AN ABSTRACT OF THE THESIS OF

DAVID WILLIAM HANN for the MASTER OF SCIENCE
(Name) (Degree)

in Forest Management presented on ____________
(Major) (Date)

Title: DETECTION OF DWARF MISTLETOE IN YOUNG-GROWTH PONDEROSA PINE FROM COLOR AERIAL PHOTOGRAPHY

Abstract approved: Signature redacted for privacy.
David P. Paine

The purpose of this study was to determine if infection levels of dwarf mistletoe on ponderosa pine could be detected with color aerial photography. The photography was taken in early September using Kodak Ektachrome Infrared Aero and Ektachrome Aero films at scales of 1/4000, 1/2000, and 1/1000.

Ground truth consisted of 214 trees classified as to healthy, lightly infected, moderately infected or heavily infected. Three photo interpreters were able to correctly classify these trees only 34 percent of the time. Statistical analysis indicated no significant differences between interpreters, film types, scales, or levels of infection. Rearrangement of the data did indicate that four interpreters were able to distinguish mistletoed from non-mistletoed trees 70 percent of the time using Ektachrome Infrared Aero film at a 1/1000 scale.

Results might be improved by using low oblique photography

taken in the spring with either Kodak Ektachrome Aero or Ektachrome Infrared Aero films, at a scale of 1/1000.

Detection of Dwarf Mistletoe in Young-Growth Ponderosa Pine From Color Aerial Photography

by

David William Hann

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

June 1970

APPROVED:

Signature redacted for privacy.

Associate Professor of Forest Management
in charge of major

Head of Department of Forest Management

Dean of Graduate School

Date thesis is presented 3/23/70

Typed by Gwendolyn Hansen for David William Hann

ACKNOWLEDGMENTS

The author wishes to extend his gratitude to the many people who guided him through this project.

My sincere thanks goes to my major professor, Dr. David P. Paine. His guidance and counseling have made this project much easier.

My deep appreciation also goes to:

Dr. Lewis Roth of the Botany Department at O. S. U., who helped me immeasurably in understanding the dwarf mistletoe characteristics of the Pringle Falls area.

Wes James of Civil Engineering at O. S. U., who loaned me his two Hasselblad cameras as well as providing good advice.

James Stewart of the Region 6 Office of the U. S. Forest Service, who not only provided the aircraft for the project but also his good advice.

John Wear of the U. S. Forest Service, who flew the aircraft and assisted me in many photographic decisions.

My minor professor, Dr. Rodger Peterson of the Statistics Department at O. S. U., who helped me in my statistical analysis.

The School of Forestry at O. S. U. for financial assistance.

The men of the "grad hut," who have contributed more to my education than can be measured.

My parents, without their encouragement and assistance this project would not have been started let alone finished.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

DETECTION OF DWARF MISTLETOE IN YOUNG-GROWTH PONDEROSA PINE FROM COLOR AERIAL PHOTOGRAPHY

INTRODUCTION

Dwarf mistletoes (*Arceuthobium spp.*) have been classified as one of the most economically important parasites in the coniferous forests of the western United States (Gill, 1935). Korstian and Long (1922) termed dwarf mistletoe as ". . . the most widely distributed and one of the most serious enemies of the western yellow pine . . ." Childs and Shea (1967) have estimated that 73 percent, or 29 million cubic feet, of the annual ponderosa pine (*Pinus ponderosa* Laws.) disease loss in Oregon and Washington can be attributed to dwarf mistletoe.

The purpose of this study was to develop aerial photographic techniques for detecting and classifying levels of infection of dwarf mistletoe (*Arceuthobium campylopodum* Engel. *f. campylopodum* Gill) in young-growth ponderosa pine. The ability to positively identify and classify the level of infection on ponderosa pine by dwarf mistletoe would be of benefit to the forest manager by giving him the information needed to initiate and evaluate dwarf mistletoe control procedures.

This study was limited to young-growth ponderosa pine for two reasons. First, it was believed that dwarf mistletoe has more far reaching economic importance in young-growth than in old-growth ponderosa pine. Once an infected pine reaches maturity, the damage in reduced growth and poor bole quality has occurred, and the only control procedure is to cut the tree. However, with young-growth pine, not only can the tree be cut with subsequent smaller loss of wood volume due to small tree size, but the tree can also be pruned in order to effect control.

The second reason for limiting the study to young ponderosa pine is that, over most of the pine region of Oregon, the heavily infected old-growth stands have been greatly modified by sanitation-salvage or other selective cutting (Roth, 1969). The heavily infected trees are the first to be removed because of the large evident brooms found in them. As logging of the overstory continues, the residual overstory will become healthier, and young-growth management will become more important.

Figure 1 shows an area of heavily infected old-growth ponderosa pine. Compare this to the area shown in Figure 2, which was heavily infected in 1953, but subsequently has been selectively logged four times.

It was hoped that if dwarf mistletoe could be identified and classified on aerial photography, the capacity to evaluate dwarf mistletoe could be incorporated in a general aerial survey of the ponderosa pine type to detect forest insects and diseases, obtain volume measurements, revise maps, etc. The mode of this survey might be either by satellite or aircraft.

Figure 1. Old-growth ponderosa pine heavily infected with dwarf mistletoe.

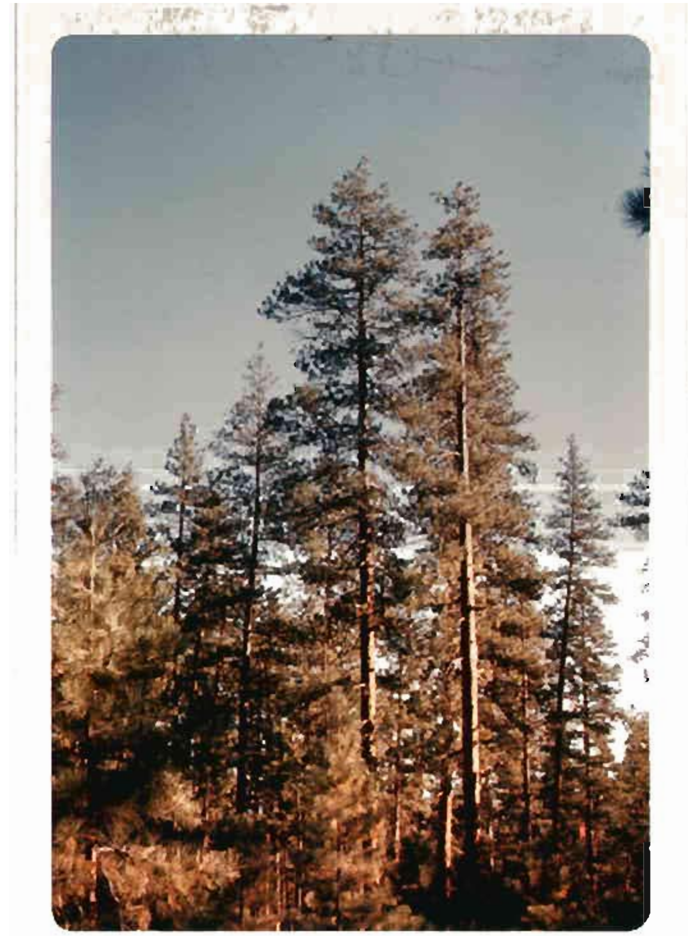


Figure 2. Old-growth ponderosa pine after several selective harvests.

LITERATURE REVIEW

Photography

The use of color and color infrared film is a relatively recent development. In his forward to the Manual of Color Aerial Photography, Swanson (1968) sketched the history of color aerial photography.

> Before World War II many individuals and organizations . . . tried to obtain acceptable color aerial photography; they met with little success. In the face of these discouragements, interest in the development of the techniques for using color in aerial photography was almost nonexistent.
>
> During the latter part of the fifties, however, with the improvement of aerial cameras and film, there was again awakened interest in developing the use of color aerial photography. New wide-angle-lens cameras with color-corrected lenses were developed. New and faster color emulsions were coated on stable base materials. Processing equipment and chemicals for the developing of the new color emulsions were improved and thus the processing of color materials became more reliable.

