for the PRT-5 video scan interface. Three swimming pools located at motels in the Portland area were selected and approved by FAA for conducting limited low-altitude tests. Tests were flown at noon under full sunlight. A video technician from Oregon Audio Video Systems Co., manipulated the gear in the helicopter while the principal investigator gathered "ground truth" at each pool. A thermometer on a semifloating platform served to record surface temperatures of the water during the overflight.

Results of these and other tests previously described are reported in the next section.

RESULTS

ENVIRONMENTAL EFFECTS VERSUS PHYSIOLOGIC VARIABLES

Even without the added influence of *Poria weirii* infection, external environmental factors affect the vigor and well-being of Douglas-fir trees. Thus, it seems especially important to identify these influences concurrent with the seasonal development of infection in study trees. From the large array of data that were collected at Wind River during the summer of 1969, two sample periods (July and September) were chosen to show the interaction of physical environmental factors, and particularly how seasonal relationships change during the course of a buildup of water deficits in the attacked trees. The sample periods chosen coincide with airborne missions and serve to illustrate "ground truth" conditions at the time of sampling.

Environmental conditions were generally ideal for thermal remote sensing through mid-September, 1969. The main soil water storage at the Wind River study site was at 78 percent of field capacity on the first day of the July multispectral flight. Tree water status data indicated

moderate (but consistent) daytime differences in both the leaf water potential and the relative rates of evapotranspiration between healthy and diseased trees. Both the vapor pressure deficit data (Fig. 17) and the potential evaporation data indicated that conditions were nominal for high rates of transpiration in healthy trees with the high level of incident energy. Mean net radiation data for healthy versus diseased trees on July 14 (Fig. 17) indicate that infected trees exhibited slightly higher apparent temperatures than healthy trees. Accumulated energy for the entire day, considering the reflected and emitted component together, was 16 percent higher for the diseased trees.

"Net energy" data is interpreted as follows: low net energy (as measured with a net radiometer) results from higher reflective and emissive components which are subtracted from the incident energy component. Leaf radiant flux density (Fig. 18) is a measure of the true leaf temperature corrected for emissivity, and is the energy level measured by a thermal airborne detector. Although leaf radiant flux density differences are small, midday is indicated as the best time to measure thermal differences between healthy and infected trees. The same basic environmental relationships held for the July 15 airborne sampling as prevailed the previous day. Energy levels were slightly higher (Fig. 19 and 20). Vapor pressure deficit and potential evaporation data suggest higher rates of evaportanspiration which tend to increase the energy differential between the healthy and diseased trees. Leaf radiant flux density differences occurred between 1000 and 1500 hours suggesting higher thermal emission (and the possibility of thermal airborne discrimination) for the Poria weirii infected firs.

The University of Michigan's multispectral mission over the Wind River study site in September was accompanied by generally poorer environmental

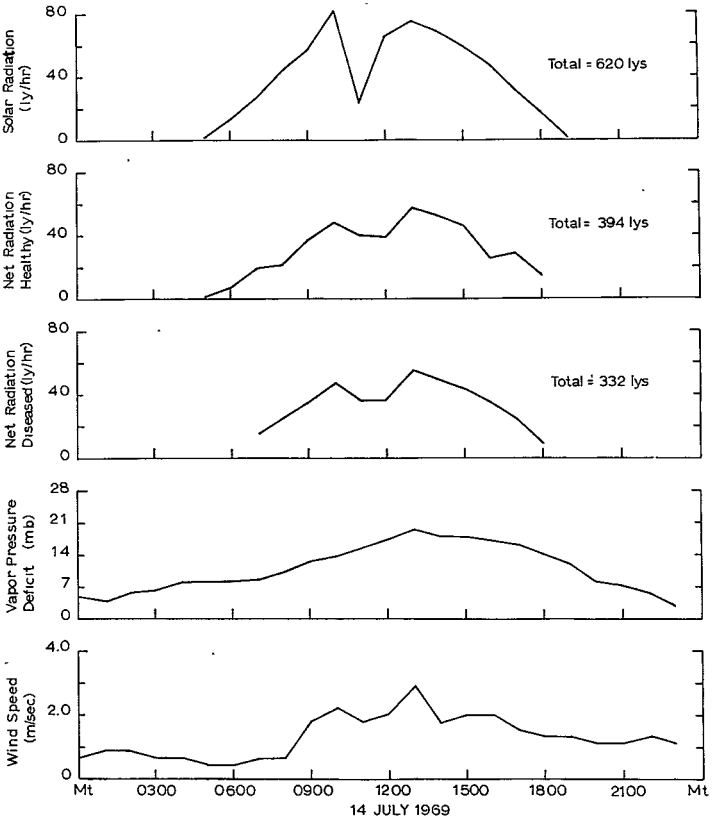

Figure 17--Total net radiation from healthy trees (394 lys) is greater than radiation from diseased trees (332 lys). Maximum net radiation from both conditions classes is at midday.

