REMOTE SENSING APPLICATIONS IN FORESTRY

REMOTE SENSING APPLICATIONS TO FOREST VEGETATION CLASSIFICATION AND CONIFER VIGOR LOSS DUE TO DWARF MISTLETOE

by

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PREFACE

On October 1, 1965, a cooperative agreement was signed between the National Aeronautics and Space Administration (NASA) and the U.S. Department of Agriculture (USDA) authorizing research to be undertaken in remote sensing as related to Agriculture, Forestry and Range Management under funding provided by the Supporting Research and Technology (SR&T) program of NASA, Contract No. R-09-038-002. USDA designated the Forest Service to monitor and provide grants to forestry and range management research workers. All such studies were administered by the Pacific Southwest Forest and Range Experiment Station in Berkeley, California in cooperation with the Forestry Remote Sensing Laboratory of the University of California at Berkeley. Professor Robert N. Colwell of the University of California at Berkeley was designated coordinator of these research studies.

Forest and range research studies were funded either directly with the Forest Service or by Memoranda of Agreement with cooperating universities. The following is a list of research organizations participating in the SR&T program from October 1, 1965, until December 31, 1972.

1. Forest Service, USDA, Pacific Southwest Forest and Range Experiment Station, Berkeley, California.

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

3. School of Forestry and Conservation, University of California, Berkeley, California.

4. School of Forestry, University of Minnesota, St. Paul, Minnesota.

5. School of Natural Resources, University of Michigan, Ann Arbor, Michigan.

6. Department of Range Management, Oregon State University, Corvallis, Oregon.

This report summarizes the significant findings of this research and identifies research results which have been applied or are ready for application. In addition, the work carried on for the reporting period October 1, 1971, until December 31, 1972, is described in detail.

A listing of all research reports produced under NASA SR&T funding for forest and range studies can be found in the Appendix of this report.

ABSTRACT

The primary objective of this project was to establish criteria for practical remote sensing of vegetation stress and mortality caused by dwarf mistletoe infections in black spruce sub-boreal forest stands. The project was accomplished in two stages: (1) A fixed tower-tramway site in an infected black spruce stand was used for periodic multispectral photo coverage to establish basic film/filter/scale/season/weather parameters; (2) The photographic combinations suggested by the tower-tramway tests were used in low, medium and high altitude aerial photography.

At a variety of scales color infrared proved to be the most effective film used, not only because of the healthy-versus-stressed vegetation color contrasts attained at lower altitudes, but also because of the generally better atmospheric penetration at extremely high altitudes. Actually, the physical characteristics of the infection centers (e.g., the "moth-eaten" appearance) were generally visible on all film-filter-scale combinations, once the stands had been identified as black spruce. But spectral differences *per se* between dead and healthy vegetation survived scale reduction to only medium scale, and then only on the color infrared photography.

Image enhancement, by means of optically combining multispectral imagery and the masking and density slicing of single emulsions, generally tended to improve the ease of visual detectability of stress but did not appear to improve, or extend, the actual threshold of detection. In general, the study suggests the use of high altitude imagery to identify spruce forests and locate questionable stand openings therein -- then

following up with relatively large-scale color infrared aerial photography of the suspected problem areas for final location and assessment of actual infection centers.

Since vegetation classification is basic to most forest management decisions (including tree stress considerations), a study was made in our ERTS-oriented study of the applicability of very small-scale aerial photography. Practicing professional foresters were able to classify vegetation to an 85 percent level of accuracy on 1:118,000 infrared color photography taken in the fall of the year. Accuracy levels were reduced with color photography and by using summer season photography (color and infrared color). The usefulness of very small-scale aerial photography for multi-stage forest vegetation classification and sampling was obvious.

Additional subprojects which were initiated, but which are not yet finished, involve possible applications of remote sensing to the detection of hypoxylon canker of aspen, *Armillaria* root rot of pine plantations, and post-logging controlled burn planning and management. In all cases, a high degree of success was achieved, and the development of a variety of practical techniques for these purposes appears assured for the very near future.

ACKNOWLEDGEMENTS

The research described here is part of the Earth Resources Survey Program in Agriculture/Forestry which was sponsored, and financially assisted, by the National Aeronautics and Space Administration (Contract R-09-038-002). The following constitutes the final report of this cooperative study with the U.S. Department of Agriculture, Forest Service, and the University of Minnesota College of Forestry. NASA funding of projects under the terms of Contract R-09-038-002 terminated in April, 1972, before this project (among others) was completed. However, the work underway was continued and brought to a logical conclusion as a result of funding by the University of Minnesota College of Forestry, the Minnesota Agricultural Experiment Station[1] and a most timely grant from NASA's Office of University Affairs.

Credit for findings of practical value produced by this project cannot be claimed by the investigators alone since much of what was accomplished came as a result of significant inputs in the form of encouragement, advice, facility availability and personal assistance provided by many individuals and agencies. Our special thanks go to Dr. Thomas F. McLintock of the USDA, Forest Service, who made it possible for us to initiate this project in 1970; the Minnesota Department of Natural Resources, Division of Lands and Forestry (in particular, District Foresters Eugene Wroe and Elmer Homstad), who provided field assistance, advice and test areas; Chippewa National Forest Staff Officer M. B. Hathaway, U.S. Forest Service, who, along with a number of other professional personnel of the Forest Service, provided advice, test sites, ground truth, and interpretation assistance

[1]Authorized for publication as Scientific Journal Series Paper No. 8156 by the University of Minnesota Agricultural Experiment Station.

in the forest vegetation classification subproject; Dr. Peter Dress of the Pennsylvania State University School of Forestry who provided statistical advice; Robert C. Heller, project leader in charge of research in remote sensing at the Pacific Southwest Forest and Range Experiment Station, whose staff and facilities played an important role in a number of phases of the investigation; and Dr. Gene Thorley, Director of the University of California Forestry Remote Sensing Laboratory, and Mr. Harry W. Camp, Director of the U.S. Forest Service Pacific Southwest Forest and Range Experiment Station who, with members of their staffs, really "put it all together" for all of us involved in these investigations.

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INTRODUCTION

Efforts by the National Aeronautics and Space Administration (NASA) to launch a satellite for observing earth resources have created an interest in the application of small-scale imagery to the natural resource field. In an effort to determine the knowledge needed for utilization of the data generated by the Earth Resources Technology Satellite (ERTS) program, scientists throughout the world have embarked upon a multidisciplined program to learn more about the use of remote sensing systems in earth resource evaluation.

Availability of very small-scale photography as a result of the NASA aircraft overflights has provided land managers with another tool to aid in making decisions. Some of the projects funded by NASA have dealt specifically with forest land problems of disease, forest cover types, and land-use classification.

Forest land managers are being asked to make decisions concerning natural resources that will affect more than three-fourths of the land area of the United States (15). The demands for food, fiber, water, minerals, and grazing resources are intensifying, and new and equally selective demands are gaining in national importance. During the past decade there has been a forestland recreational boom that has made recreation the main resource on some of the public forestlands, especially within the Eastern United States (10).

All of this means that forested lands must provide more resources at the same time the environmental quality standards of society are being met. Therefore, some form of land use planning or zoning will be needed to assist in the allocation of resources. Very high-altitude photography has been considered as a tool for wildland use planning (12).

General Statement of the Problem

This study is concerned with remote sensing techniques as they are applied to forest resource evaluation in the sub-boreal forests of Minnesota. The major emphasis is on the use of high-altitude photography to detect and locate vigor loss in trees, as caused by disease, and to classify forest vegetation over large areas.

The primary research effort was focused upon the detection of eastern dwarf mistletoe (*Arceuthobium pusillum*, Peck) within stands of black spruce (*Picea mariana*, Mill). Dwarf mistletoe causes extensive losses on black spruce and has infected an estimated 150,000 acres of Minnesota's black spruce forest (19).

Recent studies have indicated that eastern dwarf mistletoe can be controlled by the use of fire following logging (29, 42), but the lack of a good system of disease detection and location has become a major limitation to controlling the disease. Black spruce forests are dense, even-age stands that usually grow on flat, poorly drained soils and "old" bogs.

Ground travel within the black spruce forests is limited by the bog conditions. Also, there is no topographic relief sufficient to assist visual observation. Therefore, aerial photography appears to provide the best method of surveying black spruce stands for the purpose of detecting infection centers.

Another part of this study concerns the detectability of hypoxylon canker (Hypoxylon mammatum, Miller) within aspen (Populus tremuloides, Michx) stands. Hypoxylon canker occurs throughout the range of trembling aspen, except in Alaska (20). It is the lack of hypoxylon canker within the Alaskan forest that gives importance to this portion of the study. Remote sensing techniques, if available, would aid in locating the infestations of aspen in Canada. This would provide a system for monitoring any spread of this disease into Alaska, where it could pose a serious threat to the aspen stands. Aspen is an important tree species in Alaska although it rarely exceeds 70 feet in height there. It is one of the four commercial timber types of Alaska, occupying approximately 2.5 million acres (14).

This great reserve of timber could be threatened if the gap between the diseased aspen of Canada and the disease-free aspen stands of Alaska were bridged. To obtain more complete knowledge of the threat posed by H. mammatum, a system for detecting the presence of the disease and for monitoring its movement is required. The vast territory to be sampled lends itself to the use of remote sensing (20).

The use of conventional photographic scales and film-filter combinations would cause problems related to mass data handling and high costs associated with the need to obtain and interpret repeated coverages. As is the case in most of the United States, panchromatic and infrared black-and-white films are most commonly used for aerial photography in northern Minnesota (6, 26). However, other film-filter combinations should be investigated to determine the one that is best suited for detecting stressed vegetation.

The selection of the best film-filter combination requires a knowledge of film response, filter characteristics, and spectral reflectance characteristics of stressed forest trees. A seasonal variation in the vegetation's reflectivity has been well documented (21, 24). If a signature, spectral or geometric, can be found for dwarf mistletoe in black spruce, its detectability must be defined for various scales of photography. Can dwarf mistletoe infection centers that are visible on large-scale photography be detected on very small-scale photographs? What scale photos are best for detection and monitoring this disease?

Recent emphasis on very high-altitude photography of the type obtainable from Earth Resource Technology Satellites has resulted in research concerned with extraction of data from small-scale and poor-resolution imagery. Ullman uses the criteria indicated in Table 1 when discussing photographic scale (25).

Photographic scale is a function of flying height and camera focal length. Therefore, an increase in the photo scale reciprocal (sometimes called the "scale-factor") results from an increase in flying height above the terrain for any given camera focal length:

$$\text{photo scale reciprocal (PSR)} = \frac{\text{flying height above terrain } (H_o)}{\text{focal length in feet } (f)}$$

TABLE 1. DESCRIPTIVE TERMINOLOGY FOR VARIOUS IMAGERY SCALES (25)

Terminology for scale[1]	Scale reciprocal
large	less than 10,000
medium	10,000 to 30,000
small	30,000 to 100,000
very small	greater than 100,000

[1]The term microscale is presently being used by the Earth Resources Survey Program to describe the scales in the 1:400,000 to 1:5,000,000 range (2).

A system of economically detecting stress in forest trees by remote sensing techniques could provide a capability for monitoring the intensity of infection and its rate of spread. Very small-scale photography or satellite imagery might provide the means for such disease monitoring in that a small number of photographs cover a large area (1, 5, 11). The smaller the number of scenes required to fulfill a mission, the more efficient will be the handling, preparation, storage, and interpretation of the photographs. An example of this reduction in processing and handling costs is pointed out by the fact that one Apollo 9 vertical photograph covered an area of 100 x 100 miles (1).

The lack of high resolution in very small-scale photography presents some problems of data extraction. More information is buried within a photograph than is readily available to the interpreter. Ross points out that one square inch of color film is capable of recording more than a billion bits of information (22). Mechanical, optical, and electronic methods of aiding in the extraction of information are available under research conditions. Processing methods, such as masking, enhance or isolate given density levels. Another process, density level slicing, separates selected density levels. The recombining of spectral slices of the same scene can provide a picture that contains either true or false colors (9). One example of such a procedure is embodied in the system used in the ERTS-1 Satellite (8).

Objectives of the Study

At the outset, the following objectives were established:

1. To investigate the best techniques for locating disease infection

centers in forest stands through high-altitude imagery.

2. To evaluate the usefulness of very small-scale photography (1:118,000 to 1:450,000) in forest vegetation classification.

3. To evaluate selected film-filter combinations for use in stressed vegetation detection and classification.

REVIEW OF LITERATURE

In that this study is primarily concerned with the detection of disease-stressed vegetation by remote sensing techniques, a discussion of stressed vegetation and remote sensing is in order.

Stressed vegetation is that plant material which is being affected by conditions that are adverse to normal growth. Some of the adverse conditions could result from insect attacks, disease, drought, flooding, soil compaction, or mechanical injury to trees. Factors that cause serious damage to the tree bring on a change within the foliage. The symptoms can vary from loss of foliage to leaf discoloration. In any case, the tonal rendition of a "stressed" tree is altered by these adverse conditions.

Remote sensing is the obtaining of information concerning an object without actually contacting that object. Generally, the use of a system to collect reflected or emitted energy from a scene of interest and to record it in a usable manner is considered remote sensing. As it is used in forestry today, remote sensing is the collection of data by cameras or other recording systems mounted on airborne platforms or satellites (9).

The capability of detecting stressed vegetation is needed by today's forest land managers to help combat the threat of disease and insect attacks on our forest resources. Several million cubic feet of timber are lost to insects and diseases every year (4). Six percent of the annual drain on forests is attributed to insects and disease, while the direct annual loss caused by disease damage to trees is estimated to be approximately $83 million (7, 9). Dwarf mistletoes are second only to root rots in causing damage to conifers (3), including 157,000 acres of the black spruce type in Minnesota (19).

Diseases can be classed as either pathogenic or nonpathogenic. In the pathogenic class it is the parasitic organism, or pathogen, interfering with the host plant that results in the disease. Nonpathogenic diseases caused by environmental factors cause stress within plants and are widespread. These are usually deficiency related and more pertinent to agricultural crops of short rotation than to forest stands (28). However, environmental changes within forest stands caused by water table changes, ground fires, and similar events can cause stress in trees. Viruses, bacteria, and fungi can also act as pathogenic agents. Also, seed-bearing plants, such as the mistletoes, can be pathogens.

The mistletoes are dependent upon the host tree for water and nourishment. The true or leafy mistletoes are generally chlorophyll-containing species with stems and green leaves. The dwarf mistletoes (Figure 1), with only modified leaves, penetrate directly into the living host with a network of absorbing strands which obtain the required nutrients. The dwarf mistletoe shoots are inconspicuous, usually less than 3/4-inch in length, and produce berry-like fruits that eject seeds with explosive force for distances up to 50 feet (7).