With these developments, the use of color and color infrared films for disease detection became established. Manzer and Cooper (1967) found that Ektachrome Infrared Aero film recorded potato blight before visible symptoms were evident. They also found that color infrared film was more sensitive to exposure, light quality, and to the angle of incidence of the light than other forms of film. Meyer and Calpouzos (1968) used Ektachrome Infrared Aero film to detect sugar beet leaf spot. They found that, "The progress of the disease was clearly discernible--four levels of infection intensity were discriminated on the photographs." Norman and Fritz (1965) reported that the Florida Department of Agriculture had successfully used Ektachrome Infrared Aero film for the inspection of citrus trees to ascertain whether they are healthy or diseased. Meyer and French (1967) were able to use Ektachrome Infrared Aero film to detect Dutch elm disease and oak wilt. Wert, Miller, and Larsh (1969) found that Anscochrome D/200 could be used to detect air pollution damage to ponderosa and Jeffrey pines.

In the area of aerial evaluation of insect damage, both color and color infrared film have found wide acceptance. Heller, Aldrich, and Bailey (1959) found that Ektachrome Aero film was preferred over panchromatic film for the detection of southern pine beetle. Ciesla, Bell and Curlin (1967), however, found that Ektachrome Infrared Aero film was better than Anscochrome D/200 for detection of the southern pine beetle, because the Ektachrome Infrared Aero film penetrated haze better. Wear, Pope, and Lauterbach (1964) also found that Ektachrome Aero film was better than panchromatic film in the detection of Douglas-fir beetle. This information was subsequently used by Wert and Roeltgering (1968) in a survey of a Douglas-fir beetle epidemic in Northern California. Heller, Lowe, Aldrich, and Weber (1967) found that Anscochrome color film was able to record several forms of balsam woolly aphid damage. Heller (1968) also has found both Anscochrome D/200 and Kodak Ektachrome

Infrared Aero films to be equally effective at indicating visible damage in ponderosa pine caused by bark beetle attack. Previsual detection, however, was not possible.

Limited work has been done in the area of detecting dwarf mistletoe infestations from aerial photography. Meyer and French (1966) used black and white photography to measure the rate of spread of dwarf mistletoe in black spruce forests of Minnesota. Meyer and French (1967) later found that Kodak Ektachrome Infrared film was capable of recording lower levels of dwarf mistletoe infection in black spruce than were detectable by black and white photography. It was found that black and white photography enabled detection only in areas where the trees had been killed, leaving holes in the forest canopy. Ektachrome Infrared Aero film, however, displayed not only differences between healthy and dead trees, but also showed live infected trees. Optimum scale was found to be between 1/6000 to 1/8000.

Baranyay (1968), reviewing his work in detecting dwarf mistletoe of lodgepole pine, reported that preliminary ground photography indicated that color film could be used to detect coloration differences between healthy and diseased trees. Tonal differences were also noted on black and white infrared film, but nothing was evident on plain black and white film. Using these results as a basis, numerous film and scale combinations were tried in the next four years (1962-1965). Most of the photography was of poor quality due to numerous contractual problems. The photography obtained in 1965, however, did have the best, if not perfect, results. The 1965 photography was flown at 6 and 7 p.m. on September twelfth. Both vertical and oblique photography was taken. The oblique photography was tiped 15 degrees from the vertical, and faced north. Two Vinten 70 mm cameras with 105 mm lenses were used. The films tested were Tri X Pan, High Speed Infrared, Ektachrome Aero, and Ektachrome Infrared Aero films. Scales were 1/15,840, 1/7,920, and 1/2,400. He found that:

1. The evaluation of Ektachrome Infrared film was impossible due to underexposure. This is the most suitable film to detect visible colour variations, consequently the most promising for dwarf mistletoe detection.
2. Aerial photography [Tri X Pan and High Speed Infrared] failed to illustrate adequate shade difference between healthy and infected patches of trees. The dark discolouration experienced during the preliminary work could be shade effect due to topographical changes.
3. High dwarf mistletoe hazard areas can be detected on aerial photographs by stand structure anomalies. For this purpose the 1" to 660' (1:7,920) scale is more suitable than smaller scales.
4. Large scale 1" to 200' [1/2400] Ektachrome photography is suitable to detect heavily infected trees with dying, discoloured branches, and witch's brooms. It was impossible to separate trees without foliage discolouration within various infection classes. Oblique photography gave better results than vertical.

In another unpublished study, Wear and Bynum (1969) tried Ektachrome Infrared Aero film for detecting dwarf mistletoe in mature ponderosa pine. Their study area was north of Lava Butte in Central Oregon. Scales obtained were 1/4,000 and 1/1,000. Their findings were inconclusive because too much image motion caused poor resolution in the pictures. Excessive image motion was the result of slow cycling time and shutter speeds.

Dwarf Mistletoe

Dwarf mistletoe is a parasite that absorbs water, minerals and other nutrients from its host (Hawksworth, 1961). There are several characteristics of dwarf mistletoe and its resultant effects upon the host that could be useful in detecting it from aerial photography. First, from personal observations, it has been found that the visible mistletoe plant has a more yellowish to yellowish brown color than does the foliage of ponderosa pine (Figure 3). It is therefore possible that dwarf mistletoe plants could be detected from large scale color and color infrared aerial photography.

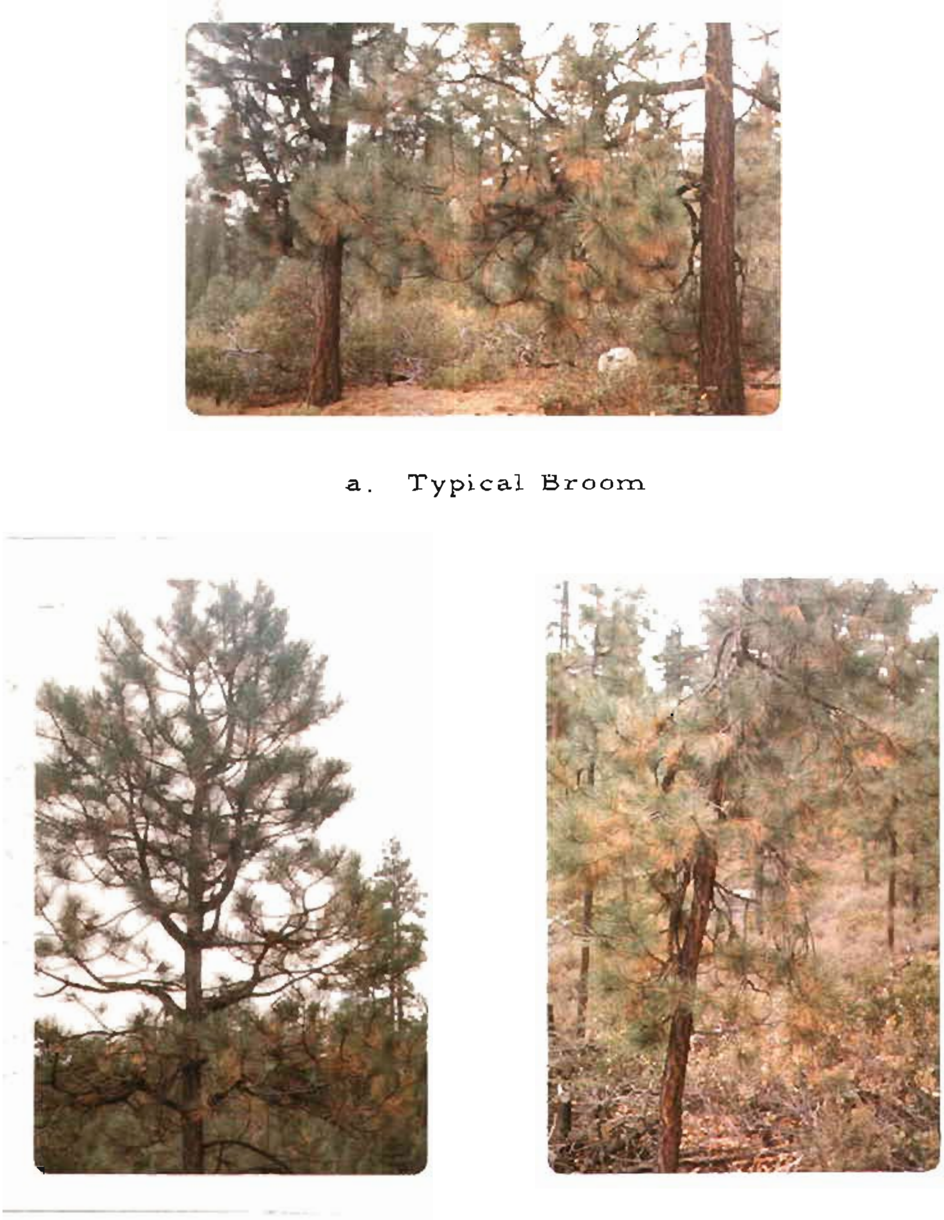
Second, Koristan and Long (1922) reported that dwarf mistletoe infected trees often have shorter needles, and fewer needles per branch than healthy trees (Figure 4). Also, needle color was often lighter. It is therefore possible that this difference in crown color and density also could be detected on color and/or color infrared photography.