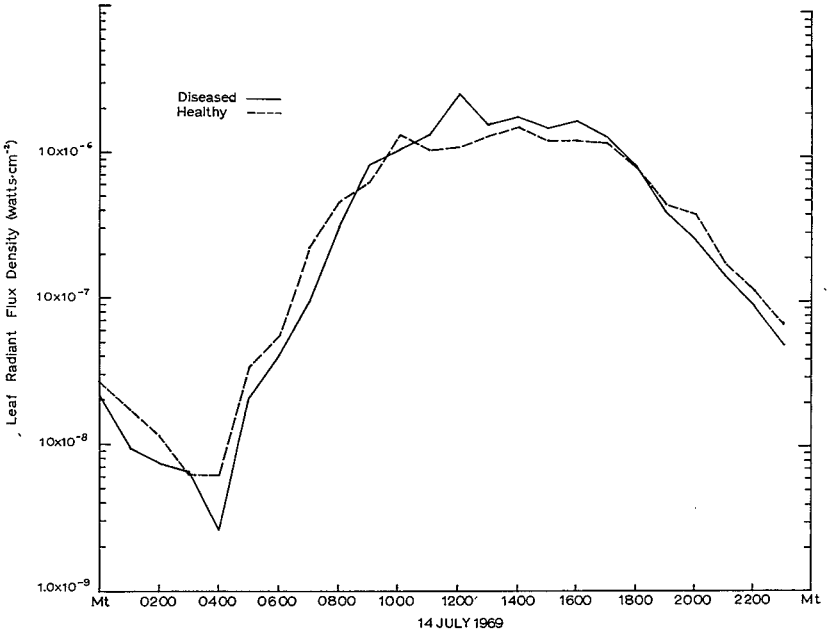

Figure 18--Leaf radiant flux density (likely to be indicative of leaf stress) is higher throughout the afternoon for diseased trees, and is lower during most of the morning.

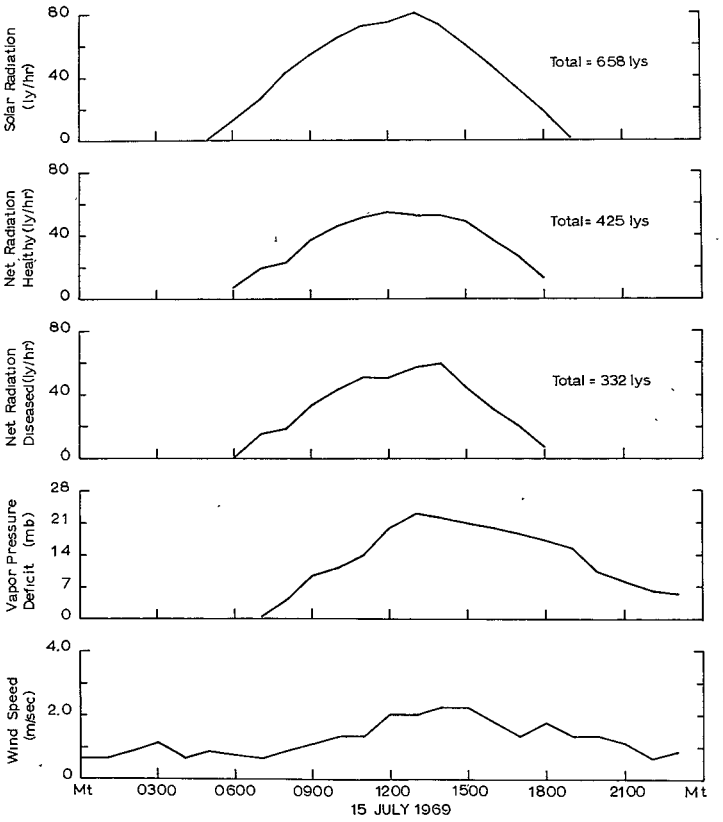

Figure 19--Total radiation from healthy trees (425 lys) is greater than radiation from diseased trees (332 lys). The relationship to Solar Radiation and Vapor Pressure Deficit can be seen.

conditions prior to and following the mission in terms of optimum thermal remote sensing. This was unfortunate because measured soil moisture deficiencies were at a level which generally leads to large thermal differences between healthy and infected trees when other environmental conditions are optimal. Incident energy level (Fig. 21) was somewhat below the ideal level, primarily due to the time of year rather than atmospheric interference. Net energy data showed an accumulated difference between healthy and infected trees but incremental differences were small. These are the differences we must deal with when using an airborne scanner. Leaf radiant flux density differences (Fig. 22) showed that the healthy trees were actually exhibiting an aggregate of higher emission rates during the 24-hour period. Higher emission rates around midday were shown by the diseased trees.

