REMOTE SENSING APPLICATIONS IN FORESTRY

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

by

R. C. Heller
R. C. Aldrich
W. F. McCambridge
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

For

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

REMOTE SENSING APPLICATIONS IN FORESTRY

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

by
R. C. Heller
R. C. Aldrich
W. F. McCambridge
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

For

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

Frontispiece.--An oblique view of a portion of the Black Hills Beetle study area looking from east to west toward Spearfish Canyon. Over two thousand ponderosa pine trees have been killed in this small drainage since 1967. The green-yellow trees are pines killed by beetle attacks in August, 1968; red trees were killed in 1967. The larger infestations (1) can be seen on simulated space photography (1:174,000 scale); smaller infestations (2) are not resolved--primarily because of low contrast with the surrounding healthy pine trees at higher altitudes.

obtained.

The 15-channel optical-mechanical scanner data collected by the University of Michigan aircraft in May 1968 were processed and interpreted by several techniques. Ten channels of spectrometer data were processed in the University of Michigan, Infrared and Optics Laboratory's analog multispectral processor. Four color coded film strips were produced by the processor to represent each of four tree condition classes. These films showed a good relationship in the faded uninfested condition class between actual number of trees on the ground and number of recognized targets.

Individual waveband analysis showed discriminating wavebands for "old kill" and faded infested trees. However, it required all 10 channels to detect nonfaded (previsual) infested trees. An analysis of 5 individual channels of reflected and thermal infrared data showed that the 2.0 to 2.6 micron channel should lead to a significant improvement in identifying nonfaded infested trees if it could be added to the multispectral analysis.

Of three single-channel infrared processing techniques, the gated analog method with reference-plate clipping resulted in the best information for locating "previsual" beetle-attacked trees.

The Purdue University LARSYSAA target discrimination program was modified to recognize six forest cover-type classifications. Five multispectral channels were found that would discriminate between these six classifications. As a result, faded (discolored) bark beetle trees were accurately detected in wavelengths shorter than 1.0 micron. However, nonfaded infested pine trees (previsual) could not be classified solely

on the basis of the 10-channel spectrometer data. Adding middle infrared (reflected) and thermal infrared channels may help make this discrimination possible in the future.

ACKNOWLEDGMENTS

This experiment is being 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. This is the fourth progress report of a cooperative study with the Forest Service, U. S. Department of Agriculture. The study involves two Forest and Range Experiment Stations, one Region, and one Area: the Pacific Southwest at Berkeley, California; the Rocky Mountain at Fort Collins, Colorado; Region 2, Denver, Colorado; the Southeastern Area, Atlanta, Georgia. Salaries of all professional employees are being contributed by the Forest Service.

We wish to thank the Homestake Mining Company, Anaconda Copper and Mining Corporation, and the Bureau of Land Management, U. S. Department of Interior, for the use of their land and timber to conduct the study.

The Spearfish and Nemo District Rangers of the Black Hills National Forest have been very helpful in providing vehicles, darkroom facilities and field equipment.

We are particularly grateful to Dr. Roger Hoffer of the Laboratory for Agricultural Remote Sensing (LARS), Purdue University, Lafayette, Indiana, for the use of the LARSYSAA digital recognition program, computer facilities, and professional guidance during the processing of 10-channel spectrometer data for the Black Hills test site.

The multispectral processing programs and results used in this report were excerpted from the doctoral dissertation by F. P. Weber which has been submitted to the School of Natural Resources, University of Michigan, Ann Arbor, Michigan.

The aerial photography used in this study and all color and black-and-white reproductions used throughout this report were skillfully produced by Richard J. Myhre, Research Forestry Technician.

We would also like to thank both Mr. Myhre and Wallace Greentree, Forestry Technician, for all photo interpretation work connected with this study.

TABLE OF CONTENTS

THE USE OF MULTISPECTRAL SENSING TECHNIQUES TO DETECT PONDEROSA PINE TREES UNDER STRESS FROM INSECTS OR DISEASES

by

R. C. Heller, R. C. Aldrich
W. F. McCambridge, and F. P. Weber

INTRODUCTION

The need to detect and locate insect infestations before epidemics get started is still a pressing one. For example, during the winter and spring of 1968-69, about 22,000[1] ponderosa pine trees in the Black Hills of South Dakota were searched out, cut down, and either sold as forest products or burned to reduce bark beetle populations. This represented a major effort for the Black Hills National Forest which spent $190,000[1] up to August 10, 1969, to control infestations in the most accessible areas. If environmental conditions favorable to beetle development continue during 1969-70, a two- to threefold increase in tree loss and control costs is possible.

Remote sensing techniques developed from NASA studies conducted during the past three years permitted us to derive estimates of timber loss in the Black Hills for 1969. Using recommendations from the September, 1968 report, we photographed ten 10-mile-long sample strips with color film at a scale of 1:8,000. Mortality estimates were based on a combination of photo interpretation and ground visits--using probability sampling proportional to prediction of tree loss. This kind of survey proved to be more efficient, more rapid, and less costly than ground surveys having the same accuracy of estimate.

---

[1] Information furnished by personal communication with Supervisor's Office, Black Hills National Forest, Custer, South Dakota.

Most of the ground investigations of spectral reflectance, emission temperatures, and physiological data were completed in 1968 (Heller et al, 1967; Heller et al, 1968). We found that spectral differences between healthy and dying trees could be resolved on color films. We also discovered that temperature differences of 2° to 6°C occurred at certain times during the day before visual symptoms showed up (in May--8 months after beetle attack). We made some additional apparent emissive temperature measurements from foliage of dying and healthy trees in August, 1969; those were taken at the time of the overflights by the University of Michigan airplane equipped with the 17-channel scanner.[2/]

The main efforts during the past year were directed toward: (1) establishing optimum altitudes, scales and films for making bark beetle surveys over large areas, (2) simulating space photography to learn at what scales large infestation centers are still visible, and (3) processing and interpreting 15 channels of scanner data collected by the Willow Run Laboratories in May, 1968.

LOCATION OF STUDY AREAS

The same two study areas (Fig. 1) reported in the September, 1968 progress report were used again this year. The optical-mechanical scanner imagery (15-channel multispectral scanner) was obtained over Area I in May, 1968. Area I was a highly instrumented site where physiological and meteorological data were collected. All of our efforts to

---

[2/] The multispectral scanner from the University of Michigan, IROL, is operated from a C-47 aircraft and breaks up the spectrum into 17 discrete wavebands from 0.4 to 13.8 microns. The first 12 (.40 to 1.0 micron) are in near-perfect registration; the near IR and thermal bands are not. Only 15 of the 17 wavebands can be recorded at one time.

spectral [illegible]

captures, and other [illegible] data were [illegible] 1969; Heller et al. 1958). We found that [illegible] very healthy and dying trees [illegible] also discover at that temperature [illegible] certain times during the day [illegible] 3 months after beetle attack [illegible] contrasts were recorded [illegible]

[illegible] University of Michigan [illegible]

The data [illegible] (1) early [illegible] beetle surveys over [illegible] learn [illegible] (3) properly [illegible] and [illegible] by the [illegible] low [illegible] laboratories [illegible]

[illegible] courtesy report were used [illegible] multispectral [illegible] scanner imagery [illegible] channel [illegible] Area 7 in May 1980. Area 1 was [illegible] logical and meteorological [illegible]

---

* The multispectral scanner from the University of Michigan [illegible] it operated from a C-47 aircraft and breaks up the spectrum into 17 [illegible] wavelengths from 0.4 to 13.5 micrometers. The first 12 [illegible] near-perfect registration [illegible] of the 17 [illegible] bands can be recorded at one time.

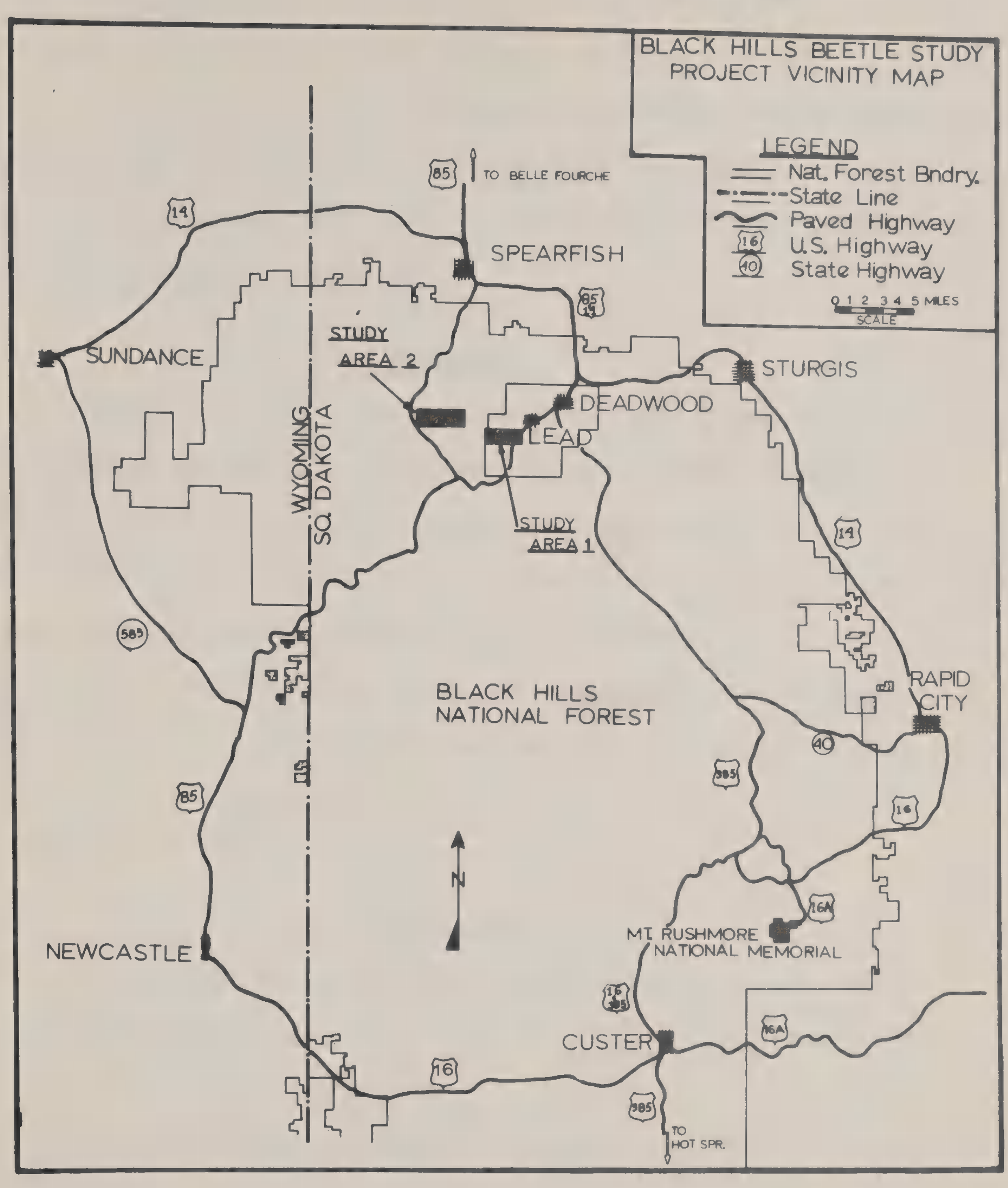


Figure 1. Study Areas I and II near Lead, S. D. Study Area I is the site of the multispectral flight conducted in May, 1968. Study Area II (1 x 3 miles) is representative of an area where no beetle control efforts were expended. All photographic scale tests were conducted over Area II.

the present time to process this multispectral imagery were made with airborne data collected over this site.

Study Area II is nearly rectangular and covers one by three miles. All film and scale tests were made over this site. It is an area in the Black Hills where no beetle control efforts were expended nor forest management practices exercised.