Finally, dwarf mistletoe infections often cause witch's brooms, which might be evident either from looking at the sides of the trees, or at the shadows of the trees. In this case, color and color infrared

Figure 3. Dwarf mistletoe plant.

Figure 4. Short, tufted, chlorotic needles of a heavily infected ponderosa pine.

photography should have no apparent advantage over black and white photography. Hawksworth (1961) found that *Arceuthobium vaginatum f. cryptopodum* caused three forms of brooming. From personal observations, these forms are also caused by *Arceuthobium campylopodum f. campylopodum*. Figure 5a illustrates the type of brooming that Hawksworth called "typical brooms," which are approximately spherical in shape. Figure 5b is an example of Hawksworth's "volunteer leader brooms," caused by the tendency of the branches to grow vertically up. Finally, Figure 5c shows his "weeping brooms," which grow vertically down.



a. Typical Broom

b. Volunteer Leader Broom

c. Weeping Broom

Figure 5. Types of brooms found in ponderosa pine.

METHODS

Photographic

Films and Filters

The films used were Kodak Ektachrome Infrared Aero film, type 8443, and Kodak Ektachrome Aero film, type 8442. A glass yellow filter, equivalent to a Wratten number 12 filter, and an EF2200 filter were used with the Ektachrome Infrared Aero film (hereafter called "color infrared film") in accordance with manufacturer's suggestions. A Wratten HF-3 gelatin filter was used with the Kodak Ektachrome Aero film (hereafter called "color film").

The basic difference between these two films is that the color infrared film is sensitive to green, red, and infrared radiation while regular color film is sensitive to blue, green, and red radiation (Fritz, 1967). The use of a yellow filter with the color infrared film is to eliminate the blue portion of the spectrum for which the film is not sensitized. The EF2200 filter was supplied by the manufacturer to correct color balance. The HF-3 filter used with the color film is a standard aerial haze filter. An EF2400 filter was supplied by the manufacturer for color correction, but it was not used because it had been found by Wear (1969) not to improve results.

These two films were chosen because of their wide use in the field of aerial photographic interpretation. Color film[1] and color infrared film have been preferred over conventional black and white photography for interpretation work because the human eye can differentiate between ". . . an almost infinite number of different colors, but at most only a few hundred different shades of grey" (Strandberg, 1968). This ability greatly enhances photo interpretation effectiveness.

The film was purchased in 100 foot rolls. They were then cut into 16-foot lengths and hand rolled into cassettes at the civil engineering photo laboratory, Oregon State University.

Cameras

Two Hasselblad 500EL/70 cameras with Zeiss-Sonnar f. 4.0/ 150 mm lenses (Figure 6) were used in this project. This camera is electrically driven by means of an internal battery pack. The magazine holds enough 70 mm film, loaded in cassettes, to take 70 pictures. The lens is equipped with a between-the-lens diaphragm shutter and is capable of speeds up to 1/500 of a second. The camera can run both automatically, taking 70 pictures in 65 seconds, or it can be manually activated a picture at a time. Because of the use of film cassettes, the camera magazine can be loaded without a darkroom. The film is held for exposure by a pressure plate.

---

[1] Not limited just to Kodak Ektachrome Aero Film.

Figure 6. The two Hasselblad 500EL/70 mm cameras in their submount.

The cameras were fired by push button, which was part of an external battery pack. With this device, which was basically an electrical switch, the cameras could be triggered simultaneously for individual frames. However, when the cameras were set for automatic operation, they would fire independently. With the cameras set for taking individual pictures, they could be fired about every 1.5 seconds.

These cameras were chosen for this project because of their identical specifications, enabling simultaneous exposure of the two types of film. This reduces flying time in half, and made possible examination of exactly the same areas on both types of film, at the same scale and time of exposure. The cameras were available on loan from the School of Engineering, Oregon State University.

The cameras had the added advantage of small size compared to more conventional aerial cameras, which made them easier to mount side by side for simultaneous operation and small enough to get into single engined aircraft. These cameras used 70 mm film, which is cheaper to use than 9½ by 9½ inch film and is more convenient to use in the field (Carneggie and Reppert, 1969). The Hasselblad cameras were further desirable in having a faster shutter speed than most conventional aerial cameras. They are not as fast, however, as specially designed 70 mm aerial cameras with speeds up to 1/7000 of a second. The cycling time of the Hasselblad camera on automatic is faster than conventional cameras, but, again, it is slower than special 70 mm aerial cameras available for this project. However, the shutter speeds and the cycling times were fast enough with the Hasselblad system to get adequate stereo coverage at the desired scales.

Airplane

The project was flown by Mr. John Wear, research forester for the U. S. Forest Service Pacific Southwest Forest and Range Experiment Station, through arrangement with Mr. James Stewart, pathologist for the Region Six Office of the U. S. Forest Service. The U. S. Forest Service Cessna 180 airplane, which had been specially modified for aerial photography, was used. This plane was equipped with a NR1A main mount for aerial cameras.

Camera Mount

A submount was designed to hold the two Hasselblad cameras in the NR1A main mount of the airplane. Figure 6 shows the cameras in this submount. The submount was designed to hold the cameras firmly after "bore sighting." Bore sighting consisted of aligning the cameras so that they took the same picture when fired simultaneously. Because the cameras were single-lens reflexes, bore sighting was accomplished by adjusting the cameras until their view finders covered the same area at 1000 feet from the cameras.

The submount was designed from measurements obtained from Western Aerial Contractors, Inc. of Eugene, Oregon. No opportunity presented itself to try the submount in the main mount before the flight was made.

Flight Strip Determination

In June 1969, two days were spent at Pringle Falls Experimental Forest, Deschutes County, Oregon, establishing preliminary flight lines. The Pringle Falls Experimental Forest was chosen as the test area because of the extensive work done there by Dr. Lewis F. Roth, pathologist at Oregon State University, on dwarf mistletoe. Because of his work, maps, showing levels of infection, were available as aids in laying out the flight lines. Dr. Roth also spent one day in helping to choose the areas for flight lines.

