REMOTE SENSING APPLICATIONS IN FORESTRY

A report of research performed under the auspices of the

Forestry Remote Sensing Laboratory,
School of Forestry and Conservation
University of California
Berkeley, California

A Coordination Task Carried Out in Cooperation with

The Forest Service, U. S. Department of Agriculture

For

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

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REMOTE SENSING OF
VIGOR LOSS IN CONIFERS DUE TO DWARF MISTLETOE

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by

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ABSTRACT

This project was initiated in 1970 for the purpose of developing remote sensing techniques for the detection and evaluation of vigor loss in conifers due to dwarf mistletoe infection. The initial operation of a multiband/multidate tower-tramway test site in northeastern Minnesota for the development of specifications for subsequent multiband aerial photography of more extensive study areas has now been completed. Multiband/multidate configurations suggested by the tower-tramway studies have been flown and will be flown again with local equipment over the Togo (extensive) test site; additionally, this test site was photographed by the NASA RB57F aircraft in August and September, 1971 (film processing in progress). It appears that, of all the film/filter combinations attempted to date (including optical recombining of several spectral band images via photo enhancement techniques), Ektachrome Infrared film with a Wratten 12 filter is the best for detecting dwarf mistletoe, and other tree diseases as well. Using this film/filter combination, infection centers are easily detectable even on the smallest photo scale (1:100,000) obtained to date on the Togo site.

In view of the existence of unusually interesting "targets of opportunity" in the vicinity of the dwarf mistletoe study sites, the overall project has been enlarged to include certain other economically-important examples of forest tree (and stand) stress. Preliminary multiband/multidate aerial photography has been obtained and ground examinations have been made on (a) red pine (Pinus resinosa) plantations differentially infected with Armillaria root rot (Armillaria mellea); and (b) aspen (Populus tremuloides) stands infected with hypoxylon canker (Hypoxylon

mammatum). The preliminary data are under study and overflights and ground checks are continuing.

ACKNOWLEDGEMENTS

The research described here is part of the Earth Resources Survey Program in Agriculture/Forestry which is sponsored, and financially assisted, by the National Aeronautics and Space Administration (Contract R-09-038-002). The following constitutes the second annual progress report of a cooperative study with the Forest Service, U. S. Department of Agriculture, and the College of Forestry, University of Minnesota. Most of the salary items and a significant portion of the operational costs of the project were borne by the University of Minnesota, College of Forestry, and the Agricultural Experiment Station*.

We appreciate the continued assistance of District Foresters Elmer Homstad and Eugene Wroe of the Minnesota Department of Natural Resources, Division of Lands and Forestry. We also would like to thank Dr. Robert H. Miller, Remote Sensing Coordinator of the USDA, Agricultural Research Service, for his advice and assistance; and the personnel of the Earth Observation Aircraft Program, MSC, Houston, who arranged, scheduled and photographed our test areas on a contingency basis.

Administrative chores are always tedious and difficult so, for their cheerful, competent handling of these difficult tasks and for keeping us informed, on schedule and out of serious trouble, we wish to thank Mr. Harry S. Camp, of the Forest Service's Pacific Southwest Forest and Range Experiment Station, and Dr. Gene Thorley, Director of the University of California Forestry Remote Sensing Laboratory. Their efforts have significantly enhanced our investigative capabilities.

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INTRODUCTION

Tree diseases such as dwarf mistletoe cause major losses in many of our valuable forest tree species. Control methods have now been developed for some of these diseases, but not for others. One of the requirements of a successful forest tree disease control program is a practical means of detection and assessment of the extent and severity of the disease. Because of the large land areas usually involved, and the associated difficulties of ground access and enumeration, the development of locally-adaptable remote sensing techniques appears to be the essential key to the design, and successful application, of most control problems.

As a case in point, Eastern dwarf mistletoe (*Arceuthobium pusillum*) in black spruce (*Picea mariana*) has become controllable essentially in the period during which this study has been under way. Prescribed burning was initially suggested as a control measure by French, et al. (1968). Subsequent investigation and experimental burning by Irving and French

(1971) has resulted in what appears to be a very effective control technique -- a technique which is, of course, dependent upon an adequate system of aerial surveillance in view of the extreme difficulties of ground travel and horizontal visibility experienced in spruce forests.

Experience gained at the tower-tramway multiband/multidate sub-project at the Cromwell test site, as applied to preliminary low to medium-altitude aerial photography of the extensive Togo test site, indicates that the possibilities of detecting dwarf mistletoe infection centers using small scale photography are very bright, indeed. Analysis of the RB57F imagery, flown in August of this year, and ultimately, the ERTS-A imagery which will become available next year, will permit us to identify the optimum photographic configuration and scale required to monitor this disease and related features.

Since applications of the newly-developed prescribed burning control technique for dwarf mistletoe are now taking place, and since control measures also require assessment, remote sensing again appeared to be the most efficient, economical means for accomplishing post-burn surveys. Such a possibility was suggested by the initial dwarf mistletoe detection overflights with Ektachrome Infrared aerial photography accomplished in an adjacent area in Koochiching County (Meyer and French, 1967) in 1965. Quite inadvertently, during these overflights, several ground locations containing black spruce slash burning were recorded (see Figure 1), which appear to indicate the possibility of using similar remote sensing techniques for assessing the pattern, extent, intensity and thereby judge the relative success of the prescribed burn.

