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

By

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Frontispiece--Typical appearance of Poria weirii root rot damage in a 30-year-old Douglas-fir stand. Note total deterioration of root systems on two large "downed" trees, as indicated by arrows. Infected pockets emanating from these foci continue to expand rapidly and to weaken and kill trees of all ages. Diseased trees with partial root systems are readily subject to both "rot throw" (note random falling pattern) and "wind throw." Even healthy trees on the periphery of large openings are frequently "wind thrown." Douglas-fir beetles frequently attack and expedite the killing of trees weakened by Poria weirii root rot.

ABSTRACT

Remote sensing research was continued in an effort to discriminate between healthy and Poria weirii infected Douglas-fir trees. Promising results were obtained this year in the thermal infrared (8.0 to 14.0 micron) band of the electromagnetic spectrum. Spectrometric tests conducted in the visible (0.4 to 0.7 micron) band and near infrared (0.7 to 0.9 micron) band indicate that properly selected black-and-white film-filter combinations have a high probability for separating healthy trees both from diseased trees without visible crown symptoms and from diseased trees with visible crown symptoms. Foliage samples were analyzed from 45 trees, representing three tree condition classes, three stand-age classes, and three seasons of collection. Data from a special multiband reconnaissance mission flown by a NASA Convair 240 aircraft are now being programmed for interpretation and analysis and results are not included in this report.

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The time and experience of many of these technical and professional scientists was willingly provided at no cost to NASA in the development of techniques and methods to solve the root rot disease problem that so vitally affects one of our major natural resources. Their contributions to this research study are gratefully acknowledged.

TABLE OF CONTENTS

The Development of Spectro-Signature Indicators
of Root Disease on Large Forest Areas

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INTRODUCTION

Multispectral remote sensing techniques show great promise as a means of appraising certain critical forestry problems that are of economic and physical importance. The research program conducted this year and described herein is a continuation and expansion of research started last year under NASA contract R-09-038-002 and reported under NASA-CR-78-781. In this research, remote sensing techniques are being developed and tested to evaluate a serious forest disease problem. The disease is caused by a fungus, Poria weirii, (Murro) that reduces tree growth and causes extensive losses of timber in the United States.

If these techniques will enable the forest manager to locate and identify centers of distressed timber that would otherwise be unsalvaged and would continue to spread, he will then be able to protect the forest resources more effectively and maximize the use of diseased timber. By such means remote sensing techniques could greatly reduce the serious impact of forest diseases on our world timber supply.

Continuing attacks and spread of Poria weirii root rot disease destroy or degrade approximately 170 million board feet of timber in the United States each year (Timber Resources Review, 1958). This represents more than half of all disease induced timber losses suffered in the United States. Heavy losses occur in extensive stands of Douglas-fir (Pseudotsuga menziesii (Mirb. Franco), a major commercial timber species of the Pacific Northwest, because of this disease (see Frontispiece). Disintegration of a tree's root system makes the tree subject to both "rot throw" and "wind throw."

Figure 1 shows the scattered distribution pattern of root rot centers. Generally these centers are relatively inaccessible and the timber volume affected in any given center is likely to be insufficient to warrant economic salvage. However, if the location of all such centers were accurately known at an early date the forest manager could remove economically all stages of diseased timber and thereby minimize spread of the disease.

The standard ground survey methods to locate and appraise centers of infection over large and frequently inaccessible mountainous terrain are costly and time consuming. "Ground truth" requires drilling trees (extracting increment cores, see Figure 2) or digging into root systems. Forty days are generally required for a 2-man crew to survey a single section (640 acres) of timbered land. New remote sensing techniques which the present research seeks to develop may provide much more efficient survey methods for locating and evaluating the incidence of root rot disease centers in forested areas.

During the period covered by this report, remote sensing research on Poria weirii root rot disease was continued in three spectral zones of the electromagnetic spectrum--visible, reflectance infrared, and thermal infrared. Some sampling techniques initiated last year were repeated on an expanded base. Major consideration was given to the multispectral capabilities of the NASA Convair 240 reconnaissance aircraft for providing data on the six research study plots in early August, 1967.

Figure 1.--Scattered open patches in the oblique view represent the typical root rot disease distribution pattern found in an 80-year-old stand of Douglas-fir in Washington. If other centers of infection adjacent to the openings were known, forest managers could make plans for economic salvage of distressed timber.

Figure 2.--Pathologist of U.S. Forest Service studies Poria weirii on increment cores taken from the stems of diseased and healthy Douglas-fir trees on research study plots. Two to four increment cores are taken of each dominant or codominant tree selected for inclusion as a sample tree. Darkened patterns represent root rot infections which have spread into the tree stems.

LITERATURE REVIEW

A search of the literature on Poria weirii root rot revealed few additional publications that were not included in the NASA-CR-78-781 report, as submitted during the previous year by the principal investigator. The additional references are given in the Bibliography. Further review was made of previously listed publications and reports as well as publications on other root rot diseases such as Fomes annosus and Phytophthora lateralis for insight on other survey techniques that might be applicable. T. W. Childs, a noted pathologist and authority in investigating Poria weirii root rot in the Northwest, was consulted for any new developments or techniques considered pertinent to this remote sensing problem, but he was unable to offer new suggestions on program orientation. He did indicate the need for more intensive field work to determine the rate of spread of this root rot disease underground, and to ascertain the amount of root deterioration required to kill Douglas-fir trees of various age classes.

JUSTIFICATION

Forest diseases create a greater destructive impact on our forest than either fire or insects. Forty-five percent of the growth loss in forested areas of the United States is attributable to diseases. Root diseases accounted for the loss of 300 million board feet of sawtimber in 1952 (Timber Resources Review, 1958). Such losses seriously affect our decreasing supply of timber and are of great concern to earth resource analysts.