Flight lines were chosen in order to offer as much variety as possible. The 2500 foot, north-south flight line (Figure 7) covered infected and uninfected young-growth ponderosa pine that had been thinned. It also covered infected and uninfected, unthinned ponderosa pine. The 1500 foot, east-west flight line covered released young-growth pine, both infected and uninfected, and a specially thinned area where uninfected trees were cut and infected trees were left. Trees on these two flight strips had heights that ranged from one to 75 feet.

Flight Strip Markers

Flight strip markers were established at Pringle Falls two days before the flight in order to insure that they would be in good condition for the photography. Figure 8 shows one of the markers. The markers were constructed on the ground at points allowing best visibility from the air. Each marker consisted of crossed three by ten foot pieces of white and orange poster paper. Three markers were placed on the 2500 foot long, north-south flight line, two at the ends and one in the middle. End markers only were placed on the 1500 foot long, east-west flight line.

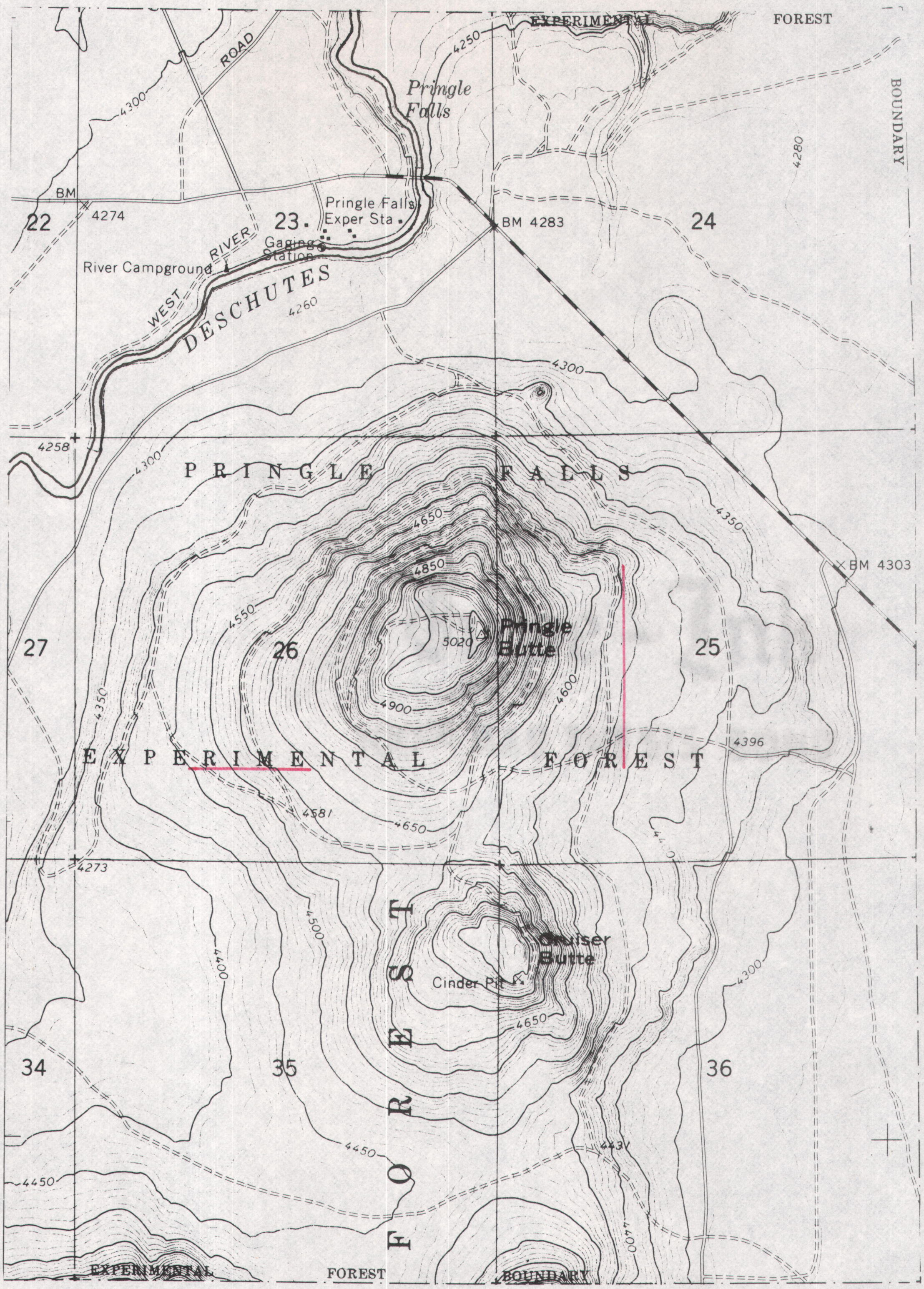


Figure 7. Pringle Falls Area. Red lines indicate flight lines.

Figure 8. Flight Strip Marker.

Flight Specifications

Flying specifications needed by the pilot are height and speed. The flying speed is limited by the specifications of the plane, and is a function of the amount of overlap desired and the desired scale. With the Cessna 180, minimum flying speed is about 60 miles per hour.

Flying height is a function of average ground elevation, desired scale, and the focal length of the camera. The only factor that is not fixed in the function for flying height is scale.

For this study, it was decided that scales of 1/2000 and 1/4000 would be used. Two scales were chosen in order to determine if scale was an important factor in interpretation of dwarf mistletoe infection. Obviously, if equal results could be obtained with both scales, it would be cheaper to use the 1/4000 scale photography because it would cover a larger area per photograph.

The 1/4000 scale was chosen because it was the same scale used by Wear and Bynum (1969) in their dwarf mistletoe project. It was desired to make this study as compatible as possible with their study. The 1/2000 scale was chosen because it was the largest scale possible with the equipment being used (see Appendix I for calculation of this limiting scale).

The focal length of the camera is known, and the average ground elevation was found from topographic maps of the area. With this information, flying heights for the various flight lines and scales were calculated (see Appendix II).

Speed of the plane was set at 70 miles per hour, which was considered a safe minimum speed. With this speed, the cycling time for the 1/2000 scale photography was established as one picture per second, and the cycling time for the 1/4000 scale photography was established as one picture every two seconds. The one picture per second rate required automatic operation of the cameras, therefore non-simultaneous firing of them. However, the one picture every two seconds rate used individual firings, and subsequently produced simultaneous firings of the cameras.

The Flight

On the morning of September 2, 1969, pilot John Wear, aerial photographer Pete Orr, and the author met at the U.S.F.S. hangar in

Troutdale, Oregon in preparation for the flight over Pringle Falls. After loading the necessary equipment, the group flew to Redmond, Oregon. Here, the rear seat was removed and the main mount installed. The submount with cameras was then tried in the main mount. It was found that two holes were needed in the submount in order to keep it from rotating in the main mount. Also, another bubble was needed at right angles to the first bubble in order to keep the cameras level. A sighting device would also have been beneficial.

The first problem was temporarily solved by taping the submount into the main mount. A level bubble borrowed from the airport mechanics helped to solve the second problem. These problems should, however, be solved if this mount is to be used again.

With the photographer in position in the back of the plane, the plane proceeded to Pringle Falls. The cameras had been loaded with film at Redmond. The shutter speed was set at 1/500 of a second for both cameras. Aperture openings were set at f/4.0 for the color infrared film and f/5.6 for the color film. These settings were based upon assumed A.S.A. values of 160 for the color film, and 140 for the color infrared film. A light meter reading was made of the forest area while proceeding to Pringle Falls, and the above aperture settings computed.

In order to insure adequate coverage, two photographic runs were made over each flight line and at each scale. This precaution was necessary because of the rough flying conditions over the Pringle Falls area. The time of photography was from 1:00 to 2:30 P.D.T.

The 1/2000 scale photography of both flight strips was taken on the first magazine loading. The magazines were then reloaded in the air in about five minutes and with no problems. During this time, another light reading was made and the aperture setting on the color infrared film was changed from f/4.0 to f/5.6. The color film remained the same. The 1/4000 scale photography was subsequently flown.