The dwarf mistletoes are found only on conifers. They cause the

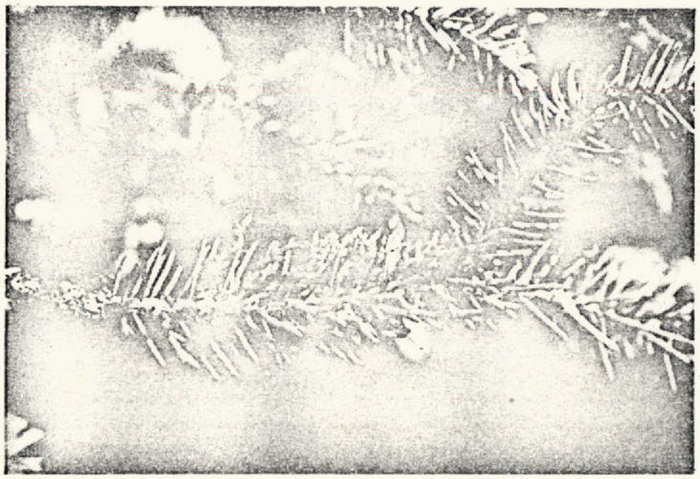


Figure 1. Dwarf mistletoe infection on black spruce branch.

Figure 2. Hypoxylon canker on trunk of aspen tree.

greatest economic damage on the ponderosa pine (Pinus ponderosa, Laws), lodgepole pine (Pinus contorta, Loud), Western hemlock (Tsuga heterophylla, Sarg.), and western larch (Larix occidentalis, Nutt) (28). The species Arceuthobium pusillum is the only dwarf mistletoe that occurs in the Eastern United States, where it ranges from Minnesota eastward to New Jersey (7). Boyce (7) states that, although it is most commonly found on black spruce, eastern dwarf mistletoe has been reported on other eastern conifers. In Minnesota, A. pusillum occurs on white spruce (Picea glauca (Moench) Voss.) and eastern larch (Larix laricina (Du Roi) Koch.).

One of the more common methods of classifying forest diseases is on the basis of the portion of the tree affected (7, 28,). Therefore, such terms as wilt, dieback, trunk canker, and root rot have become part of the forester's vocabulary. When the disease directly affects the foliage, stem, or roots, it generally causes foliar discoloration or atrophy that can be detected by remote sensing techniques. Unfortunately, all serious forest tree diseases do not advertise their presence, at least in early stages, by causing foliar discoloration. Studies show that the destructive root rot of Douglas-fir (Poria weirii) is detectable on aerial photographs only after the infected trees have blown down (27).

Canker diseases cause serious losses among forest trees. Hypoxylon canker of aspen (Hypoxylon mammatum, Miller) is responsible for an annual loss of 112 million cubic feet of timber. Once the fungus has entered its host, the mycelium spreads through wood and bark (Figure 2), eventually girdling and killing the tree. Decay fungi in the wood behind the canker and also H. mammatum itself can weaken the tree trunk, eventually resulting in breakage (3).

METHODS OF INVESTIGATION

Introduction

Five substudies in the sub-boreal forests of northern Minnesota comprise the overall investigation of this study:

1. Detection and location of dwarf mistletoe in black spruce stands.

2. Detection and location of hypoxylon canker in aspen.

3. Detection and location of *Armillaria* root rot in red pine plantations.

4. Classification of major forest vegetation cover types with very high-altitude photography.

5. Remote sensing evaluation of post-burn surveys.

A brief introduction to each substudy follows, including test site descriptions and locations, along with the investigative methods and techniques employed.

Eastern Dwarf Mistletoe

Eastern dwarf mistletoe was selected because of its importance, geographic range, and potential for detection (Figure 3). It is an economically important pathogen occurring over the range of black spruce. While it is in most cases parasitic to black spruce, it does cause losses in other spruce species and eastern larch. It has been estimated that seven percent of the two and a quarter million acres of black spruce forest type in Minnesota are infected with dwarf mistletoe (19).

This pathogen is well suited for a study in remote sensing in disease detection for the following reasons (20).

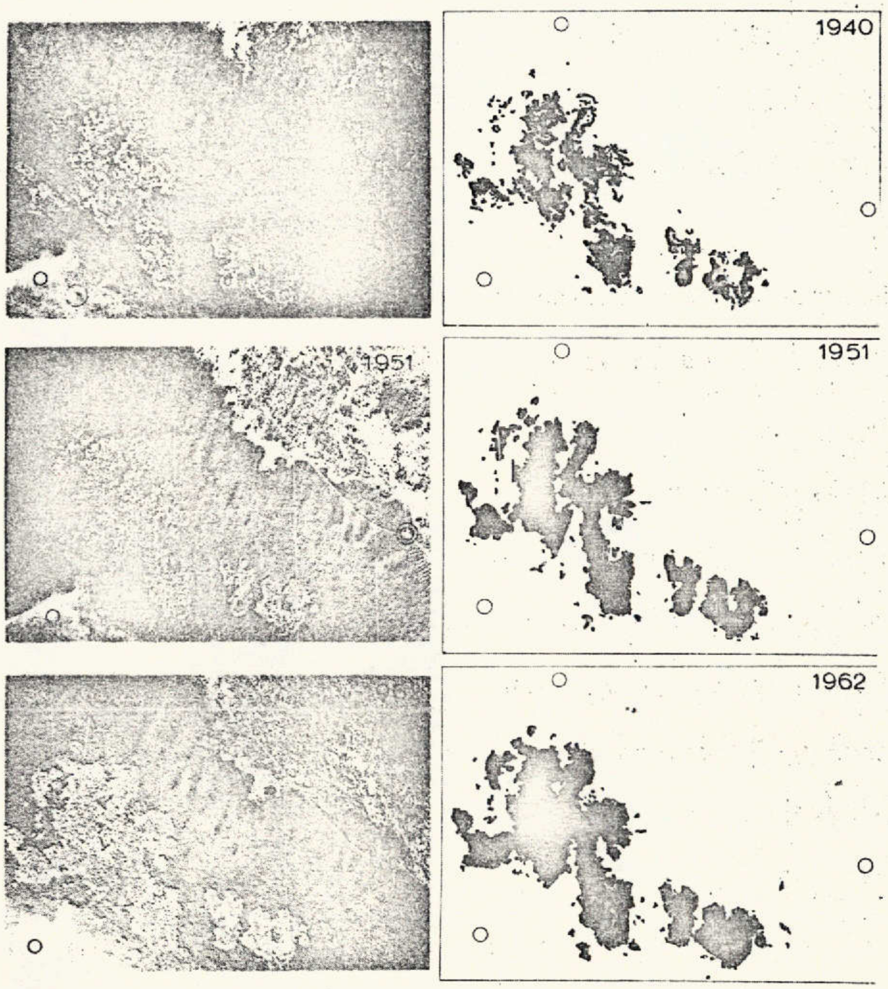


Figure 3. Aerial photographs and trace maps showing the spread of dwarf mistletoe during a 22-year period.

1. The disease development is uniform.

2. It occurs within pure stands of black spruce.

3. Only one species of dwarf mistletoe is present.

4. All stages of disease development are present.

5. The infected stands are even-aged and generally uniform in height so as to be very suitable for aerial photographic interpretation.

6. Its main host, black spruce, is easy to detect on aerial photographs.

Within recent years, studies have indicated that successful control of dwarf mistletoe can be obtained by removal of infected trees accompanied by prescribed burning of the cutover land (13). Since a control is known, a technique for location, detection, and monitoring becomes a necessity if an operational eradication program is to be effective.

Study sites (Figure 4) were originally established at two locations in northern Minnesota. A fixed-scene site was established near Cromwell in Carlton County, and an extensive survey area was delineated north of Togo in Koochiching County (Figure 4).

Hypoxylon Canker

Hypoxylon canker is the most important disease affecting aspen (3, 20). The causal organism, H. mammatum, is a canker-forming fungus that girdles and kills the tree. Since the disease takes from three to ten years to kill a tree, the infections appear more endemic than epidemic, because the dead trees appear singularly rather than in concentrated disease centers as is the case with many other diseases.

Aspen trees with cankers tend to retain their leaves into the winter

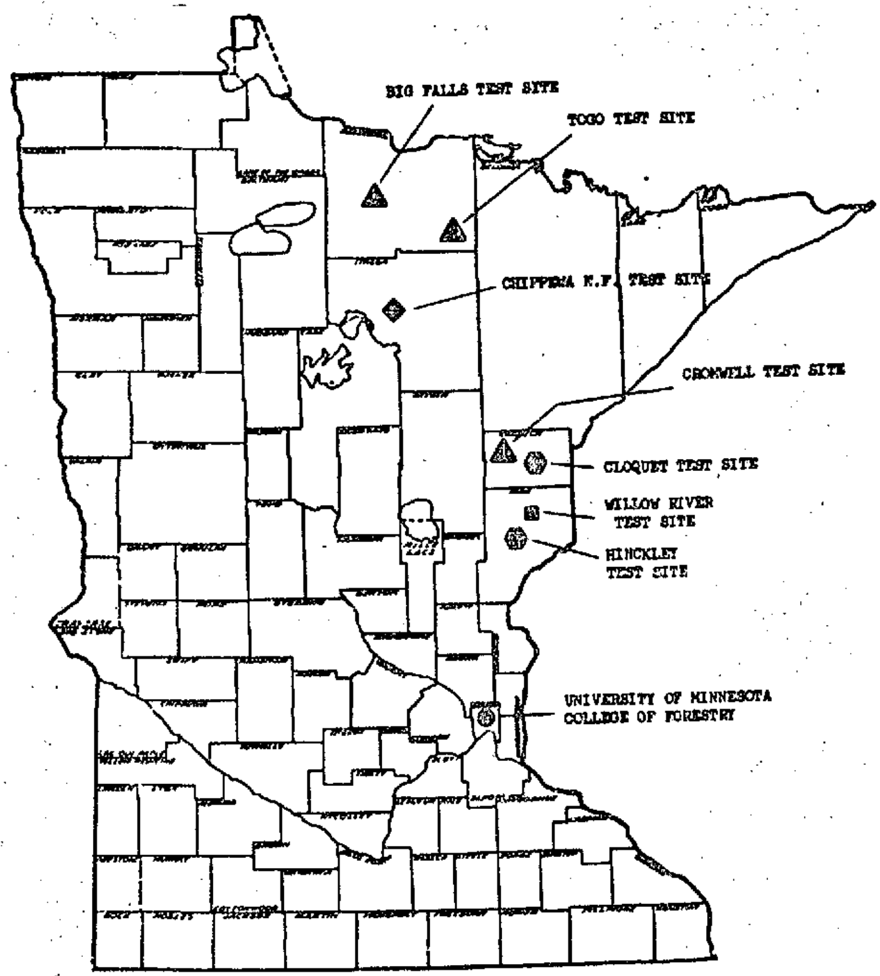


Figure 4. Map showing the locations of the seven test sites in Minnesota.

months (Figure 5), even though the leaves are brown (3, 20). This is a phenomenon which lends itself to possible aerial survey detection. The foliage of girdled trees turns brown in the summer. By August, the brown leaves should exhibit their highest contrast with the healthy green leaves on live vegetation.

Approximately 15 percent of the aspen trees in the 21,000,000 acres of aspen forest type in Minnesota, Wisconsin, and Michigan are infected (20). The significantly important fact to note here is that while hypoxylon canker is endemic to the Lake States and Canada, it has not been reported in Alaska. Hegg reports that the aspen timber type is one of only four in Alaska (14). The 2.4 million acres of aspen forests in that state represent a major resource reserve.

A system of detection and location of hypoxylon canker would enable a monitoring program to be established. This would enable more exacting mapping of the disease's range and its migration direction if there is one.

Originally, two test sites were selected in Minnesota to study the hypoxylon-caused stress on aspen. One site is along Interstate 35 at Hinckley in Pine County and the other is on the Cloquet Experimental Forest in Carlton County. The Cloquet site was abandoned when the area proved to be unsuitable.

Armillaria Root Rot

Armillaria root rot (*Armillaria mellea*, Kummer), or shoestring rot, is a fungus that is pathogenic on many tree species all over the world. The disease is most common on forest plantations where the trees are placed artificially in an unnatural setting. As a result, some plantations

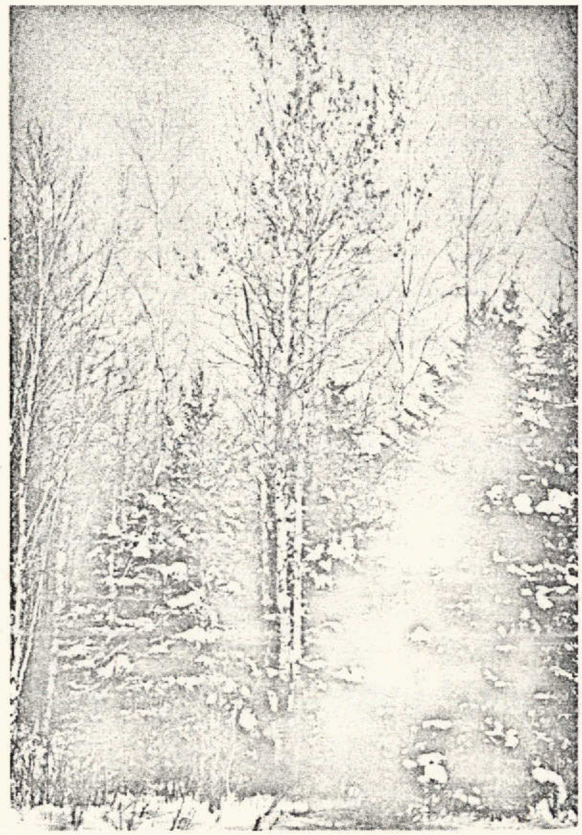


Figure 5. Winter view of aspen tree showing the leaf retention that is associated with hypoxylon canker infection.

of red pines within Minnesota have lost as many as 55 percent of the trees to this disease. Ten percent mortality due to shoestring rot is common. A part of an active plantation management program calls for replanting in areas having mortality losses to maintain the integrity of the stand. An economic detection system, perhaps airborne, would provide the manager with the information to plan on replantings or to change species. Red pine plantations in Pine County were selected for the Armillaria study sites.

Forest Vegetation Classification

The Marcell Ranger District of the Chippewa National Forest in Itasca County served as a study site. This site was used to test levels of difference in ability to interpret major forest vegetation cover types on very small-scale photography. Studies by Aldrich indicate that the use of Apollo 9 photography reduced the sampling error by 58 percent in a multistage forest inventory in the Lower Mississippi Valley (1). Also, satellite imagery provides the advantage of synoptic views which can be used for several levels of sampling to achieve greater informational gains (1).

To what extent can the upper stage of the sample, the satellite or very high altitude imagery, be used in stratifying the forests being inventoried? By working with the very small-scale photos of the Marcell Ranger District, this study will measure the ability of skilled photographic interpreters of various disciplines to interpret the same major forest cover types of northern Minnesota.