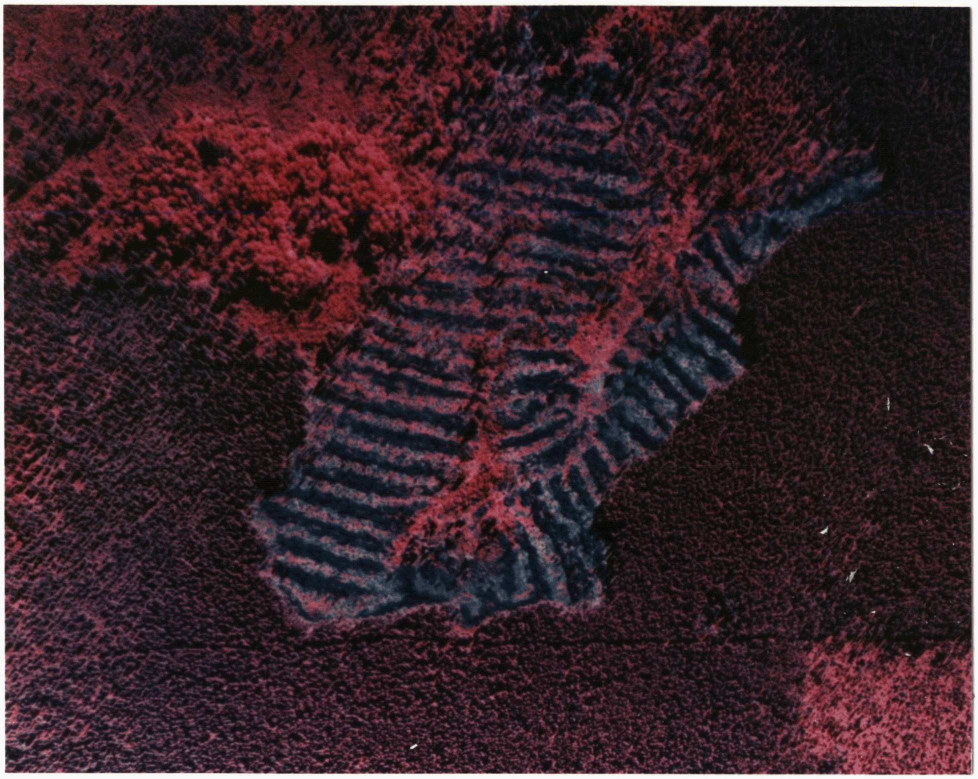


Figure 1. Vertical view of a black spruce harvest area following burning of the windrowed slash (Ektachrome IR film/Wratten 12 filter, Zeiss RMK A 15/23 camera, scale of 1:5,000, flown August 28, 1965). The details of the burned areas were also clearly visible at photo scales of 1:13,500, and 1:24,000 flown a few minutes earlier.

In view of the proximity and close association of the dwarf mistletoe test areas and research with certain other forest tree stress problems, the project was expanded this year to encompass certain "targets of opportunity". One of these is Armillaria root rot (Armillaria mellea), a fungus disease which has caused losses as high as 55% in red pine (Pinus resinosa) plantations in Minnesota. Losses of similar magnitude have ocuurred in other geographic areas and with species other than red pine. Normally losses are of less magnitude, but 10% mortality is not uncommon. Detection of diseased trees, estimating losses, planning replacements and most important, recognition of problem areas can best be accomplished with remote sensing methods. If this disease could be detected economically, mortality in these plantations could be correlated with previous cover types and thus planting plans for the future adjusted to avoid these unnecessary losses. The plantations selected for study have, at the present time, been thoroughly enumerated and mapped on the ground and multiband coverage at a variety of scales has been secured on two different dates. Data analyses are in progress.

Another target of opportunity of considerable commercial importance which was added to the project this year was hypoxylon canker (Hypoxylon mammatum), the most important disease of aspen (Populus tremuloides). This disease occurs over most of the range of this tree species, but does not occur in Alaska. In the Lake States of Minnesota, Wisconsin and Michigan, over 15% of the aspen trees on 21 million acres of this forest type are infected; the fungus girdles and kills trees in from 3 to 10 years. There are 2.4 million acres of commercial aspen in the Alaskan Interior.

In fact, aspen is one of only four major tree species in that region and, next to white spruce, probably has the greatest potential as a resource of the future.

Although no direct evidence is available, there is no question about the fact that the fungus causing hypoxylon canker can survive in Alaska and kill the aspen trees in that region just as it does in the Lake States and Canada. The fungus needs only to be introduced to Alaskan aspen stands, carried over the zone between where it now occurs in Canada and Alaska, to cause tremendous losses.

We need to know where the disease exists now, how much of a barrier actually exists between where the fungus is now active and the Alaskan Interior; and whether or not the distribution of the disease is changing from year to year. We believe that the intervening area has a climatic barrier unfavorable for the development of hypoxylon canker, and that the disease may be permanently restricted, but we need to know whether or not these assumptions are true.

If we can establish what is the present distribution of the disease and follow its movements over the next few years, we will be in a better position to deal with the problem of protecting the vast aspen resource in the Interior of Alaska. We feel the obvious way to accomplish this is through remote sensing, and we think this can be done.

Infected aspen trees retain their leaves through the fall and much of the winter, in contrast to healthy trees which lose their leaves. Infected trees can be detected rather easily from some distance away, which suggests the possibility of aerial detection of the presence of hypoxylon canker during the fall season when the leaves have dropped from the healthy trees. Additionally, during the summer, the foliage of trees which have been girdled by the fungus turns brown, which also suggests the possibility of detecting the disease in the summer. The best months, we think, would be August or October. August is best of the summer months because most of the foliage on the affected portions of the trees would be dead by this time; October is best for the dormant season in that the dead foliage will, in time, be removed from the trees by wind, rain and combinations of snow and ice.

If we can ascertain where hypoxylon canker is now distributed in Canada, and can determine whether the disease is moving in a northwesterly direction, we can then devise more effective control measures to protect the valuable Alaskan aspen resource. If the disease were to reach Alaska, we expect losses would be extensive. As a warning of the potential hazard, despite more than 20 years of research effort, no practical control measures for hypoxylon canker have been developed.

At the present time, we have selected and gathered preliminary data on the ground in two study areas and accomplished preliminary multiband aerial photography of both of them.

STUDY AREA LOCATIONS, CHARACTERISTICS

Cromwell Test Site (see Figure 2) is located in a black spruce stand on the Fond du Lac State Forest in Carlton County, Minnesota, and involves the tower-tramway portion of the study (now completed). This area received NASA RB57F overflights in August and September, 1971, and will be studied

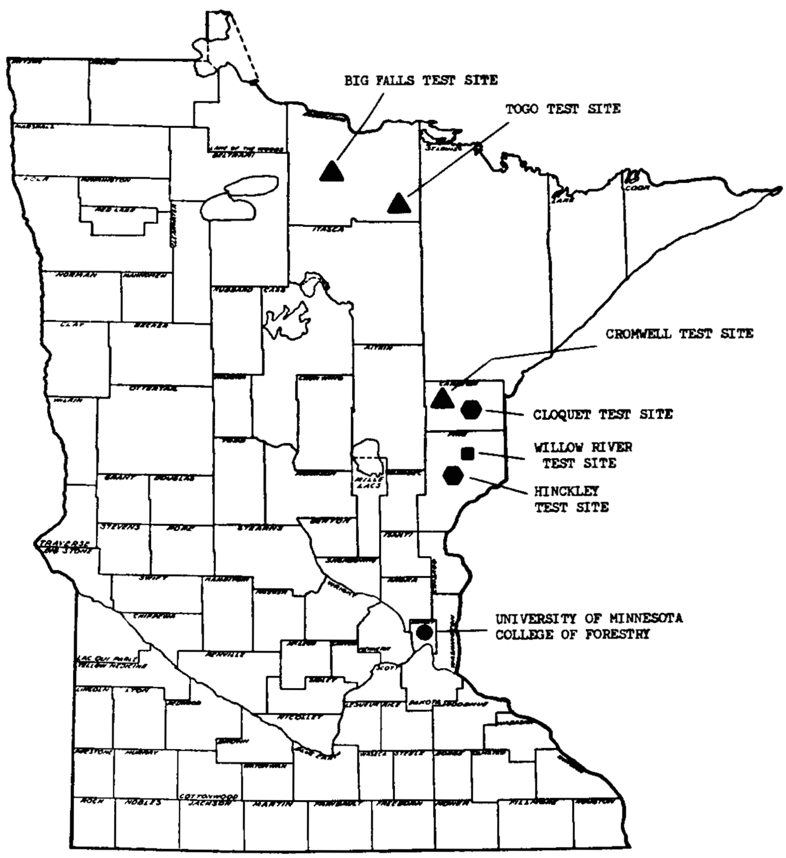


Figure 2. Minnesota test site locations.

from the standpoint of this coverage when it is received. An oblique photograph (Figure 3) shows the nature of the test site.