There was film left at the end of the scheduled photography, so it was decided to fly a 1/1000 scale flight strip over the north-south flight line until film ran out. Film ran out about half way along this flight strip.

The plane then proceeded back to Troutdale, with an intermediate stop at Redmond to dismantle the equipment and install the rear seat.

Processing and Transparency Evaluation

The film was carefully packed and mailed to Kieth Cole Photography, in Redwood City, California, for processing. The processed film was received five days later.

Examination of the transparencies showed the color film to be overexposed, but not badly enough to render the film worthless. The roll of color infrared film that had been exposed at f/4.0 was slightly overexposed while the roll that had been exposed at f/5.6 had excellent color quality. No satisfactory answer has been found as to why the color film was overexposed. Obviously, an assumed A.S.A. value of 160 was incorrect for this 100-foot roll of film.

Another problem was the lack of overlap between scales, and the presence of crab between individual photos. These two problems are more serious in 70 mm photography than in larger format photography because of the small area that each picture covers. It, therefore, does not take much drift or air roughness before crab and scale overlap become problems. The roughness of the air on the day of flight, and the slowness of the plane, necessitated by the slow cycling time of the Hasselblad cameras, produced some problems. However, due to the efforts of pilot and photographer, crab was not critical, and only the specially flown 1/1000 scale photography did not overlap with the 1/2000 scale photography.

Resolution of the transparencies seemed to be excellent, with no noticeable image motion even under four power magnification.

Interpretation

Ground Truth

After the developed transparencies were received, the rolls were cut into individual frames and arranged for stereo viewing. They were numbered and placed into acetate sleeves in order to protect them.

September 16, 17, and 18 were spent at Pringle Falls collecting "ground truth" information. Ground truth collection is the process of correlating what is seen on the photos to what actually exists on the ground.

Ground truth was collected in the following manner. Areas were selected on ground that had a variety of infection levels in them. These areas were then viewed under stereo, with the aid of a portable light table. A piece of frosted acetate was placed over one picture of the stereo pair, and individual trees were marked and numbered. These trees were then located on the ground and a verbal description of each was made on magnetic tape. This description included needle color and length, branching characteristics, amount of crown, and damage caused by factors other than dwarf mistletoe. Some of the trees were also photographed with 35 mm Kodak Ektachrome film.

Each tree was also classified, with respect to mistletoe severity, according to a system developed by Hawksworth and Lusher (1956) for merchantable ponderosa pine. In this system, trees were given a rating of zero to six. To get this rating, the tree crown was divided into thirds, and each third was given a zero if there was no infection, a one if there was light dwarf mistletoe infection, and a two if there was heavy dwarf mistletoe infection. The sum of the values for each third gave the rating for intensity of infection. This system was believed to be the best for measuring infection impact (Stewart, 1969), and it was used by Wear and Bynum (1969) in their study of dwarf mistletoe infection in old-growth ponderosa pine. Figure 9 shows examples of the seven infection levels.

Appendix III summarizes the number of trees in each class for each scale that were used in this study.

Interpretation Technique

Interpretation of the photographs was designed as a two phase process. The first phase consisted of an overall examination of the photos in order to determine criteria for classifying infected and non-infected trees. The second phase was to determine if these criteria could be effectively used by interpreters to classify trees as light, medium, heavy, and non-infected.[2]

The first phase was done by the author, because of his experience with the ground conditions.

The second phase was to statistically test the system in order

---

[2]Because of the believed difficulty of this project, the one to six classification system used in "ground truth" collection was combined to form the following classification system for interpretation work. Non-infected trees were the zero rated trees. Lightly infected trees were the one and two rated trees. Moderately infected trees were the three and four rated trees, and heavily infected trees were the five and six rated trees.

a. Zero

b. One

c. Two

d. Three

Figure 9. Examples of the seven infection levels used for ground truth collection.

e. Four

f. Five

g. Six

Figure 9. (Continued)

to determine if it could be used as a key for dwarf mistletoe classification. For this phase, three people were used as interpreters. In order to train the interpreters, an area on the photographs was designated for the specific use of training. After explaining to the interpreter the guide lines set by the proposed classification system, through use of oral, written and pictorial descriptions, the interpreter would classify the trees in this test area, using a two power stereoscope, as to levels of infection. The true classification of these trees was then shown to the interpreter so that he might improve upon his classifying ability.

After testing, the order of interpretation for the film types and scales of the other areas proceeded in the following manner:

1. Color photography, 1/4000 scale.
2. Color infrared photography, 1/4000 scale.
3. Color photography, 1/2000 scale.
4. Color infrared photography, 1/2000 scale.
5. Color photography, 1/1000 scale.
6. Color infrared photography, 1/1000 scale.

This procedure was designed in order to reduce the possibility of carrying over information gained from one type of film or scale to the other type of film or scales.

Statistical Techniques

Upon completion of interpretation, the percentage of trees correctly classified for each interpreter, film type, scale and classification were tabulated. The arcsine transformation was then performed on the proportions in order to change them into values which can be used in a four factor analysis of variance. This transformation was used by Heller (1968) in his study of ponderosa pine bark beetle detection. The arcsine transformation tends to spread the proportions near zero and one in order to increase their variance, but it does not correct for differences in cell size[3] (Snedecor and Cochran, 1967). For proportions based on cell sizes greater than 50, the transformation of:

$$\text{Angle} = \text{arcsine} \sqrt{\text{percentage}}$$

was used (Snedecor and Cochran, 1967). For proportions based on cell sizes of 50 or less, the transformation of:

$$\text{Angle} = \tfrac{1}{2}\left[\text{arcsine}\sqrt{\frac{x}{n+1}} + \text{arcsine}\sqrt{\frac{x+1}{n+1}}\right]$$

n = cell size

x = number of trees correctly identified in that cell

---

[3]Cell size was the number of trees with a particular infection classification for a certain scale, film type and interpreter. In the calculation of the percentage of interpretations that are correct, it represents the denominator, and is symbolized as "n" in Snedecor and Cochran (1967).

was used (Mosteller and Youtz, 1961). This transformation produces better results for cell sizes under 50 (Snedecor and Cochran, 1967).

The four factor analysis of variance was performed on the Oregon State University CDC 3300 computer, using the *ANOVA4 program of the statistical library.

RESULTS

Scale Determination

The actual scales of the flight strips were determined by comparing the dimensions of the flight strip markers on the photographs to their known ground dimensions. Table 1 summarizes the scales obtained for each flight line.

Table 1. Photography scales obtained in study. The "A" refers to flights made over the 2500 foot, north-south flight line, and the "B" to flights made over the 1500 foot, east-west flight line.

Flight Line	Scale
A	1/1320
A1	1/2025
A2	1/3670
B1	1/2050
B2	1/3520

Interpretation

During ground truth collection and literature review, three characteristics of dwarf mistletoe and its effects were noted as being a possible basis for a classification system. First, it was believed that if the dwarf mistletoe plant could be distinguished on the photos, it could be a very important classification characteristic. Second, the tendency of infected trees toward short, tufted, and chlorotic needles might be detected as color differences on the film. Finally, the presence and amount of brooming in the tree branches would be another indicator of dwarf mistletoe.

As the first step in interpretation, a careful examination of the photographs was made by the author in order to determine if these characteristics could be used in an aerial classification key. From this preliminary examination, no indication of the dwarf mistletoe plant was seen. Indications of the other two characteristics were noted, so the following classification key was developed.

1. Healthy tree -- good needle color and no brooming.
2. Lightly infected tree -- good needle color, brooming on lower 1/3 of crown.
3. Moderately infected tree -- needle color normal to possibly light. Brooming on lower 2/3 of tree and needles possibly tufted.
4. Heavily infected tree -- needle color light to possible normal. Whole tree deformed and needles tufted. Tree generally smaller with a smaller crown.