Post-burn Survey Analysis

The possibility for making post-burn analyses was suggested after the initial overflight in 1965. Several locations of black spruce slash burnings were included on infrared color photographs. Photo interpretation indicated that the potential might exist for assessing the pattern, extent, and intensity of the burn. These variables could be used to rate the success of the prescription burn developed by Irving and French as a technique for controlling dwarf mistletoe (16).

Dwarf Mistletoe Detection

Aerial Photography and Field Data Collection

Cromwell Test Site. The intensive test site at Cromwell was selected to investigate the variables affecting spectral signatures of the infested black spruce. The work at this site was begun in the spring of 1970. The variables first considered in looking for an indicative spectral signature for dwarf mistletoe were:

Effects of sun angle

Light intensity

Season of the year

Atmospheric conditions

Condition of infected trees

Development stage of the parasite

A two-tower tramway system (Figure 6) was constructed so that a camera platform could be moved across the site at a height of approximately 100 feet. The towers were placed 100 feet apart, enabling the tramway to cover a section of black spruce bog that contained trees with several stages of infection. The University of Minnesota's quadricamera mount was used on a trolley. Fifty millimeter lenses were used in the four 70 mm Hasselblad cameras to

Figure 6. Fixed tower-tramway installation used at the Cromwell intensive test site.

gain approximately 100-foot-wide coverage. An electric shutter trip mechanism was installed to permit photographic exposures at predetermined stops along the tramway (19).

During the investigation of variables 1 and 2 (sun angle and light intensity), simultaneous exposures were made with all four cameras at 10-foot intervals along the tramway three times a test day at 0900, 1200, and 1500 local sun time. The season of the year and the development of the pathogen were considered in the scheduling of photo missions at approximately 10-day intervals beginning on July 22 and ending on September 26, 1970.

Atmospheric conditions were checked at the start of each photo mission. The following observations were made and recorded:

1. Wet and dry bulb temperatures as obtained with a sling psychrometer at the top of a tower.
2. Wind speed and direction.
3. Estimate of horizontal visibility, using known distances.
4. Type of clouds and sky condition estimates.
5. Net radiation measured with a recording pyrometer located 10 miles east of the tower site.

The film-filter combinations used in the regularly scheduled photo missions in the 1970 season were as follows:

Camera	Film	Filter - Wratten No.
1	Panchromatic Plus-X	58
2	Panchromatic Plus-X	25A
3	Aero-Infrared	89B
4	Ektachrome Infrared	12

A two-tone grey scale of known spectral characteristics was placed on a platform at approximately tree height. Also, a black-and-white resolution panel was placed on the ground.

Timing of photo coverage was changed for the 1971 season (May to July) because of conclusions reached from interpretations of the 1970 photography. Although the 10-day interval was maintained, the morning and afternoon missions were not continued. The film-filter combinations were changed to provide for more experimentation in determining spectral signatures. The film-filter combinations used during the 1971 season are given in Table 2.

The NASA RB57F aircraft flew a 22-mile line across the Cromwell test site on August 6, 1971, and on September 29, 1971 (Figure 7). The cameras, films and filters used are listed in Table 3.

A 100-x 100-foot area was marked out and surveyed by a field team. In September 1970, 48 trees were located, numbered, and their positions recorded on a working sheet. Dr. French examined and classified each tree for dwarf mistletoe infection: Twenty trees were not infected and 28 had signs of the pathogen.

Togo Test Site. The Togo test site on the George Washington State Forest is located in section 33, township 64, range 23. It was chosen as the extensive dwarf mistletoe study area because of a large, contiguous stand of infected black spruce forest. Through the cooperation of state forestry officials, it was agreed the stand would be left uncut until the study was completed. Most of the area is swamp which supports black spruce northern white cedar (*Thuja occidentalis*, L.) and stands of aspen. Some scattered red pine and hardwoods are present on the higher ground.

TABLE 2. FILM-FILTER COMBINATIONS USED AT THE CROMWELL TEST SITE DURING THE 1971 SEASON

Camera	Film	Filter-Wratten No.
1	Ektachrome Infrared (8443)	12
2, 3, 4	Combinations included:	
	Ektachrome Infrared	12
	Ektachrome MS	2A or none
	GAF-1000	3
	GAF D-200	2A or none
	Panchromatic Plus-X	none
	Aero Infrared	89B

Line 1 - Togo site
Line 2 - Cromwell site
Line 3 - Chippewa site

Figure 7. Locations of flight lines photographed by the NASA RB57F.

TABLE 3. PHOTOGRAPHIC COVERAGE SUPPLIED BY NASA RB57F AIRCRAFT

Flight Date[1]	Camera	Focal Length	Film	Filter Wratten	Data
August 6, 1971	RC8	6 in.	2443	15	Ekta IR
	RC8	6 in.	SO397	2A	Ekta
	Hasselblad	40 mm	2424	89B	B&W IR
	Hasselblad	40 mm	2402	25	B&W
	Hasselblad	40 mm	2402	58	B&W
September 29, 1971	RC8	6 in.	2443	15	Ekta IR
	RC8	6 in.	SO397	2A	Ekta
	Zeiss	12 in.	2443	15	Ekta IR
	Hasselblad	40 mm	2443	15	Ekta IR
	Hasselblad	40 mm	356	11	Color
	Hasselblad	40 mm	2424	89B	B&W IR
	Hasselblad	40 mm	2402	25	B&WL
	Hasselblad	40 mm	2402	58	B&W

[1]Same dates and camera configuration for the test sites at Marcell, Cromwell, and Togo sites.

Some scattered red pine and hardwoods are present on the higher ground.

Ground trips were made into the Togo test site to obtain a general orientation of the area, to check on tree species at specific locations, and to collect data on ground conditions at the time of the NASA RB57F overflight on August 6, 1971.

The timber on the test site is classified as 5-to 9-inch diameter black spruce. The 5- to 9-inch diameter trees are approximately 200 years old. Occasionally, the two classes occur on the same site to create a two-story stand. Much of the open, logged-over area is covered with Laborador tea (Ledum groenlandicum, L.), sphagnum mosses, and bog laurel (Kalmia angustifolia, L.). Openings within the stand of black spruce contain bunchberry (Cornus canadensis, L.), Laborador tea, sphagnum mosses and speckled alder (Alnus rugosa, DuRoi).

Travel into the Togo test site was very difficult during the warmer weather because of the bog conditions there (Figure 8). Ground data pertaining to the dwarf mistletoe pathogen were mapped and described during the winter of 1971-1972 while the area was open to snowmobile access.

The decision was made to concentrate on color and color infrared films while photographing the extensive site. The decision was based upon the findings at the intensive study site in 1970 and 1971 by Meyer, et al (20).

Through the use of a light aircraft modified to accept the College of Forestry's quadricamera system, photography was obtained of the test site. Large-scale photographs were taken to locate disease centers and identify tree species. Progressively smaller scales were obtained in

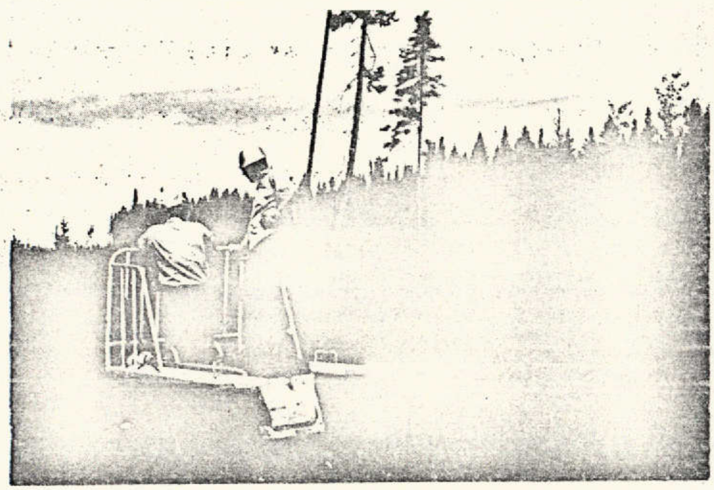


Figure 8. All-terrain vehicles or snowmobiles were used to enter spruce bog at the Togo test site.

order to give a representative range of scales up to the RB57F photography for photo interpretation.

Aerial photo coverage of the Togo test site was 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 quadricamera unit, is shown in Table 4. Additional coverage was flown by the NASA RB57F aircraft on August 6 and on September 29, 1971, at which times a 17-nautical-mile line was flown at 60,000 feet across the test site with the same camera/film/filter configurations used on the Cromwell test site (see Table 3).

Dwarf Mistletoe Image Analysis

Three methods of image processing were used: (1) optical recombining, (2) masking, and (3) density-level slicing by photographic and digital means.

The process of optical combining through use of an additive color system, as described by Lauer and Colwell, is becoming a widely used technique (9, 17, 18). There appear to be two main reasons for this: first, it provides a key to obtaining more data from the imagery, and second, because the additive-color system promises to be very useful in recombining the imagery obtained from ERTS-1 (8).

Masking is the photographic process of enhancing or isolating photographic densities by rephotography through superimposed negatives or positive transparencies of selected spectral sensitivities (22).

Finely slicing certain density levels out of the photograph can uncover tones that were lost within the general photo (22). This density-level slicing can be done photographically or by a vidicon system capable of

TABLE 4. SUMMARY OF AERIAL PHOTOGRAPHY OF THE TOGO TEST SITE TAKEN WITH THE COLLEGE OF FORESTRY QUADRICAMERA SYSTEM

Photo Scale[1]	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

[1] 50 mm lenses used in all cases

converting signals from analog to digital.

Arrangements were made with International Imaging Systems of Mountain View, California, to provide a masking and density-slicing job on the Togo test site area. The use of their Addcol and Digicol systems was part of the contract.

Glass mounts were made from each of the three simultaneous exposures of the NASA Hasselblad photographs taken on August 6, 1971, at a scale of 1:462,000. The film-filter combinations used to produce the black-and-white transparencies were those used in the standard NASA RB57F package to simulate the channels of the ERTS-1 return-beam vidicon system. The three spectral slices obtained are listed in Table 5. They were the commonly used combination of green, red, and deep red filters (Wratten numbers 58, 25, 89B) with panchromatic black-and-white film number 2402 and infrared black-and-white film number 2424.

Several combinations of masks involving positive and negative prints on high-and low-contrast paper were made by the technicians at the International Imaging Systems (I^2S) Laboratories.

The scene selected for the masking investigation was in frame number 9539 of the August 6, 1971, NASA RB57F overflight. This 9-x 9-inch 1:118,000 scale exposure was taken on Ektachrome infrared film through a Wratten 15 filter with an RC-8 camera from a flying height of 59,000 feet. The color infrared film was selected because of its clear scene and superior tonal balance.

I^2S photo engineer Paul Fedilchak prepared the high-and low-contrast positives and negatives. These were used in various combinations by placing

TABLE 5. APPROXIMATE SPECTRAL SENSITIVITY RANGES PRODUCED BY THE FILM-FILTER COMBINATIONS EMPLOYED IN THE NASA HASSELBLAD PACKAGE

Film (Eastman Kodak Number)	Filter (Wratten Number)	Approximate Spectral Slice (nanometers)
2402 B&W Pan	58	480-620
2402 B&W Pan	25	520-720
2424 B&W IR	89B	680-900

a positive in registration with a negative and photographing onto a high-or low-contrast film as a positive or as a negative. The infrared color positive was used in some of the combinations.

Registration of a negative onto a positive transparency causes the loss of much of the background density. A small edge enhancement is caused around the densitites not eliminated by the masking. This enhancement, or unsharp masking, is brought about by the total film thickness created in stacking of the negatives and positive.

A complete mechanical density-level slicing package was prepared from the most promising separation in the masking procedure. This was a red separation using an A-29 filter. It was made of the high-contrast negative-to-positive mask on panchromatic film.

A high-contrast negative on a high-contrast positive, when photographed onto a low-contrast film, produces a subtractive effect that removes some of the background. On the other hand, the use of high-contrast film highlights the reds within the scene. The latter combination was chosen for the complete density level separation.

Sixteen density slices were made of the red separation on black-and-white film by I^2S. The first separation was black and the next seven were printed on separate transparencies in another color. Separations 9 through 16 were color-coded in the same order as separations 1 through 8. The color coded slices were enclosed in a folder to ensure their proper registration.

A video-aided density slicing approach was undertaken by using the I^2S Digicol Image Enhancer. The red separation positive mentioned above was studied on the Digicol system. This system gives an instant read-out on a color television screen of up to 36 density levels. Photographic records were made on 35 mm slides of the images exhibited on the Digicol screen. Attempts were unsuccessful in using the color infrared positive on the Digicol. The light source on the video camera was not strong enough to penetrate the color densities.

Hypoxylon Canker Detection

The Hinckley study area is approximately 2 miles north of Hinckley, Minnesota, along Route I-35. It was chosen because of the high percentage of aspen in the overstory, the confirmed presence of hypoxylon canker, and the easy access into the area.

Three plots were established by photographic interpretation. Two of these were treated as 1/10-acre plots for ground data collection. The third was used only as a check on the photo interpretation.

A team of pathologists under the leadership of Dr. David French located the plots using the aerial photographs as maps. The two 1/10-acre plots were inventoried on October 26, 1971. Ground level photographs were obtained of selected infected trees within the plots. Difficulty was encountered in locating the exact plot centers even with the photos in the field because of the flat terrain and dense undergrowth.

Two aerial missions were flown over the Hinckley site and the imagery obtained is listed in Table 6.

The decision was made to use color photography for the hypoxylon study because of the results of the tramway investigations at the Cromwell

TABLE 6. SUMMARY OF HINCKLEY TEST SITE PHOTOGRAPHY TAKEN WITH THE COLLEGE OF FORESTRY QUADRICAMERA

Date	Film	Filter (Wratten No.)	Scale
August 11, 1971	Ektachrome Infrared	15	1:6,000
	Ektachrome Infrared	21	1:6,000
	Ektachrome MS	2A	1:6,000; 1:15,840
	Ektacolor	2A	1:6,000
September 19, 1971	Ektachrome Infrared	15	1:6,000; 1:15,840 1:31,680
	Ektachrome Infrared	34A	1:6,000; 1:15,840 1:31,680
	Ektachrome	2A	1:6,000; 1:15,840 1:31,680
	Ektacolor	2A	1:6,000; 1:15,840 1:31,680

test site. It was decided that Ektachrome infrared and Ektachrome MS films would be the best to use for detecting the trees killed by the hypoxylon canker. Two cameras were loaded with Ektachrome infrared film. A Wratten 15 filter was used to produce the standard "false-color" rendition, while a Wratten 21 or Wratten 34A filter was used on the second camera to produce false-color pictures of deeper orange and reds. Camera number three contained the standard Ektachrome MS film with a 2A filter to produce a normal color scene. In anticipation of needing prints, the fourth camera was loaded with Ektacolor film.

Armillaria Root Rot Detection

The Willow River test site is located in Pine County, Minnesota. It consists of one flight line across a red pine plantation known to be infected with the Armillaria root rot. A commercial flight was made over the test site on July 8, 1971, with the quadricamera unit and 50 mm lenses. On August 28, 1971, a follow-up overflight was made. The imagery obtained for this test site is listed in Table 7.