Togo Test Site (see Figure 2) is located in extensive spruce forest stands on the George Washington State Forest in Koochiching County, Minnesota. Low to medium-altitude aerial photography has been concentrated on a specific section (640 acres) of this black spruce forest. The small scale coverage, however, involves many square miles of the area. Figure 4 shows the nature of this forest and the general terrain.

Big Falls Test Site (see Figure 2) involves a black spruce harvest area approximately 10 miles west of Big Falls, Minnesota, which is about 135 acres in size. Ground views of the site before, during and after the prescribed burn are in Figure 5.

Willow River Test Site (see Figure 2) consists of extensive red pine plantations on the General C. C. Andrews Nursery of the Minnesota Department of Natural Resources near Willow River in Pine County, Minnesota. Ground views of a healthy tree and trees infected with Armillaria root rot are shown in Figure 6.

Hinckley/Cloquet Test Sites (see Figure 2) involve aspen stands with hypoxylon canker at two different locations. The Hinckley site is near Hinckley, Minnesota in Pine County and the Cloquet site is in the southwest corner of the University of Minnesota, College of Forestry Cloquet Forest in Carlton County, Minnesota. A ground view of an infected tree in winter is portrayed in Figure 7.

Figure 3. View of the Cromwell test site where the tower-tramway system was located. This portion of the overall project has been completed.

A

B

C

Figure 4. Ground views of the Togo test site showing: (A) and (B) character of the terrain and forest, and (C) examining dwarf mistletoe-infected black spruce reproduction in a previously-harvested area. The primary reason for prescribed burning of infected areas is to insure disease-free reproduction.

A

B

C

Figure 5. Ground views of dwarf mistletoe control prior to, during and after the prescribed burn.

A B C

Figure 6. Ground view of healthy red pine at A; and red pine infected with Armillaria mellea (Tree B was infected in 1971 and is dying; Tree C was killed in 1970).

Figure 7. Winter view of an aspen tree infected with hypoxylon canker. Note that its leaves are retained -- as contrasted to the adjacent healthy trees which have no leaves.

PHOTO AND FIELD DATA ACQUISITION

Dwarf Mistletoe

Cromwell (Intensive Tower-Tramway) Test Site. This tower-tramway system, consisting of two 100 foot towers spaced 100 feet apart in a black spruce bog with trees differentially infected with dwarf mistletoe, was designed to give sequential multiband photography during a full photographic season extending from May into October (i.e., from bud break in spring to leaf fall in autumn). Beginning in July 1970, and terminating in October of 1970, multiband imagery was taken at 10 foot intervals along the tramway at approximately 10 day intervals at 0900, 1200 and 1500 local (sun) time on each photographic day. The following film/filter combinations, utilizing a 50 mm lens in each of the four 500EL Hasselblad cameras, were used:

Plus-X/58 filter

Plus-X/25A filter

Aero Infrared/89B filter

Ektachrome Infrared Type 8443/12 filter

Review and analysis of the 1970 photography during the past winter resulted in a decision to alter the timing and character of the photography for the remaining coverage period. Consequently, during the period May 1971 to July 1971, photography was taken at 25 foot intervals along the tramway, once a day (1200 local sun time), and approximately every 10 days with the following film/filter combinations:

Combination Used Every Time	Combinations Used Interchangeably
- Ektachrome Infrared Type 8443/Wratten 12 filter	- Ektachrome IR and MS/with and without 2A filter

Combinations Used Interchangeably (Cont.)

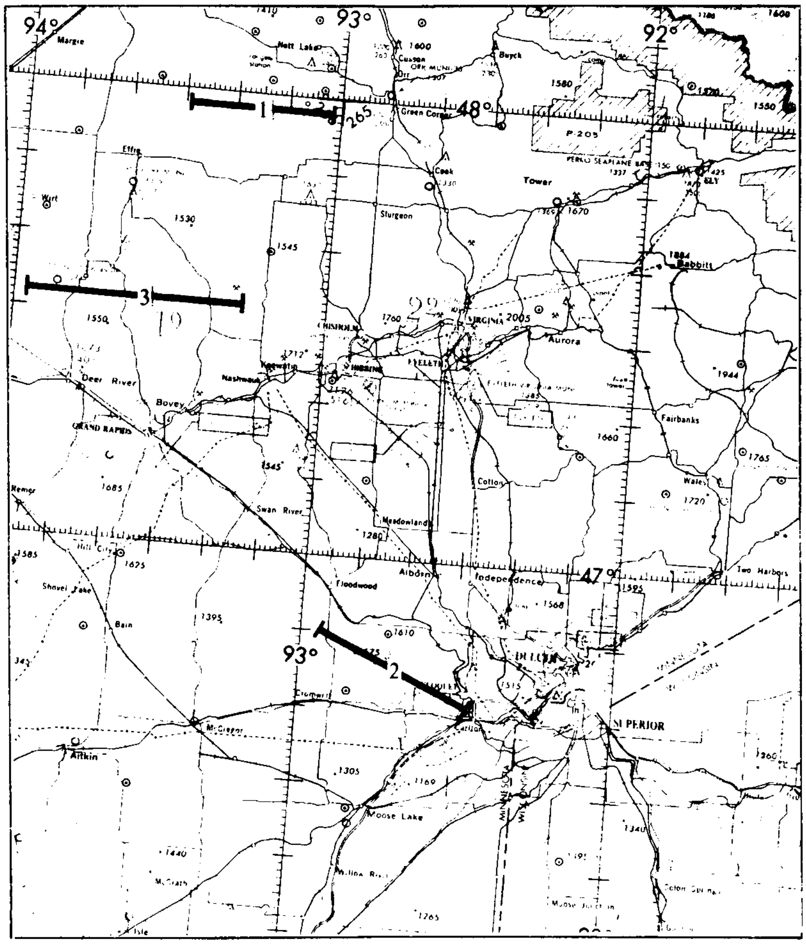
- GAF-1000 Blue Insensitive/3 filter
- GAF D-200/with and without 2A filter
- Plus-X/no filter
- Aero Infrared/89B filter

Concurrent with each tramway overflight series, weather variables were recorded for later correlation with resulting imagery. Wet and dry bulb temperatures, wind speed and direction, haze conditions and cloud cover were observed as well as two types of light meter readings.

The study plot was limited to a 100 x 100 foot area as seen by 50 mm lenses from the tramway. It was, by design, located on the edge of an infection center and contained trees ranging from those which were healthy, through lightly and heavily infected, to dying and dead trees, Also included was an open area with normal ground cover including tree seedlings. Each tree on the plot was mapped and the type, severity and character of infection (if any) categorized. Other aspects of the area were characterized and numerous ground photographs were taken.