PROCEDURES

As mentioned above, most of the effort during this reporting year was spent in processing and interpreting the 15-channel imagery taken in May, 1968. During July and August, 1969, we took, processed and interpreted color and color infrared 70mm photos of Study Area II at medium and very small scales (1:8,000 to 1:174,000). At the time of photography in mid-July, multispectral imagery was collected from three altitudes; however, no processing and analysis are yet available to report.

AERIAL

Photography

The Forest Service Aero Commander was used to get all 70mm aerial photography. The following scales and films were obtained on July 21, 1969:

			SCALES			
FILM (FILTER)	1:8,000	1:16,000	1:32,000	1:64,000	1:128,000	1:174,000
Anscochrome D/200 (HF-3)	X	X	X	X	X	X
Ektachrome Infrared (Wratten 12)	X	X	X	X	X	X
Anscochrome D/200 (Wratten 12)			X			
Plus X (A-25)			X			

On August 7, a NASA-sponsored flight with an RB-57 airplane flew two north-south flight lines over the insect-infested areas of the Black Hills.

The following camera and film-filter combinations were used from very high altitude (54,000 feet above ground level):

	CAMERAS	FILMS	FILTERS	EXPECTED SCALES
1.	Hasselblad (80mm)	8442 (color)	2A	1:216,000
2.	Hasselblad (80mm)	8442 (color)	12	1:216,000
3.	Hasselblad (80mm)	8443 (IR color)	15	1:216,000
4.	Hasselblad (80mm)	3400 (Pan)	25A	1:216,000
5.	Hasselblad (80mm)	3400 (Pan)	58B	1:216,000
6.	Hasselblad (80mm)	2424 (IR)	89B	1:216,000
7.	RC 8 (6")	8442 (color)	HF-3	1:108,000
8.	RC 8 (6")	8443 (IR color)	15	1:108,000
9.	Zeiss (12")	8443 (IR color)	15	1:54,000

The RS-7 thermal scanner (8.0-14.0 microns) was also operating during the photography. Duplicates of the photo coverage will be forwarded from the Manned Spacecraft Center as soon as they become available (probably October, 1969).

Multispectral Scanning Imagery

On July 22-23, the Michigan optical-mechanical scanner was flown over one flight line 2 miles long (Fig. 2). Four diurnal periods were selected:

(Times are local sun time)

1. 0730 - 0830
2. 1000 - 1100
3. 1230 - 1330
4. 1430 - 1530

During each time period, imagery was taken from 3 altitudes above ground (mean elevation 6,000 feet)--1,500 feet, 5,000 feet, and 7,000 feet. Only a 13,000 foot altitude was attainable with the Michigan aircraft under

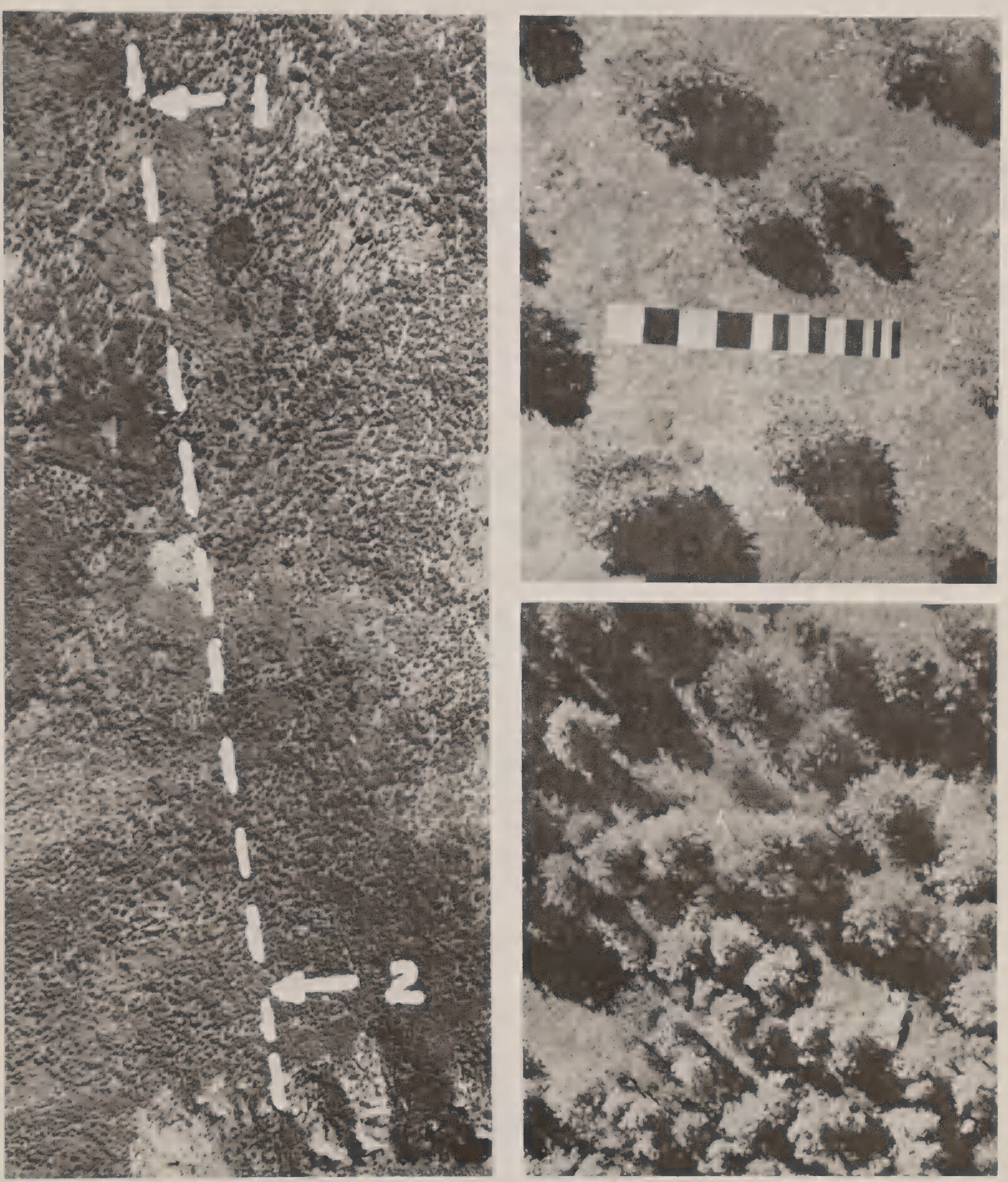


Figure 2. Location of flight line selected for the 17-channel multispectral scanner west of Lead, S. D. The thermal resolution target (upper right) was set up at location 1. The 70-foot tower (lower right) was erected at location 2. Some of the newly discolored trees appear on this July date.

its present loading configurations and with the likelihood of electronic equipment failures and loss of liquid helium above 13,000 feet in an unpressurized environment. A total of 36 flight runs were conducted during the two days.

GROUND

Temperature Emission Measurements

A precision radiation thermometer (Barnes PRT-5) was used from the top of a 70-foot steel tower which was erected along the edge of one Black Hills beetle infestation (160 dying pines). The foliage of one healthy and three infested trees was monitored during all flight runs so that temperature correlations might be established later on the thermal imagery. The temperatures of the foliage were relayed to the aircraft via handy-talky radios. This information permitted the technicians in the aircraft to set the hot and cold calibration plates on the thermal scanner around the foliage temperatures.

Apparent emitted temperatures (radiometric) were also obtained for the forest floor in the sun and shade. Between flight periods, readings with the PRT-5 were obtained of a specially built thermal resolution target with black and aluminum surfaces. Surrounding rocks and the sunlit ground vegetation were also monitored for temperature.

Weather conditions for the flights were ideal; more than 80 percent of the runs were under clear skies and warm temperatures.

INTERPRETATION OF COLOR AND INFRARED COLOR PHOTOS

Photo interpretation (PI) was completed before any ground work was started so that the interpreters would not be biased in their photo

interpretations. Aerial photos were taken on July 21 and two interpreters completed the photo interpretation August 8. The "ground truth" was done from August 11-15. We found that some of the foliage changed color from green to yellow during this interim period. Reconciliation of the PI data with the ground data and the PI analysis was completed by mid-September.

Photo Interpretation, Collection of Ground Data, and Reconciliation of Both

Photo Interpretation

All films were edited by delimiting the boundaries of the study area, marking the edges of sidelap and overlap on the transparencies and numbering all flight lines and photos.

The smallest scale (1:174,000) photos were interpreted first--the largest scale (1:8,000) last. To assure that each film had an equal chance to be examined first, the interpretation order was randomized. Beginning at the 1:32,000 scale, where more than one flight line was needed to cover the study area, flight lines and films were randomly selected. On alternate photos in the roll, each interpreter made a template on which he plotted, numbered, and counted trees within all suspected Black Hills beetle infestations. These templates were compared with the "ground truth" following the ground examination. Two interpreters examined all photo coverage.

The amount of photo handling decreased as the scales became smaller, but, except in one case (1:63,000), the reduction never reached the expected 4:1 ratio (Table 1). That is, as scale is doubled, area increases fourfold.

TABLE 1: Number of photo templates required by scale for interpretation of a 1- by 3-mile area.

	FLIGHT LINE						RATIO TO NEXT LARGER SCALE
SCALE	1	2	3	4	5	TOTAL	
1:7,920	13	15	13	13	13	67	--
1:15,840	8		8		8	24	2.8:1
1:31,680		4		4		8	3:1
1:63,000			2			2	4:1
1:126,000			1			1	2:1
1:174,000			1			1	1:1

The two smallest scales (1:126,000 and 1:174,000) more than adequately covered the area with three photos and should not be considered in any efficiency comparisons for such a small area.

An experienced third PI, whose data were not considered in the PI test, examined only the largest scale color photos. He transferred the locations of obvious infestation centers to black and white prints taken especially for use in the field. Anomalous images (disease-affected trees, old-killed trees, discolored hardwoods, etc.) were included for field checking so that commission-type errors could be identified when ground and photo data were reconciled.

Collection of Ground Data

Two 3-man crews spent 5 days combing the 3-square mile study area. Each crew had a set of the marked black and white photos showing suspected beetle spots. Stereoscopic coverage was a tremendous aid in finding inaccessible infestations. Also, the fact that the pictures were only 3 weeks old showed road networks and timber cutting boundaries which did not show on older photos.

The ground crews found 211 beetle infestations; they visited a total of 261 suspected infestations. Thus, 50 plotted spots, not too unlike new beetle infestations, were anomalies. In the three-week delay between photography and ground examination, many of the infested trees which had been green, and mostly nonvisible on film in July, became yellow in August. This fact had to be taken into account both on the ground and during data reconciliation.

Reconciliation of Photo and Ground Data

A composite of all infestations was made on a mosaic (Fig. 3) constructed at the largest scale (1:7,920). The composite was used to check PI templates at all scales on both films. This was a long tedious job to compare 211 infestations and separate correct identifications from omission and commission errors.[3/] A minimum of 5164 cross-checks had to be made, and these did not include commission errors.

As mentioned above, counts of discolored trees found on the ground had to be adjusted back to foliage conditions three weeks earlier.

MULTISPECTRAL PROCESSING OF 1968 IMAGERY

Image interpretation took on a more sophisticated approach with the availability of the Michigan multispectral processing system. Unlike the multispectral equipment used the previous two years, this system included some components which reflected advanced technology in the field of multispectral image processing. The processing equipment at the University of Michigan's Infrared and Optics Laboratory (IROL) permitted us to broaden our interpretation objectives. A primary objective was to detect dead and dying beetle-infested trees, especially those which still appeared as healthy trees in the field. Secondly, it provided the opportunity to determine the unique combination of the original 15-channel data for best multispectral recognition of several tree condition classes, e.g., healthy, faded (discolored) infested, nonfaded-infested.

[3/] Commission errors are caused by interpreters identifying images as infested pine trees when they are actually something else--other species, needle disease, etc.