During the summer field season the regime of leaf radiant flux density values was identified. It is unfortunate that all tram-mounted radiometric instruments were not available this summer to record emission temperature differences directly for correlation with airborne thermal data. These instruments will be the primary feature of future field data collection systems.

CALIBRATION OF PRT-5 VIDEO SCAN SYSTEM

Temperatures at each swimming pool were recorded during helicopter hoverings at 100', 150' and 200'. Although each pool was of a different temperature, ranging from 71° to 83°, the electronic output from the PRT-5 infrared radiometer indicated only a fraction of a degree difference at the various heights above the water body at each pool. At 200' the rotor blast was sufficient to ripple the water, at 150' the water was streaked

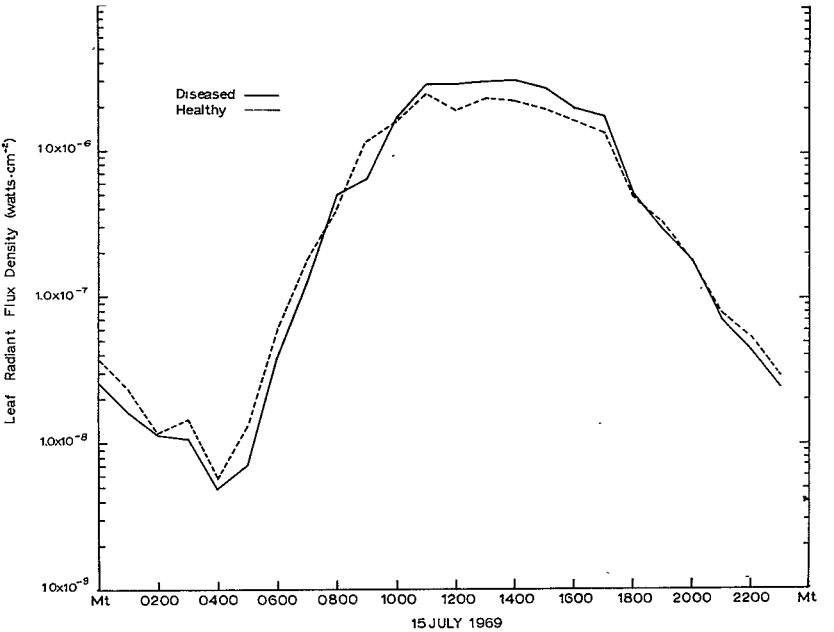

Figure 20--Leaf radiant flux density follows the pattern of LFD of 14 July, higher in the afternoon and lower in the morning.

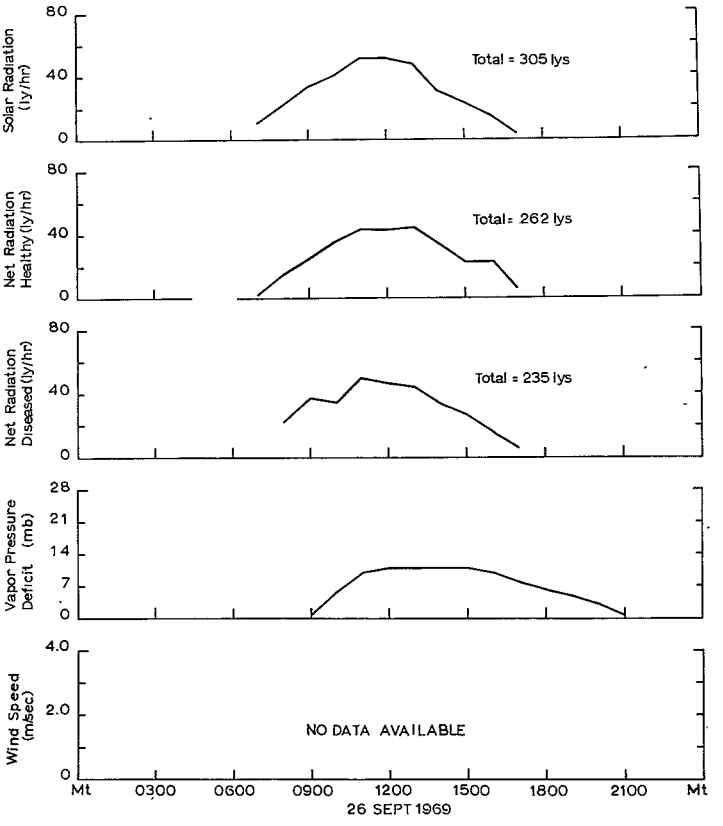

Figure 21--Total net radiation was higher for healthy trees (262 lys) than diseased trees (235 lys).