In August, and again in September 1971, a 22 nautical mile line was flown at 60,000 feet across the Cromwell test site with the NASA RB57F (see Figure 8), using the following camera/film/filter combinations (film processing in progress):

Camera	Film/Filter
RC8 (f = 6'')	S0397/2A
RC8 (f = 6'')	2443/15



LINE 1 = TOGO TEST SITE
LINE 2 = CROMWELL TEST SITE

Figure 8. Location of lines flown at 60,000 feet by the NASA RB57F in August and September, 1971.

Zeiss (f = 12")	2443/15
Hasselblad (40 mm)	2402/58
Hasselblad (40 mm)	2402/25A
Hasselblad (40 mm)	2424/89B
Hasselblad (40 mm)	2443/optimum
Hasselblad (40 mm)	2402/12
Hasselblad (40 mm)	S0356/optimum

Togo (Extensive) Test Site. Aerial photo coverage of the Togo test site has been accomplished at a variety of scales with a number of film/filter combinations on different dates. Coverage as of September 15, 1971, with the College of Forestry Hasselblad quadricamera unit, is shown in Table 1. Additional coverage was flown by the NASA RB57F aircraft in August and on September 29, 1971, at which times a 17 nautical mile line was flown at 60,000 feet across the test site (see Figure 8) with the same camera/film/filter combinations used on the Cromwell test site. Processing of the NASA overflight films is in progress.

The initial field examinations of the Togo site were for the purpose of verifying the location of dwarf mistletoe infection centers in the area of coverage and to check the various vegetation cover types. Questionable infection centers which may ultimately show up on subsequent photography will be examined on the ground by a forest pathologist when necessary.

All imagery and ground information on this site, as necessary to bring the dwarf mistletoe investigation "on line" for the commencement of ERTS-A imagery delivery and analysis in 1972, is now either currently at hand or due for delivery prior to the end of 1971.

Photo Scale*	Film/Filter Combination			
	Ektachrome MS w/2A filter	Ektachrome IR w/12 filter	Aero Infrared w/89B filter	Ektacolor w/2A filter
1:8,000	7-8-71	7-8-71	7-8-71	---
	8-3-71	8-3-71	8-3-71	8-3-71
1:31,680	7-8-71	7-8-71	7-8-71	---
1:63,360	7-8-71	7-8-71	7-8-71	---
1:100,000	8-3-71	8-3-71	8-3-71	8-3-71

* 50 mm lenses used in all cases.

Table 1. Dates and types of photography flown on the Togo test site with the College of Forestry 70 mm Hasselblad quadricamera unit in 1971. A final overflight in late September or early October is planned, pending suitable weather.

Big Falls (Control Measure) Test Site. The Big Falls site provided an opportunity to monitor the application of the dwarf mistletoe prescribed burning control technique, developed by Irving and French. The sale area had been cut earlier, the slash distributed in the proper manner and thoroughly analyzed and mapped on the ground. On August 3, 1971, the study area was flown at scales of 1:6,000 and 1:16,000 with the following film/filter combinations (50 mm lenses):

Ektachrome MS/2A filter

Ektachrome Infrared Type 8443/12 filter

Aero Infrared/89B filter

Ektacolor/2A filter

Following the burn the site was again examined and mapped on the ground in order to relate the pattern and intensity of the burn to the original condition and placement of the slash. The post-burn overflight on the Big Falls test site has been planned and is now pending.

Armillaria Root Rot

Willow River Test Site. The existence of pine plantations with root rot mortality on the aircraft travel routes to (and from) the dwarf mistletoe test site, provided an excellent target of opportunity for study. The test site was initially flown on July 8, 1971, by a commercial aerial photography firm using the College of Forestry 70 mm quadricamera unit. The following film/filter combinations, exposed with 50 mm focal length lenses, were employed to obtain photography at scales of 1:2,400 and 1:15,840:

Ektachrome MS/2A filter

Ektachrome Infrared Type 8443/12 filter

Infrared Aero/89B filter

GAF-1000/21 filter

In a general photographic sense (exposure, coverage, geometry), the results were good, although an overflight time delay did result in a sun spot in one margin.

On the ground, sample row portions (this was a plantation) were selected along the line of flight and a total of 309 trees were examined, located on the photographs and placed in the following categories:

Healthy -- 265 trees

Trees which died in 1968 -- 5 trees

Trees which died in 1969 -- 11 trees

Trees which died in 1970 -- 13 trees

Trees currently dying -- 15 trees

A follow up overflight was made over the area on August 28, 1971, using the following film/filter combinations at scales of 1:2,000 and 1:8,000:

Ektachrome MS/no filter

Ektachrome Infrared Type 8443/12 filter

GAF-1000/12 filter

Ektacolor/no filter

Hypoxylon Canker of Aspen

Hinckley/Cloquet Test Sites. The problem of hypoxylon canker infection of aspen having been of concern, and under study by French in Minnesota for a considerable period of time, the location and designation of test sites were comparatively simple. The two sites chosen, near Hinckley and Cloquet, were photographed on August 11 at scales of 1:6,000 and 1:15,840 and on September 19 at scales of 1:6,000, 1:15,840 and 1:31,680 with the following film/filter combinations:

Ektachrome MS/2A filter

Ektachrome IR/15 filter

Ektachrome IR/34A filter

Ektacolor/2A filter

Ground work is scheduled for this fall.

PHOTO AND DATA ANALYSIS

Dwarf Mistletoe

Cromwell (Intensive Tower-Tramway) Test Site. Since the work on the Cromwell test site has now been completed, this constitutes a final report on this portion of the overall project.

Objectives

The objectives of the Cromwell sub-project were to attempt to answer the following questions regarding the detection and assessment of dwarf mistletoe with remote sensing techniques:

1. Is there a consistent, definitive spectral signature associated with mistletoe infected black spruce?

2. Can a multispectral photographic system such as ours, using the ERTS selection of spectral bands and using color enhancement, successfully detect infection centers?

3. If so, what are the optimum characteristics of such a system (i.e., how can the multispectral image best be re-combined, enhanced and re-photographed)?

4. If such a system cannot be used, what other aerial photographic techniques might be used?

5. Are there significant phenological characteristics which would prove advantageous to aerial photographic detection?

6. From a research methodology standpoint, how useful is ultra-low altitude aerial photography?

Image Enhancement

Preliminary work conducted to test the feasibility of a simple color-enhancement system indicated that a far more costly and elaborate system was needed than was practical to build here at the University of Minnesota. Therefore, arrangements were made to utilize the optical combiner belonging to the Forestry Remote Sensing Laboratory at the University of California at Berkeley. A representative sample of the imagery procured up to that time was selected and diapositives were made. These were taken to Berkeley where they were re-combined; the spectral content was manipulated and the images were re-photographed.

During this process it became evident that an independent camera system such as this has a number of inherent limitations when used within the context of ultra-low altitude photography. Since it was not, at that time, feasible to obtain the services of single camera type multispectral photography, that portion of the project was dropped when photography was begun again in spring.

Photo Interpretation

Systematic, but qualitative, interpretation was carried out on both the re-photographed enhanced imagery and on the several single band emulsions. After a modicum of referring back and forth between the imagery and the record of ground truth, the location and condition of each tree was thoroughly memorized. Thus, any spectral differences which existed could quickly be assessed as to their correlation with mistletoe infection.