Sample row portions were selected along the line of flight. The trees within these samples examined were classified by the following system:

Healthy

Trees which died in 1968

Trees which died in 1969

Trees which died in 1970

Trees currently dying

TABLE 7. SUMMARY OF WILLOW RIVER TEST SITE PHOTOGRAPHY TAKEN WITH THE COLLEGE OF FORESTRY QUADRICAMERA

Date	Film	Filter	Scale
		(Wratten No.)	
July 8, 1971	Ektachrome MS	2A	1:2,400; 1:15,840
	Ektachrome Infrared	12	1:2,400; 1:15,840
	Infrared Aero	89B	1:2,400; 1:15,840
	GAF-1000	21	1:2,400; 1:15,840
August 28, 1971	Ektachrome MS	none	1:2,000; 1:8,000
	Ektachrome Infrared	12	1:2,000; 1:8,000
	GAF-1000	12	1:2,000; 1:8,000
	Ektacolor	none	1:2,000; 1:8,000

Forest Vegetation Classification

Location and Description. The study area for forest vegetation classification was established on the Marcell Ranger District of the Chippewa National Forest (Figure 9). It is approximately 13 miles by 14 miles in size and lies astride the subcontinental divide approximately 20 miles north of Grand Rapids, Minnesota. The landscape on the Marcell Ranger District is varied in that it includes glacial lake bottom, ground moraine and outwash plains, and terminal moraine deposits. This variety in landscapes helps to produce a variety in timber types present in the district.

Study Design. The photography used in this test was listed earlier in Table 3. The photographs were prepared in sets according to scale, film type, and season of the year. The seven sets of photographs involved in the testing are listed in Table 8. All seven sets were photographed by the NASA RB57F flying at 60,000 feet above mean sea level. Positive transparency duplicates prepared by NASA-Houston were used in all seven sets. Stereoscopic viewing was accomplished on a Richards portable light table. Although several kinds of stereoscopes were available for use, all five interpreters elected to use the folding Abrams CF-8 pocket stereoscope because of their familiarity with the instrument.

Interpreters. Five skilled photo interpreters from the staff of the Chippewa National Forest agreed to act as observers in this study. Skilled personnel with experience in the field were used rather than persons unfamiliar with the Chippewa National Forest. This was done to approximate the real-life conditions that would occur if the high altitude aerial photographs were available to foresters on a working basis.

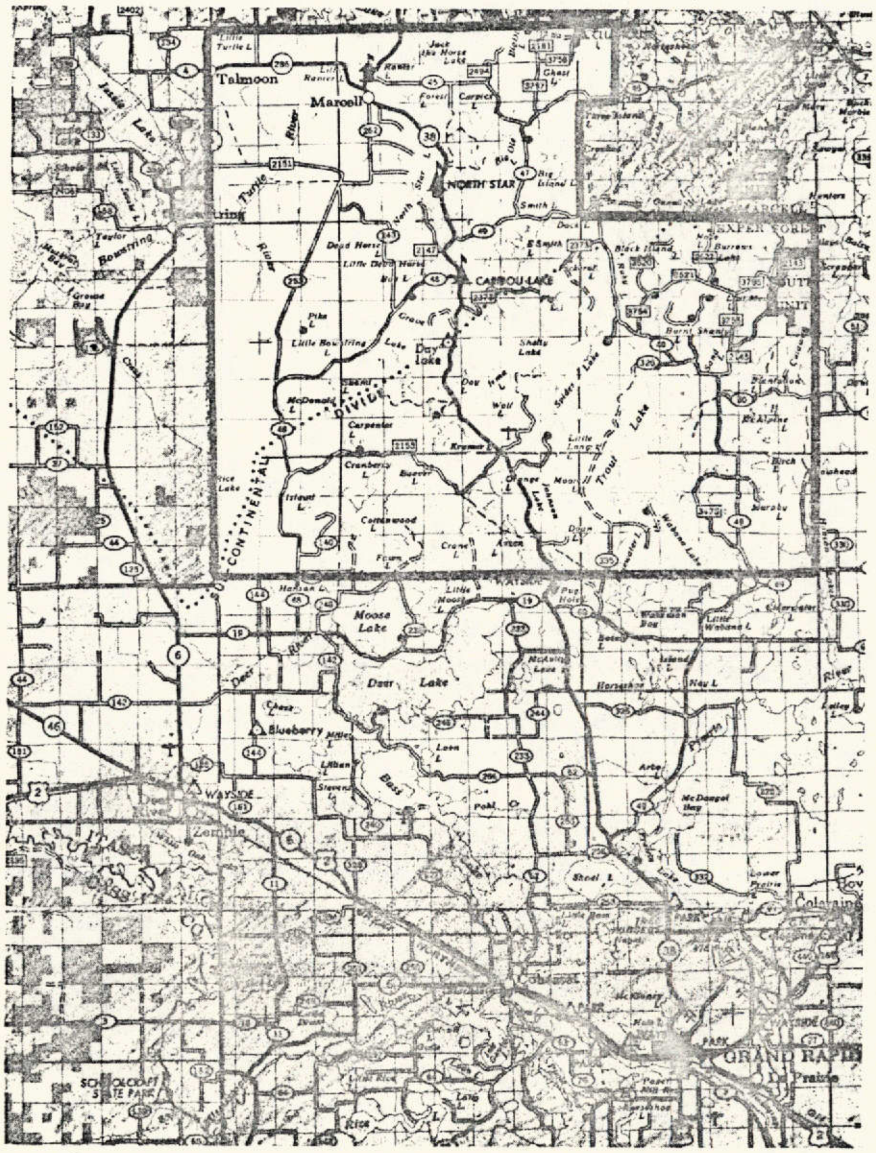


Figure 9. Map showing the location of the vegetation cover study area on the Chippewa National Forest.

TABLE 8. SUMMARY OF THE FILMS, SCALES, AND DATES OF PHOTOGRAPHY USED IN THE FOREST VEGETATION CLASSIFICATION TEST

Set	Film		Scale	Date
1	IR color		1:59,000	9/29/71
2	IR color		1:118,000	8/6/71
3	IR color	9 x 9 inch	1:118,000	9/29/71
4	color		1:118,000	8/6/71
5	color		1:118,000	9/29/71
6	IR color	70 mm	1:462,000	9/29/71
7	color		1:462,000	9/29/71

Although the interpreters were selected to give a cross section of photo-user personnel on a forest, no effort was made to compare the proficiency of the various professions involved.

Each of the five interpreters had a different job background:

Resource forester

Soils scientist

Timber management assistant

Engineering technician

Wildlife biologist

Interpretation. The interpreters were given the test one at a time. After a briefing by the investigator, the interpreter was given a key to the vegetation cover types as the types appeared on the various sets of photographs in the test. Five plots that appeared on a training stereo-pair for each set were marked for study and reference by the interpreters. These five plots were the same on each set and occurred just east of the designated study area. Although only four types were involved in the study, five were marked on the training pair. This was done because jack pine (*Pinus banksiana*, Lamb) and red pine were discernible to the trained interpreter even though all pines were lumped generically in the test. This step was taken to allay confusion over what was actually pine on the photograph interpretation.

The five plots marked on each training stereo-pair were:

1. Aspen
2. Spruce-fir
3. Red pine
4. Jack pine

5. Northern hardwoods

Plot Selection. Plots for interpretation were selected randomly for each cover type to eliminate bias of the program designer. This was accomplished by gridding a vegetation cover type map (Figure 10) of the Marcell Ranger District and numbering the grid intersections. The grid numbers were then selected by using a table of random numbers (23). All of the plot selection was completed on the vegetation cover map supplied by the Chippewa National Forest without consulting the aerial photographs. This procedure was followed to prevent bias from influencing the plot choice based upon the investigator's ability to interpret the plot.

In order to produce cells with equal numbers, two plots of each type were chosen randomly for each set of photographs. Since there were four cover types, eight plots were selected for each of the seven sets. This made a total of 56 plots that each observer was to interpret.

Administration. Eight numbered plots were marked on each set of photographs with india ink. An answer form with the corresponding numbers was given to the interpreter with each set of photographs. The sets were given out one at a time and collected with the answer sheets as the interpreter completed the questionnaire form. No time limits were placed upon the interpreters other than those existing relative to their contributing time away from other duties.

Analysis of Study Results. Analysis of the results was made by using factorial designs to test for significant differences related to scale, film type, timber type, and observer. Dr. Peter Dress, Associate Professor of Forestry of the Pennsylvania State University, acted as a consultant

Figure 10. Map of plot locations within the Chippewa Study Area.

in setting up the statistical analysis. The statistical analysis was performed on the IBM 360/71 computer at the Pennsylvania State University Computer Center using standard analysis of variance programming.

The responses of the interpreters were analyzed using multiple and single classification analyses of variance to test the following null hypotheses.

I.

Hypothesis I_A - There is no significant difference in the scores of the interpreters by scale, type of film, or vegetation cover type.

Hypothesis I_B - There is no significant interaction among the scales, film types, and vegetation cover types and the interpreters' scores.

A 2 x 2 x 4 factorial was used in this test of significant difference. The main effects were scale (2 levels), film type (2 levels), and vegetation cover types (4 levels).

II.

Hypothesis II_A - There are no significant differences among the scores by scale and vegetation cover type on infrared color film.

Hypothesis II_B - There are no significant interactions between the scale and vegetation cover types on infrared color film.

A 3 x 4 factorial was used in this test of significant difference. The main effects were photo scale (3 levels) and timber type (4 levels).

III.

Hypothesis III_A - There is no significant difference among the scores of the five interpreters.

A one-way classification of a fixed model was used to test the effect of the treatment. Tukey's procedure for testing the significant difference was used to determine if the observers' scores were significantly different from one another.

The questionnaires were hand scored and the scores entered by scale, film, and type for each set so that the scores could be used as units or as cells in the ANOVA.

Publications of the University of California Forestry Remote Sensing Laboratory indicate that many of the statistical designs used in analyzing remote sensing experiments have been weak because the one-way analysis is used in most instances (2). This study has attempted to avoid the problem of isolating only the two sources of variation associated with one design. The factorial designs used were designed to isolate more sources of variation and to reduce the error term (23).

Post-burn Survey Analysis

The Big Falls test site is located in Koochiching County, west of Big Falls, Minnesota. It is a clear-cut black spruce stand where the slash had been distributed in the proper manner for prescribed burning.

One overflight was made on August 3, 1971, prior to the prescribed bu ure 11). The quadricamera system with 50 mm lenses was used to get simultane

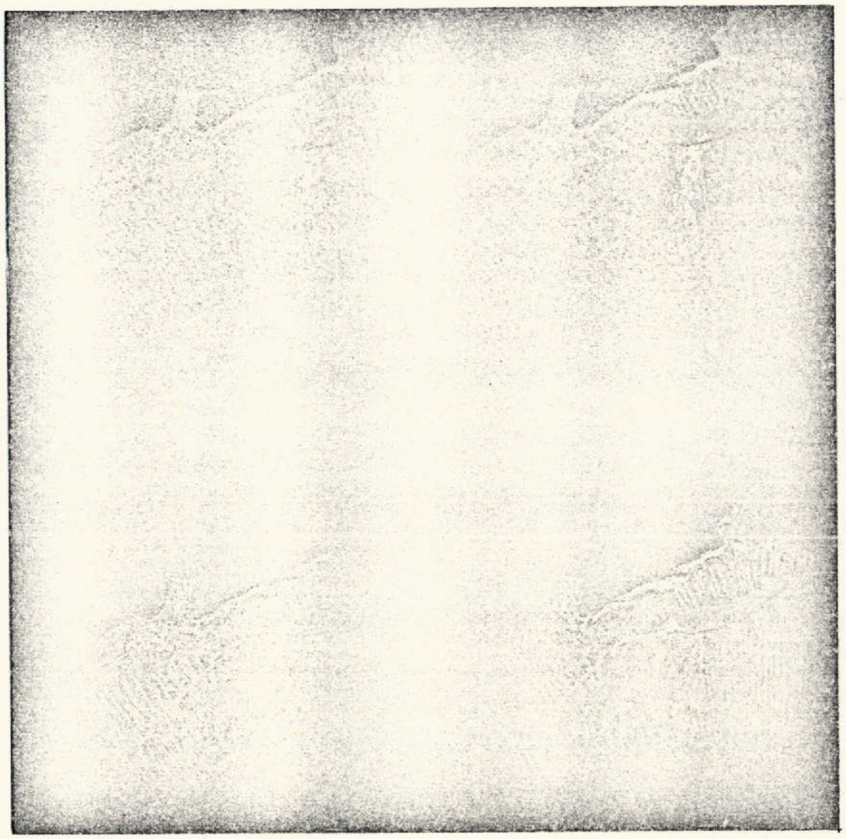


Figure 11. Stereograms of 70 mm Ektachrome infrared/W12 and Ektachrome MS/2A film-filter combinations showing a portion of the Big Falls test site. (1:15,840 scale) The study area is at the top (north) center of the harvest area and has the evenly distributed slash.

exposures using the following film-filter combinations:

Film	Filter
Ektachrome MS	2A
Ektachrome Infrared 8443	12
Aero Infrared	89B
Ektacolor	2A

The mission was flown to achieve scales of 1:6,000 and 1:16,000 (see Figure 11). Unfavorable weather delayed the burn until too late for the post-burn mission in 1971.

The cut-over area was entered on the ground for the purpose of analyzing and mapping the slash distributed on the area. Following the burn, the site was again examined and mapped in order to relate to the pattern and the intensity of the prescribed burn.

This substudy will be completed at a later date when the post-burn imagery is available.

INVESTIGATION RESULTS

Dwarf Mistletoe Detection

Cromwell Test Site

A definite spectral signature associated with dwarf mistletoe was not evident. Non-visible physiological differences that might be induced by dwarf mistletoe were not detected by any combination of films and filters, and the foliage of partially infected trees gave no spectral indication of stress that registered in the tramway photography.

The disease kills the tree over a period of several years; therefore, portions of the crown on trees that appear healthy on the photographs actually are dead. Trees with a great deal of dead foliage had a signature approximately the same as that of dead trees. Only dead trees gave a consistently different spectral signature from non-infected trees.

Recombining of multispectral photography to produce a color-enhanced image was performed at the University of California Remote Sensing Laboratory in Berkeley. Several combinations of colored filters were used in the three projectors to give color to the projected image. The color enhancement approximating the tri-emulsion Ektachrome infrared film presented the most favorable color-enhanced image for interpretation.

In no case did the optical combining display any situation that was not detectable on the Ektachrome infrared film. Also the two-camera display was as good as the three-camera display. The use of photography taken on panchromatic film 2402 with a Wratten 58 filter did not add detail to the projected image.