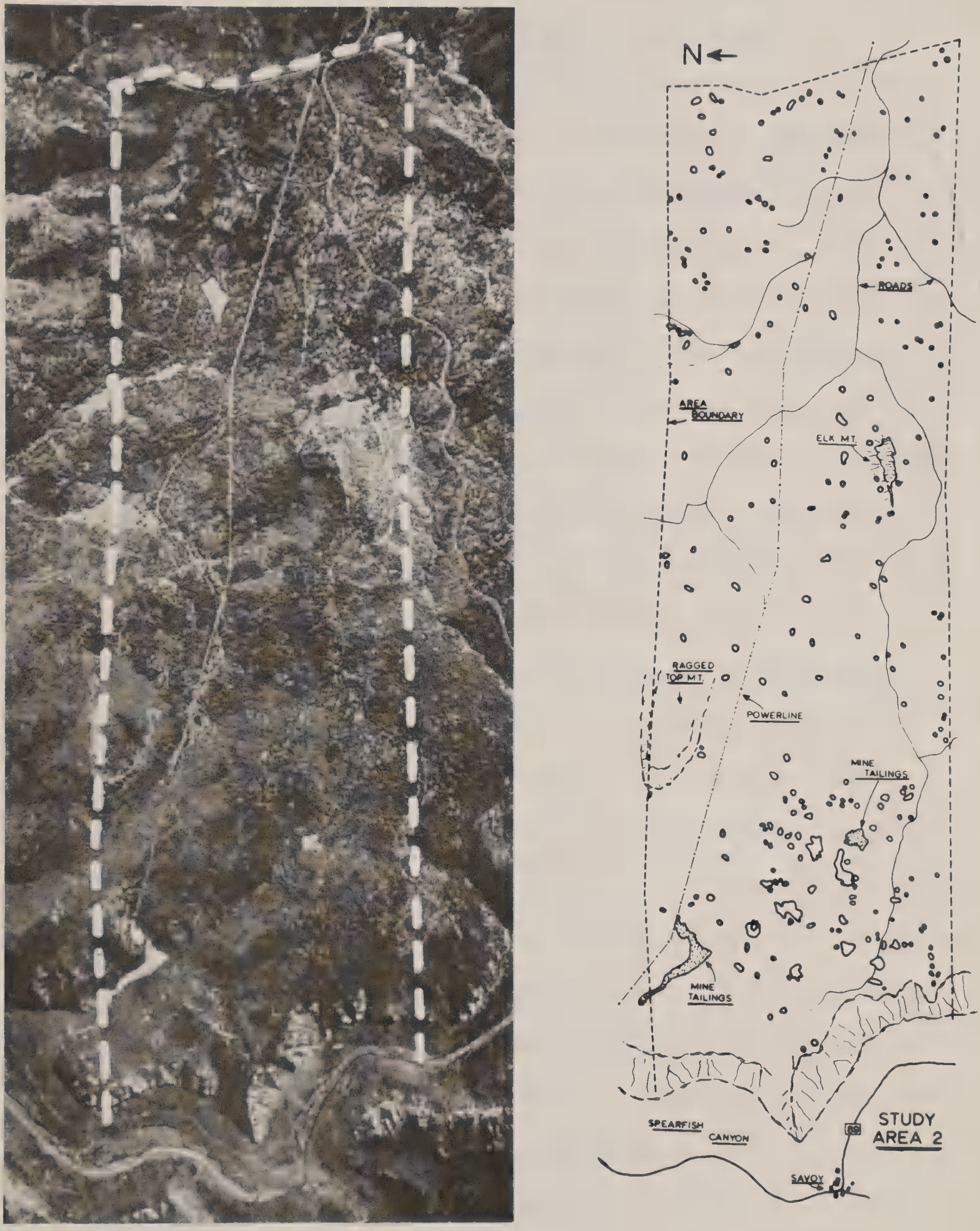


Figure 3. Aerial mosaic on left of 1- by 3-mile study area near Savoy, S. D. On right, the 211 infestations are plotted at the same scale.

Multiband Processing in Wavebands 0.4 to 1.0 Micron

Ten channels of spectrometer data collected over the Black Hills test site in May 1968 were in near-perfect registration, a requirement for the most useful multiband signal processing techniques. Several multiband techniques were tried ranging from very complex statistical processing to the simple addition and subtraction of wavebands to arrive at an optimum waveband combination. The details of the multispectral discrimination technique which employs a tape-loop training device are described by Hasell *et al*. (1968). In applying this technique, an attempt was made to recognize four basic tree condition classes. They were: (1) healthy trees, (2) old-killed trees with few or no needles, (3) faded (discolored) infested trees, and (4) nonfaded-infested trees.

The recognition analogs were printed on a 70 mm. film strip for each visible and reflective infrared channel. The analog output preserves shape and pattern relationship of the original scanner imagery. The recognition of the targets of interest in the forest scene in this study was first displayed on individual transparent film strips with the recognition spots color coded. Each color-coded strip with its respective recognition spots was then placed over the analog of the original imagery to establish spatial orientation with respect to the study area. A color negative was made of the composite overlay which contained the individually color-coded targets of interest. The usable output of this multispectral recognition technique is a photographic color print which shows the total forest scene with each of the tree condition classes of interest recognized as a different color spot.

Single-band Processing

The remaining five channels of reflective and thermal infrared imagery had to be processed individually because they did not meet the registration requirement for multiple-channel processing. Special effort was made to identify nonfaded beetle-infested trees using three different signal processing techniques on 8.2 to 13.8 micron thermal imagery.

Normally, single-band imagery processing at the University of Michigan's IROL involves reproducing the tape recorded airborne scanner data onto 70 mm. film strips to postflight playback. The resulting film strip has a calibrated relationship between the video signal voltage from the magnetic tape and film tone through a 16-step linear voltage scale. The analog video gain can be adjusted in playback to expand any part of the tape signal over a preselected gray-scale range.

An analysis and printout technique that had great usefulness involved the subtraction of extraneous signals created by thermal responses outside the range of temperatures of the conifer trees being studied. The calibrated gray scale was then fully expanded within the range of ground-recorded foliage temperatures.

During the airborne mission, hot and cold reference plate temperatures were set at just above and below the ground-recorded range of needle temperatures so that the full gray-scale expansion from black to white represented a 5 to 10 degree centigrade spread, depending on ground conditions. In processing, the voltage gain could be clamped electronically to the calibration reference levels and the printout would recognize mostly objects which had emitted temperatures within that range. An extension of

this technique permitted selective clipping of the signals within the 5 to 10 degree reference plate range; objects emitting temperatures warmer or colder than the reference temperatures were essentially eliminated. That is, if the emitted temperature range between the reference plates was preset at 18° to 28°C, objects with temperatures outside that range would not give a recognizable analog response on film. If, for example, the temperature range of the healthy trees was below 22°C, the analog signal could be electronically clipped on the hot side, and the printout would show only those objects with a temperature between 18° and 22°C. Likewise, a similar stepwise isolation of warmer objects could be accomplished by clipping signals on the cold side, until only objects having a temperature within range of the beetle-infested trees would be printed out on film.

The second single-band analog processing technique that was very useful is called "displaced 'A' scope trace." By this technique, individual scan lines are printed out on film at a greater than normal spacing between scan lines and with Y-axis or Y- and Z-axis displacement which is proportional to the energy response of the object on the ground. This effect causes a steeper angle of deflection on the cathode ray tube and closer apparent spacing of the scan lines for higher energy spots. For instance, the response from the south-facing crown of a dominant pine at midday would create a steep contour in contrast to the relatively flat contour of the cool background of the forest floor.

The third single-channel processing technique tried involved the display of individual scan lines which selectively sampled trees of the

various condition classes. Each selected scan line was displayed as an "A" scope trace of the analog voltage variation along the scan line. The Y-axis peak heights were associated with higher energy spots in the forest scene and the base line represented the shaded (cold) forest floor. Polaroid photographs were taken of the "A" scope traces against an X-Y grid so that the relative voltage values, as displayed on the grid, could be digitized for intensive statistical analysis. This type of display permits peak-height analysis for relating to high-energy targets and also for analysis of the gradient (edge definition) between background and individual tree crowns.

Digital Recognition Program

Coincident target recognition research was conducted at the Laboratory for Agricultural Remote Sensing (LARS), Purdue University using digital techniques.[4/] Multispectral data collected by the University of Michigan remote sensing aircraft over our Black Hills test site in May, 1968, were digitized and subjected to intensive analysis at the LARS facility. As in the case of analog processing at Michigan, the target recognition tasks at Purdue were to accurately identify and classify (1) red-topped and otherwise discolored ponderosa pine trees and (2) green (nondiscolored) infested pines within the same forest stand.

[4/] This phase of the research on the Black Hills Study was conducted by Joseph C. Bell, Jr., U. S. Forest Service, Southeastern Area, Survey Specialist, while he was on educational leave at Purdue University. The Forest Service is grateful to the Laboratory for Agricultural Remote Sensing (LARS), Purdue University, for the use of their LARSYSAA digital recognition program, facilities, and guidance during this work.

The LARS computer program is normally used for recognition and classification of agricultural crop cover types. Targets for classification in a forest ecotype (especially a conifer site) are quite unlike the large geometric patterns of the agricultural landform. To compensate for the anticipated differences, modifications were made in the digitizing routine and in the handling of the multispectral data in the computer target recognition program.

The total effort during this past year concentrated on modification of the normal data processing routine around the use of ten spectrometer channels which provided data between 0.4 and 1.0 micron. Five additional channels of middle and thermal infrared were available, but time restrictions did not permit the integration of these data into the recognition program.

RESULTS

EVALUATION OF AERIAL PHOTOGRAPHY

Ground Data

There were over two times as many active bark beetle infestations in the study area in 1969 as there were in 1968. The tabulation below

Size Class (number of trees)	Number of Infestations		Percent of Total in Class		Average of Largest Dimension (feet)	
	1968	1969	1968	1969	1968	1969
1-3	48	109	50	52	17	16
4-10	18	49	19	23	42	43
11-20	12	27	12	13	80	80
21-50	12	16	12	8	182	124
51-100	4	3	4	1	171	181
101 +	3	7	3	3	445	385
	97	211	100	100	---	---

shows that in spite of this large increase (over 100 percent), the distribution of infestations by size class is nearly the same.

Another point of interest from this tabulation is the fact that the average dimension of infestations in each class is similar for the two years. The only exception is the 21-50 tree class. In 1968, this class average was high because of a larger number of infestations on the high end of the class range. Weighting these yearly averages by the number of infestations in each class enabled us to compute the weighted average for each size class. These weighted averages, tabulated below, tell us the target resolution in feet that must be resolved by a remote sensor to detect infestations in the six size classes.

Size Class (number of trees)	Weighted Average Largest Dimension (feet)*
1-3	16
4-10	43
11-20	80
21-50	149
51-100	175
101 +	403

*Since these infestations were mostly circular or only slightly irregular in shape, only the largest dimension is given.

Photo Interpretation

One year ago, in August, 1968, the aerial photographic film-scale test was made to determine the accuracy of detecting black hills beetle infestations (Heller et al. 1968). This pilot test showed that as both

the images and infestation sizes became smaller, photo interpretation accuracies decreased. On the smallest scale, simulated space photography (1:116,000), three interpreters using pocket stereoscopes were only able to detect 9 percent of the infestations on color film and 7 percent on infrared color. No infestations of 1-3 trees in size could be detected. This is important because entomologists feel that an increasing number of infested trees in small groups of 2 to 5 trees indicate that an endemic situation is turning into an epidemic. Only when infestations enlarged to 21-50 trees, and on the average over 150 feet in size, did they have a 50-50 chance of being detected on the simulated space photography.

The film-scale test was repeated this year and in the remainder of this section we will compare 1969 results with the results of the 1968 test. There were differences in methods and also differences in the timing of the photography and ground survey between the two years. These differences have caused a number of discrepancies in the results. The significance of these discrepancies will be brought out later in the discussion.