Results

The results of these procedures, in terms of the study's objectives, are given within the framework of the questions originally posed:

1. A consistent, definitive spectral signature associated with mistletoe infected black spruce was not found and may not exist. The relative spectral signatures of the overall crowns of the several trees studied remained virtually constant throughout the time span studied. Generally there appeared to be slightly less energy returned from the crowns of the infected trees in the infrared portion of the photographic spectrum than from the crowns of healthy trees. It is suspected, however, that this differential is due at least partially to differences in the amount of dead material in the crown rather than to differences in the spectral signatures of the leaves themselves. Our tree #30, for example, was an infected 3.5 inch d.b.h. tree with several small brooms displaying very little dead material to the aerial view and had an overall spectral signature quite indistinguishable from its healthy, uninfected neighbors. Tree #35, however, was a 4.1 inch d.b.h. heavily infected tree which displayed a great deal of dead material to the aerial view and had an

overall spectral signature much closer to the totally dead trees than to any of the live trees.

Physiological differences induced by mistletoe, however, may result in spectral differences. Tree #12 was an infected 8.7 inch d.b.h. tree with two small brooms. It did not display much dead material to the aerial view due to its apparently still vigorous condition. A nearby tree, #5, was an 8.2 inch d.b.h. uninfected tree and, visually at least, appeared to be equally as vigorous. Of these two, #12 consistently appeared less reddish on Infrared Ektachrome than #5. There seemed to be a general trend of this in numerous examples, but several noticeable and consistent exceptions exist.

The only definitive, consistently different spectral signature observed was that of dead trees. The composite spectral signature of the ground cover in the open areas was also distinctively different from that of the trees: healthy, infected or dead. These differences are more pronounced in the infrared portion than in the visible portion of the photographic spectrum.

Perhaps the most important result of this study with regard to spectral signature is the firm recognition that very little can be said about spectral signatures per se using this method. While it has many advantages over traditional laboratory methods with regard to composite, in situ signatures the spectral steps are too large to be very meaningful. What is required is a highly portable spectrophotometer which could be carried on the tramway arrangement to secure more detailed signatures.

2. We found that our multiple camera arrangement had numerous limitations to its use in multispectral color-enhancement. Highly accurate registration of the re-combined images was found to be virtually impossible. This resulted from several factors. One factor was differential parallax due to the small differences in placement of the cameras. Another factor was time differences due to bracketing. In order to insure proper exposure, we bracketed during each photo session. If one part of the re-combined image came from the early bracket and another part from the late bracket, the images contained slightly different sun angles (usually about 10 minutes apart) and because of different wind sway were taken at different points which added to the differential parallax mentioned above. Still another factor related to the optical combiner which, while one of the best available, still contained numerous weaknesses which precluded consistent perfect registration. In addition to registration problems was the problem of vignetting. The Hasselblad cameras with 50 mm lenses contained a significant light fall-off toward the edge of the frame. This has since been documented (Keenan, 1970). Our system included photography and re-photography with this camera and the resulting imagery suffered badly as a result.

This system also lacked any method for sensitometric calibration. It appears that a rudimentary, but probably satisfactory, sensitometry procedure could be added by simply flashing a stepwedge on the leader and/or trailer of the film.

In total, therefore, it appears that in the multispectral approach as it was then being operated was not too promising. The imagery which resulted was fair (in spite of the limitations) and served as the basis for some interpretation noted below.

3. Ours was not found to be an optimum system for the recombination enhancement and re-photography of our tramway multiband photography. In our study, variations in the spectral slices for the taking camera were not studied. We simulated the ERTS-A slices. Spectral assignment in the recombination phase was briefly considered, however. The combinations (Table 2) were found to be quite useful, but should not be considered to be an exhaustive list. A representative sample of the enhancement results is shown in Figure 9.

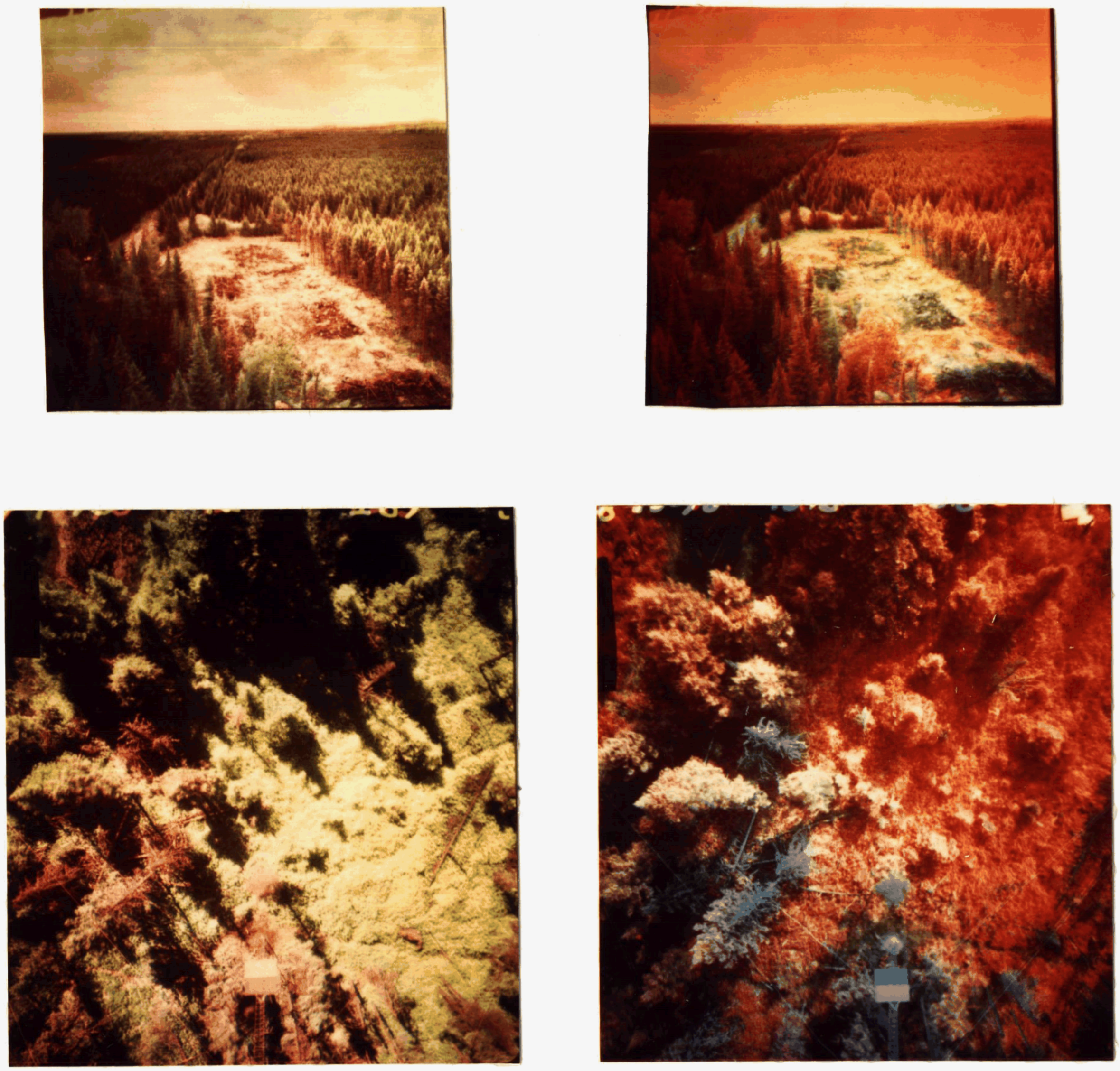
Clear criteria for spectral assignment in the recombined image are lacking, and apparently would depend on the physiology of the eye and some rather subtle psychological aspects of interpretation. Such items were not the subject of this study.