The tower photography was difficult to use in the University of California optical combiner. Orientation and registration of the multispectral imagery was time-consuming. Highly accurate registration of the recombined image was impossible,and the imperfectly registered photographs caused highlights on the projected image that were confusing to the interpreter. Differential parallax, caused by camera placement in the mount, interfered with exact registration. In certain cases, because of exposure bracketing and photograph selection procedures, the images being superimposed were not simultaneous. The short period in time between exposures permitted some sun movement and disorientation by wind sway.

Considerable light fall-off occurs toward the edges of Hasselblad photography when the 50 mm lens is used. Rephotography of the combined image done with the same system resulted in poor reproduction because of the light fall-off problem.

Togo Test Site

Ground Data Collection. Infection centers of dwarf mistletoe, occurring both as openings and as clusters of standing, but infected, black spruce trees, were found in Section 33. Some single infected trees were plotted in scattered locations. However, dwarf mistletoe is so slow in killing a tree that infected trees may have large amounts of healthy foliage. Isolated infected trees checked on the ground had invariably been killed by some cause other than dwarf mistletoe. Many isolated dead trees were identified as balsam fir (Abies balsamea, Mill). During the several years dwarf mistletoe takes to kill the infected black spruce tree, mistletoe seeds spread the disease to neighboring trees (7).

The photographs in Figure 12 show areas plotted during the field work. Most of the ragged openings on the southwest edge were results of dwarf mistletoe. Two of the most distinctive openings in the black spruce canopy were not caused by dwarf mistletoe and could serve as comparative areas. All of the other openings in the spruce stand are the results of dwarf mistletoe.

On two infection centers, all of the infected trees are still standing (see plots 4 and 5 on Figure 12). Plots 4 and 5 are, respectively, 300 and 1500 square feet in area.

Both of the openings not caused by dwarf mistletoe are covered by

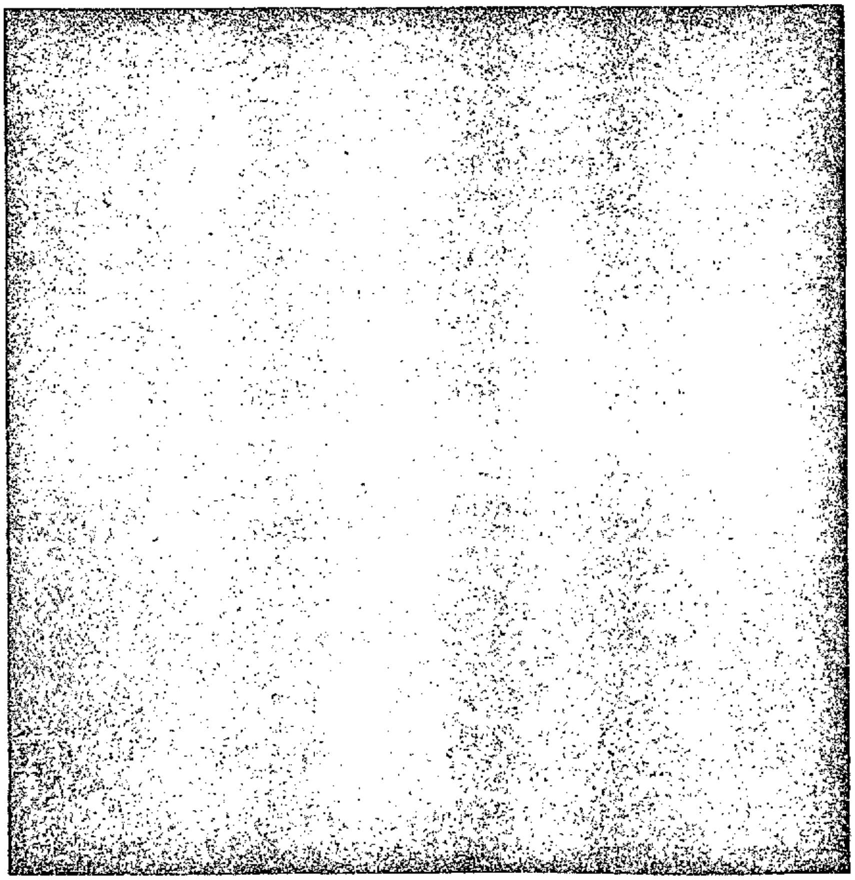


Figure 12. 70 mm stereograms of Ektachrome MS/2A and Ektachrome infrared/ W12 film-filter combinations (1:8,000) showing areas of black spruce infected with dwarf mistletoe and of openings not related to dwarf mistletoe.

speckled alder (Alnus rugosa, Du Roi), Labrador tea, and sphagnum moss (see Figures 13 and 14). These openings are approximately 20,000 square feet in area, whereas the individual disease center openings are less than 10,000 square feet. In the southeastern quarter, where many of the infection centers of long standing have united, speckled alder is also present.

Large Scale Image Interpretation. Simultaneous 70 mm exposures were made at a scale of 1:8,000 on Ektachrome MS Aerographic Film 2448 with a 2A filter, on Ektachrome infrared (8443) film with Wratten 12 filter, and Ektacolor with a 2A filter. Success and ease of locating dead black spruce were the criteria used in evaluating film types. The positive transparencies were viewed on a Richards light table with and without magnification. Generally, however, magnification was avoided except in specific instances so as to be able to judge effects of photo scale.

Ektachrome MS film. The infected and dead spruce were very difficult to detect unless all the foliage was missing. Even then, the location of these "spikes" or "snags" was generally in openings where they were contrasted to the deciduous or herbaceous ground cover. The two large ground plots of infected trees were not distinguishable at this scale.

Ektacolor prints. Eight-by eight-inch color prints made from the Ektacolor negatives had excellent color balance and sharpness at a scale of 1:2,360. Dead foliage showed up brown while the dead trees without foliage were grey. Plot 5 is clearly detectable,but plot 4 is not. The larger infected area of plot 5 contained more dead trees and is more easily identified than plot 4. Some browning of the foliage is visible on these photo prints

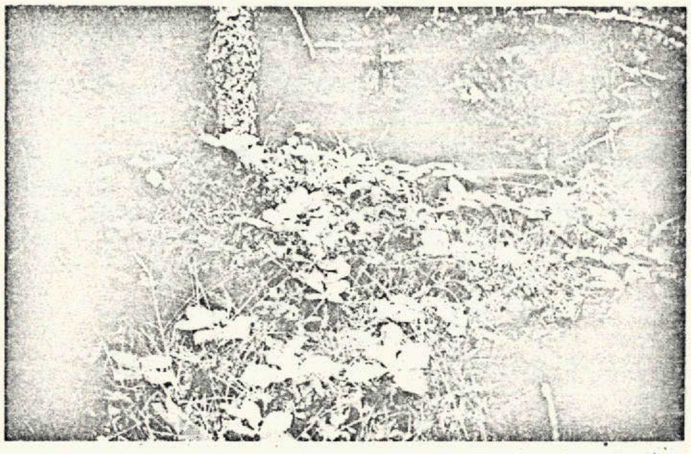


Figure 13. Ground cover of sphagnum moss and bunchberry on forest floor and in small openings within black spruce forest.

Figure 14. Ground cover of Labrador tea, bog laurel, and sphagnum moss occupying large openings in black spruce forest.

at plot 4. No tonal differences are apparent between the dead spruce of the non-infected and infected openings.

Apparent, heavily infected spruce stands were easily located on these prints, and ground checking verified the interpretation of dwarf mistletoe areas. The two non-infected stands were the exceptions because they were interpreted as being dwarf mistletoe centers.

Ektachrome infrared film. The dead spruce foliage exhibited the characteristic blue tone generally associated with dead trees on false-color film. Plot 5 is visible as clusters of blue crowns as are other infection centers in the area with standing trees (Figure 12). The clusters of blue crowns are not apparent on plot 4 in spite of the ease of locating the many single dead trees that show up readily on this film.

No tonal differences appear between the non-infected openings and the infection centers containing alder. The more common situation occurs where many scattered trees in various stages of infection are present. These areas have a ground cover lacking alder and appear pink rather than red (Figure 12).

A scattered ring of dead (blue) spruce is evident around the openings, indicating that those openings are enlarging. This ring is present on the two non-infected openings as well as the infected ones.

Small-Scale Image Interpretation. Three flying heights were used to obtain imagery with the 70 mm Hasselblad cameras. 1:31,680, 1:63,360, and 1:100,000 scale photographic coverage was obtained during the summer of 1971.

Plot 5 is detectable on the 1:31,680 photography and is detectable, but difficult to interpret, on the 1:63,360 photography. The other areas of standing infection centers and the edge rings are either missing or very difficult to locate on both scales of photography. Detection of the blue of the dead trunk or the brown of the dead foliage was impossible at scales smaller than 1:63,360.

The August overflight of the NASA RB57F did not include any small-scale photography. A 12-inch focal length Zeiss camera provided 1:59,000 scale infrared color photography taken on the September 29, 1971, NASA overflight of the Togo test site. Haze and clouds were present over the test site on September 29, 1971, so that the quality of the imagery is reduced. Fortunately, the test site itself was open and photographed with acceptable tonal and resolution qualities.

The 9 x 9-inch Zeiss positive transparency provided resolution superior to the equivalent scale of 70 mm photographs; however, it provided less information on the presence of dwarf mistletoe. No contrast in tone was detectable between the live canopy and the infected area of plot 5. September 29 would be in a period of a marked drop in the infrared reflectance of all tree species including conifers; therefore, the likelihood of detecting a tonal contrast related to vegetative stress is not as probable in the fall as it is in the summer (24).

Very Small-Scale Image Interpretation. RB57F overflights on August 6 and September 29, 1971, provided photographs taken with the 6-inch focal length Wild RC-8 cameras from a flying height of 59,000 feet. On both flights, the superiority of infrared film over color film for high-altitude photography was demonstrated. Scene brightness and atmospheric penetration we superior on the infrared color imagery; therefore, most interpretive work was accomplished on this film.

No evidence of a spectral signature related to the dying or dead spruce trees could be located visually on the 1:118,000 photography. Any spectral reflectivity attributed to small numbers of infected trees was integrated into the total reflectivity of the stand.

Openings of one-half chain radius (i.e., 33 feet) were detectable on the infrared color film taken during both overflights. The summer photograph presented a much brighter scene, because the infrared reflectivity of the alder, sphagnum, and Labrador tea was at a high level. This made the location of the one-half chain radius plot easier to detect on the summer infrared photography than on the fall infrared photography. Magnification was required to detect the small plots on color film.

The visibility of the many small openings produces an irregular, spotty pattern within the otherwise uniform tone and texture of the black spruce stand. This pattern has a "moth-eaten" appearance when viewed on very small-scale photography. Figure 15 shows an example of this pattern resulting from openings mostly associated with the dwarf mistletoe infections.

Microscale Image Interpretation. Direct interpretation of the microscale (1:462,000) photography indicated that the moth-eaten pattern of extensive dwarf mistletoe infestations could be located under certain conditions. The location of the infected area was difficult on the duplicates supplied by NASA, so high-contrast copies were made of the three black-and-white film types taken on August 6 (see Table 9).

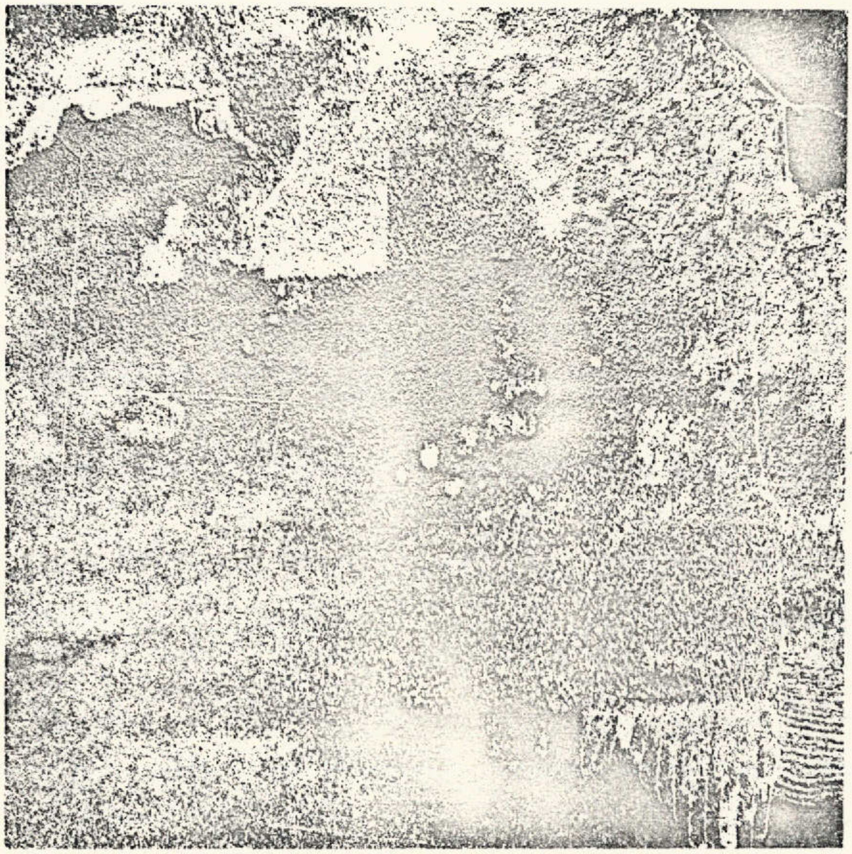


Figure 15. The "moth-eaten" pattern associated with dwarf mistletoe is detectable at all scales used in this investigation (1:8,000 to 1:462,000).

TABLE 9. EVALUATION OF INFRARED AND PANCHROMATIC BLACK-AND-WHITE 70 MM MICROSCALE NASA IMAGERY FOR DETECTING DWARF MISTLETOE PATTERNS

Film type	Filter	Date	NASA copy	High contrast
Pan 2402	58	8/6/71	unsatisfactory	unsatisfactory
Pan 2402	25	8/6/71	satisfactory	good
IR 2424	89B	8/6/71	good	satisfactory

The panchromatic film type 2402 with a Wratten 58 filter did not show the infestation on either the NASA duplication or the high-contrast copy without magnification; however, magnification (2.4X) revealed some of the pattern. Panchromatic film type 2402 with a Wratten 25 filter showed the dwarf mistletoe pattern clearly and without magnification on the high-contrast copy. Although the pattern was detectable on both copies of the black-and-white infrared film (type 2424) with a Wratten 89B filter, it was most satisfactory on the NASA copy and not on the high-contrast copy. This resulted from too many density levels being exaggerated by the high-contrast copy.

<u>Optical Recombining</u>. The three spectral slices contained on the NASA Hasselblad imagery were combined optically into one false-color image. This was done on the Addcol viewer at the International Imaging Systems office by projecting the combined picture onto the backlit screen at approximately 10 power magnification. This enlargement enabled detailed study of the scene; however, rephotographing had to be done to obtain a permanent record. While in theory recombination of the three spectral slices is supposed to be superior to a tri-emulsion photograph, it has not in fact proven to be so in all cases. Nothing could be detected on the optical recombination that did not show on the tri-emulsion at the 1:118,000 scale. The recombined photograph, however, produced a color-enhanced scene superior to any of the single images.