Poria weirii root rot is by far the most destructive disease of Douglas-fir in Washington and Oregon. Douglas-fir is the most important timber species in the Pacific Northwest, representing fifty-seven percent of the total sawtimber volume in that region; hence an efficient root rot disease survey techniques would provide tangible benefits to the forest economy of the United States.

Land managers and foresters require adequate disease detection, as a first step toward reducing the impact of such diseases. Current research is directed toward the development of techniques for rapid and efficient disease detection surveys that may be used worldwide from orbital altitudes.

METHODS AND PROCEDURES

The research covered in this progress report is a continuation of the three phases begun last year. These three phases--spectrometric analysis of foliage, aerial photographic reconnaissance, and infrared heat sensing of individual trees--will be considered separately. A resume of the multisensor NASA "flyby" will be described.

A major addition to this year's program was the selection of a new test site near Elma, Washington. This new test site represents a forest growing condition of higher quality than the Wind River site near Carson, Washington. In terms of its timber-growing capacity, the new area is a low site II to high site III condition that has characteristics of better soil, more year-round moisture, and faster growth capabilities than the low site III to high site IV plots of the Wind River area. The research study consists of 90 trees on six 10-acre plots located in three stand-age classes on two different site conditions.

Fifteen trees in each of three stand-age classes, young growth (40 to 80 ft.), second growth (90 to 120 ft.), and old growth (130 to 225 ft.), were selected on the ground in the Elma test site area by a pathologist from the Insect and Disease Control Branch, Timber Management Div. R-6, U. S. Forest Service. Five were selected in each age class and tree condition class. The three classes used were (1) healthy, (2) root-rot-infected with no visible crown symptoms, and (3) infected with visible crown symptoms. The pathologist made positive determinations of the presence or absence of root rot disease by taking tree cores with an increment borer about six inches above ground level. Foliage color, length of needle, tree vigor, and general appearance were criteria for separating the two classes of diseased trees. The difference between healthy and diseased trees is clearly shown in the increment core samples (Figure 2). The darkened portion represents root rot infection. In some instances the root rot does not invade the stem of a Douglas-fir tree during the first several years of growth (see increment core sample that is second from the left in Figure 2).

More permanent and highly visible tree markers were fabricated and installed in the 90 test trees prior to actual aerial sampling from a helicopter or taking aerial photography this year. The new streamer markers, four 3-inch-wide strips (4 feet long) of highly fluorescent cloth (Figure 3) were attached to a heavy nylon cord with copper staples about 12 inches apart. A large washer was tied to each end of the cord and the strips were folded into a small packet that could be easily thrown from a helicopter into a tree top. Each streamer marker was a specific color that represented a particular tree condition class as follows: "yellow" for healthy trees; "orange flame" for diseased trees without visible crown symptoms; and "hot pink" for diseased trees with visible crown symptoms. Markers were thrown into the tree tops from a Hughes 300 helicopter flying at slow speed.

Figure 3.--Three colors of fluorescent cloth used in fabricating streamer markers for identifying individual trees in each tree-condition class--healthy(yellow), diseased without visible crown symptoms (flame orange), and diseased with visible crown symptoms (hot pink). Markers in the trees deployed from a helicopter, are visible for more than a mile.

These brilliantly colored markers were visible for more than a mile and were most helpful on the NASA "flyby" to pinpoint flight lines. Portable radios operating on U. S. Forest Service frequency provided good communications between ground and airborne personnel while re-marking trees particularly in the old-growth stands where dense brush frequently hid the ground personnel from view and in the dense young-growth stands. Radio communications on the Forest Service net also provided an excellent safety feature. Crash helmets were worn by the air crew (Figure 4) and fluorescent orange-colored hard hats were worn by the ground men. The same safety procedures as last year were followed.

A. Spectrometric analysis

A major effort has been made to improve the quality of light reflectance measurements in the .4 to 1.0 micron band of the electromagnetic spectrum on the foliage of healthy and diseased trees. The aerial photographic tone signature of a particular tree depends primarily on the amount of light reflected to the camera from the top of the tree within the spectral band used to take the photograph (Developments reported). Last years' report describes the special techniques and equipment for aerial sampling of tree top foliage by helicopter, the methods and procedures for collecting "ground truth" data, and the collecting and tabulating of reflectance data from the G. E. spectrophotometer.

Douglas-fir foliage was collected from 45 trees at three different sampling periods (overwintering, full new growth, and late summer hardening) at the Wind River test site last year. This intensity of sampling was considered adequate for statistical analysis to determine the best film-filter combination for discriminating healthy from diseased trees.

Figure 4.--Operator using a Barnes PRT-5 radiometer to record infrared heat emissions from individual trees. The helicopter is flown about 150 feet above the trees in a flat circling pattern around each specifically marked tree.

Consequently additional foliage samples from treetops were not obtained this year at either of the two test sites. The efficient helicopter sampling technique that was developed last year will be incorporated into future foliage collections as spectral analyses of foliage require. U. S. Forest Service, Pacific Southwest Forest Experiment Station Research Note 131 describes the special pole pruner and techniques for collecting treetop foliage samples.

Spectral reflectance curves from treetop foliage were derived from the G. E. spectrophotometer and programmed with 4 photographic films and 23 Eastman filter curves for the SANTAD, IBM 7094 Fortran IV computer program. This program utilizes the relationships between the spectral characteristics of black-and-white films, filters, and targets to predict what film-filter combinations are likely to produce unique tone values for each target feature that is to be identified. Although the spectrometric curves of foliage cover the .4 to 1.0 micron band of the electromagnetic spectrum, the SANTAD program was specific for the panchromatic (.4 to .7 micron band), and the black-and-white infrared (.7 to .9 micron band). The potentials of the Ektachrome and Ektachrome Infrared films have not been programmed as yet.