Detection of Infestations

When 1:7,920 scale photography was used, only 71 percent of all infestations could be detected on color and only 70 percent could be detected on infrared color (Fig. 4). This is a drop from 81 to 88 percent detection on color and infrared color films, respectively, used in the 1968 film-scale test. There is a similar relationship between the

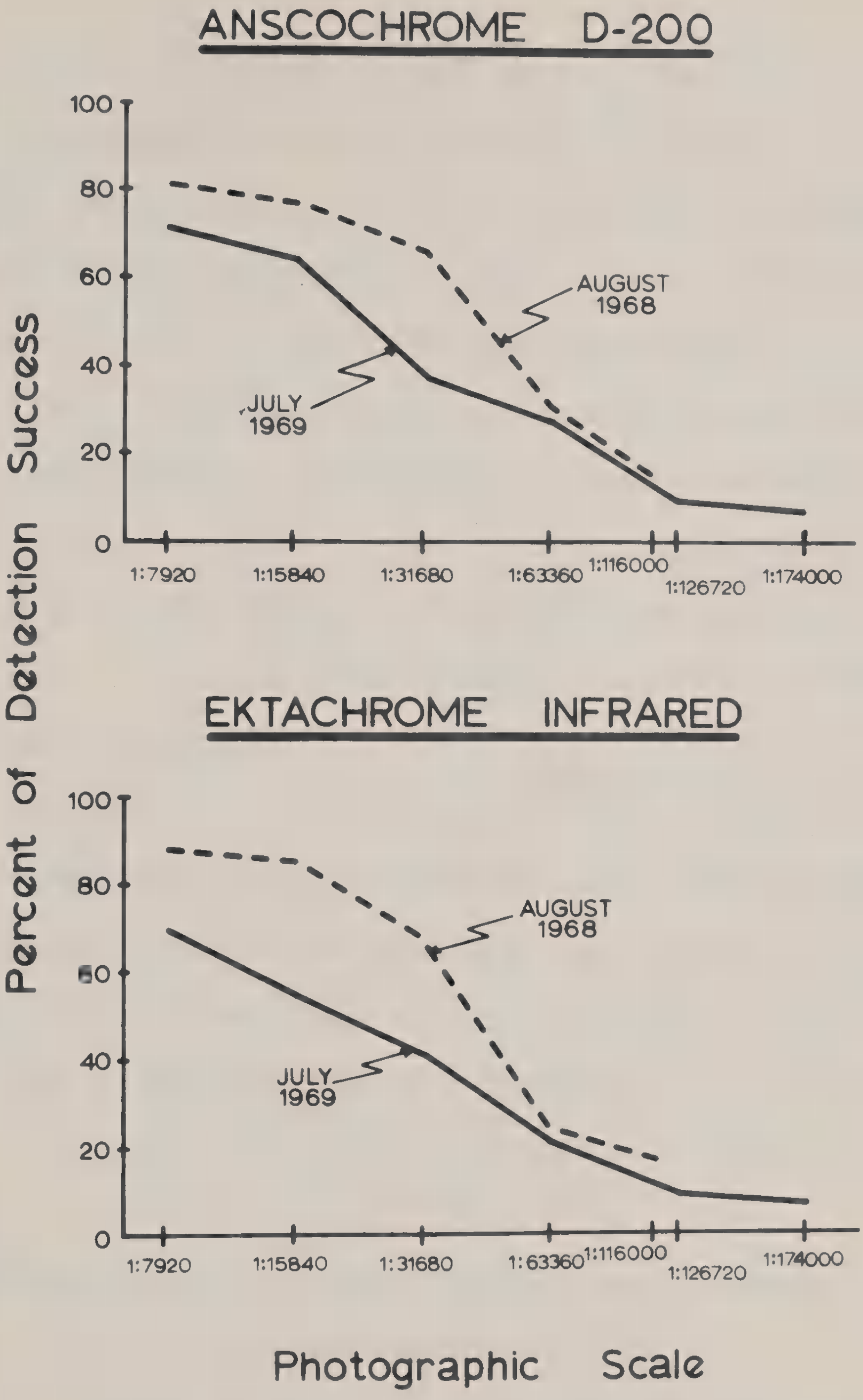


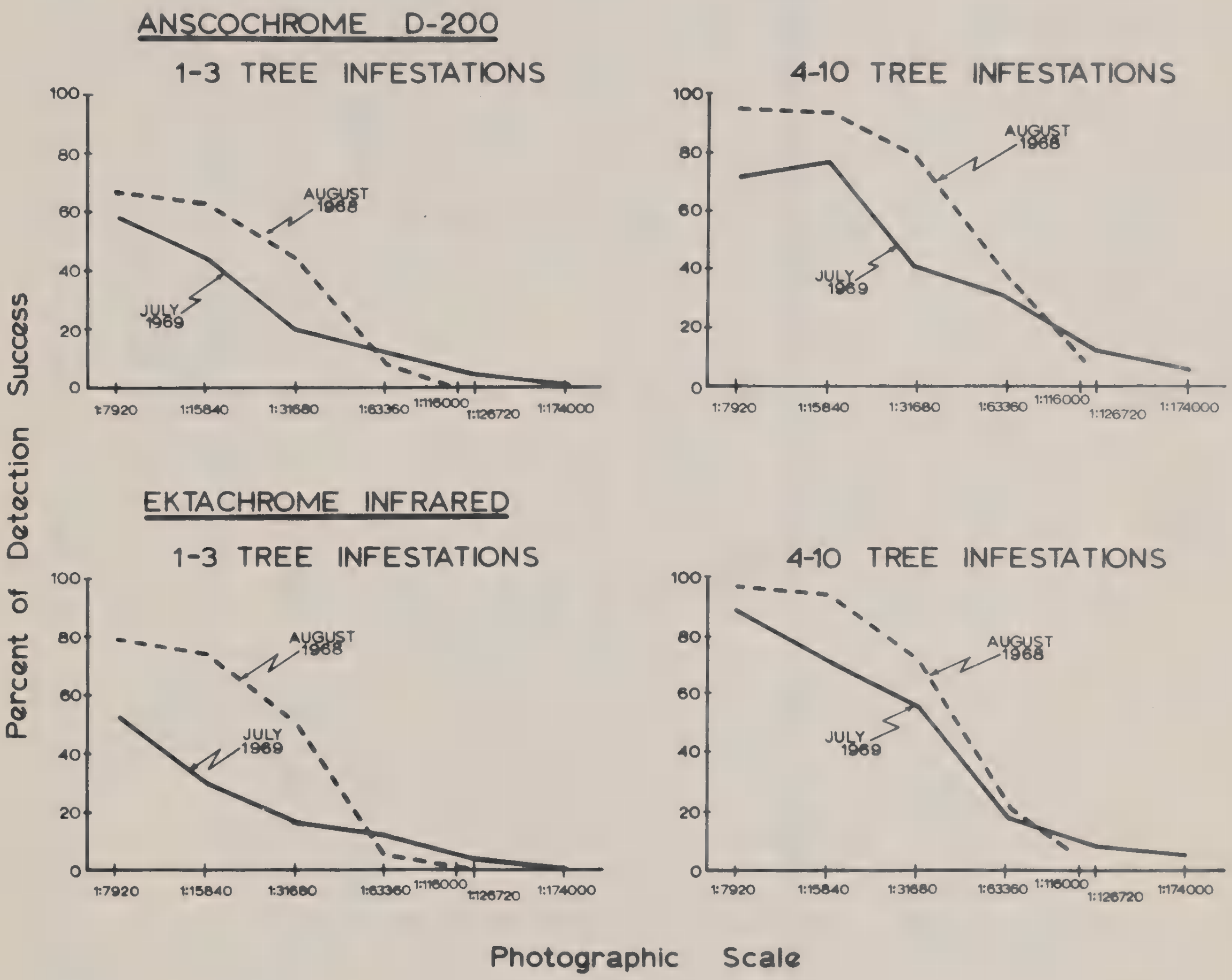
Figure 4. A comparison of 1968 and 1969 bark beetle infestation detection. The 1968 data represent the mean for three interpreters and the 1969 data represent the mean for two interpreters. The plotted data are expressed as a percent of the total number of active infestations present. The upper graph is a comparison made for Anscochrome D/200 film and the lower graph is the same comparison for Ektachrome Infrared color film. Notice the significant drop in 1969 detection.

two years for both 1:15,840 and 1:31,680 scales. The smaller scales show only slight differences between the two years. Although color infrared film seemed to show an advantage for detection in 1968, there does not seem to be any consistent advantage in 1969.

For detecting small infestations which entomologists feel are indicative of a rising insect population, there was far greater success in 1968 than in 1969 (Fig. 5). The data show no conclusive evidence that detection with one film is better than the other. Furthermore, there appears to be very little difference in detection on the largest scales used in the test. One can do almost equally as well at 1:31,680 as at 1:7,920 in small infestations.

When interpreters tried to detect infestations on the smallest scales simulating space photography they had varied results (Table 2). The data show that detection was slightly better at the 1:126,720 scale than at the 1:174,000 scale. When a stereomicroscope was used at 7.5 X power, detection success was improved only slightly. The differences between detection success on color and infrared color film are only slight and not significant.

The greatest number of infestations that were undetected by the interpreters fell in the smallest size class (1-3 trees). This accounts for well over 60 percent of the omission errors on any scale or film. As the photographic scale decreases, the percentage is reduced because a larger proportion of these errors occur in the larger size classes. On the 1:7,920 scale, 75 percent of the infestations omitted on color film were in the 1-3 tree class; on the infrared color, 81 percent were in this class.



ANSCOCHROME D-200

1-3 TREE INFESTATIONS

4-10 TREE INFESTATIONS

EKTACHROME INFRARED

1-3 TREE INFESTATIONS

4-10 TREE INFESTATIONS

Figure 5. A comparison of 1968 and 1969 detection success for small bark beetle infestations. The 1968 data represent the mean for three interpreters and the 1969 data represent the mean of two interpreters. The plotted data are expressed as a percent of the total number of active infestations present. The upper left and right graphs compare detection of 1-3 and 4-10 tree size classes on Anscochrome D/200 film. The lower left and right graphs compare detection for 1-3 and 4-10 tree size classes on Ektachrome Infrared film. Notice the significant drop in 1969 detection.

Table 2. Comparison of infestation detection in percent[1] on 1:126,720 and 1:174,000 scale color and infrared color transparencies; with and without a Bausch and Lomb stereomicroscope.

Infestation Size Class	No. of Spots in Size Class[2]	Detection on Color Film				Detection on Infrared Color			
		Without Stereo Microscope		With Stereo Microscope		Without Stereo Microscope		With Stereo Microscope	
		Scale		Scale		Scale		Scale	
		1:126,720	1:174,000	1:126,720	1:174,000	1:126,720	1:174,000	1:126,720	1:174,000
Trees		Percent				Percent			
1-3	109	4	4	5	2	4	5	5	2
4-10	49	11	5	7	5	7	6	13	8
11-20	27	7	6	17	11	13	2	17	7
21-50	16	31	16	41	28	19	16	44	28
51-100	3	33	33	17	33	33	17	50	17
101+	7	79	64	64	71	64	43	86	50
Total	211	--	--	--	--	--	--	--	--
Percent	--	10	8	12	9	9	7	15	8

[1] Average of two interpreters

[2] As found by ground survey

Commission Errors[5/]

Commission errors came from several sources. The greatest contributing source was a needlecast disease that affected pines (usually single trees) making them appear very much like new beginning faders. On the average, this source accounted for 41 percent of all commission errors on 1:7,920 scale color film and 47 percent of the errors on 1:7,920 infrared color (Table 3). As the scale decreases, the number of commission errors goes down. Regardless of scale, needlecast disease and 1968 faders are the greatest sources of commission errors, together accounting for well over 50 percent.

As with omission errors, commission errors are most numerous in the smallest infestation size class (1-3 trees). In general, as the scale decreases, the percentage of commission errors in this class decreases also. The tabulation below illustrates this point.