Some thought has been given to the question of whether any multispectral color enhancement system would be useful in detecting dwarf mistletoe infected black spruce. Generally it seems doubtful. In terms of basic information content, the enhanced image has little advantage over a tri-pac emulsion or even over the black-and-white slices from which it is made. The superficial dyeing of the image may make subtle differences more vivid, but the differences must pre-exist. Resolution is significantly less and several cumbersome steps are added to the process. While a wide flexibility is afforded the user in the choice of spectral slices and in the redyeing possibilities, each array of targets will require a substantial research effort to take advantage of this flexibility. If the resulting choice

Film/Filter Used in Aerial Photography	Projector Filter	
	Set A	Set B*
Plus-X/58	47a	47a
Plus-X/25A	30a	58
Aero IR/89B	102	25

* Closely resembles Ektachrome IR/Wratten 12 photography.

Table 2. Filter combinations used to re-combine multispectral images of dwarf mistletoe infection centers.



Filter Set A (47a, 30a and 102)

Filter Set B (47a, 58 and 25)

Figure 9. Samples of image enhancement resulted obtained with the Cromwell dwarf mistletoe test site spectral slices (i.e., Plus-X/58, Plus-X/25A, Aero IR/89B). Dead foliage is pinkish on Set A, blue-green on Set B.

closely approximates any of the available tri-pac emulsions, there is little to recommend its use.

4. Since no definitive spectral signatures were obtained and the immediate development of a multispectral color enhancement system did not seem feasible, it was felt that, at least in the short run, the use of single based multi-emulsion films would offer the most promising avenue of research.

The site was photographed with a number of available tri-pac emulsions and the imagery was correlated with the known conditions on the ground. Results are as follows:

a. True color film. Essentially three different true color films were tested:

(1) Ektachrome (both types 2448 and 5257), GAF-200 (type 7230) and Ektacolor (type 5026, with interpretation of both color negatives and color prints). Ektachrome exhibited good resolution (probably the best of the multi-emulsion films), but suffered from a saturation of green. It is relatively easy to pick out dead trees from live, but differentiation among the various categories of live trees was virtually impossible.

(2) GAF-200 exhibited many of the same characteristics of Ektachrome but tends to a slightly heavier emphasis on the longer wavelengths. It has a slightly higher overall sensitivity and a slightly lower resolution.

(3) Ektacolor prints were used in attempting to differentiate between healthy and infected trees and were not found to be particularly suited for this use. The additional printing surely reduced latitude, color fidelity and resolution as well as denying the use of transmitted

light for interpretation. In order to regain the use of transmitted light and eliminate the losses in printing, an attempt was made to interpret color negatives directly. Little advantage was found in this interpretation. It is, at least initially, extremely difficult to think in negative color.

In general, true color films exhibited their many well known advantages, but could not offer differentiation between the infected and uninfected trees.

b. False color films. Two false color films were used:

(1) GAF-1000 (type 7575) and Ektachrome Infrared (type 8443). The GAF-1000 is an experimental blue insensitive film which appears to hold some promise for spectral differentiation of vegetation. Unfortunately our sample was improperly processed by the manufacturer and consequently had an extremely short latitude and gave no differentiation of crowns. After several other attempts, we eventually secured one sample of correctly exposed and processed GAF-1000 (over a diseased pine plantation as part of a related project). Dead and dying pine trees are vividly displayed, indicating some potential for this film.

(2) Ektachrome Infrared type 8443 was the other false color film tested. Of all film/filter combinations tested (including the multispectral work), this film was the most successful for distinguishing between categories of trees. Both the open ground cover and the dead trees are vividly displayed with this medium. Also, with this film any tree which offers to the aerial view a substantial amount of dead material may easily be distinguished from one that does not. Whether the reduced reddish color

which seems to correlate with infected trees (as mentioned in 1 above) is a useful key or not must remain conjectural for the moment. Further testing over a more extensive area is required.

5. Throughout the entire season there did not appear to be any appreciable change in relative spectral signature of the several categories of trees. Thus it appears that choice of photographic date can depend on weather, equipment availability, etc., rather than on phenological characteristics.

One minor anomaly was observed in late September. Heavily infected trees suffered a substantial die-back apparently induced by the advent of cold weather. In fact our tree #46 essentially died in late September and, on the October 15 photography, all the needles which had previously been indistinguishable from those on a healthy tree had turned red. The following spring, all of these red needles were gone. Portions of the crown of several other heavily infected trees suffered the same die-back. The red needles usually represented a rather small proportion of the entire crown, however, and their presence is rather short lived. It is doubtful that one could operationally capitalize on this phenomenon.

6. We found that the taking of fixed site, ultra-low altitude photography was a worthwhile research technique, but we would limit its use to early stages of such studies.

Such a technique has the marked advantage of safely providing extremely large scale, intensive photography of a given area. Very detailed ground truth can be gathered for that limited area. Repeatability in terms of time and place can be easily achieved.

Its major disadvantages revolved around many of the same characteristics. Firstly, because it is a fixed location and of limited areal coverage, the sample size available is severely limited. In our study, for example, there seems to be some positive correlation between infection and loss of infrared reflectance in most trees. There were, however, enough instances to the contrary to preclude any definitive statements. A larger sample size might have eliminated this restriction.

Another disadvantage had to do with the method's inability to display patterns of infection. The total study area covered only 10,000 square feet. The pattern of development of many phenomena such as mistletoe infection centers reaches over extensive areas and this pattern itself may be sufficiently distinctive to provide detection. It is suspected, for example, that the slowly expanding edge of these dwarf mistletoe infection centers with its "annual ring" of dead trees will, by itself, provide detection capability. Such patterns cannot be studied from the tramway. Other work on this project will focus on these extensive aspects.

Togo (Extensive) Test Site. Photo and data analysis are in the preliminary stages; not all photo coverage for 1971 has as yet been received and catalogued. A sample of the multiband coverage obtained on the site in 1971 is shown in Figure 10.

Big Falls (Control Measure) Test Site. Site study is in a very preliminary stage with only the pre-burn photography accomplished to date (see Figure 11).