In the current SANTAD program a sample of reflectance curves is taken from each of the target populations. The predicted relative density is computed for each observation for a specific film-filter combination. Variance and the <u>t</u>-statistics are calculated for each pair of target populations. The higher the probability of <u>t</u> the more likely that there is a real difference between the densities of the two target populations. SANTAD saves the probabilities and goes on to a new film-filter combination. After exhausting all combinations SANTAD picks out one film and filter for each population pair, namely the one with the maximum probability of t for that pair. Probabilities of all other film-filter combinations are also printed. Tables 1, 2, and 3 list the top three film-filter combinations that are most likely to provide meaningful differences between the different tree-condition classes. These are discussed under RESULTS.

B. Aerial photography

A thorough assessment of aerial photographic imagery obtained at the three Wind River test-site plots in 1966 was performed by two U. S. Forest Service interpreters. The 1/2500 and 1/5000 scale photography, both Ektachrome Aero (.4 to .7 microns) and Ektachrome Infrared (.5 to .9 microns), was studied stereoscopically under 4X magnification using an Old Delft scanning stereoscope. No outstanding spectral signature indicators of the root rot infected trees could be discerned with any degree of certainty on either film type. Some slight differences in colors of tree crowns were noted by the interpreters but were considered subjective impressions rather than positive identifications of distressed trees.

Replicated photographic tests of the Wind River test site and Elma test site were scheduled for 1967. Photography from the U. S. Forest Service's Cessna 180 was to be obtained at 1/2500 scale using K-17 12-inch focal length camera with Ektachrome Infrared film and several promising black-and-white film-filter combinations (derived from the spectrometric analysis of foliage samples collected in 1966). Aerial photography was to coincide as much as possible with the infrared heat sensing of the 90 trees on the two test-site areas. Continuous cloudy and showery weather in May precluded suitable photographic conditions for securing the desired imagery. Photography in early July, scheduled to coincide with the early stages of new foliage growth, was scrubbed because no aerial photographer was available. This factor was not considered serious, however, because the scheduled NASA flight in August provided Ektachrome Infrared imagery and multispectral black-and-white photography with the 9-lens Itek camera of the six test plots. Early August photography probably is optimum since it coincides with the period of full succulent new growth of Douglas-fir foliage. Photography in late September with the U. S. Forest Service airplane and photographic equipment would record the appearance of the 90 trees for the late-summer hardening period. Processing, interpretation, and analysis of the NASA imagery have not been completed. Reporting of the photographic phase will be deferred until later.

C. Infrared heat sensing techniques

Tree vigor and availability of moisture in the tree crown for transpiration are two important factors governing the temperature of a tree. A tree of declining vigor caused by drought, partial destruction of root systems, or inability to absorb and transport moisture through the roots and stem to the tree crown frequently shows changes in physiological characteristics. Needle growth may be shorter, foliage color may be abnormal (desiccated or yellowish), and the tree in general may appear "sick." Trees in this condition are under severe moisture stress and may not be able to transpire as readily and stay as relatively cool as healthy trees. Reduced transpiration rate and vigor of a tree caused by root rot infection appear to affect the temperature of the tree at certain times of the day and seasons of the year. Plant physiologists cannot explain this phenomenon precisely but have good indications that "sick" trees having the above characteristics exhibit higher temperatures than healthy trees.

However, some diseased trees exhibit significantly lower temperatures than adjacent healthy trees. Consequently considerable tree physiological research is needed in various tree species and age classes to ascertain the reasons for differences in tree temperatures. The trees manifest this temperature difference by radiating in the thermal infrared portion of the electromagnetic spectrum.

The most encouraging preliminary result of the *Poria weirii* disease research in 1966 was that significant differences in infrared emissions occurred between healthy and diseased trees at certain times of the day. Temperature differences taken in the 8.0 to 14.0 micron band of the electromagnetic spectrum, between healthy and diseased trees (either with or without visible crown symptoms) were highly significant in the early morning. Only 15 second-growth Douglas-fir trees from a Wind River test-site plot had been used in the initial 1966 test with a Barnes PRT-4 radiometer. Further tests and replications were planned for 1967 with a PRT-5 radiometer to verify and corroborate these findings. The experiment was to extend to other Douglas-fir stand-age classes, site conditions, and times of the year when different tree moisture conditions could be expected.

1. Equipment

A Barnes Engineering Co. PRT-5 infrared heat sensing radiometer was secured for measuring infrared emissions from trees in different condition classes. The transistorized PRT-5 operates from either 110-volt a.c. or from three self-contained rechargable batteries. This feature greatly enhances the instrument's versatility in the field. Three temperature ranges are available: -20° to $+15^\circ$C., $+10^\circ$ to $+45^\circ$C., and $+40^\circ$ to $+75^\circ$C. Three ~~bandwidths~~ sensitivity ranges of 0.3, 3.0, and 30.0 may be selected for desired precision.

Accuracy of the PRT-5 is specified at $\pm$ 1/2° C. The effect of ambient air on temperature readings over the 8.0 to 14.0 micron band is supposed to be less than 1/4 of 1%.

The PRT-5 was synchronized with a 110-volt Varian G-11 recorder that had been modified to provide chart speeds of one inch and six inches per minute. A.C. power for the recorder was obtained through the helicopter's 12-volt d.c. battery to a Motorola T 101-6A converter (110-volt a.c., 60-cycle output).

The PRT-5 radiometer used was one of first manufactured by Barnes Engineering Co. and has required adjustments and recalibration for quality operational use. Some variations in signal output of the PRT-5 were experienced at different sampling periods which in turn affected the Varian recorder readings. Two recalibrations were made this summer. The Instrument Laboratory of the Bonneville Power Administration's Ross Substation, Vancouver, Washington, was most helpful in testing, synchronizing, and calibrating the two instruments for accurate recording of infrared emission data (Figure 5). Some fluctuation in 110-volt power to the Varian recorder from the small helicopter battery through the Motorola converter has been measured which is likely to affect infrared temperature readings. To eliminate this possibility a new type of chart recorder has been found that is compatible with the PRT-5 radiometer. The Cole-Parmer Mark VII recorder is transistorized and operates either from self-contained rechargable batteries or from 110-volt alternating current. The combination of two independently powered instruments should provide greater recording accuracy and increased flexibility for securing "ground truth" at remote field points. It is anticipated that the Barnes PRT-5 and the Mark VII can be collated at the factory this winter.