Photographic Scale	Percentage of Commission Errors in 1-3 Tree Class	
	Anscochrome D/200	Ektachrome IR
1:7,920	90	94
1:15,840	63	88
1:31,680	65	81
1:63,360	53	71
1:126,720	0	0
1:174,000	0	0

Commission errors are greatest in number at the 1:7,920 scale and decrease as the scale gets smaller (Table 4). Errors made on normal color

---

[5/] Commission errors result when images other than bark beetle-infested trees are identified and called new faders.

Table 3. Percent of total commission errors by source of error, by film, and by scale; mean percentage for two interpreters.

Scale	Total Errors[1/]		Needlecast Disease		Porcupine Damage		1968 Faders		Other	
	Color	IR	Color	IR	Color	IR	Color	IR	Color	IR
	No. Errors		Percent							
1:7,920	89	78	41	54	7	7	13	6	39	33
1:15,840	51	33	51	48	2	9	18	15	29	28
1:31,680	9	21	22	29	11	10	33	24	34	37
1:63,360	19	12	32	33	11	10	26	17	31	40
1:126,720	2	0	50	0	0	0	0	0	50	0
1:174,000	1	0	100	0	0	0	0	0	0	0

[1/] When compared with ground count

Table 4. Total number of commission errors by interpreter, by film and by scale.

	Ansco D/200 Interpreter			IR Color Interpreter		
Scale	1	2	Mean	1	2	Mean
			Number of errors			
1:7,920[1/]	22	33	27.5	18	58	38.0
1:15,840[2/]	18	16	17.0	7	10	8.5
1:31,680	8	9	8.5	9	34	21.5
1:63,360	6	28	17.0	3	18	10.5
1:126,720	2	0	1.0	0	0	0.0
1:174,000	1	0	0.5	0	0	0.0
Total	57	86	71.5	37	120	78.5

[1/] Only flight line 2 was interpreted by both interpreters.

[2/] Only flight line 3 was interpreted by both interpreters.

film seem to be quite consistent between the two interpreters and there is probably no significant difference in the data. On infrared color film, however, it is obvious that interpreter 2 is different from interpreter 1. The inconsistent and high numbers of commission errors would indicate that this interpreter is not sure of himself when using this film--something that could be quite common because of difficulties in getting used to the false colors. Because of this and the fact that detection on normal color film is as good as or better than on infrared color, we still feel that normal color photography is superior for forest insect surveys.

Discussion of Photo Interpretation Results

Why was detection in 1969 so much lower than in 1968? The first thought might be that the interpreters in 1968 were more experienced and better at the task. However, this was not true. The two interpreters in 1969 had five and two years experience; the interpreters in 1968 were inexperienced college students and had never interpreted insect damage before. Thus, it is not probable that we can ascribe the disagreement between years to interpreters.

There is a logical explanation for the discrepancies. First of all, there was a difference of one month between dates of photography. In 1968, the photography was taken on August 20; the 1969 photography was taken on July 21, one month earlier. This means that if all factors associated with tree fading were equal during both years, the 1969 faders had not progressed as far in fading as the 1968 faders. As a result, some infestations were undoubtedly overlooked because foliage discoloration had not progressed

enough at the time of photography. This was evident at the time ground checks were made three weeks later. Figure 6 illustrates the difference in fading between the date of the 70 mm. photography and the date of the ground examination. The portion of a 9 x 9 inch color transparency shown was taken three weeks after the 70 mm. transparency. The amount of fading that can occur between mid-July and August 20 is best illustrated in the 1967 annual report (Heller _et al_. 1967). An increase of 15 to 20 percent in detection of fading trees was reported between the two dates using 1:1,584 scale photographs for interpretation (Fig. 7).

Another explanation for discrepancies in detection involves the difference in the albedo on July 21 as opposed to August 20. There is a considerable change in sun angle between these two dates--on August 20 the sun angle at 0930 hours suntime (time of photography in 1968) was 8.5 degrees lower than at 1330 hours suntime (time of photography in 1969) on July 21. This lower sun angle plus better atmospheric conditions resulted in emphasized reds, yellows, and green-yellows and much better color saturation on the 1968 photographs. The increased color contrast helped separate faders and healthy trees.

There are also physiological factors involved. For instance, on August 20, metabolism rates are much lower than on July 21. This causes changes in the chemical content and structure of leaves which in turn can change the reflectance of solar energy from vegetation. These reflectance differences can be observed on the color and infrared color films where hardwoods and conifers can be separated much better on August photography. It also makes the difference between faders and healthy ponderosa pines much more pronounced.

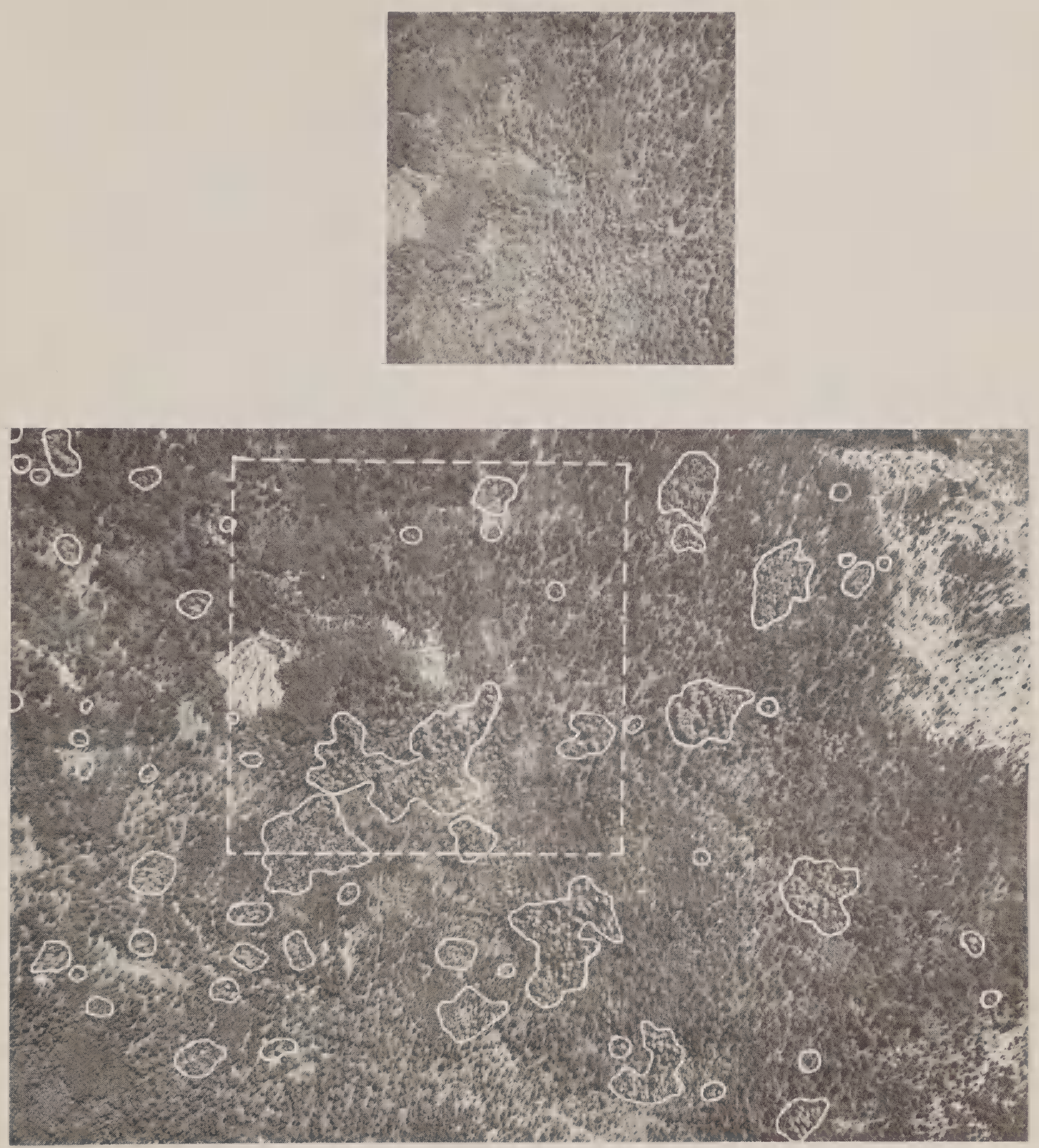


Figure 6. The lower color photograph was taken from a 9 x 9 inch color transparency exposed on August 11, 1969. Green-yellow patches outlined in white are ponderosa pine trees killed by 1968 Black Hills bark beetle attacks. The area within the dashed white line represents the coverage of the 70 mm. photograph in the upper part of the figure. This picture was exposed on July 21, 1969. Notice the large increase in number of faded trees during the three week period between dates of photography.

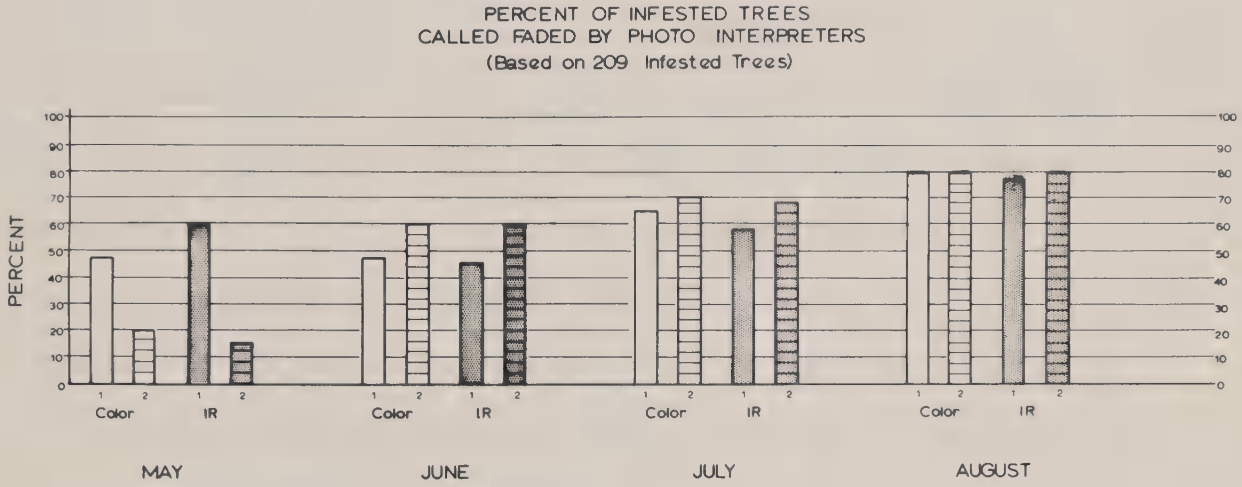


Figure 7. Comparison of photo interpretation results from two experienced photo interpreters using Anscochrome D/200 and Ektachrome Infrared Aero film at 1:1,584 scale with total number of ground-infested trees. Note the increased ability to detect infested trees as the season progresses and also the greater consistency of results obtained by the two interpreters. (Illustration taken from Heller et al. 1967.)

What does all this mean? If nothing else, it tells us that the timing of aerial photographic surveys for insect damage is very important--probably a great deal more important than we have realized in the past. Color photography should take advantage of maximum tree fading and also the best photographic conditions to maximize tree species differentiation as well as the detection of insect-infested trees.

MULTISPECTRAL IMAGE PROCESSING (1968)

Visual inspection serves for a cursory examination of optical-mechanical scanner imagery if other methods are lacking. It is possible, to some extent, to determine successes; but, one would never assert that a mission was a failure on the basis of visual inspection techniques alone. It is, for example, possible to determine if the flight path traversed the intended ground line and if the equipment was operating. It was clear from the start of this study that no "analysis" of scanner data would be done without the aid of more sophisticated image-processing techniques.

The ten channels of visible and reflective infrared data which were collected in near-perfect registration the last week in May 1968 were processed at IROL of the University of Michigan. The optimum waveband combinations were selected for discrimination of forest tree condition class (Tables 5 and 6). As mentioned under PROCEDURES, the multispectral image processor was set up to recognize and classify four basic targets: (1) healthy pines, (2) old-killed pines, (3) faded infested pines, and (4) nonfaded infested pines. Table 6 shows the results of the multispectral

Table 5. Ten-channel spectrometer channels used for target recognition at Michigan and Purdue and their respective spectral color.