Figure 16 shows the individual black-and-white photographs of the spectral slices used in the recombining process. The color-enhanced product of this recombining is shown after passing through the rephotographing

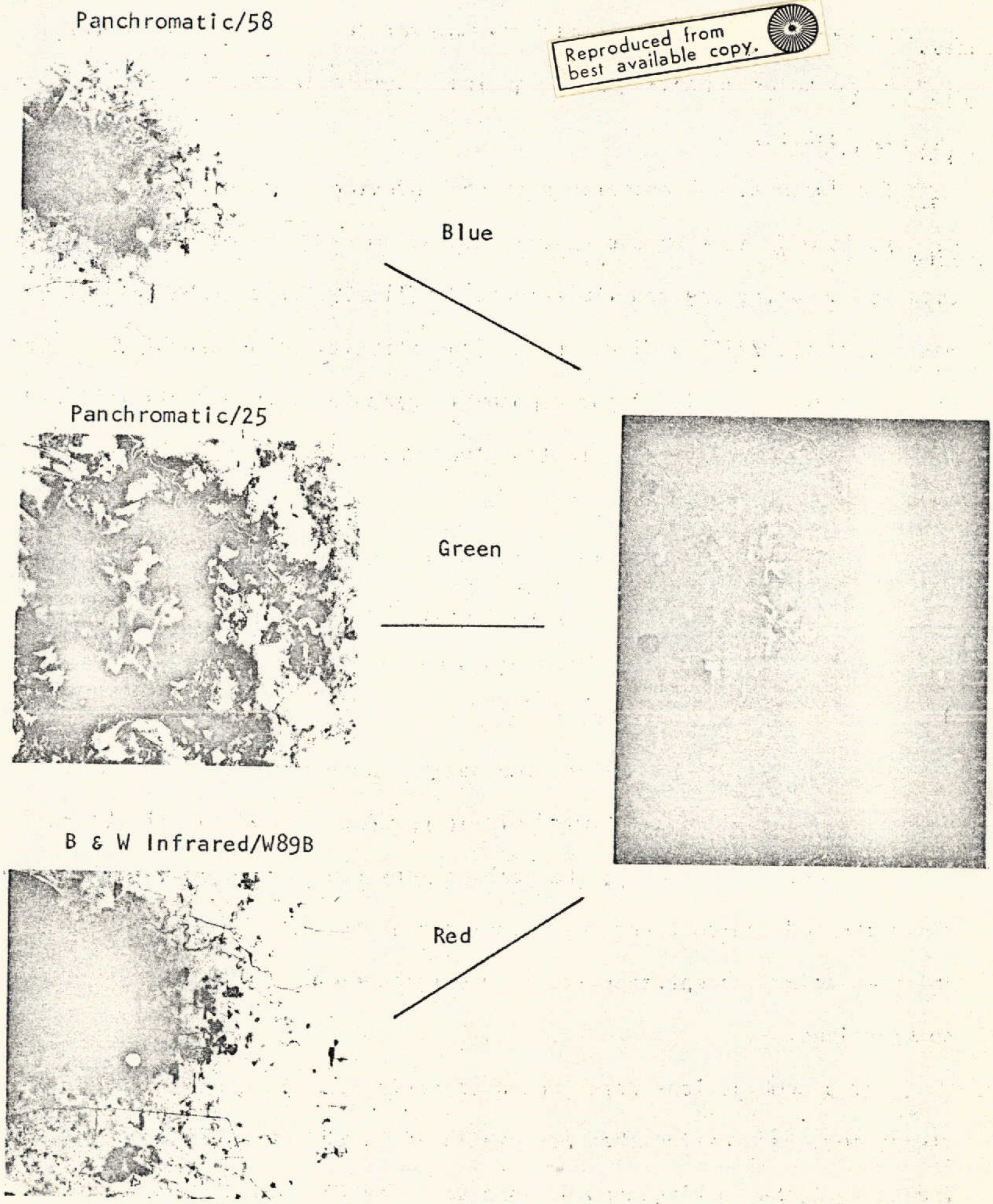


Figure 16. Optically recombining the three spectral slices produces a microscale, color-enhanced image highlighting the dwarf mistletoe infection areas within the black spruce forest.

process by a Yashica 35 mm camera on Kodachrome II film. Some detail within the color-enhanced scene was lost in this extra step required for its publication.

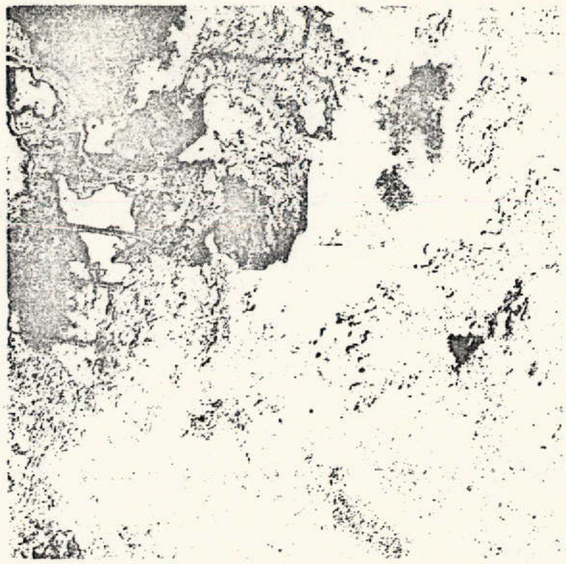
The "moth-eaten" appearance of the infected black spruce stand is detectable with ease on the color-enhanced image. The optimum scene was obtained by using the red (infrared 2424 film/89B) and green (panchromatic 2402 film/25A) projectors at high intensity. The use of the third projector with the blue light component (panchromatic 2402 film/58) did not appear to make any contribution that was helpful in locating the dwarf mistletoe infections.

Although no special effects could be brought out by changing intensities and filters on different projectors, the overall infection area could be high-lighted. The use of red and green projectors provided the scene needed to locate these areas.

Masking. Several masking combinations were used to locate density differences resulting from dwarf mistletoe infection within the black spruce stand. Essentially, the combinations used in the masking employed the high- and low-contrast positives, negatives, and films available. The infrared color transparency itself was included in some of the masking combinations.

Three combinations were chosen as having the greatest promise of providing more information than was available in the infrared color positive. The best of the masking combinations used are listed in Table 10.

Figure 17 shows the Togo test site as it appears on each of the three selected masks listed in Table 10. Mask number 1 creates a harsh black-



Low-contrast positive
High-contrast negative
High-contrast film

Low-contrast positive
High-contrast negative
Low-contrast film

High-contrast positive
High-contrast negative
High-contrast film

Figure 17. Three masks selected for Togo Test Site Study.

TABLE 10. MASKING COMBINATIONS SELECTED FOR INTERPRETATION AND EVALUATION FOR USE IN DWARF MISTLETOE DETECTION

Number	Positive	Negative	Film
1	low contrast	high contrast	high contrast
2	low contrast	high contrast	low contrast
3	high contrast	high contrast	high contrast

to-white contrast by eliminating most of the densities except for that of the black spruce stand and some shadows. This brings out many small spots of dwarf mistletoe infection and any other density not caused by black spruce or shadows. All of the field-checked openings are visible, including the one-half-chain radius plot, when the mask is viewed on the light table. However, none of the infected plots of standing trees are displayed. Openings in the black spruce can be detected on this mask that are not visible on the color infrared positives. Mask number 1 rates a superior for opening detection and a good for location of those openings in relation with their surroundings.

Mask number 2 (low-contrast positive and film with high-contrast negative) is more interpretable in that it contains more density levels than mask number 1. Because of the many density levels remaining on the film, the black spruce stand is easily located. An "unsharp" masking effect is present on mask number 2; however, it may be the result of registration rather than the result of the masking combination. Mask number 2 rates a good for ease of opening detection and a superior for opening locations.

Mask number 3 uses high-contrast positive, negative, and film. This high-contrast combination reverses the effect created by the other masks. It eliminates the density for the black spruce and causes the openings to show up as dark tones. It does detect the openings in the black spruce; however, the openings are difficult to separate from similar spots showing all over the photograph. Small spots appear whenever the film density is similar to the density of the openings. This causes the clear background to be cluttered with thousands of unrelated spots with very little to use in orientation and location of the spots. Mask number 3 rates a good for opening detection but a poor for location.

Of the three masks selected, number 1 would provide the greatest information on infection centers that have caused openings. The combination of the positive, the negative, and the film used in obtaining mask number 2 is a good compromise. It provides most of the information that was present in mask combination number 1, as well as being easier to use for plot location. The difficulty in using mask number 3 for plot location would reduce its value in a disease survey from a high altitude.

Density Level-Slicing. The color-enhanced density separations present an impressive appearance, but do not provide any more information than is available on the infrared color transparency. This would agree with the findings at the Cromwell site, where no distinct spectral signature could be determined for infected black spruce trees.

Orientation problems exist in trying to locate disease-related densities because of the loss of background detail. Using overlays for ground detail causes registration and lighting problems that confound detailed interpretation. Figure 18 shows the test area as it appears when all 16 density slices are stacked together.

The Digicol electronic image enhancer (Figure 19) enabled the different densities to be highlighted and colored with ease. It detected density differences in and around the black spruce stand that were not visible on the photography. These density differences, however, were unrelated to dwarf mistletoe. Density differences related to the disease

Figure 18. "Stack" of 16 color-enhanced density separation transparencies showing the Togo test site.

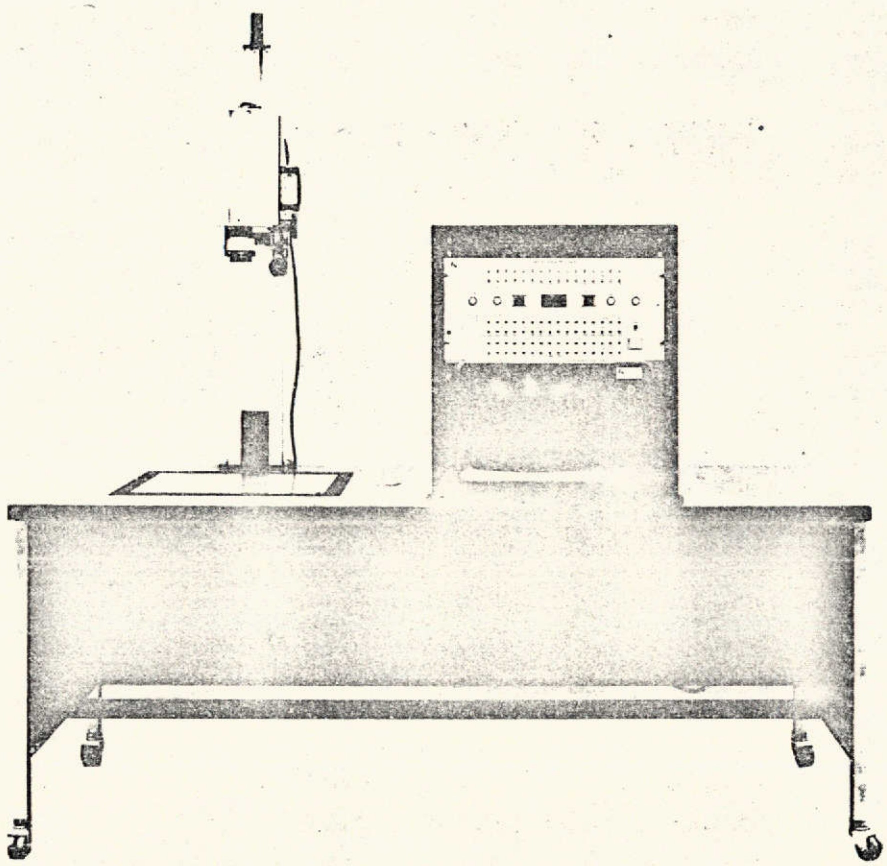


Figure 19. Digicol system model 4010 used in making the video density slices of the dwarf mistletoe infection sites. (Courtesy, International Imaging Systems)

were detectable on the photograph. Figure 20 presents the Togo test site as it appears on the color infrared film, on the black-and-white high-contrast film used in the Digicol, and on the Digicol video screen.

Hypoxylon Canker Detection

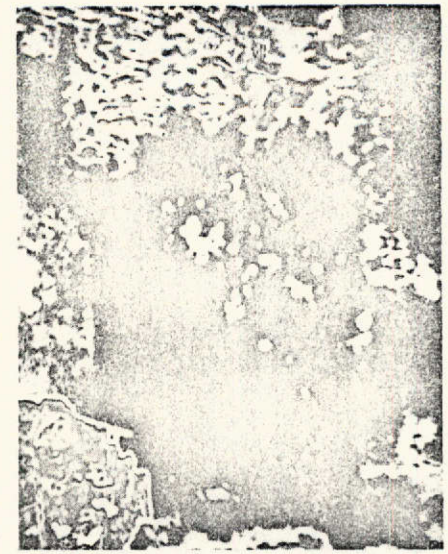
No film-filter combination from the Hinckley test site showed an advantage over the others for interpretation at the 1:6,000 scale. However, the forest pathologists stated that the true-color films (Ektachrome MS and Ektacolor) were more suitable for their use in locating landmarks and diseased trees. The use of the Wratten 21 filter with Ektachrome infrared film produced a false-color scene that contained more orange than the usual Ektachrome infrared photographs. Since the orange scene provided no more information than the normal false-color picture, the Wratten 21 filter was not used on the later flight.

Both Ektachrome MS and Ektachrome infrared film at the 1:15,840 scale exhibited sufficient detail for use in detecting the trees killed during the current year. The aspen killed by H. mammatum during the current year still retained their dead foliage; however, the trees killed in previous years had no foliage and were not detectable at this scale. Dead trees without foliage can be located on the 1:6,000 scale photography (Figure 21).

Individual trees are difficult to pick out on Ektachrome MS or Ektachrome infrared film at the 1:31,680 scale. Even though Ektachrome infrared was superior to Ektachrome MS for detecting the current year's hypoxylon kill, it did not produce a good contrast between dead and healthy vegetation. The 1:31,680 scale photography was flown in mid-September when the

Ektachrome infrared

Mask #2



Color-enhanced video presentation

Figure 20. The electronic image enhancer was used to separate density levels on the black-and-white mask made from an Ektachrome infrared photograph of the Togo test site.