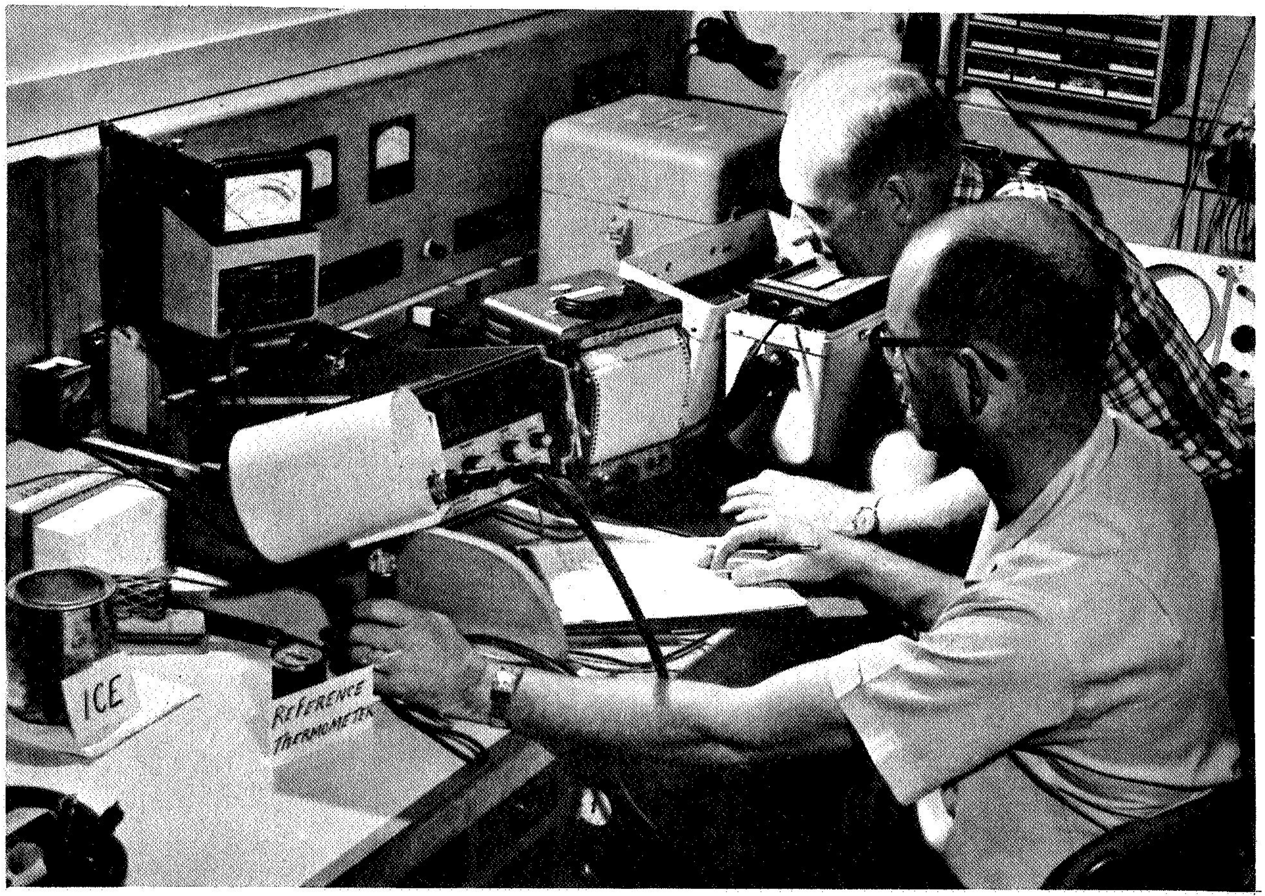


Figure 5.--Ross substation instrument laboratory personnel check accuracy of PRT-5 radiometer and correlate Varian recorder readings with PRT-5 radiometer output.

2. Scanning Techniques

Aerial scanning techniques of individual trees on the study plots were quite similar to those used last year. The PRT-5, Varian recorder, and power accessories were mounted in a Hughes 300 helicopter. A circular pattern was maintained around each tree at an elevation of approximately 150 feet above the tree canopy. At this height the optical head of the PRT-5, by scanning the conventional 3° cone, senses the thermal emissions from an 8-foot diameter area of tree crown. Sightings are concentrated within the upper 30 percent of the tree crown, but more than 10 feet down from the treetop. This technique minimizes the chance of including spurious temperature readings from other trees or openings. The high chart speed of the Varian recorder (6 inches per minute) was used while sighting on individual trees of a test-sight plot and switched to one-inch-per-minute chart speed while ferrying between plots.

3. Graph analysis

Temperature indications on the Varian charts at the six-inches-per-minute speed were readily spotted and tallied. To expedite the handling and tabulating of long rolls of data, a simple strip roller was devised and constructed (Figure 6). The temperature indications for each tree were averaged and converted to the actual Fahrenheit temperature.