This classification key, the photos, templates, and instructions were sent to the Region 6 Office of the U. S. Forest Service in Portland, Oregon for interpretation. Interpretation was performed by four people who were experienced interpreters. One interpreter did not evaluate the color photography, so his results were not used in the statistical analysis.

Table 2 shows the percentage of correct classifications for each interpreter and scale.[4]

Table 2. Percentage of correct classifications for each interpreter and scale.

	Interpreter		
Scale	A	B	C
1/3670	50.0	25.3	19.5
1/2025	46.6	39.1	22.4
1/1320	27.9	41.4	33.6

These results are well below the arbitrary 80 percent level that was considered minimal for practical use of aerial photography for classification. Statistical analysis indicated no difference between scales, film types, interpreters, or tree classification (see Appendix IV for the ANOVA table).

Table 3 shows how well the interpreters were able to distinguish infected from non-infected trees.[5]

[4] Film types and tree classifications were combined for each interpreter and scale.

[5] Film types were combined for each interpreter and scale.

Table 3. Percentage of trees classified correctly as to infected or not infected for each interpreter and scale.

	Interpreter		
Scale	A	B	C
1/3670	60.3	40.8	43.7
1/2025	59.8	56.9	43.7
1/1320	50.7	72.2	70.5

A three factor analysis of variance indicated no difference between scales, film types, or interpreters (see Appendix V for the ANOVA table). The analysis of variance did show that scale was almost significant, and possibly another interpreter could show significance between scales. The original interpretation had four interpreters, but one of them failed to interpret the color film so his results have not been used in the analysis so far. However, because of the low significance of film type in all previous tests, the elimination of the color film data from the results of the other interpreters, and the addition of the fourth interpreter's results could prove interesting. Table 4 shows the percentages when this is done. Rearrangement of the data in this manner pushes sound statistical techniques and was, therefore, not statistically analyzed. However, the table does indicate almost 70 percent success at the largest scale, which is much better than for either of the other two scales.

Table 4. Percentage of trees classified correctly as to infected or not infected for each interpreter and scale using color infrared film.

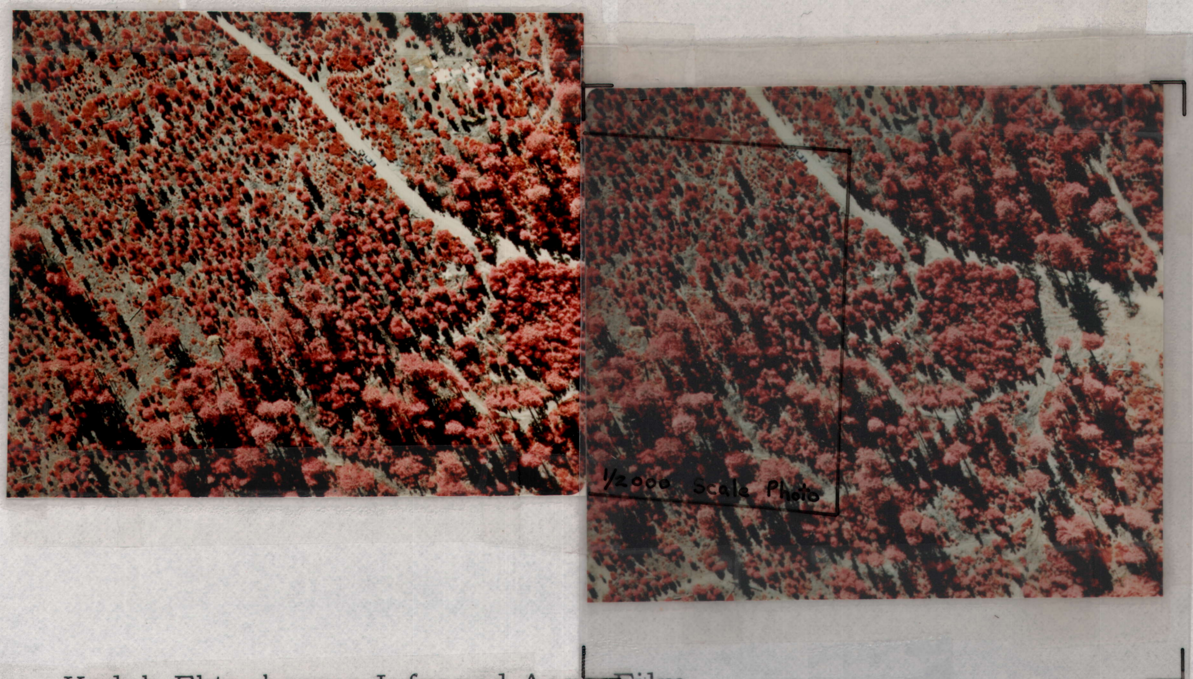
	Interpreter				
Scale	A	B	C	D	Average
1/3670	59.8	41.4	48.3	46.0	48.9
1/2025	56.0	56.3	44.8	54.0	52.8
1/1320	67.8	71.0	65.7	69.4	68.5

Examples of Photography

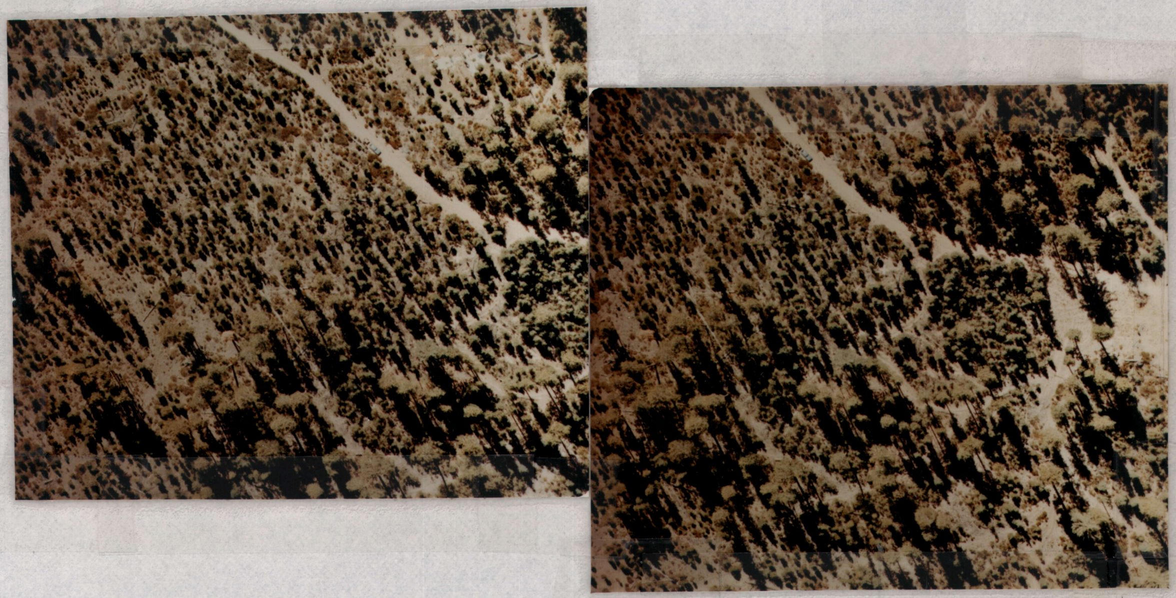
The photographs in Figures 10, 11, and 12 are examples from the areas studied in this project. The acetate templates mark the trees that were used. The tables in Appendix VI give the individual classifications of each tree. Figure 10 is an example of the 1/3670 scale photography from the north-south flight line. The area marked on the template corresponds to the 1/2025 scale photographs found in Figure 11. Table 1 in Appendix VI is the key for Figure 11. Figure 12 is an example of the 1/1320 scale photography flown over the north-south flight line. Unfortunately, this photography did not overlap with the 1/2025 scale photography. Table 2 in Appendix VI is the key for this 1/1320 scale photography.