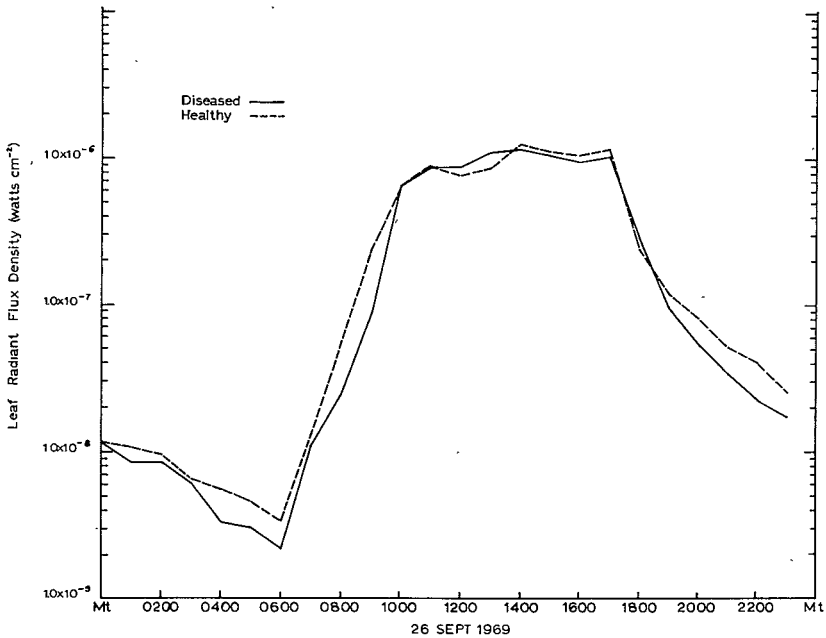

Figure 22--Leaf radiant flux density at midday is higher for diseased than healthy trees. On the previous two dates (14 and 15 July) the LFD for diseased trees remained higher than that for healthy trees throughout the afternoon. The difference on 26 September, possibly can be attributed to high stress of healthy trees due to low moisture conditions.

with wind vectors and one/half inch wavelets, but at 100' the water was rough with three-inch high choppiness. Wind velocity at 100', due to the helicopter's rotor blast, was estimated at about 30 mph. Because of the downdraft from the rotor blades, heat measurements of a tree canopy made beneath a helicopter hovering at very low altitude are likely to be unreliable. However, no significant temperature differences could be noted on any of the pools of water at the three flying heights. The helicopter hovered at each altitude for approximately two minutes.

In addition to the thermal infrared test over the swimming pools, a flight was made over all the test trees on the Wind River test site Plot #1 at approximately 1330 hours on May 22. Electronic readout from the PRT-5 radiometer on each of the second-growth Douglas-fir trees with a hovering time of one minute at 150' above the tree gave the following:

	Healthy Trees	Diseased With no Visible Crown Symptoms	Diseased With Visible Crown Symptoms
	.42	.44	.44
	.43	.43	.44
	.43	.46	.45
	.45	.44	.45
	.46	.45	.46
Average	.438 26.5°C	.440 26.6°C	.446 26.8°C

It was not possible to establish exact tree temperature readings for tree crowns at this particular point in time with any installed instrumentation systems. It is quite probable that the system of taking needle temperature readings in the upper tree crown of the study trees

this summer will provide a reasonable technique for checking the accuracy of temperature readings recorded by the PRT-5 radiometer and video scan system from a helicopter. Only then will we know for sure the effect of rotorblade downwash on temperatures of forest trees.

ESTIMATING TREE MORTALITY FROM APOLLO 9 IMAGERY[2/]

The flight of Apollo 9 in March, 1969, was a major stepping stone toward the Apollo 11 lunar landing. In addition, it made a major contribution to our earth resource scientists in providing an abundance of basic and applied data on our natural and cultural resources. One of the important objectives of the remote sensing imagery taken from an orbiting satellite platform is to determine the feasibility of estimating tree mortality in forested areas.