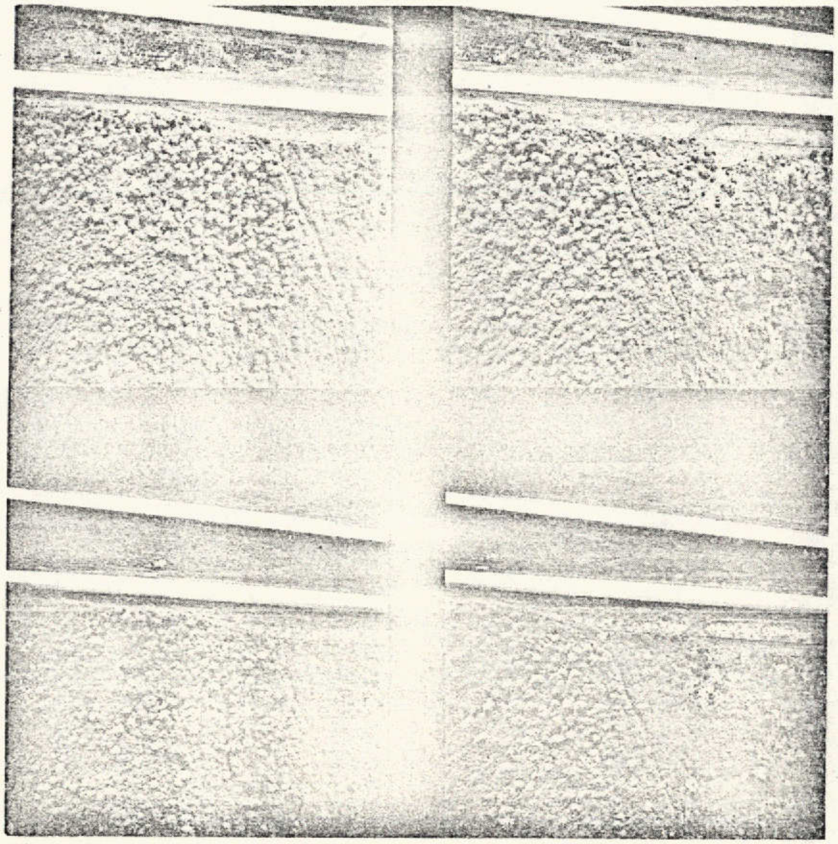


Figure 21. 70 mm stereograms taken with Ektachrome MS/2A and Ektachrome infrared/W12 film-filter combinations (1:6,000 scale) of the Hinckley test site. Hypoxylon-killed trees from present year (dead leaves present) and from previous year (no leaves) are visible.

infrared reflectance on all vegetation had declined. Even the large-scale infrared color photography taken in September exhibits this loss in contrast.

In field checking, Dr. D. W. French found that every one of the hypoxylon-killed overstory trees had been detected by photo interpretation. Trees under 3 inches in diameter and infected living trees were not evident on the photography, due to lack of size and foliage effects.

Those trees detected on the photographs as being dead or dying were all aspen; however, they were not all victims of hypoxylon canker. Three trees were victims of some combination of heart rot and overmaturity. Of the 25 trees with hypoxylon canker, 17 were detected on the large-scale photographs. The eight undetected, infected trees were under 3 inches in diameter (six trees) or still alive (two trees).

The 1:15,840 scale photography detected 18 of the 19 marked overstory trees. Only a partially killed crown was missed. The mid-September photography produces a darker brown tone to the dead foliage; however, it shows a beginning of fall coloration change which, along with the infrared reflectance dropoff, makes medium-scale photography difficult to interpret.

Armillaria Root Rot Detection

During the ground check of the Willow River test site, 309 trees were examined, located on the photographs, and classified as follows:

Class	Number of Trees
1. Healthy	265
2. Died in 1968	5

Class	Number of Trees
3. Died in 1969	11
4. Died in 1970	13
5. Currently dying	15

On the July 8, 1971 photography (Figure 22), interpreters were able to detect only those trees which had died in 1970, and with some slight difficulty the trees which had died in 1969 (Table 11). 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 1961 could be detected on either of the two film types (Ektachrome MS and Ektachrome infrared).

Forest Vegetation Classification

Statistical Investigation

Null Hypothesis I (Film, Season, and Cover type). A three-way factorial was designed to investigate the relationships and interactions of film, season, and vegetation cover type. Color infrared and color RB57F photography taken on August 8 and September 29, 1971, at a scale of 1:118,000 was used in this analysis.

The effect of film was significant at the 95 percent level, while the effect of the season was significant at the 99 percent level. Vegetative cover type did not have a significant influence on the scores at the 95 percent level. Based on the significance of the two effects, Null Hypothesis I_A must be rejected.

Interpreters scored 64 out of a possible 80 on the color infrared film and 53 out of 80 on the color film. Fall photography was superior

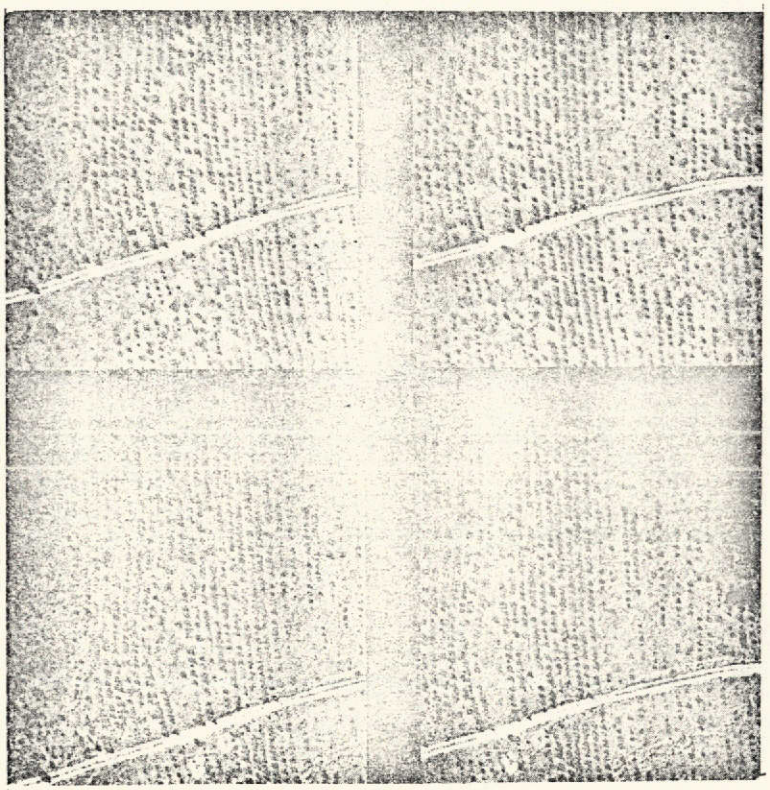


Figure 22. Stereograms of the Willow River test site taken with Ektachrome MS-2A and Ektachrome infrared/W12 film-filter combinations (1:2,000 scale). The obviously off-color red pine trees were killed during the previous year by Armillaria root rot.

TABLE 11. PHOTOGRAPHIC DETECTION OF *ARMILLARIA* ROOT ROT MORTALITY IN A RED PINE PLANTATION BY YEAR OF KILL

Years since death	Detection success rate
currently dying	none
current year	low
one	high
two	low
three	none

to summer photography by a score of 66 to 51. No significant difference in identification of vegetative cover type was shown in this experiment.

Interaction between the film type and the season proved to be highly significant (99 percent level) while the other first-order interactions were not significant. The second-order interaction of film, season, and cover type was significant at the 95 percent level. Based on the significance of the interactions, Null Hypothesis I_B must be rejected (see Table 12).

The summer-color film scored 19 out of a possible 40 while the other three combinations each scored 32 (infrared color film in both summer and fall) or 34 (color film-fall). Season made no difference in the interpretation of the infrared color film. This is contrary to the comments of the interpreters who stated that they had difficulty with the summer infrared color.

Null Hypothesis II. A two-way factorial analysis was designed to investigate the relationships and interactions of photograph scale and vegetation cover types. Color infrared photographs taken on September 29, 1971, at scales of 1:59,000, 1:118,000, and 1:462,000 were used in this test.

The effect of photographic scale was significant at the 99 percent level. Vegetation cover type did not have a significant effect at the 95 percent level. Null Hypothesis II_A should be rejected because of the significance shown in the Analysis of Variance summary in Table 13. Since no significance can be attached to the effect of interactions, there is no basis for rejecting Null Hypothesis II_B.

TABLE 12. ANALYSIS OF VARIANCE SUMMARY TABLE FOR FILM, SEASON, AND COVER TYPE TREATMENTS

Source	Sum of Squares	DF	Mean Squares	F. Ratio	Probability
1 (Film)	1.5125	1	1.5125	4.400	0.040
2 (Season)	2.8125	1	2.8125	8.182	0.006
3 (Type)	1.9375	3	0.6458	1.879	0.142
12	2.8125	1	2.8125	8.182	0.006
13	0.3375	3	0.1125	0.327	0.806
23	0.8375	3	0.2792	0.812	0.492
123	3.6375	3	1.2125	3.527	0.020
Error	22.0000	64	0.3438		

TABLE 13. ANALYSIS OF VARIANCE SUMMARY TABLE FOR PHOTOGRAPHIC SCALE AND VEGETATION COVER TYPE TREATMENTS

Source	Sum of Squares	DF	Mean Squares	F. Ratio	Probability
1 (Scale)	3.0333	2	1.5167	5.056	0.010
2 (Type)	0.4500	3	0.1500	0.500	0.684
12	2.300	6	0.3833	1.278	0.285
Error	14.4000	48	0.3000		

Scores of 38, 32, and 27 out of a possible 40 were made respectively on 1:59,000, 1:118,000, and 1:462,000 scales of photography (see Table 13).

Hypothesis III. A one-way classification was made to test for differences among the interpreters' scores. The analysis of variance analysis produced an F-ratio that was not significant at the 95 percent level; therefore, the Null Hypothesis III_A is not disproven. This implies that there are no significant differences among the interpreters' scores (see Table 14).

No multiple-comparison procedure was performed on the data because the F-ratio showed no significant difference in the scores. Steel and Torrie (23) recommend against making multiple-comparison tests when the F-ratio is not significant.

General Observations. All of the interpreters agreed that the pocket stereoscope was satisfactory for use with the NASA photography even though some situations required that both photographs in the stereo pair be rolled. Since transparencies are used on a light table, no overlap is possible in the area being viewed. The 9-inch x 9-inch format photography will overlap when viewed through a pocket stereoscope; therefore, the overlapping portions must be rolled out of the viewing area. This operation was quickly mastered by all of the interpreters.

The interpreters commented that the fall photography with color infrared film was superior to the other film-season combinations for vegetative and soils analysis. Each man stated that he could do better work with less effort on that combination. Summer color photography was considered to be the least desirable combination. The interpreters were

TABLE 14. ANALYSIS OF VARIANCE SUMMARY OF TEST FOR DIFFERENCE AMONG INTERPRETERS' SCORES

Source of Variation	DF	Sum of Squares	Mean Square	F-Ratio
Treatment	4	18.743	4.68575	2.008
Error	30	70.000	2.333	
TOTAL	34	88.743		

Table value for $F_{4,30(.05)} = 2.69$

ANOVA value for $F = 2.008$

Since $2.008 < 2.69$ we cannot reject the Null Hypothesis III_A

more concerned about their ability to interpret the film-season combinations and did not express much preference to any scale.

The interpreters ranked the film in order of ease in interpretation. The results of this ranking are given in Table 15.

SUMMARY AND CONCLUSIONS

Dwarf Mistletoe Detection

No spectral signature for stress in black spruce as related to dwarf mistletoe was detected in this study. If the need to identify such a signature becomes important, an investigation employing sensors other than the film-filter combinations used here might be performed. However, the lack of a detectable spectral signature did not prohibit dwarf mistletoe detection by means of aerial photographs.

Findings at the Togo test site indicated that the "moth-eaten" pattern associated with dwarf mistletoe infections was detectable on all photographic scales investigated. Even though all openings in the black spruce canopy were not caused by dwarf mistletoe, the disease centers do make up most of the characteristic "moth-eaten" pattern.

Openings of 1/10-acre in area were visible on infrared color film at scales as small as 1:118,000; however, centers this small were difficult to detect on scales ranging from 1:63,360 to 1:118,000 without magnification or high-contrast copies of the imagery (see Table 16). Openings 1/4-acre in size were visible on the 1:462,000 scale photography. It is the grouping of one-fourth-acre or larger openings that presents the "moth-eaten" pattern on the microscale imagery.

Ektacolor prints and color infrared film showed large groups of dead,

TABLE 15. RESULTS OF INTERPRETERS' RANKING OF THE FILM-SEASON COMBINATIONS IN THE VEGETATIVE CLASSIFICATION TESTS AND THE TEST SCORES OBTAINED

Interpreters' ranking			Correct scores on tests	
(best)	1.	Color infrared-fall	Color-fall	34 (highest)
	2.	Color-fall	Color infrared-summer	32
	3.	Color infrared-summer	Color infrared-fall	32
(worst)	4.	Color-summer	Color-summer	19 (lowest)

TABLE 16. RELATIONSHIP OF SCALE TO DETECTION OF DWARF MISTLETOE CENTERS IN THE BLACK SPRUCE FOREST TYPE

Photo scale	Infection center detectability	Comment
1:8,000	1/10-acre centers easily detected	Individual dead trees without foliage visible on Ektachrome MS/Wr 2A.
		The 300-square-foot plot (No. 4) of standing infected trees not detectable with any film-filter combination used.
		The 1500-square-foot plot (No. 5) of standing infected trees detectable with Ektacolor/Wr 2A and Ektachrome IR/Wr 12.
		A ring of dead (blue) trees around the infection centers visible on the Ektachrome IR/Wr 12.
1:31,680	1/10-acre centers detectable	The 1500-square=foot plot (No. 5) of standing infected trees detectable -- but with difficulty.
		Dead edge trees showing blue on Ektachrome IR/Wr 12 very difficult to locate.
1:59,000	1/10-acre centers detectable	No color contrast detectable between live canopy and dead foliage on Plot 5.
1:63,360	Individual 1/10-acre centers difficult to detect	Blue tone of dead trees and brown of recently dead foliage not visible on Ektachrome IR/Wr 12.
1:118,000	1/10-acre centers detectable on IR color photography -- but with difficulty. Magnification needed on color photography to detect 1/10-acre openings.	Summer season infrared color photography provided greater contrast between conifers and hardwoods than other seasons; therefore, openings were more detectable during that season.
1:462,000	1/10-acre centers not detectable, 1/4-acre centers visible.	Moth-eaten pattern of dwarf mistletoe infection most easily detected on Plus-X/Wr 25 and on Aero IR/Wr 89B black-and-white film-filter combinations.

but standing, trees; however, Ektachrome MS did not. All films investigated did show the "moth-eaten" pattern for dwarf mistletoe infections.

Color contrasts between the live canopy and the dead foliage on the 1500-square-foot plot of infected standing trees were visible on the Ektacolor and infrared color films at scales larger than 1:59,000. The blue color associated with dead, defoliated trees on infrared color was present at scales greater than 1:63,360.