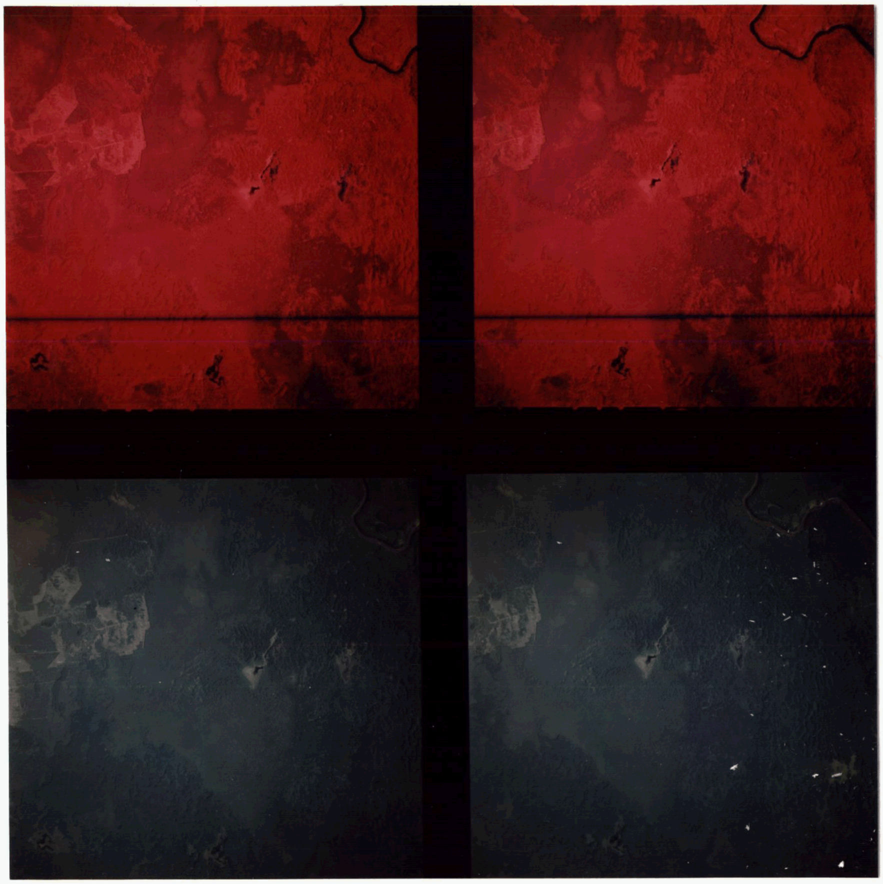


Figure 10. Stereograms of the Togo dwarf mistletoe test site illustrating 70 mm Ektachrome IR/Wratten 12 and Ektachrome MS/2A filter coverage flown August 3, 1971, at a scale of 1:100,000. The area just left of center with a somewhat "moth-eaten" look is a series of dwarf mistletoe infection centers.

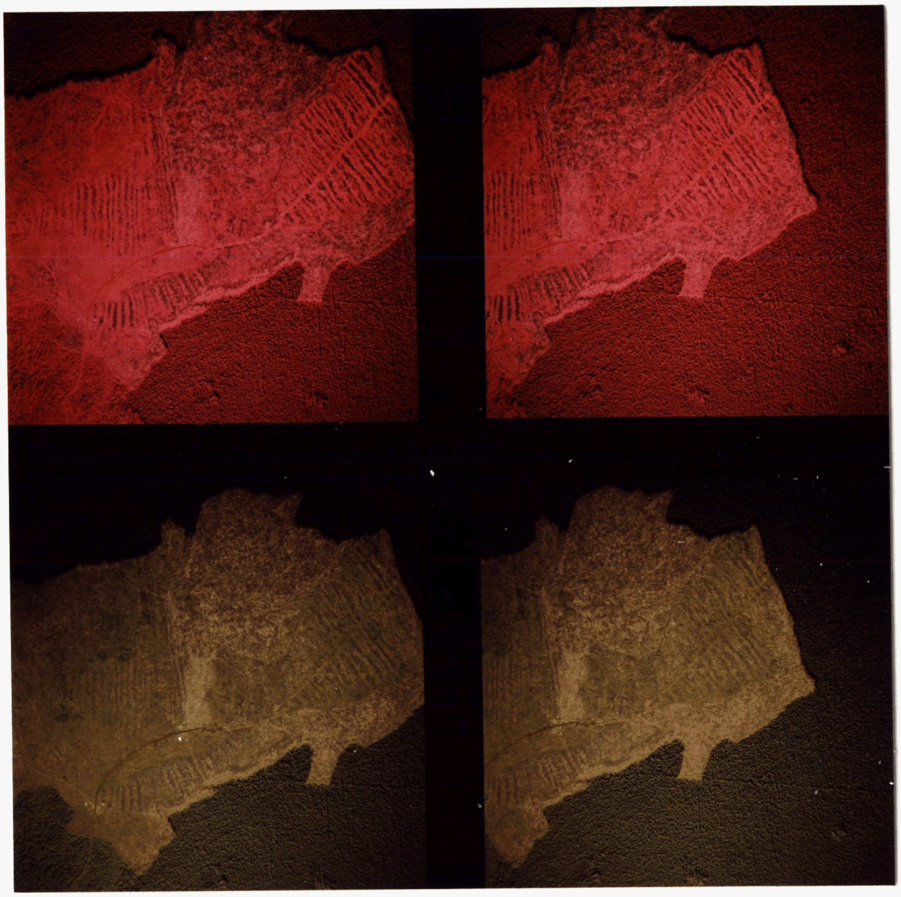


Figure 11. Stereograms of a portion of the Big Falls dwarf mistletoe control study site illustrating 70 mm Ektachrome IR/Wratten 12 and Ektachrome MS/2A filter coverage flown August 3, 1971, at a scale of 1:6,000. The portion of the harvest area having evenly-distributed slash is the study area; windrowed slash is from a previous cut.

Armillaria Root Rot

Willow River Test Site. On the July 8, 1971 photography, we were able to detect only those trees which had died in 1970, and with some slight difficulty the trees which had died in 1969. These latter trees had lost most of their foliage. Trees which died in early 1971 were detected with considerable difficulty and none of those trees which died later in 1971 could be detected on either of the two film types (Ektachrome MS and Ektachrome IR).

The August 8, 1971 photography appears somewhat more promising and is currently undergoing interpretation. Sample stereograms of the August overflight appear in Figure 12.

Hypoxylon Canker of Aspen

Hinckley/Cloquet Test Sites. Preliminary examination of the photography flown on August 11, 1971, indicates dead and dying aspen clearly visible on the Hinckley test area (see Figure 13). Interpretation of the August photography is, however, incomplete and the interpretation of the September photography is not yet underway.