As an example of how the trees look on the ground, the zero, one, two, three, four, and six rated trees in Figure 9 were taken from the middle picture of Figure 12. The corresponding tree numbers are

16, 18, 20, 8, 2 and 12 respectively. The tree rated number five was tree number 11 in the right photograph of Figure 11.

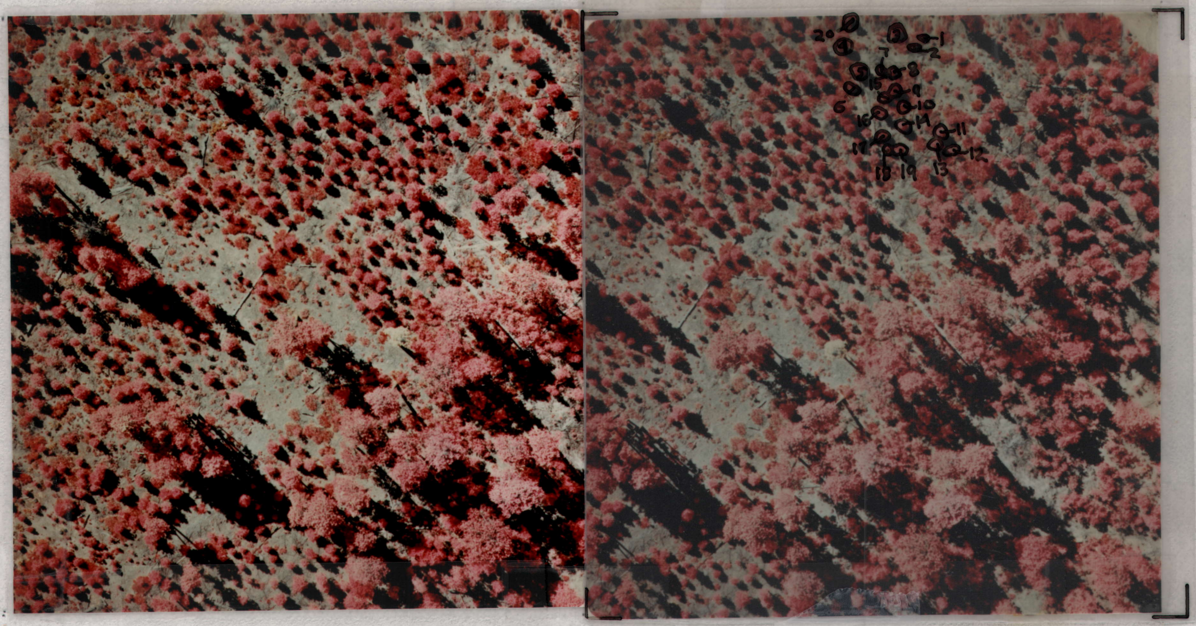


a. Kodak Ektachrome Infrared Aero Film

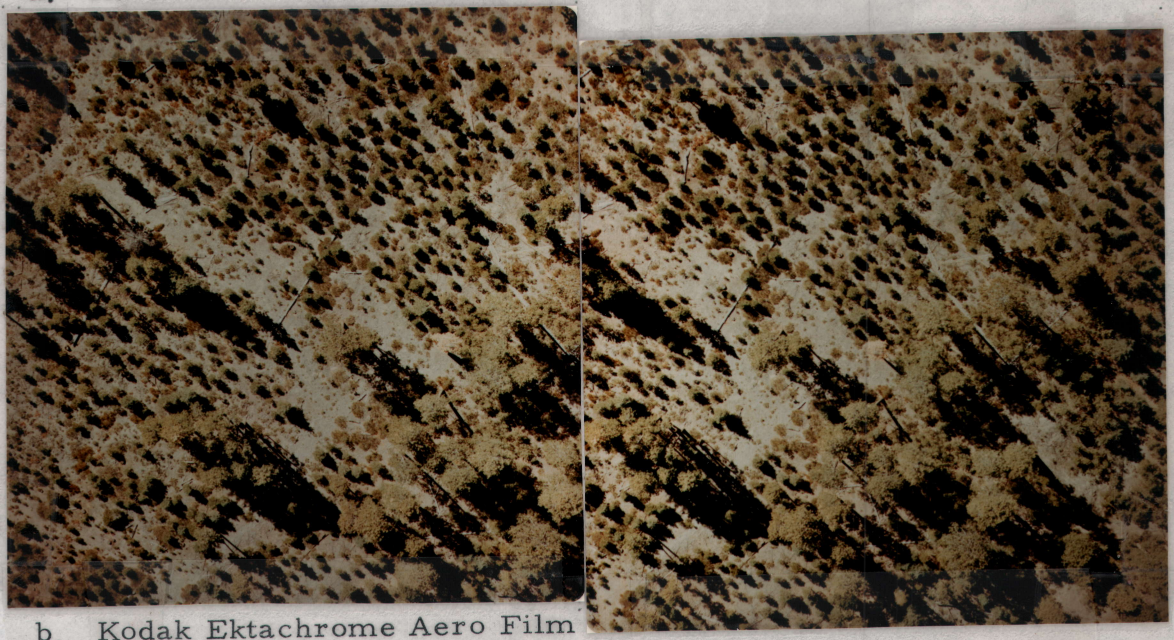


b. Kodak Ektachrome Aero Film

Figure 10. Example of the 1/3670 scale photography.