SPECTRAL COLOR	WAVELENGTH (Microns)	CHANNEL NUMBER
Violet	.40 - .44	1
Blue	.46 - .48	2
Blue Green		
Green	.50 - .52	3
Yellow Green	.52 - .55	4
	.55 - .58	5
Yellow		
Yellow Red	.58 - .62	6
Light Red		
	.62 - .66	7
Deep Red	.66 - .72	8
	.72 - .80	9
Infrared	.80 - 1.0	10

Table 6. Ten-channel spectrometer channels selected by the Michigan multispectral processor as optimum for target recognition.

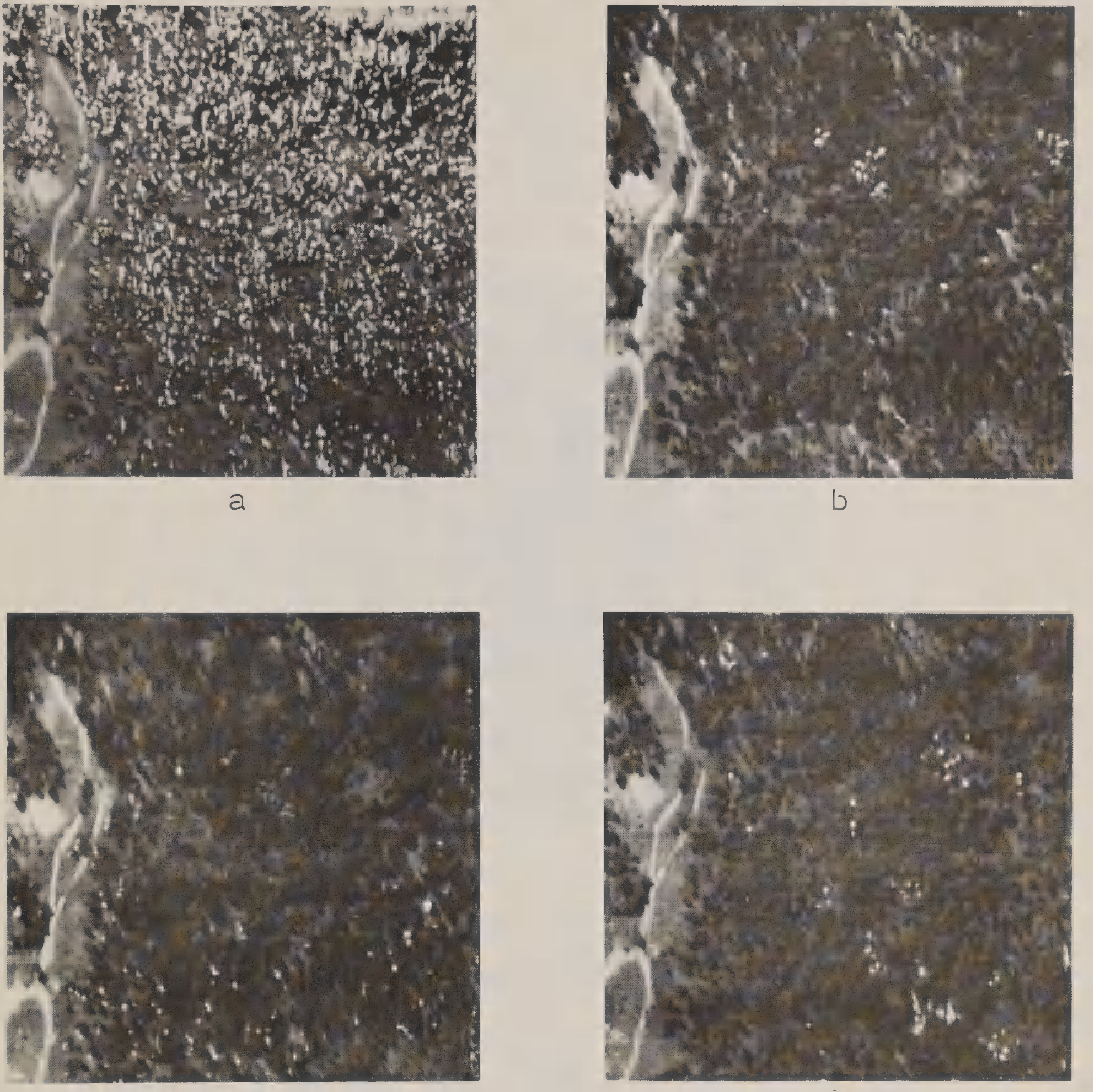
TARGET	WAVELENGTH CHANNELS	THRESHOLD VOLTAGE
Healthy trees	1, 4, 5, 6, 7, 8, 9, 10	2.00
Old-killed trees	1, 2, 7, 8, 9, 10	1.00
Faded infested trees	4, 7, 8	2.87
Nonfaded infested trees	1, 2, 3, 4, 5, 6, 7, 8, 9, 10	1.75

processing effort which set the interpretation parameters for recognition of the targets of choice in the forest habitat.

After the processor was "trained" to recognize each of the condition classes on the basis of unique spectral qualities, it was programmed to trigger a recognition signal through the processor/printer each time the exact spectral qualities of the training model were encountered. These recognition spots were printed on the analog of the forest scene and also on clear film on later runs. Since each of the condition class categories was recognized separately on successive passes of the tape analog over the study area, the end product of much trial and error was four analogs of the Black Hills study area, each with the recognition spots of the different tree condition classes (Fig. 8). Secondly, there were produced four clear 70 mm film strips with only the target recognition imprinted as a dark spot on the otherwise clear film. Although the pictorial scene was not present on the clear film, spatial relationships were maintained between recognition spots.

The next step in the identification process was to color-code each of the four clear 70 mm film strips with the individual condition class trees recognized as a different color spot. These films were then overlaid upon one another to create a composite color overlay. The color composite was then photographed and a color print produced (Fig. 9). In the resulting photo illustration the healthy pines are coded green, the old-killed pines are coded blue, the faded infested pines are red, and the nonfaded infested pines are amber.

All target types that existed in the study area were recognized by this process of color-coding target recognition. There was a particularly



a

b

c

d

Figure 8. Targets recognized are superimposed on the analog background for each of the four condition classes identified: (a) healthy, (b) faded infested, (c) nonfaded infested, and (d) old-killed.

Figure 9. This color composite shows the Black Hills study area with four forest tree condition classes shown in different colors. Healthy trees are green, old-killed pines are blue, faded infested pines are red, and nonfaded infested pines are amber.

good relationship for the faded infested condition, between the actual number of trees on the ground and the number of recognition spots (Table 7). This was ascertained by registering the number of target recognitions on a digital display and relating that count to actual ground and photo-interpretation counts.

There were false recognitions of the commission error type. These were very low (less than 9 percent) for groups of faded infested and old-killed trees. Omission errors (Table 8) were zero for these two classes. Considerable control is exercised over error type by setting threshold limits for acceptance of a target. By tightening the threshold, commission errors are reduced; but, omission errors increase. The best accuracy was maintained with the threshold parameters shown in Table 6. The greatest errors were made in the recognition of nonfaded infested trees. This is no surprise as the processor is programmed to recognize a very subtle spectral condition by unique combination of all spectrometer channels--a condition which a human interpreter cannot perceive in color on film at the same photographic scale. Although the number of commission errors was high, at least all but one of the known groups of nonfaded infested trees were recognized (Table 8).

Individual waveband analysis of the ten spectrometer channels showed that old dead pines with few remaining needles were best recognized in the blue-violet wavelength channel, 0.40 to 0.44 micron, whereas the faded infested pines were best illustrated in the yellow-red and red channels, 0.62 to 0.66 micron and 0.66 to 0.72 micron. Because a combination of ten spectral channels (Table 6) is necessary to illustrate the nonfaded infested

Table 7. Summary of errors involved in the recognition of faded infested class trees at 2.87 volt threshold.

SPOT NUMBER	ACTUAL COUNT	RECOGNIZED TARGETS[1/]	PERCENT OMISSION
1	5	3	40
2	33	14	58
3	18	8	56

[1/] All errors were omission type.

Table 8. Summary of analog multispectral processor results as compared to actual ground and photo interpretation results.

CLASSIFICATION	ACTUAL GROUPS	RECOGNIZED GROUPS	ACTUAL TREES	NO. TARGET TYPES
Healthy trees	--	--	--	--
Old-killed trees	8	9[1/]	146[2/]	384[3/]
Faded infested trees	3	3	56	29
Nonfaded infested trees	6	11[4/]	72	148[5/]

[1/] Includes one group of unfoliated hardwoods.

[2/] Actual standing dead timber having no foliage.

[3/] Includes unfoliated hardwood recognition and fallen dead timber.

[4/] Five actual infestation spots were recognized along with six erroneous spots which showed as two or more trees.

[5/] This number varies widely with changing voltage threshold.

condition, it can only be "visualized" through the color coding recognition process. Visual response differences which relate to other than the healthy tree condition show as varying and lighter shades of gray-white on the photographic prints of the spectrometer data.

Three additional photographic representations in the reflective infrared (middle IR) were taken at the same time as those generated by the ten-channel spectrometer. The sensors for these three wavelength channels are located on the opposite end of the same scanner which captured the spectrometer data, so that their comparison with the spectrometer channels does not provide a real time registration of information. Although registration of the two ends of the detector is only microseconds apart, the speed of the aircraft moving over the target area contributes to the restricted present use of these data channels in the target recognition processor for enhancement of the 10-channel spectrometer data. It was shown on this study that if 2.0 to 2.6 micron data were added to the 10-channel spectrometer data, there would be a significant improvement in the accuracy of identifying the nonfaded infested condition class trees.

Single-Channel Infrared Processing

A concerted effort was made to identify nonfaded beetle-infested trees on the 8.2 to 13.8 micron imagery. Sufficient environmental data and corresponding data on the state of tree energy were collected on the ground. At times, these data indicated a distinct energy profile for the nonfaded infested pines. With these known temperature differences, we

hoped to be able to discriminate the subtle energy state difference on thermal infrared imagery.

Of the various single-channel processing techniques tried at IROL, the gated analog method with reference plate clipping resulted in the best information for locating the "previsual" beetle-attacked trees. We studied the thermal flight data generated at 1411 hours on the afternoon of May 28, 1968. From the vast array of processing data accumulated by using different reference plate gains with different combinations of reference plate clipping levels, a set of parameters (such as voltage levels, tape speeds, gate widths, and clipping levels) was derived which led to the identification of nonfaded beetle-infested trees on the basis of their warmer emitted temperatures.

As with multichannel processing, the single-channel exercise of voltage gating and reference plate clipping to eliminate extraneous thermal information, produces filtered signals which are input for the final interpretation. All of the light-toned objects (warmer than cold plate) remaining after cold plate clipping were color-coded blue (on Ozalid blue-sensitive film) and all the light-toned objects (colder than surrounding hot plate) remaining after hot plate clipping were color-coded green (Fig. 10). When the two color-coded photo strips were made to overlay one another, there resulted a tricolor mosaic (Fig. 11). The resulting dark blue color images were interpreted as being the nondiscolored beetle-infested pines, the green images were interpreted as objects with higher energy emission rates, while objects colder than the targets of interest remained blue. There were interpretation errors,

Figure 10. The two photo strip outputs shown illustrate the gated analog reference-plate clipping technique using data generated over the Black Hills study area at 1411 hours on May 29, 1968. The upper strip shows objects with temperatures between the 3.0 volt hot reference-plate clipping level and the 2.0 volt cold reference-plate clipping level. The lower strip shows objects with temperatures between the 5.0 volt hot plate clipping level and the 3.0 volt cold reference-plate clipping level.