CONCLUSIONS

Dwarf Mistletoe

Cromwell (Intensive Tower-Tramway) Test Site. As is so often the case, unequivocal answers were in short supply. A great deal has been learned, however, and is briefly summarized as follows:

1. Definitive, consistent spectral signatures were not found for

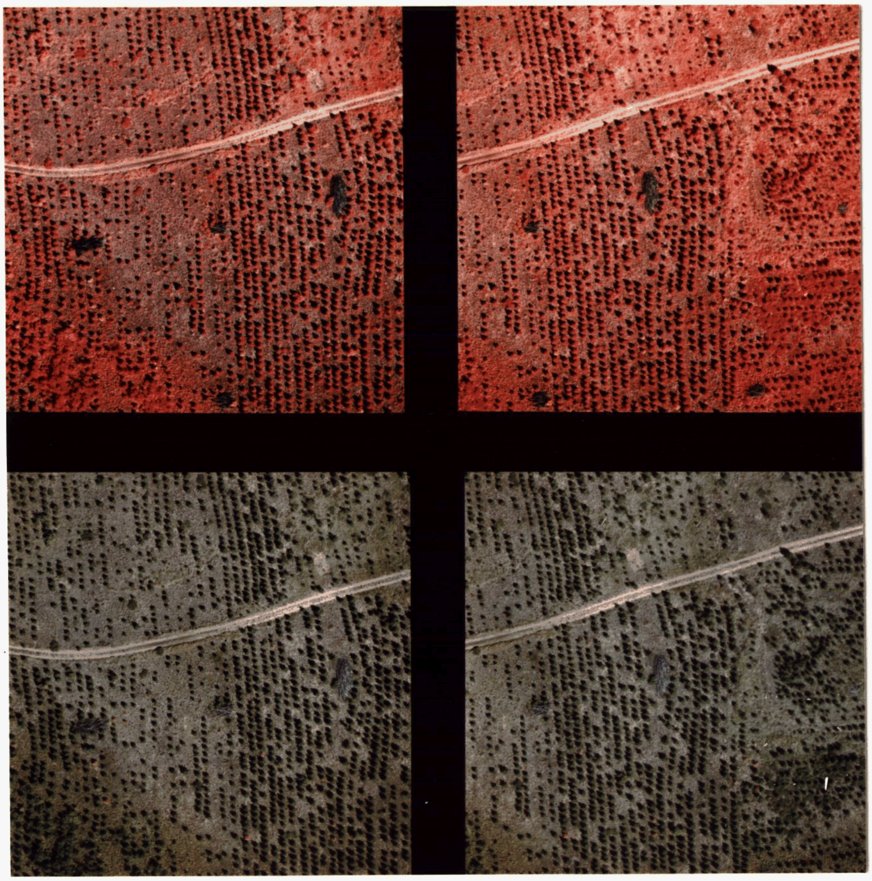


Figure 12. Stereograms of the Willow River Armillaria root rot test site illustrating 70 mm Ektachrome IR/Wratten 12 and Ektachrome MS/2A filter coverage flown on August 28, 1971, at a scale of 1:2,000. The obvious off-color trees died in 1970.

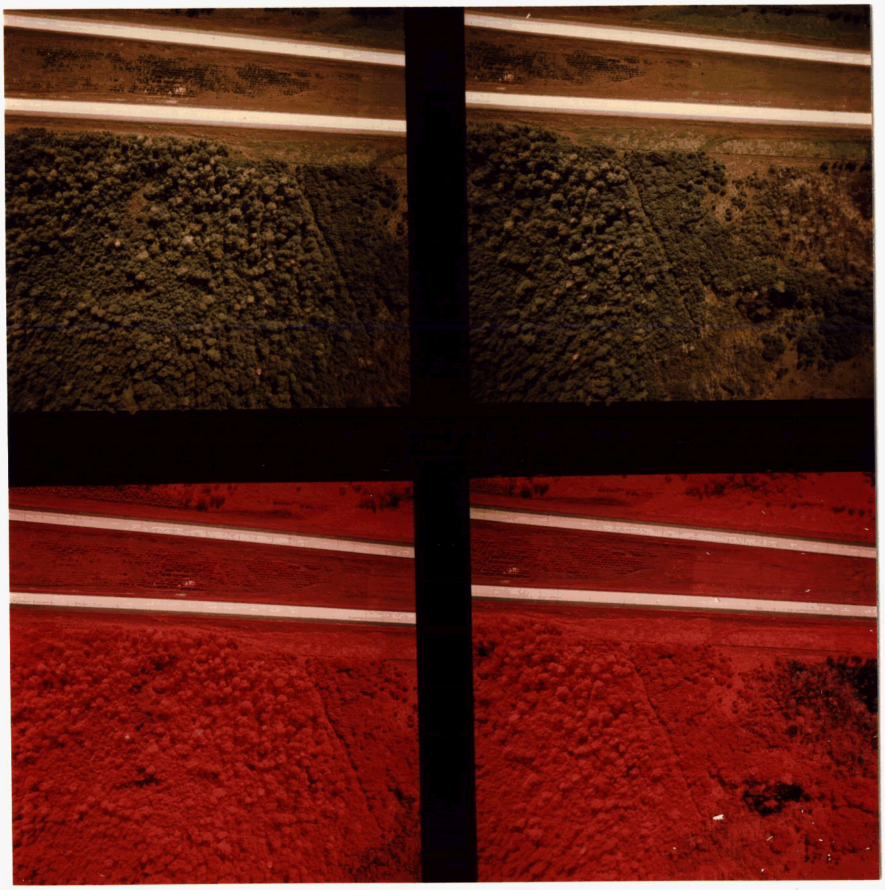


Figure 13. Stereograms of the Hinckley hypoxylon canker of aspen test site illustrating 70 mm Ektachrome MS/2A and Ektachrome IR/Wratten 12 filter coverage flown August 11, 1971, at a scale of 1:6,000. Trees with newly-dead crowns (leaves retained) and old dead trees (bare) are plainly visible.

any of the several classes of infected trees (except, of course, completely dead). Indeed, if one uses this method, only crude inferences can be made about spectral signatures. It generally appears that total energy returned in a photographic spectrum from dead and dying crowns is less than from healthy crowns and that the energy returned is more concentrated in shorter wavelengths.

2. A multispectral system such as ours does not lend itself to color enhancement techniques. Therefore, optimum characteristics for such a multispectral color enhancement system were not determined, but it generally appears that our red and infrared bands contributed more information than the green band. How various colors may be assigned in the recombined image remains highly conjectural. Our cursory search indicates that a recombination approximating Ektachrome Infrared may well be as good as any other.

3. Since a multispectral color enhancement approach did not appear promising, a number of single based film/filter combinations were studied. Generally, it appeared that Ektachrome Infrared film with a Wratten 12 filter would record any spectral differences which exist between the several categories of trees better than any of the other available multi-emulsion films studied.

4. This study did not show any particular growing season date to be significantly better for photography than another.

5. This ultra-low altitude photography has been found to be fairly easy to procure (especially with regard to repeated coverage of the same area) and should be a useful tool for much remote sensing research. At

the present, however, it appears that the most fruitful line of research for this project should be with regard to patterns of distribution and other extensive aspects which cannot be researched with this medium.

Since data collection and analyses are still in progress on the following test sites, conclusions are not possible at this time: Togo, Big Falls, Willow River and Hinckley/Cloquet.

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