The early part of the Apollo 9 mission tested the capabilities of the astronauts to maneuver space equipment outside the primary capsule, to practice landing techniques with the "spider" module for a lunar approach on the Apollo 10 mission, and to practice "docking" or rejoining the lunar orbiting satellite as did Apollo 10 and Apollo 11 on their return trips to earth.

The latter part of the Apollo 9 mission on March 8-12, 1969, was devoted in part to taking multispectral space photography for earth resource analysis. This was a minor part of the overall Apollo 9 mission, but one of extreme interest and value to use. There were problems with this aspect of the mission which are considered in greater detail below.

A pod of four Hasselblad cameras with 80mm lenses was loaded with

---

[2/] Based on a paper presented by John Wear at the Semi-Annual National Meeting, American Society of Photogrammetry, Hilton Hotel, Portland, Oregon, September 24, 1969.

Ektachrome IR (SO-180) with a 15 filter , black-and-white IR (SO-240) with 89B filter, Pan XX (3400) with 25A red filter, and Pan XX (3400) with 58 green filter. The pod was attached to the window frame of the hatch door; the cameras were operated when the capsule was so oriented that the optical axes of the cameras were pointed vertically downward.

The preplanned flight path of Apollo 9 was west to east across the United States at about 32° latitude. A 75-mile wide photographic strip was expected to start south of Los Angeles, cross north of El Paso, go over Biloxi, Mississippi and finish over Cape Kennedy. It was realized at the outset that no further multispectral remote sensing imagery was likely to be forthcoming from the Apollo satellite series nor from other satellites for at least 2 years. Therefore, every effort was exerted to make the most of the opportunity.

The objectives of the forestry tests from Apollo 9 imagery included: (a) identifying forest species and delineating major timber types, (b) detecting forest stands under stress from disease, insects, or fire, and (c) evaluating rangeland and wildland resources.

Because of my remote sensing research and aerial survey techniques development for forest insects and diseases in western forests, I was directed to select test sites along the Apollo 9 flight path that showed heavy incidence of disease or insect activity. From current Regional Forest insect and disease survey map data, and with the help of U. S. Forest Service Regional entomologists and pathologists, I selected three test sites--one in California, one in Arizona and one in New Mexico. One forested area having significant disease stress characteristics is located on the Cleveland National Forest about 30 miles northeast of San Diego, where Elytroderma needlecast disease is epidemic in the ponderosa pine stands.

The second site was about 10 miles northeast of Prescott, Arizona, where both insects and disease are killing ponderosa pine trees. Ips beetles are the primary tree killers there. The third site showed heavy Lophodermium needlecast disease in fall, 1968. It lies on the Lincoln National Forest, about 10 miles north of Tulorosa, New Mexico.

The two types of needle diseases and the Ips beetles all cause the foliage of infested trees to range in color from yellow-orange to red and such abnormalities are generally visible on suborbital color photography most of the year. But environmental factors, such as winter storms, heavy rain or hail, or new growth features, may affect the appearance of stressed trees.

How much detail of these dead and dying trees and what size mortality groups would be discernible on the satellite photography depends upon several factors: the spatial resolution capabilities of the camera system, the atmospheric and ground target conditions (appearance of foliage, snow cover, etc) over the test site at the time of exposing the film, and the stereoscopic parallax of the satellite photography. Good stereoscopic parallax is extremely important for high quality and efficient interpretation of tree mortality on remote sensing imagery.

During the Apollo 9 overflight, members of the U. S. Forest Service's Remote Sensing Research team and other research teams from various universities were gathering "ground truth" data on various forestry, range, and wildland test sites. Richard Driscoll, Range Resource Analyst from the Rocky Mountain Forest and Range Experiment Station, and I concentrated on photographing forest and range test sites in New Mexico and Arizona. The Arizona test site near Prescott was eliminated because snow covered the ground and trees. Simultaneous 35mm oblique photography was taken of New

Mexico range and forestry test sites by using Ektachrome, Ektachrome IR and Eastman SO 121 color films from a Cessna 182 at 500 to 1,000 feet above terrain. Two Exakta cameras were mounted base-to-base and fired together at each target. A third camera was fired at almost the same point in time. Navigation to successive range test site areas was done by following vegetative range patterns on a color print from the Apollo 6 mission. Ground analysis was scheduled to follow the aerial reconnaissance and photography of each range test site. The 1:1,000 scale oblique photos of forest test sites in New Mexico would be collated with the best available suborbital photographs for precise locations of tree mortality groups. These photos in turn would be referenced to Apollo 9 imagery.