D. NASA flyby

Mission 55 for the NASA 926 Convair 240A was scheduled and implemented during the week of August 14. Site 156 pertained to the application of multiple sensors of the electromagnetic spectrum to the Poria weirii root rot problem in the Pacific Northwest. The types of sensors to be employed in this aerial reconnaissance of Site 156 were limited to some extent by the findings of last year's research. The sensors that were

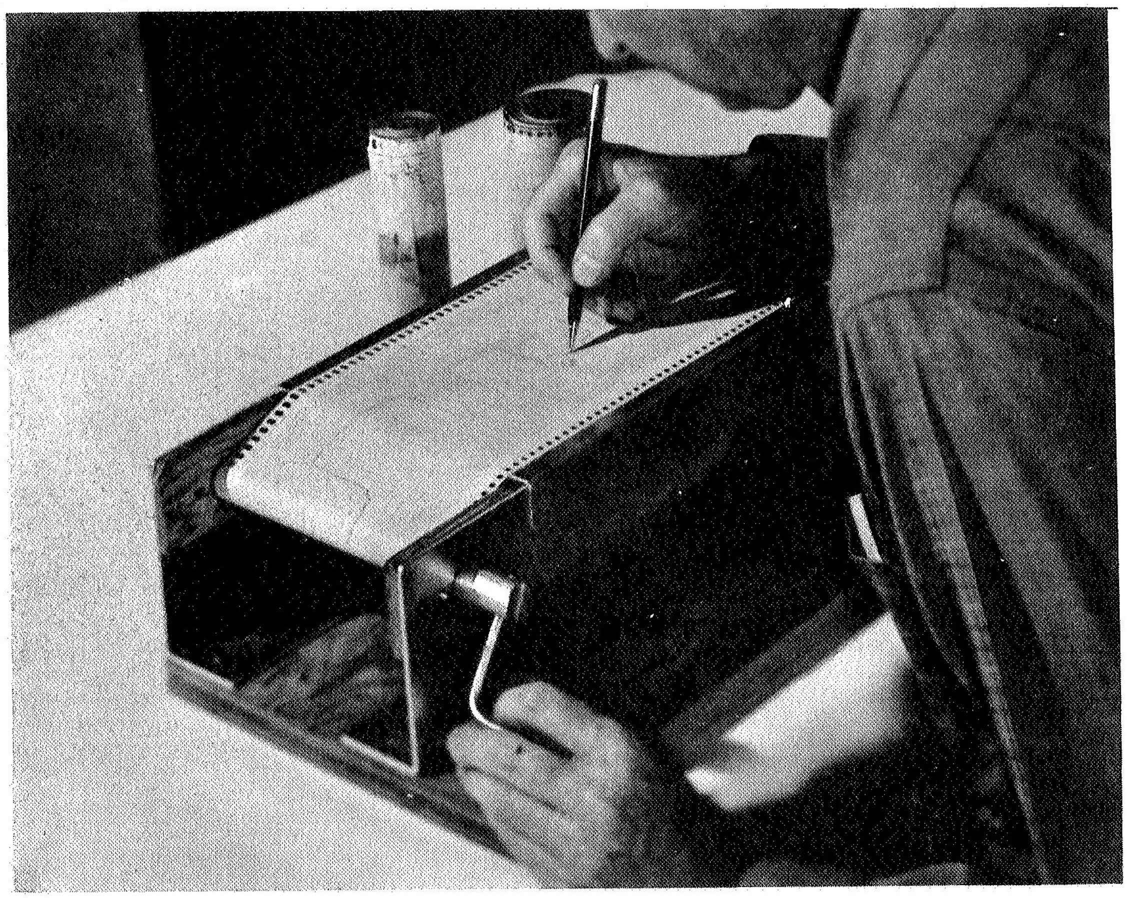


Figure 6.--Data from the Varian recorder chart rolls are easily tabulated when using this simple roller device. The temperature indications at systematic intervals are collected, averaged, and converted into a Fahrenheit temperature for each tree.

activated in NASA 926 for Site 156 are: (1) RC-8 aerial camera (9-by-9-inch format) with Ektachrome Infrared film, (2) 9-lens Itek camera (70 mm.) with black-and-white films and 9 filter combinations, (3) a Reconofax IV infrared imaging system, and (4) an AAS-5 two-channel U.V. detector using an S-11 photo multiplier with filter to pass all wave lengths below .405 microns, and an S-20 photo multiplier without filter to peak at .440 microns.

Prior to the NASA flyby an 8' x 36' resolution target (Figure 7) was constructed and installed at the Wind River test site, Line 1, to determine the spatial resolution capabilities of the various sensors assigned to the Site 156 program. Evaluation of the imagery at the resolution target would help to reveal the need for modifying subsequent technical procedures (film, filters, scale, etc.) and sensors to procure adequate definition of timbered areas of different tree heights, crown diameters and crown closures.

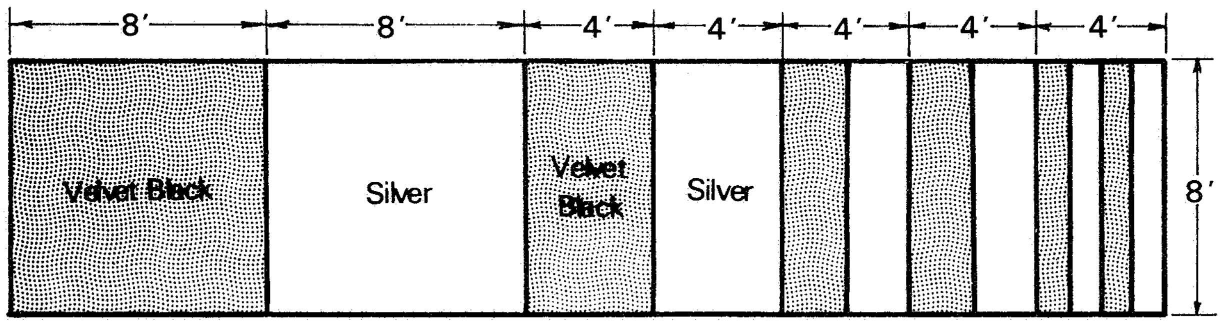
NASA 926 and the 8-man flight crew arrived in Portland on August 14. A late-evening briefing indicated that only two flight periods (0800 hours and 1200 hours) could be scheduled for August 15. A third flight at 1600 hours was scrubbed because of an overloaded flight schedule on the 16th. All sensors were considered operational to provide imagery on Site 156.

The principal investigator flew on the missions to help orient the flight crew on target areas in the rough mountainous terrain. He was completely familiar with all areas both as a photopilot with the U. S. Forest Service and infrared radiometer operator on all plots sensed from helicopters. Considerable flight time for the NASA 926 was saved by his being able to locate line strips with minimal search time.