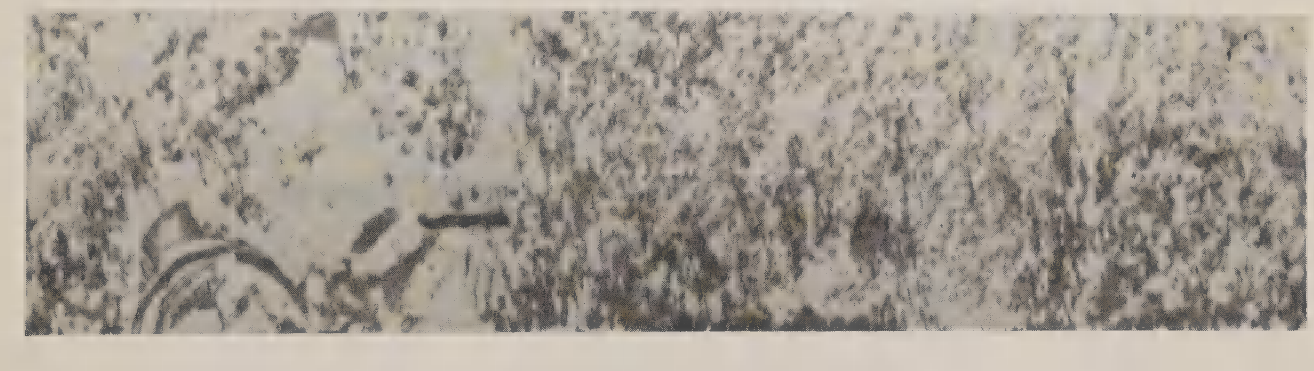


Figure 11. This tri-color mosaic shows the result of color coding the film strip outputs from the hot and cold reference-plate clipping technique. The resulting dark blue images were interpreted as being within the thermal profile of beetle-infested pines, the green images were interpreted as objects with higher energy emission rates, while objects colder than the targets of interest remained blue.

mostly from objects which happened to have the exact energy emission state as the nonfaded beetle-infested trees. Although the interpretation technique was not carried beyond this step, the next logical step would be to process successive flight data, made under different diurnal conditions. Even with the inherent problems associated with image scale control and alignment, comparison of the resulting color-coded mosaics may reduce the interpretation.

A second thermal processing technique proved to be useful for studying the energy state of trees in several condition classes under different environmental conditions. The "A" scope trace method took two forms, and each played a role in the thermal identification of beetle-infested trees. First, a continuous displaced "A" scope trace with two and three axis displacements, served for the first level of interpretation of the thermal variations, produced as contours, over the Black Hills study area. By this process, the larger the energy gradient of a tree crown or from opposing sides of the tree, the steeper the contour displacement. For example, in early morning when the sun strikes only one portion of the crown, a temperature gradient is created between the sunlit and shaded portions. Over the forest canopy, the "taller" an object appears on the displaced "A" scope trace, the greater the energy transfer state (Fig. 12).

The second "A" scope trace technique involved the display of an individual thermal scan line over a fixed measurement grid which was photographed with a Polaroid camera for permanent record (Fig. 13). The Y-axis displacement at any point on the resulting Polaroid print was proportional to the thermal energy detected by an individual detector resolution element.

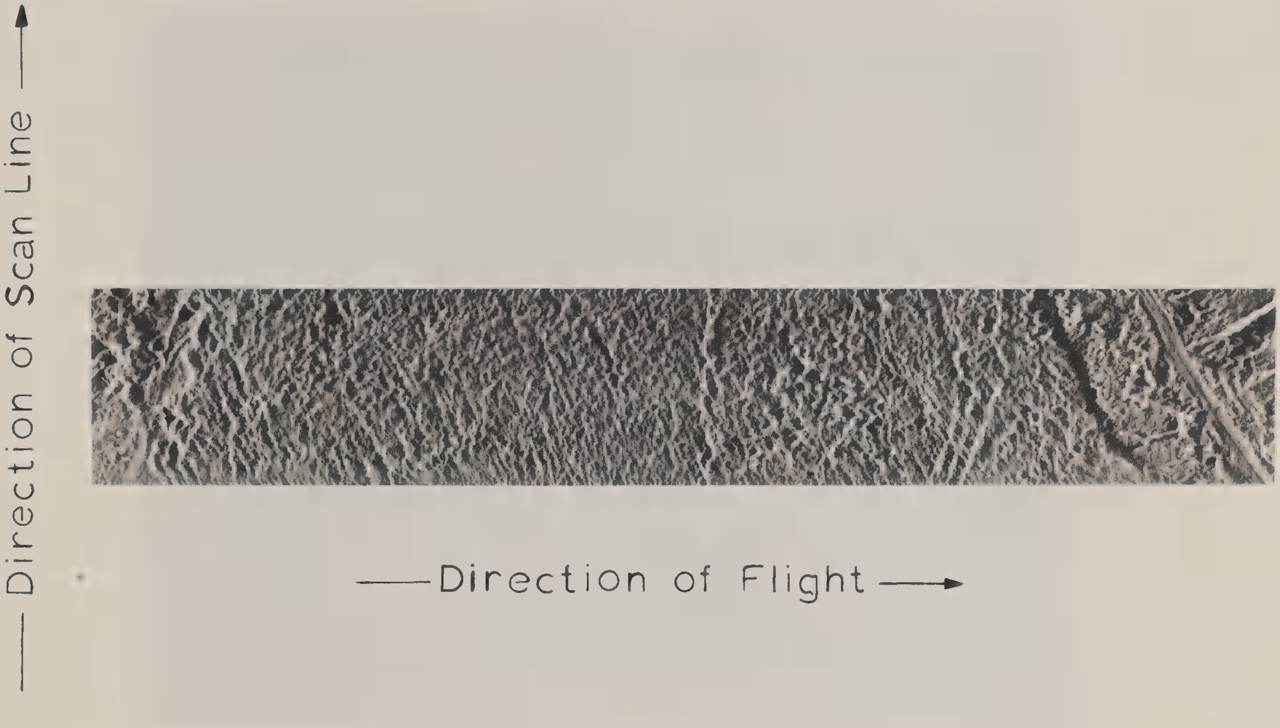


Figure 12. A displaced "A" scope trace of a thermal contour over the Black Hills test site. This scan line was generated from energy response on the 8.2 to 13.8 micron detector on the 0730 hour flight, May 30, 1968. The single axis displacement of the scanner trace is called an X/Y contour.

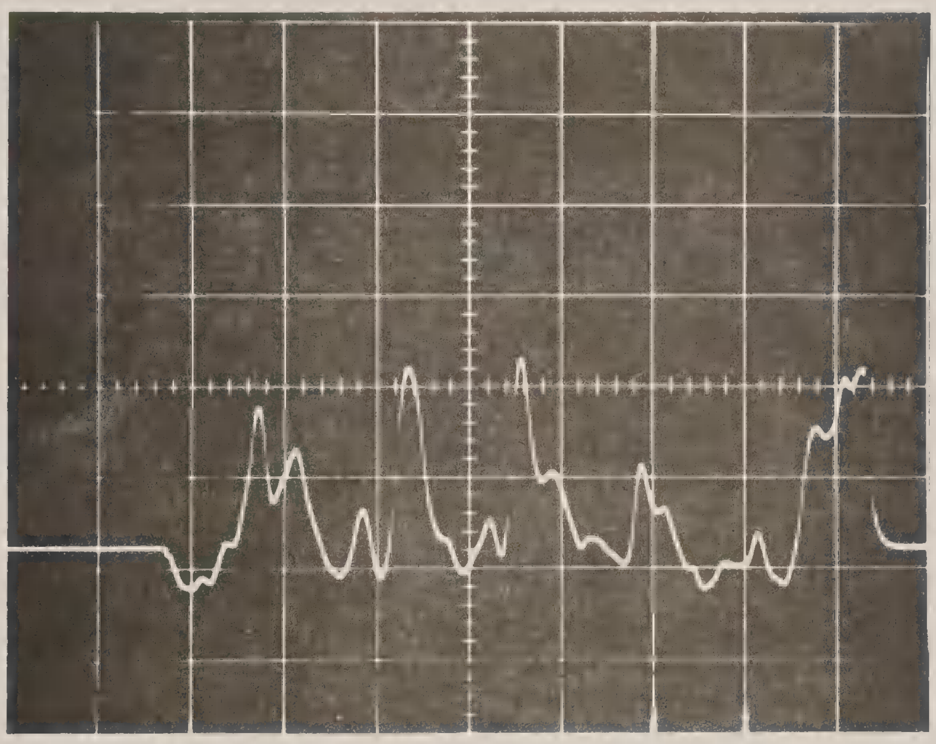


Figure 13. The Polaroid photograph of the "A" scope shows the energy response for a single scan line from the 8.2 to 13.8 micron imager. The Y-axis displacement at any point along this line is proportional to the thermal energy emitted by the corresponding ground target and detected by a single scanner element.

In practice, individual scan lines over known beetle-infested trees, chosen from the displaced "A" scope trace, could be displayed individually on the Polaroid prints for peak height association with the warmer beetle-infested pines. Sufficient individual "A" scope traces were run to demonstrate the uniqueness of the associated peak height over beetle-infested trees. As research techniques, the two "A" scope display methods derive a great deal of pictorial information about the energy state of trees of different condition classes. However, beyond a small sample of the data available from one flight mission, a researcher would be well advised to digitize the "A" scope traces for computer analysis and identification of tree condition class.

Digital Recognition Program

The same Michigan spectrometer data were processed through LARSYSAA program. In this case the Black Hills test site was separated into six cover type classifications. These were: (1) faded (discolored) trees, (2) healthy trees, (3) shadows, (4) pasture (open grass), (5) bare soil and rocks, and (6) dead and fallen trees.

Uniform training samples which were reasonably well represented by their class histograms were obtained after affecting changes in the preclassification computer subroutine. Choosing the faded tree samples was the most difficult task because a single faded tree crown was often represented by only two digital sample points. As a result, the $ SELECT subroutine offered little help in the refining process. Manipulation of the $ SELECT subroutine and coincident spectral plots indicated that the best

multispectral channel combination for all six cover type classifications was: 0.40 to 0.44 micron, 0.50 to 0.52 micron, 0.58 to 0.62 micron, 0.66 to 0.72 micron, and 0.72 to 0.78 micron (Table 9). The related spectral colors for the selected channels are (in the same order): violet, green, yellow-red, deep red, and deep red-infrared (Table 5). The separation of faded trees from all other classes of materials was given primary selection consideration.

Results of the class percentage test showed that the classification area contained: 1.4 percent faded infested trees, 47.0 percent healthy trees, 35.6 percent old dead and fallen trees, 8.2 percent shadows, 6.1 percent grass-covered openings, and 1.7 percent rocks and exposed mineral soil (including roads). Overall training class performance was 98.9 percent.

A subjective comparison of ground truth photography (Fig. 14) with the $ Display printouts (Fig. 15), showed that the overall classification was reasonably accurate with the exception of the class for old-dead trees. The $ Display and the Class Percentage Test gave an accurate estimate and location of faded infested trees when compared to the large-scale color photography.

The estimate of 35.6 percent cover type for old-dead trees obviously contained many misclassifications. An estimate of 5 to 10 percent would seem to be more realistic. A possible explanation for this error is that classification was influenced by energy returns from the branch litter and dead vegetation which cover the forest floor. In addition, the classification track included a large stand of unfoliated hardwoods which

Table 9. Ten-channel spectrometer channels selected by the Purdue LARSYSAA target classification program.