Robert C. Heller, in charge of remote sensing research at the Pacific Southwest Forest and Range Experiment Station, and photographer Richard J. Myhre flew the U.S.F.S. Aero Commander from Berkeley, California, to photograph the disease test site in southern California on the last day of the Apollo 9 mission. Both 70mm and 35mm vertical photos were taken of the disease area at 1:7,000 and 1:40,000 scales using Ektachrome IR, Aero Neg Ektachrome and Eastman SO 121 films. Unfortunately, an unusual and severe snow storm had hit the test site in southern California several days before, precluding satisfactory interpretation of stressed trees. Clouds over the test site on March 12, followed by snow covering trees and ground detail at the end of the mission, eliminated this disease test site from the remote sensing research.

The Lophodermium needlecast area near Tulorosa, New Mexico, at the time of the Apollo 9 overflight, had changed considerably since fall, 1968. New spring foliage obscured what remained of older red needles not removed by winter storms. Consequently, still another disease-mortality test site

had to be scrubbed.

Aerial reconnaissance was started to find another suitable tree-mortality site. No significant insect or disease mortality groups could be located within a radius of 50 miles, but an excellent "proxy" type bark beetle kill area of group mortality was located about 10 miles south of Ruidoso, New Mexico. The orange-colored "faders" were part of a controlled burning experiment on the Mescalero-Apache Indian Reservation and involved scattered groups ranging in size from a few acres to more than 40 acres (Fig. 23, 24, 25). At first glance from 500 feet above terrain and with light snow on the ground, only faint indications of actual fire kill could be discerned (apparently a controlled ground fire). At higher altitudes, the dead and dying trees could be easily mistaken for bark beetle-caused mortality. I considered this a reasonable example of group mortality with fading trees representative of either bark beetles or scattered spot fires. Thirty-five mm color photography was taken of various "proxy" mortality groups at low altitude.

About 3 weeks after splashdown, multispectral imagery from Apollo 9 was made available. The Apollo 9 flight path across the United States had deviated almost 1 degree further north than anticipated and eliminated many test sites where extensive "ground truth" had been completed. During the first photographic overflight on March 12, considerable film had been expended to provide 60% stereo overlap on all test sites. Unfortunately, heavy cloud layers extended over much of the western United States during the photo run. Consequently, the subsequent photo overflight several days later under better atmospheric conditions had to stretch the available film and resulted in photo coverage with only 15% overlap.

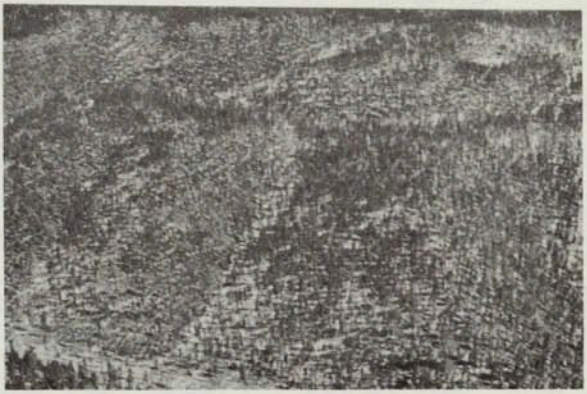

Figure 23--An oblique aerial view of the ponderosa pine type south of Ruidoso, New Mexico showing "proxy" mortality caused by controlled burning experiments. Original slide (35mm) was taken on Ektachrome color.

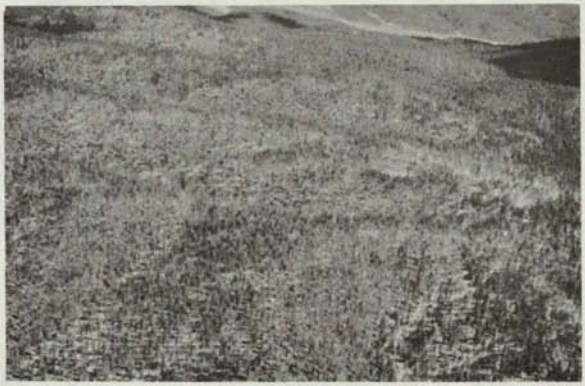

Figure 24--Ektachrome IR color of the same area as Figure 23 indicating multispectral enhancement and delineation potentials. Burned areas are quite readily discerned from unburned.