A cursory inspection of part of the preliminary flight data for Site 156 has been made. It is doubtful that satisfactory coverage or adequate

Figure 7.

Resolution Target for NASA Convair 240 Flyby



Four feet by eight of Celotex fibre board covered with paper-backed foil and alternately painted with 3M velvet black paint.

imagery for detailed analysis can be provided to discriminate between specific trees on the study plots at this time. More detailed interpretation and analyses of these data will be made in the coming months and results given in subsequent progress reports.

RESULTS

The investigations this year of three portions of the electromagnetic spectrum in the visible, reflectance infrared, and thermal infrared bands for differentiating healthy Douglas-fir trees from those infected with Poria weirii root rot provided both tangible results and some promising leads. The spectrometric analysis of foliage taken from the top of dominant trees via helicopter will be considered first. The infrared heat sensing of different tree-condition classes and stand-age classes will be considered second. No results from the NASA flyby are available at this time.

A. Spectrometric analysis

The SANTAD computer program analyzed the reflectance curves from the foliage samples in terms of the corresponding tone values that these reflectances would produce with 23 filter types, when used in conjunction with four film types. The film types were Orthochromatic, Panchromatic Plus-X, Panchromatic Super-XX, and black-and-white Infrared Aerographic. Foliage collections had been made at three different periods corresponding to three different tree moisture conditions (i.e., those prevailing during overwintering, full new growth, and late-summer hardening) to determine any significance in season of the year for discriminating healthy from diseased trees. Tables 1, 2, and 3 represent data from the three sampling seasons. The film-filter combinations showing the best probability of separating different tree-condition classes are listed in order of decreasing promise.

Table 1.--Black-and-white film filter combinations showing best probability in effectiveness of discriminating healthy from diseased trees. In each instance the three combinations are listed in order of decreasing suitability.

Overwintering foliage condition--second growth stand

1. To differentiate healthy trees from diseased trees <u>without</u> symptoms:
    a. Orthochromatic film with WR-90 filter
    b. Orthochromatic film with WR-15 filter
    c. Orthochromatic film with WR-12 filter
2. To differentiate healthy trees from diseased trees <u>with</u> symptoms:
    a. IR film with WR-87C filter
    b. IR film with WR-47B filter
    c. IR film with WR-2C filter
3. To differentiate healthy trees from <u>both</u> types of diseased trees:
    a. IR film with no filter
    b. Orthochromatic film with WR-15 filter
    c. Orthochromatic film with WR-90 filter
4. To differentiate diseased trees <u>without</u> symptoms from diseased trees <u>with</u> symptoms:
    a. Orthochromatic with no filter
    b. Orthochromatic with WR-2C filter
    c. Orthochromatic with WR-8 filter

Table 2.--Black-and-white film filter combinations showing best probability in effectiveness of discriminating healthy from diseased trees. In each instance the three combinations are listed in order of decreasing suitability.

New spring growth condition--second-growth stand

1. To differentiate healthy trees from diseased trees without symptoms:

   a. Plus X film with WR-89B filter

   b. Orthochromatic film with WR-61 filter

   c. Plus X film with WR-61 filter

2. To differentiate healthy trees from diseased trees with symptoms:

   a. Plus X film with WR-89B filter

   b. Super XX film with WR-89B filter

   c. Plus X film with WR-29 filter

3. To differentiate healthy trees from both types of diseased trees:

   a. Plus X film with WR-89B filter

   b. Orthochromatic film with WR-61 filter

   c. Plus X film with WR-61 filter

4. To differentiate diseased trees without symptoms from diseased trees with symptoms:

   a. Super XX film with WR-29 filter

   b. Super XX film with WR-25 filter

   c. Super XX film with WR-30 filter

Table 3.--Black-and-white film-filter combinations showing best probability in effectiveness of discriminating healthy from diseased trees. In each instance the three combinations are listed in order of decreasing suitability.

Summer hardening condition--second-growth stand

1. To differentiate healthy trees from diseased trees without symptoms:

   a. Orthochromatic film with WR-35 filter

   b. Super XX film with WR-47B filter

   c. Orthochromatic film with WR-47B filter

2. To differentiate healthy trees from diseased trees with symptoms:

   a. IR film with WR-47B filter

   b. IR film with WR-35 filter

   c. IR film with WR-89B filter

3. To differentiate healthy trees from both types of diseased trees:

   a. Orthochromatic film with WR-35 filter

   b. Super XX film with WR-47B filter

   c. Orthochromatic film with WR-47B filter

4. To differentiate diseased trees without symptoms from diseased trees with symptoms

   a. IR film with WR-89B filter

   b. IR film with WR-29 filter

   c. IR film with WR-25A filter

The tables apply only to the trees in the second-growth stand. Slight discrepancies in the data from the other stand-age classes precluded a perfect SANTAD analysis.

It is interesting to note that there is no consistent film-filter combination for the three moisture periods of the year. Each season has its own particular grouping of film-filter combinations. For the over-wintering foliage condition the separation of healthy trees from both types of diseased trees is most likely to be accomplished by using infrared film with no filter. Orthochromatic film shows greater promise for separating healthy from diseased trees without symptoms while infrared film would appear best for diseased trees with visible symptoms.

During the new spring growth period Panchromatic Plus-X film with a Wratten 89B filter would be best for separating healthy trees from both types of diseased trees. During the summer hardening period the best probability for separating healthy trees from both types of diseased trees would be through the use of Orthochromatic film with a Wratten 35 filter. It is likewise the best probability for separating the healthy trees from the diseased trees which do not exhibit visible crown symptoms.