Based on the findings of this study, a multistage sampling project could be designed for use with very high-altitude photography. Very small-scale or microscale photography (1:120,000 to 1:462,000 scale) taken on color infrared film through a deep yellow filter could serve as the upper stage. This scale of photography would give maximum area coverage with a small number of photographs. Ground checks could be used as the second stage of the project.

Optical recombining can be used to create a color-enhanced scene from black-and-white photographs. Specific points of interest can be highlighted by varying the color combinations and light intensities; however, no hidden information was made available by the use of the optical recombination. Everything that was visible on the color-enhanced scene was also visible on the spectral slices and on the tri-emulsion films.

Although two masking combinations were given high ratings for detection or location of dwarf mistletoe patterns, none of the masks revealed infection centers that were not present on the color infrared photograph used in making the masks. The expense and interpretation difficulties of masking as an image-enhancement technique were not justified by any information return.

Density-level slicing and color coding were not useful in the location of dwarf mistletoe. The electronic image enhancer did enable densities to be highlighted. None of these newly highlighted densities aided in the detection of dwarf mistletoe. In light of the success, although very limited, of the electronic image enhancer, further studies should be made in the area.

Hypoxylon Canker Detection

Detection of hypoxylon canker in aspen stands based upon the presence of persistent dead foliage is possible from large-scale (1:6,000) and medium-scale (1:15,840) photography. The small-scale (1:31,680) photography did not provide satisfactory definition of the individual trees to permit the detection of single dead crowns.

Satisfactory hypoxylon canker detection was achieved on all the film-filter combinations used at the 1:6,000 scale. The Ektacolor and Ektachrome photographs were reported to be easier to work with in the field because of the field team's inexperience with infrared color photography.

At the 1:6,000 scale, the photography showed individual dead trees that had no foliage. These snags were the result of hypoxylon kill during previous years. Although the snags are not identifiable on the 1:15,840 photography, individual trees of the current year's mortality are detectable because of the persistent dead foliage associated with the hypoxylon canker infections. The 1:31,680 scale photography was not successful in detecting single dead trees as is necessitated by the character of this disease. Therefore, the small-scale photography taken for this study did not prove to be of value for direct interpretation of hypoxylon canker in aspen.

Further investigation of hypoxylon canker detection by remote sensing techniques will be carried out to study the effects of seasons on detectability.

Armillaria Root Rot Detection

The Willow River Study indicates an *Armillaria* root rot detection program could be successful if done with large-scale photography. Only red pine mortality of the previous year had a high rating of detectability -- trees killed during any other year were difficult, or impossible, to detect. These findings indicate that an aerial detection or survey program for *Armillaria* root rot should be designed to utilize the fact that only the previous year's mortality is readily detectable.

Forest Vegetation Classification

The scale of the photographs had a very significant effect (0.010 probability) on the interpreters' ability to identify the vegetation cover types. Scores of 38, 32, and 27 out of a possible 40 were made respectively on 1:59,000, 1:118,000, and 1:462,000 scale photography. However, the interpreters commented that they had no preferences for any of the scales that they had used in the sub-study.

The vegetative cover types did not have any significant effect on the interpreters' scores when considered as a treatment or within an interaction.

The observer's comments were mostly concerned with the season that the photographs were taken. The season did have a significant effect on the interpreters' scores. The fall photography produced higher scores than did the summer photography (66 for fall; 51 for summer) for all scales.

Color infrared film produced the highest score, with 64 correct plots out of an 80 possible score. Color film produced a score of 53 out of a possible 80. However, the film-season combination of fall-color produced the highest score. The interpreters' stated preference was for the infrared color film exposed during the fall season even though this combination produced a lower score in the study than did the color-fall combination. The summer-color combination produced the poorest results in this sub-study.

This study suggests that very small-scale fall photography on color infrared film could be used to stratify areas by vegetation cover types and thereby serve as the first, or second, stage of a multistage sampling project.

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APPENDIX A

NASA-USDA FORESTRY AND RANGE REMOTE SENSING RESEARCH PROGRAM "REMOTE SENSING APPLICATIONS IN FORESTRY" SERIES

1966 Annual Reports

STAR* No.	Title
N67-19905	Carneggie, D. M., W. C. Draeger and D. T. Lauer. The use of high altitude, color and spectrozonal imagery for the inventory of wildland resources. Vol. I: The timber resource. School of Forestry and Conservation, University of California, Berkeley. 75 pages.
N66-39698	Carneggie, D. M., E. H. Roberts and R. N. Colwell. The use of high altitude, color and spectrozonal imagery for the inventory of wildland resources. Vol. II: The range resource. School of Forestry and Conservation, University of California, Berkeley. 22 pages.
N67-19939	Carneggie, D. M. and R. N. Colwell. The use of high altitude, color and spectrozonal imagery for the inventory of wildland resources. Vol. III: The soil, water, wildlife and recreation resource. School of Forestry and Conservation, University of California, Berkeley. 42 pages.
N66-39304	Heller, R. C. et al. The use of multispectral sensing techniques to detect ponderosa pine trees under stress from insect or pathogenic organisms. Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, USDA. 60 pages.
N66-39386	Lauer, D. T. The feasibility of identifying forest species and delineating major timber types in California by means of high altitude small scale aerial photography. School of Forestry and Conservation, University of California, Berkeley. 130 pages.
N66-39700	Wear, J. F. The development of spectro-signature indicators of root disease on large forest areas. Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, USDA. 24 pages.

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*Available through NASA Scientific Technical and Information Facility, P. O. Box 33, College Park, Maryland 20740.

STAR No.	Title
N66-39303	Lent, J. D. Cloud cover interference with remote sensing of forested areas from earth-orbital and lower altitudes. School of Forestry and Conservation, University of California, Berkeley. 47 pages.
N66-39405	Weber, F. P. Multispectral imagery for species identification. Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, USDA. 37 pages.

1967 Annual Reports

N68-17406	Draeger, W. C. The interpretability of high altitude multispectral imagery for the evaluation of wildland resources. School of Forestry and Conservation, University of California, Berkeley. 30 pages.
N68-17494	Lauer, D. T. The feasibility of identifying forest species and delineating major timber types by means of high altitude multispectral imagery. School of Forestry and Conservation, University of California, Berkeley. 72 pages.
N68-17671	Carneggie, D. M., C. E. Poulton and E. H. Roberts. The evaluation of rangeland resources by means of multispectral imagery. School of Forestry and Conservation, University of California, Berkeley. 76 pages.
N68-17378	Wear, J. F. The development of spectro-signature indicators of root disease on large forest areas. Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, USDA. 22 pages.
N68-17408	Heller, R. C., R. C. Aldrich, W. F. McCambridge and F. P. Weber. The use of multispectral sensing techniques to detect ponderosa pine trees under stress from insect or pathogenic organisms. Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, USDA. 65 pages.
N68-17247	Weber, F. P. and C. E. Olson. Remote sensing implications of changes in physiologic structure and function of tree seedlings under moisture stress. School of Natural Resources, University of Michigan. 61 pages.

STAR No.	Title
	1968 Annual Reports
N69-16461	Lent, J. D. The feasibility of identifying wildland resources through the analysis of digitally recorded remote sensing data. School of Forestry and Conservation, University of California, Berkeley. 130 pages.
N69-25632	Carneggie, D. M. Analysis of remote sensing data for range resource management. School of Forestry and Conservation, University of California, Berkeley. 62 pages.
N69-16113	Lauer, D. T. Forest species identification and timber type delineation on multispectral photography. School of Forestry and Conservation, University of California, Berkeley. 85 pages.
N72-74471	Driscoll, R. S. and J. N. Reppert. The identification and quantification of plant species, communities and other resource features in herbland and shrubland environments from large scale aerial photography. Rocky Mountain Forest and Range Experiment Station, U.S. Forest Service, USDA. 62 pages.
**	Wear, J. F. The development of spectro-signature indicators of root disease impact on forest stands. Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, USDA. 27 pages.
N69-16390	Poulton, C. E., B. J. Schrumpf and E. Garcia-Moya. The feasibility of inventorying native vegetation and related resources from space photography. Department of Range Management, Agricultural Experiment Station, Oregon State University. 47 pages.
N71-37947	Heller, R. C., R. C. Aldrich. W. F. McCambridge, F. P. Weber and S. L. Wert. The use of multispectral sensing techniques to detect ponderosa pine trees under stress from insect or pathogenic organisms. Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, USDA. 45 pages.
N69-12159	Draeger, W. C. The interpretability of high altitude multispectral imagery for the evaluation of wildland resources. School of Forestry and Conservation, University of California, Berkeley. 68 pages.

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STAR No.	Title
N72-74472	Langley, P. G. and D. A. Sharpnack. The development of an earth resources information system using aerial photographs and digital computers. Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, USDA. 26 pages.
N69-15856	Olson, C. E. and J. M. Ward. Remote sensing of changes in morphology and physiology of trees under stress. School of Natural Resources, University of Michigan. 43 pages.

1969 Annual Reports

N70-41162	Olson, C. E., J. M. Ward and W. G. Rohde. Remote sensing of changes in morphology and physiology of trees under stress. School of Natural Resources, University of Michigan. 43 pages.
N70-41164	Heller, R. C., R. C. Aldrich, W. F. McCambridge and F. P. Weber. The use of multispectral sensing techniques to detect ponderosa pine trees under stress from insect or diseases. Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, USDA. 59 pages.
N70-42044	Langley, P. G., D. A. Sharpnack, R. M. Russell and J. Van Roessel. The development of an earth resources information system using aerial photographs and digital computers. Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, USDA. 43 pages.
N70-41064	Driscoll, R. S. The identification and quantification of herbland and shrubland vegetation resources from aerial and space photography. Rocky Mountain Forest and Range Experiment Station, U.S. Forest Service, USDA. 55 pages.
N70-41282	Colwell, R. N. et al. Analysis of remote sensing data for evaluating forest and range resources. School of Forestry and Conservation, University of California, Berkeley. 207 pages.
N70-41063	Poulton, C. E., E. Garcia-Moya, J. R. Johnson and B. J. Schrumpf. Inventory of native vegetation and related resources from space photography. Department of Range Management, Agricultural Experiment Station, Oregon State University. 66 pages.

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STAR No.	Title
N70-41217	Wear, J. F. and F. P. Weber. The development of spectro-signature indicators of root disease impacts on forest stands. Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, USDA. 58 pages.
	1970 Annual Reports
**	Wilson, R. C. Potentially efficient forest and range applications of remote sensing using earth orbital spacecraft -- circa 1980. School of Forestry and Conservation, University of California, Berkeley. 199 pages.
**	Aldrich, R. C., W. J. Greentree, R. C. Heller and N. X. Norick. The use of space and high altitude aerial photography to classify forest land and to detect forest disturbances. Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, USDA. 36 pages.
**	Driscoll, R. S. and R. E. Francis. Multistage, multiseasonal and multiband imagery to identify and quantify non-forest vegetation resources. Rocky Mountain Forest and Range Experiment Station, U.S. Forest Service, USDA. 65 pages.
**	Personnel of Forestry Remote Sensing Laboratory. Analysis of remote sensing data for evaluating vegetation resources. School of Forestry and Conservation, University of California, Berkeley. 171 pages.
**	Meyer, M. P., D. W. French, R. P. Latham and C. A. Nelson. Vigor loss in conifers due to dwarf mistletoe. School of Forestry, University of Minnesota. 21 pages.
N71-36770	Langley, P. G., J. Van Roessel, D. A. Sharpnack and R. M. Russell. The development of an earth resources information system using aerial photographs and digital computers. Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, USDA. 32 pages.
N72-28321	Weber, F. P. and J. F. Wear. The development of spectro-signature indicators of root disease impacts on forest stands. Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, USDA. 46 pages.
**	Heller, R. C., F. P. Weber and K. A. Zealear. The use of multispectral sensing techniques to detect ponderosa pine trees under stress from insects or diseases. Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, USDA. 50 pages.

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STAR No.	Title
N72-27375	Olson, C. E., W. G. Rohde and J. M. Ward. Remote sensing of changes in morphology and physiology of trees under stress. School of Natural Resources, University of Michigan. 26 pages.
	1971 Annual Reports
N71-32815	Dana, R. W. Calibration of color aerial photography. Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, USDA. 14 pages.
N72-28327	Driscoll, R. S. and R. E. Francis. Multistage, multiband and sequential imagery to identify and quantify non-forest vegetation resources. Rocky Mountain Forest and Range Experiment Station, U.S. Forest Service, USDA. 75 pages.
N72-28328	Amidon, E. L., D. A. Sharpnack and R. M. Russell. The development of an earth resources information system using aerial photographs and digital computers. Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, USDA. 7 pages.
N72-28324	Personnel of the Remote Sensing Research Work Unit. Monitoring forest land from high altitude and from space. Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, USDA. 179 pages.
N72-28326	Poulton, C. E., D. P. Faulkner, J. R. Johnson, D. A. Mouat and B. J. Schrumpf. Inventory and analysis of natural vegetation and related resources from space and high altitude photography. Department of Range Management, Agricultural Experiment Station, Oregon State University. 59 pages.
N72-28325	Meyer, M. P., D. W. French, R. P. Latham, C. A. Nelson and R. W. Douglass. Remote sensing of vigor loss in conifers due to dwarf mistletoe. School of Forestry, University of Minnesota. 40 pages.
N72-28037	Olson, C. E., W. G. Rohde and J. M. Ward. Remote sensing of changes in morphology and physiology of trees under stress. School of Natural Resources, University of Michigan. 77 pages.
**	Personnel of Forestry Remote Sensing Laboratory. Analysis of remote sensing data for evaluating vegetation resources. School of Forestry and Conservation, University of California. 195 pages.

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STAR No.	Title
	1972 Annual Reports
**	rec'd 7-30-73 Driscoll, R. S. and R. E. Francis. Multistage, multiband and sequential imagery to identify and quantify non-forest vegetation resources. Rocky Mountain Forest and Range Experiment Station, U.S. Forest Service, USDA. 42 pages.
**	Amidon, E. L., D. A. Sharpnack and R. M. Russell. The development of an earth resources information system using aerial photographs and digital computers. Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, USDA. 23 pages.
**	rec'd 7-30-73 Poulton, C. E. Inventory and analysis of natural vegetation and related resources from space and high altitude photography. Range Management Program, Agricultural Experiment Station, Oregon State University. 48 pages.
**	rec'd 7-30-73 Personnel of the Remote Sensing Research Work Unit. Monitoring forest land from high altitude and from space. Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, USDA. 200 pages.
**	rec'd 7-30-73 Olson, Jr., C. E. Remote sensing of changes in morphology and physiology of trees under stress. School of Natural Resources, University of Michigan. 26 pages.
**	rec'd 7-30-73 Personnel of the Forestry Remote Sensing Laboratory. Analysis of remote sensing data for evaluating vegetation resources. School of Forestry and Conservation, University of California, Berkeley. 245 pages.
**	rec'd 7-30-73 Douglass, R. W., M. P. Meyer and D. W. French. Remote sensing applications to forest vegetation classification and conifer vigor loss due to dwarf mistletoe. College of Forestry, University of Minnesota. 86 pages.

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