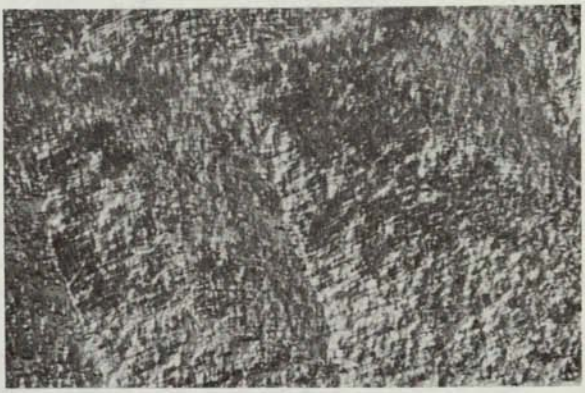

Figure 25a--Oblique close-up of "proxy" area of bark beetle type mortality on Ektachrome color with snow background.

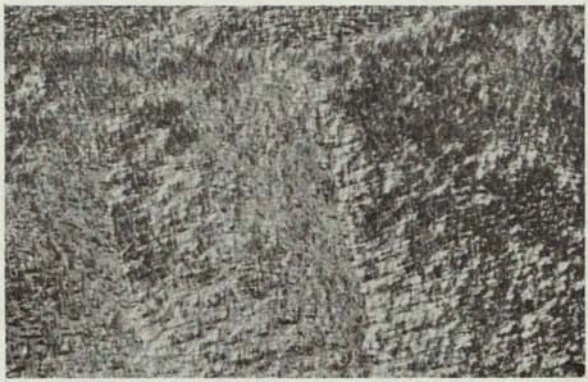

Figure 25b--Close-up of the same area as Figure 25a using Ektachrome IR color film. Low altitude obliques provide excellent "ground truth" for small scale suborbital and orbital imagery.

The color balance and resolution of individual satellite photos taken 126 miles above the earth are of excellent quality. Geomorphic and terrestrial features show clearly. Although I was interpreting from a third generation 70mm color transparency with a 15X microscope, it was not difficult to pinpoint field locations in mountainous terrain. The scale of photo AS9-26-3805 (Fig. 26) is about 1:2,549,500. This is 40 miles per inch or 5 miles per 1/8 inch, which means that image quality must be exceptional to delineate small ground details and specific features such as a group of dead trees.

Most noticeable on the photograph is the snow distribution pattern along the mountains with the heaviest concentrations (solid white) at the higher elevations and scattered fingers of snow along ridges several thousand feet lower. Hydrologists will have an excellent opportunity to make snow estimates and potential water resource analyses from this photography. The black area that looks like two small lakes joined by a narrow channel is actually a jagged mass of lava. The white bull's eye near the reservoir on the left edge of the photo is the site of the first atomic bomb explosion and is about 5 miles across. The tonal contrast between an image and its background (determined by the hue, value and chroma of the image itself) and the image sharpness (indicated by the distance on the photograph between images of varying tonal contrast) are critical factors of image quality. Thus in forested areas significant color contrast and image sharpness are needed to separate bare ground, cutover land, or rocky outcrops from groups of dead or dying trees.

Monoscopic interpretation under 15X magnification of AS9-26-3805 (Fig. 26) in the forested area south of Sierra Blanca Mountain along the edge of the photo indicated several brownish spots in the vicinity of