B. Infrared heat sensing

Satisfactory infrared heat sensing readings with a nonimaging PRT-5 radiometer have been obtained at two periods of moisture condition: May 25 and July 22, 1967. A third sample will be taken in early October, 1967 to complete the series. An analysis of variance for the radiometer readings of the 45 trees at the Wind River test site was programmed for the IBM 7040 computer at the Dept. of Interior Bldg., Portland, Oregon. The program tested the significance of data collected from 15 trees in each of three stand-age classes (young growth, second growth, and old growth), three tree condition classes (healthy, diseased trees without symptoms, and diseased trees with symptoms).

Table 4 summarizes the results of the test of significance for the two sampling periods (May and July) for morning, noon and late afternoon readings, and for three stand-age classes; young growth, second growth, and old growth. The July morning readings indicate the highest potential of providing differences between trees of the three different condition classes in all three stand-age classes. In May the second-growth stand shows significant differences between healthy and diseased in the early morning while the old-growth trees register highly significant temperature differences between trees at noon. Results of the second-growth data for May coincide with the data obtained last year with the PRT-4 (NASA-CR-78-178). Radiometer readings on other age classes were not obtained last year.

Tables 5 through 10 show the temperature readings for all trees included in the analysis for the test of significance. Table 5 shows that the average temperatures of all healthy trees in each stand-age class are lower than those of diseased trees, and are highly significantly different in the second-growth stand. At noon (Table 6) only the old-growth stand has a highly significant difference (diseased trees warmer). Table 7 for the late afternoon period shows no significant differences. Table 8 for morning readings in July indicates healthy trees are somewhat warmer than diseased trees. There are no explanations for this apparent reversal. It is highly significant in the young-growth stand but only significant in the second- and old-growth stands. Noon readings for the young-growth stands are significantly higher for the diseased trees. Differences

Table 4. Test of Significance for Infrared Heat Sensing Parameters on Three Douglas-fir Age Groups, at Three Periods of the Day, and at Two Tree Growth Periods.

May

Age Group	A.M.	Noon	P.M.
Young Growth	n.s.	n.s.	n.s.
Second Growth	**	n.s.	n.s.
Old Growth	n.s.	**	n.s.

July

Age Group	A.M.	Noon	P.M.
Young Growth	**	*	n.s.
Second Growth	*	n.s.	n.s.
Old Growth	*	n.s.	*

** Highly Significant
* Significant
n.s. Non-significant

Table 5.--Temperatures in degrees Fahrenheit of healthy and *Poria weirii* infested trees scanned by a Barnes PRT-5 radiometer, Wind River test site, May 25, 1967.

	Healthy		Diseased without	Diseased with
Young Growth		8:45 am		
	53.5		53.8	56.4
	54.0		53.6	57.4
	54.5		57.6	58.5
	56.4		55.2	58.0
	55.0		57.2	55.4
average	54.68		55.48	57.14
Second Growth		7:50 am		
	50.7		50.0	50.7
	49.2		53.6	50.3
	46.0		53.1	50.9
	47.0		53.3	53.7
	50.1		52.6	53.4
average	48.59		52.71	51.79
Old Growth		8:15 am		
	52.5		50.8	52.8
	51.6		53.5	54.4
	52.2		54.6	54.2
	53.1		53.6	51.4
	51.5		52.5	53.2
average	52.18		53.0	53.20

Table 6.--Temperatures in degrees Fahrenheit of healthy and *Poria weirii* infected trees scanned by a Barnes PRT-5 radiometer, Wind River test site, May 25, 1967.

	Healthy		Diseased without	Diseased with
Young Growth		12:45 pm		
	68.0		66.8	69.8
	69.9		69.9	66.7
	68.0		69.6	64.7
	66.8		67.2	69.7
	66.7		67.1	68.0
average	67.88		68.12	67.78
Second Growth		12 noon		
	65.0		65.6	63.7
	66.0		62.3	63.5
	64.0		63.0	62.6
	63.9		63.2	63.0
	62.9		63.1	63.5
average	64.36		63.44	63.26
Old Growth		12:20 pm		
	59.0		61.8	62.1
	60.4		62.3	60.5
	57.3		61.7	61.7
	56.3		61.4	62.4
	56.3		60.7	63.9
average	57.86		61.58	62.12

Table 7.--Temperatures in degrees Fahrenheit of healthy and *Poria weirii* infested trees scanned by a Barnes PRT-5 radiometer, Wind River test site, May, 1967. Trees in overwintered condition.

	Trees Healthy	Trees with Poria No visible symptoms	Trees with Poria Visible symptoms
Young Growth		4:20 pm Readings	
	67.6	67.1	68.3
	67.6	67.1	69.1
	67.6	67.3	67.2
	68.3	67.7	67.2
	68.5	67.6	67.4
average	67.92	67.36	67.84
Second Growth		4:00 pm Readings	
	67.8	67.8	68.9
	67.8	68.8	68.8
	67.7	68.1	67.9
	67.7	67.9	67.6
	67.6	67.5	68.0
average	67.72	68.02	68.24
Old Growth		4:45 pm Readings	
	63.0	62.6	62.6
	62.6	62.0	63.0
	63.8	62.0	63.5
	63.5	62.0	62.0
	63.4	63.2	63.8
average	63.26	62.36	62.98

Table 8.--Temperatures in degrees of Fahrenheit of healthy and *Poria weirii* infested trees scanned by a Barnes PRT-5 radiometer, Wind River test site, Trees at total new growth for 1967. Data collected July 22, 1967

	Trees Healthy	Trees with *Poria* No visible spymtoms	Trees with *Poria* Visible symptoms
Young Growth	8:15 am Readings		
	63.9	61.1	62.1
	63.6	59.8	63.9
	64.2	63.7	60.9
	65.1	62.1	61.0
	64.7	61.7	62.5
average	64.30	61.68	62.08
Second Growth	8:00 am Readings		
	57.6	56.8	58.1
	59.4	56.0	57.3
	58.6	57.8	57.8
	59.2	58.5	57.9
	59.6	57.8	57.9
average	58.88	57.38	57.80
Old Growth	8:45 am Readings		
	60.1	57.3	59.8
	58.7	59.5	59.2
	59.7	58.7	59.8
	60.3	59.2	60.4
	59.0	58.7	60.3
average	59.56	58.68	59.90

between trees in the second-and old-growth stands at noon are non-significant (Table 9). Finally, Table 10 reveals no significant temperature differences in young growth and second growth in late afternoon but significant temperature differences in old growth at this time.