TARGET	WAVELENGTH CHANNELS	VOLTAGE THRESHOLDS
Healthy trees	1, 3, 6, 8, 9	9.24
Old-killed trees	same	16.70
Faded infested trees	same	same
Shadows	same	same
Open grass	same	same
Rock and bare soil	same	same

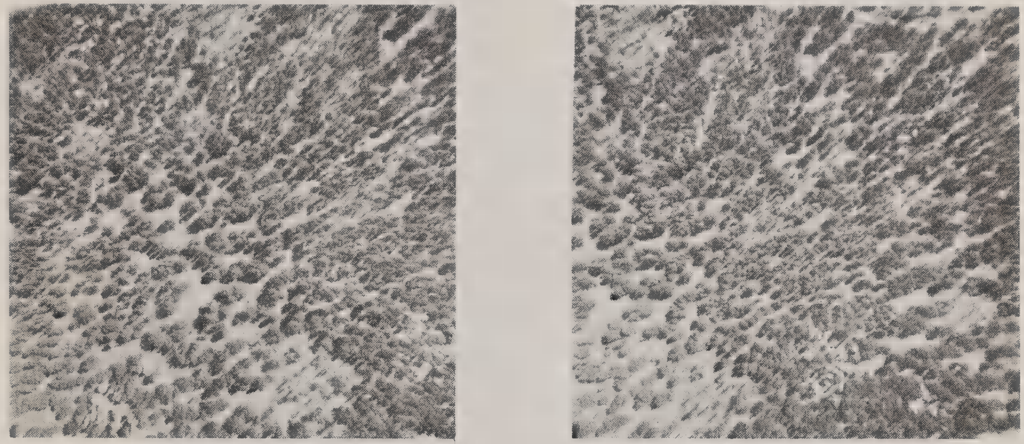


Figure 14. These aerial color photographs (stereo pair) show the approximate area covered in the $ Display printout. The photos were taken at exactly the same time (1411 hours, on May 29, 1968) as the scanner data used in the LARSYSAA target recognition program.

```
TOTAL NUMBER OF SAMPLED POINTS =       10656
```

Figure 15. The $ Display printout shows the composite classification of targets in the Black Hills study area. A comparison with the aerial color photograph in Figure 3 shows that faded infested trees were correctly located in the printout.

spectrally looks like the old-killed trees. A third explanation is offered by the possible mixing of the classification of old-killed trees with that for open grass. Much of the ground cover below the old infestation spots consists of long green grass. Even though the training model was selected over a group of old-dead trees, there is very likely considerable spectral reflectance from the grass below. Since the classification of open grassy areas appears to be low (6.1 percent), a realignment of these two classes seems appropriate in future efforts.

Overall, the attempt to classify faded (discolored) bark beetle-infested pine trees indicates that this task can be accurately performed in wavelengths shorter than 1.0 micron. However, other studies (Weber 1966) indicate that those bands between 1.0 and 2.6 microns may be very important for forestry classifications and that they may improve the classification of faded infested pine trees.

The classification of nonfaded beetle-infested pine trees (task 2) on the Black Hills test site was not completed due to time limitations up to this reporting date. Nonfaded trees could not be classified solely on the basis of the ten channels of spectrometer data (wavelengths less than 1.0 micron). Although middle infrared and thermal infrared (five additional channels) data were available, they have only recently been digitized and as yet have not been added to the classification data.

SUMMARY

For two years, the Remote Sensing Project has concentrated its main effort on film and scale tests and the analysis of imagery generated by

a 15-channel optical-mechanical scanner. As a result of these efforts we have made a number of significant observations. These observations along with some recommendations for their future benefit to the remote sensing program are summarized below.

PHOTO INTERPRETATION

The results of photographic film and scale tests can be summarized as follows:

1. There appears to be no difference between normal color and infrared color films for detecting bark beetle infestations. Since there are more commission errors made by interpreters unfamiliar with infrared color film, normal color film should be recommended for most insect surveys. Where coniferous-hardwood separation is difficult or where haze conditions are unfavorable at the time of photography, we advise using infrared color film.

2. Detection of small infestations over 4 trees in size is almost as good on 1:15,840 scale color or infrared photography as it is on larger scales. With four times the area coverage, this smaller scale should be given greater attention for insect detection surveys in the future.

3. Depending on the many photographic variables involved, 1:7,920 scale color and infrared color films detect up to 10 percent more of the 1-3 tree infestations than the 1:15,840 scale. The 1:31,680 scale will detect from 15 to 30 percent fewer small infestations between 1 and 10 trees in size than 1:7,920 scale photographs. Depending on survey objectives, smaller scales could be useful for insect damage assessment surveys--particularly if multistage probability sampling is used.

[illegible] As a result of these efforts

number of significant observations. These [illegible]

some reports [illegible] for their [illegible] the remote

[illegible] summarized below

PHOTO INTERPRETATION

The [illegible] of photographic [illegible]

[illegible]

1. There appears [illegible] infrared color films for detecting [illegible] are more [illegible] film should [illegible] surveys [illegible] conditions are unfavorable [illegible] advise using infrared color film.

2. Detection of small infestations [illegible] is almost as good on 1:15,840 scale color or infrared photographs [illegible] scales. With four times the area [illegible] smaller scale [illegible] given greater attention for insect detection surveys.

3. Depending on the [illegible] photographic [illegible] 1:7,920 scale color and infrared color films detect up to [illegible] than the 1:15,840 scale. The 1:7,920 scale will [illegible] 15 to 30 percent fewer small [illegible] 1:7,920 scale photographs. Depending on [illegible] scales could be useful for insect damage assessment [illegible] multistage probability [illegible] is used.

4. Timing insect surveys for detection purposes is very critical to get maximum results. A photographic survey made one month too early could result in missing 50 percent of small groups of 1-10 trees in size. In the Black Hills, detection is best on color or infrared color photography taken after the middle of August. This would permit detection of over 65 percent of the smallest infestations and 80-90 percent of all infestations to direct control operations to the most likely areas during the fall and winter months.

5. Simulated space photography of 1:126,720 and 1:174,000 scales will detect about 40 to 80 percent of spots over 100 trees in size (on the average 400 feet in the largest dimension). At these small scales, it is difficult for interpreters to associate differences in color with insect infestations. Very few spots less than 21-50 trees in size could be detected. There is some question as to whether those detected would have been detected in an area where less insect activity and fewer infestations of the largest size occurred.

MULTISPECTRAL SCANNING IMAGERY

An analog multispectral processor was used to analyze ten channels of spectrometer data stored on magnetic tape in 1968. The objective of this analysis was to arrive at an optimum combination of wavebands for recognizing: (1) healthy trees, (2) old-killed trees, (3) faded (discolored) infested trees, and (4) nonfaded infested trees. The most significant observations made from this analysis to date are as follows:

1. The analog multispectral image processor can be trained to recognize each of the condition classes on the basis of its unique

spectral quality. The processor scanned the 10-channel spectrometer data looking for each tree condition class on a separate run of the processor. When spots of the correct spectral quality were encountered the processor printed this location on an analog of the forest scene and also on clear film. The four analogs that were produced became a record of the occurrence of the four tree-condition classes. The best combination of band widths for detecting each of the four condition classes are given in the report.

2. Each of the four film strips produced by the processor was given a distinct color code--each color representing a tree condition class. These color coded films were then overlaid upon one another to form a color composite. The composite was photographed and a color print produced to show the location of the four condition classes. From this we have found a good relationship in the faded infested condition class between the actual number of trees on the ground and the number of recognized targets. Success in other classes was not as good but shows promise for future work.

3. Commission errors (false recognition) were very low for the faded infested and old-killed tree condition classes. There were more errors of this type in the nonfaded infested (previsual) condition class primarily because of the extremely subtle or narrow threshold, where these groups are located. The parameters for obtaining the greatest accuracy of detection with this technique are given in the test results.

4. Individual waveband analysis of the ten-spectrometer channels showed that the 0.40 to 0.44 micron band was best for discriminating

"old kills" and that two bands--0.62 to 0.66 micron and 0.66 to 0.72 micron--were best for detecting faded infested trees. It requires all ten spectrometer channels to detect the nonfaded infested conditions--at a fairly low accuracy level.

5. Although there were three reflected infrared (middle IR) bands taking data simultaneously with the 10-channel spectrometer data, poor registration would not allow use of these data in the target recognition processor. However, the study has shown that if the 2.0 to 2.6 micron data could be added to the 10-channel data, there would be a significant improvement in the accuracy of identifying nonfaded infested (previsual) condition class trees.

SINGLE-CHANNEL INFRARED PROCESSING

Five channels of reflective and thermal infrared imagery were processed individually because registration was too poor for multispectral processing. Single-channel processing using three different techniques showed the following:

1. Of three single-channel thermal processing techniques tried, the gated analog method with reference plate clipping resulted in the best information for locating the "previsual" beetle-attacked trees.

2. The continuous displaced "A" scope trace method, with two and three axis displacement, served to make first-level interpretations of thermal variations. These were produced as contours over the study area.

3. Using the "A" scope trace technique, with a Polaroid photograph of the individual thermal scan lines displayed on a measurement grid, we

were able to show that a Y-axis displacement was proportional to the thermal energy detected by an individual detector resolution element.

4. The two "A" scope techniques show a great deal of pictorial information about the energy state of trees in different condition classes. However, beyond small samples, it would be advisable to digitize the "A" scope traces for computer analysis because of the many bits of information that must be handled.

DIGITAL RECOGNITION PROGRAM

The ten-channel spectrometer data stored on tape in 1968 were processed through the Purdue LARSYSAA target discrimination program. The program was modified to recognize six cover-type classifications; (1) faded infested trees, (2) healthy trees, (3) shadows, (4) pasture (open grass), (5) bare soil and rocks, and (6) dead and fallen trees. Results of this processing indicate the following:

1. The best multispectral channel combination for discriminating between the six conditions is 0.40 to 0.44 micron (violet), 0.50 to 0.52 micron (green), 0.58 to 0.62 micron (yellow-red), 0.66 to 0.72 micron (deep red), and 0.72 to 0.78 micron (deep red infrared).

2. Faded (discolored) bark beetle trees can be accurately detected in wavelengths shorter than 1.0 micron. However, results of other studies indicate that the spectral bands between 1.0 and 2.6 microns may be very important for forestry classifications and could improve the classification of faded infested pine trees.

3. Nonfaded infested pine trees could not be classified solely on the basis of the ten-channel spectrometer data. The addition of middle

infrared (reflected) and thermal infrared channels may help to make this discrimination. The data for the five channels have been digitized but at the date of this report have not been added to the classification data for analysis.

LITERATURE CITED

1. Hasell, P. G., N. Spansail, and F. Thomson. 1968. Investigations of spectrum-matching techniques for remote sensing in agriculture. In report to U. S. Dept. Agr. by the University of Michigan, Infrared and Optical Sensor Laboratory, Ann Arbor, Michigan.
2. Heller, R. C., R. C. Aldrich, W. F. McCambridge, and F. P. Weber. 1967. The use of multispectral sensing techniques to detect ponderosa pine trees under stress from insect or pathogenic organisms. Annual Progress Report, For. Remote Sensing Lab. for Nat. Resource Prog., NASA, by the Pacific Southwest Forest and Range Experiment Station, 65 p.
3. Heller, R. C., R. C. Aldrich, W. F. McCambridge, F. P. Weber and S. L. Wert. 1968. The use of multispectral sensing techniques to detect ponderosa pine trees under stress from insect or pathogenic organisms. Annual Progress Report, For. Remote Sensing Lab. for Nat. Resource Prog., NASA, by the Pacific Southwest Forest and Range Exp. Sta., 45 p.
4. Weber, F. P. 1966. Multispectral imagery for species identification. Annual Progress Report, For. Remote Sensing Lab. for Nat. Resource Prog., NASA, by the Pacific Southwest Forest and Range Exp. Sta., 37 p.

APPENDIX

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

Pacific Southwest Forest and Range Experiment Station, Berkeley, California.

Robert C. Aldrich, Research Forester
Larry R. Burton, Audio-Visual Specialist
Harry W. Camp, Assistant Director
Robert W. Dana, Physicist
Wallace J. Greentree, Forestry Technician
Robert C. Heller, Project Leader
Richard J. Myhre, Research Forestry Technician
John E. Noble, Physical Sciences Aid
Anne L. Weber, Project Clerk
Frederick P. Weber, Research Forester

Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

William F. McCanbridge, Entomologist

Southeastern Area, Atlanta, Georgia

Joseph C. Bell, Jr., Survey Specialist