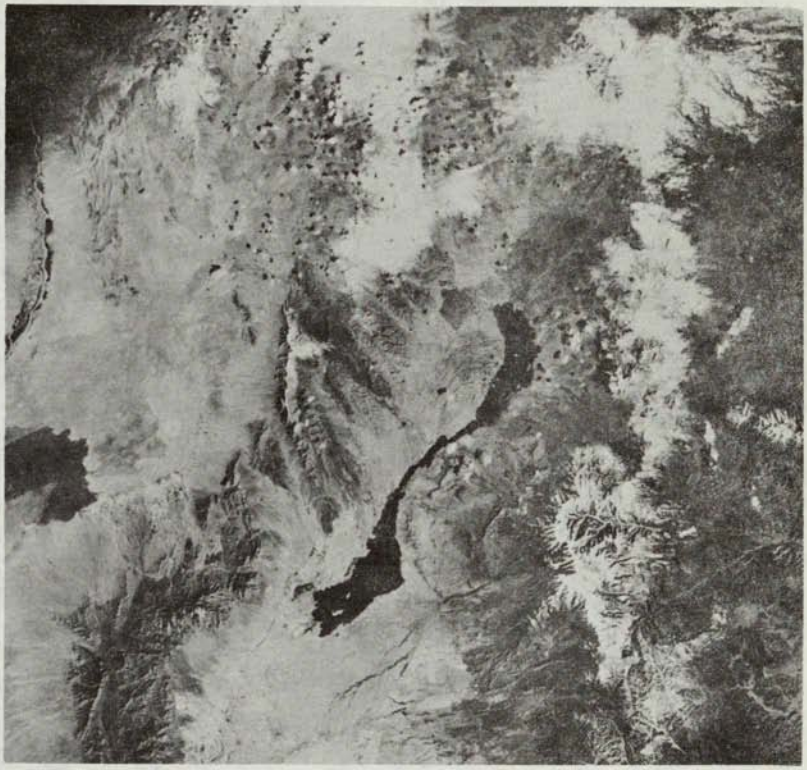

Figure 26--Enlargement (4X) of Apollo 9 imagery taken with 70mm Hasselblad camera, having an 80mm focal length, from approximately 126 miles above the earth. General land features are readily discernible. Snow predominates above forested areas (blue green). Black lava flow in the center contrasts sharply with surrounding desert shrub types. 15X magnification is needed to delineate openings at 20 acres and larger on the 1:2,549,500 scale photos.

Ruidoso, New Mexico. The general locations of some of the spots coincided with the "proxy" mortality sketch mapped during the previous aerial reconnaissance to locate test sites. Several interpreters with forest insect and disease background studied the area on the Apollo 9 imagery and concluded that monoscopic viewing of vegetative details was insufficient to identify positively only a few tree mortality groups. Their consensus was that supplementary aerial reconnaissance in the area would be of considerable value in establishing criteria for interpreting mortality groups by monoscopic viewing. Seven suspect groups ranging in size from about 20 to 60 acres were selected for field checking. A subsequent low-altitude flight over the area revealed that only two of the suspect areas were actually tree mortality groups. The commission errors consisted of a rocky outcrop, two cutover areas with light soils and bare brush, a patch of burned snags with light soils, and an opening with scattered brush. It is easy to see how monoscopic interpretation leads to errors. Omission errors were also made on the satellite photography. On the edge of the AS9 photo, small areas (less than about 20 acres) on the mountain slopes were generally overlooked.

The results of this study are not too encouraging, but I do not believe this to be a fair test of the interpretation potentials from satellite photo, and the lack of adequate stereo precluded adequate determinations of vegetative structure and height. Additional experience with satellite imagery should greatly enhance the ability of interpreters to make accurate evaluations of forest conditions.

Even with this limited experience with satellite imagery, I believe that considerable use can be made of this remote sensing technique under good conditions to identify trees under stress from insects, disease and fire.

LITERATURE CITATIONS

1. Gates, D. M., R. Alderfer and E. Taylor. 1968. Leaf temperatures of desert plants. Science Vol. 159, No. 3818. pp 994-995.
2. Leonard, R. C. and A. R. Eschner. 1968. A treetop tramway system for meteorological studies. U. S. Forest Res. Paper NE-92. NE For. Exp. Sta. Upper Darby, Pa.
3. Wear, J. F. 1967. The development of spectro-signature indicators of root disease on large forest areas. Ann. Prog. Report. Forestry Remote Sensing Laboratory for Natural Resource Program, NASA, by the Pacific Southwest Forest & Range Expt. Sta. pp 22.
4. Wear J. F. 1968. The development of spectro-signature indicators of root disease impacts on forest stands. Ann. Prog. Report. Forestry Remote Sensing Laboratory for Natural Resource Program, NASA, by the Pacific South Forest & Range Expt. Sta. pp 27.

APPENDIX

The following is a list of U. S. Department of Agriculture personnel who have made contributions to this research study and represent a major salary contribution to it:

U. S. FOREST SERVICE

PACIFIC SOUTHWEST FOREST AND RANGE EXPERIMENT STATION, BERKELEY, CALIFORNIA:

John F. Wear, Forester

F. P. Weber, Research Forester

Robert C. Heller, Project Leader

Nancy Norick, Statistician

Richard J. Myhre, Forestry Research Technician

James von Mosch, Forest Technician

Anne L. Weber, Project Clerk

PACIFIC NORTHWEST REGIONAL OFFICE, PORTLAND, OREGON:

INSECT AND DISEASE BRANCH, TIMBER MANAGEMENT DIVISION

Benton Howard, Branch Chief

Jack Thompson, Pathologist

COMMUNICATIONS BRANCH

C. V. Fontaine, Communications Officer

G. A. McLaughlin, Electronics Engineer

I&E BRANCH

James Hughes, Writer-Editor

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION, PORTLAND, OREGON:

W. C. Guy, Station Photographer

U. S. Department of Interior personnel who have made contributions to this research study are:

Ken Steen, in charge of Instrument Laboratory, Ross Substation, Bonneville Power Administration

Phil Collier, Instruments Coordinator