DISCUSSION AND RECOMMENDATIONS

The application of remote sensing techniques to the forestry problem of discriminating healthy trees from those infected with a serious root rot has provided some very encouraging results this year. The analysis of spectral reflectance data from Douglas-fir foliage and various film-filter combinations in the black-and-white (.4 to .9 micron band) portions of the visible spectrum indicates several high probability photographic materials that might be effective in solving this forest survey and protection problem. It is anticipated that several of the black-and-white film-filter combinations will be programmed for the two test sites this coming year. In addition, Ektachrome Infrared film will be tested since there are some indications that the infrared portion of the electromagnetic spectrum may differentiate subtle tone indicators of trees under stress. If further statistical analysis of foliage reflectance data indicates the need for further replications, especially of foliage samples in the young-growth and old-growth stand classes, additional helicopter samplings will be scheduled this next year at the Wind River test site and in all age classes at the Elma test site.

Infrared heat sensing techniques, using an airborne nonimaging radiometer, show the most promise in developing a practical survey method for the forest manager to assess the impact of *Poria weirii* root rot disease in Douglas-fir stands. Highly significant temperature differences were recorded at certain seasons of the year and at various times of the day.

Table 9.--Temperatures in degrees Fahrenheit of healthy and *Poria weirii* infested trees scanned by a Barnes PRT-5 radiometer, Wind River test site. Trees at total new growth for 1967. Data collected July 22, 1967

	Trees Healthy	Trees with *Poria* No visible symptoms	Trees with *Poria* Visible symptoms
Young Growth	12:15 pm Readings		
	83.6	84.7	82.2
	80.0	84.6	83.4
	80.3	82.2	83.8
	80.0	81.3	83.4
	80.0	82.2	82.6
average	80.78	83.00	83.08
Second Growth	12:30 pm Readings		
	82.5	82.8	84.6
	83.2	83.5	83.0
	83.8	83.0	82.6
	83.1	83.1	81.4
	83.5	83.7	81.6
average	83.22	83.22	82.64
Old Growth	12:00 pm Readings		
	74.4	74.2	77.0
	76.1	75.0	75.1
	75.2	74.2	74.0
	75.2	75.1	74.2
	76.3	77.0	76.9
average	75.44	75.10	75.44

between trees in the second-and old-growth stands at noon are non-significant (Table 9). Finally, Table 10 reveals no significant temperature differences in young growth and second growth in late afternoon but significant temperature differences in old growth at this time.

DISCUSSION AND RECOMMENDATIONS

The application of remote sensing techniques to the forestry problem of discriminating healthy trees from those infected with a serious root rot has provided some very encouraging results this year. The analysis of spectral reflectance data from Douglas-fir foliage and various film-filter combinations in the black-and-white (.4 to .9 micron band) portions of the visible spectrum indicates several high probability photographic materials that might be effective in solving this forest survey and protection problem. It is anticipated that several of the black-and-white film-filter combinations will be programmed for the two test sites this coming year. In addition, Ektachrome Infrared film will be tested since there are some indications that the infrared portion of the electromagnetic spectrum may differentiate subtle tone indicators of trees under stress. If further statistical analysis of foliage reflectance data indicates the need for further replications, especially of foliage samples in the young-growth and old-growth stand classes, additional helicopter samplings will be scheduled this next year at the Wind River test site and in all age classes at the Elma test site.

Infrared heat sensing techniques, using an airborne nonimaging radiometer, show the most promise in developing a practical survey method for the forest manager to assess the impact of Poria weirii root rot disease in Douglas-fir stands. Highly significant temperature differences were recorded at certain seasons of the year and at various times of the day.

In the late afternoon tree temperature differences of healthy and diseased trees are largely nonsignificant so that further testing at this period of the day should be omitted in the future. Infrared heat sensing readings of the Elma test site have not been obtained for the three stand-age classes at the three sampling periods of tree moisture condition. It is recommended that data on this test site be given high priority this coming year so that valid comparisons can be made between the two different tree growing condition classes at the Wind River test site (low site III, high site IV) and the Elma test site (low site II, high site III).

Considerable improvement in recording tree temperatures with the PRT-5 radiometer should be possible when the Mark VII Cole-Parmer recorder is synchronized with the PRT-5. The self-contained battery system of the Mark VII will provide extensive use for all types of airborne and ground operations.

In an effort to determine the potential of infrared heat sensing techniques to other timber types, an exploratory ground test was made with the PRT-5 to measure temperature differences of several lodgepole pine trees. The trees were infected with root rot disease. Readings were taken of the crowns at various levels and on several sides (bright sunlight and shade) and of the tree trunks. Differences in temperature readings were apparent but data was insufficient for statistical reliability. The feasibility of this ground approach should be studied in an effort to expedite gathering of "ground truth."

Remote sensing research on survey techniques for Poria weirii root rot disease this coming year anticipates the application of the most promising results, infrared heat sensing in the 8.0 to 14.0 micron band to a survey scan of a section of land (640 acres) in north central Washington. An attempt will be made to couple the Barnes PRT-5 and Cole-Parmer Mark VII chart recorder with an Ampex video instant replay system (VR6000 recorder **and** 6400 video camera) to grid the square mile of forest land. The various instruments would be mounted in a Bell GS-B1 or Hiller 12E helicopter and flown 150 to 250 feet above the forest canopy to develop and evaluate various survey techniques. "Ground truth" of the test area would be provided by cooperative effort of the U. S. Forest Service, state, and private timber interests.

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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:

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

Ken Steen, In charge of Instrument Laboratory, Ross Substation,
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Phil Collier, Instruments Coordinator

Max Holder, Instrument Technician