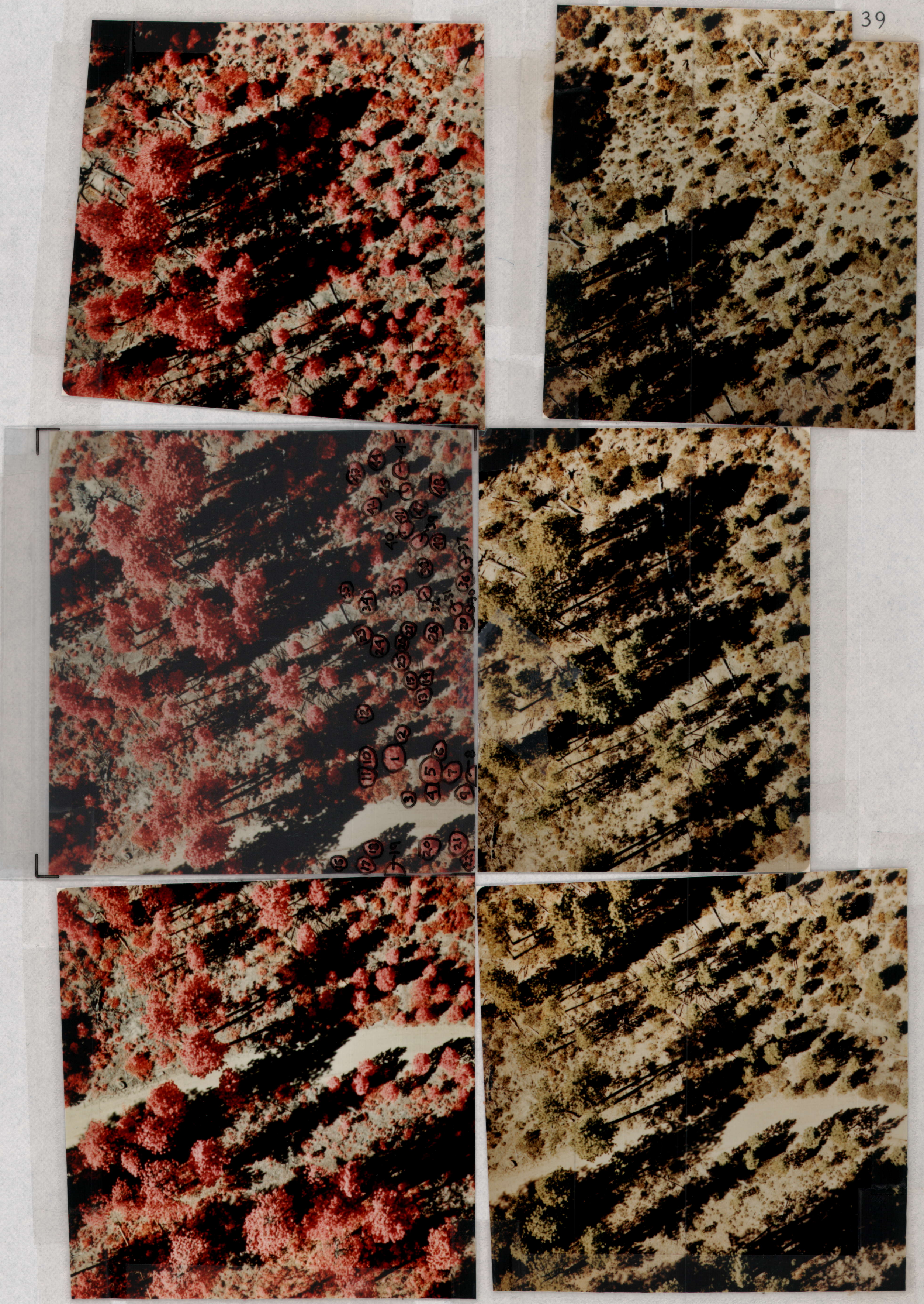
a. Kodak Ektachrome Infrared Aero Film



b. Kodak Ektachrome Aero Film

Figure 11. Example of the 1/2025 scale photography.

Figure 12. Example of the 1/1320 scale photography. Top photography, Kodak Ektachrome Infrared Aero Film. Bottom photography, Kodak Ektachrome Aero Film.



DISCUSSION

The results of this study are not encouraging. The three factors that were believed usable for aerial detection proved to be inadequate for detection from the photographs. Distinguishing the dwarf mistletoe plant from the foliage of the tree was not possible even though the photography was taken at the time of year of maximum plant development. This inability to distinguish the dwarf mistletoe plant from its host is probably due to the seven year period of time between infection of a shoot and maximum aerial development (Roth, 1969). While the infection starts in the axil of the fascicle near the branch tip (Roth, 1959), it grows very little laterally. By the time it reaches conspicuous size, the plant has come to lie well within the interior of the crown and, therefore, well hidden from the camera.

Examination of the photographs did indicate some lighter colored trees caused by differences in needle color, length and tuftedness. This characteristic, however, was limited to the very heavily infected trees. During ground truth collection, it was also found that needle color, length and tuftedness were not characteristics common to all heavily infected trees. Some trees that were rated heavily infected had very healthy looking needles. This would seem to indicate a flaw in the classification system used in ground truth collection. It has been learned that the best time of year to get maximum color differences in second growth ponderosa pine is in the spring (Roth, 1969). In this study, color differences were more easily noted on the color infrared film. However, overexposure of the color film could have masked the color differences on that film type.

Brooming was found to be the most easily identified and common indicator of dwarf mistletoe. The detection of brooms, however, also had problems. In order to detect brooms, it was necessary to see the tree's shadow. This was necessitated because of the use of vertical photography which limited the amount of crown seen from the air. The use of shadows was limited by how much of the shadow could be seen as an undeformed shape. Shrubs and other material on the ground, as well as other trees and their shadows, often obstructed the shadow of interest. Shadow characteristics were more easily seen on the color film. Shadows on the color infrared film were darker and had less detail. One thing that could possibly help broom detection would be to tip the cameras from the vertical in order to get a low oblique. This was suggested by John Wear (1969). A low oblique would show more of the crowns, and could, therefore, increase detection of brooms. However, it should be remembered that low obliques could hide short trees.

CONCLUSIONS

This study has indicated the difficulty of detecting dwarf mistletoe infection in young-growth ponderosa pine. The results would indicate that trying to classify trees as to levels of infection is improbable. It is possible, however, that 1/1000 scale color or color infrared, low oblique, photography, taken in the spring, could enable distinction of infected from non-infected trees. Only further research can answer this question.

BIBLIOGRAPHY

Baranyay, J. A. 1968. Experiment with aerial colour photography for detecting dwarf mistletoe infected lodgepole pine stands in the Alberta-Territories region. Unpublished, internal report A-12 of Forest Research Laboratory in Calgary, Alberta.

Carneggie, David M., Jack N. Reppert. 1969. Large scale 70-mm aerial color photography. Photogrammetric Engineering 35: 249-257.

Childs, T. W., K. R. Shea. 1967. Annual losses from disease in pacific northwest forests. (U. S. Forest Service Resource Bulletin PNW-20)

Ciesla, W. M., J. B. Bell, Jr., J. W. Curlin. 1967. Color photos and the southern pine beetle. Photogrammetric Engineering 33:883-888.

Fritz, Norman L. 1967. Optimum methods for using infrared-sensitive color film. A paper presented in abriged form at the 33rd annual meeting of the American Society of Photogrammetry in Washington, D. C.

Gill, L. S. 1935. Arceuthobium in the United States. The Connecticut Academy of Arts and Sciences, Transactions 32:111-245.

Hawksworth, Frank G. 1961. Dwarfmistletoe of ponderosa pine in the Southwest. 112 p. (U. S. Department of Agriculture Technical Bulletin 1246).

Hawksworth, Frank G. and Arthur A. Lusher. 1956. Dwarfmistletoe survey and control on the Mescalero-Apache reservation, New Mexico. Journal of Forestry 54:384-390.

Heller, R. C. 1968. Previsual detection of ponderosa pine trees dying from bark beetle attack. Unpublished paper from the proceedings of the 5th symposium on remote sensing of the environment, University of Michigan, Ann Arbor.

Heller, R. C., R. C. Aldrich, and W. F. Bailey. 1959. An evaluation of aerial photography for detecting southern pine beetle damage. Photogrammetric Engineering 25:595-606.

Heller, R. C., J. H. Lowe, Jr., R. C. Aldrich, and F. P. Weber. 1967. A test with large scale aerial photographs to sample balsam woolly aphid damage in the Northeast. Journal of Forestry 65:10-18.

Korstian, Clarence F. and W. H. Long. 1922. The western yellow pine mistletoe: effect on growth and suggestions for control. 35 p. (U. S. Department of Agriculture Bulletin 1112).

Manzer, Franklin E., George R. Cooper. 1967. Aerial photographic methods of potato disease detection. 14 p. (University of Maine. Maine Agricultural Experiment Station Bulletin 646).

Meyer, Dr. Merle P., Dr. Lucas Calpouzos. 1968. Detection of crop diseases. Photogrammetric Engineering 34:554-557.

Meyer, Prof. Merle P., Prof. David W. French. 1966. Forest disease spread. Photogrammetric Engineering 32:812-814.

Meyer, Prof. Merle P., Prof. David W. French. 1967. Detection of diseased trees. Photogrammetric Engineering 33:1035-1040.

Mosteller, Frederick and Cleo Youtz. 1961. Tables of the Freeman-Tukey transformations for the binomial and Poisson distributions. Biometrika 48:433-440.

Norman, Gerald G., Norman L. Fritz. 1965. Infrared photography as an indicator of disease and decline in citrus trees. Florida State Horticultural Society Proceedings 78:59-63.

Roth, Lewis F. 1959. Natural emplacement of dwarfmistletoe seed on ponderosa pine. Forest Science 5:365-369.

Roth, Lewis F. 1969. Professor, Oregon State University, Department of Botany. Personal communications.

Snedecor, George W. and William G. Cochran. 1967. Statistical methods. Sixth edition. Ames, Iowa State University Press. 593 p.

Stewart, James L. 1969. Pathologists, U. S. Forest Service, Region Six Offices. Personal communications.

Strandberg, Carl H. 1968. The sensation of color. In: Manual of color aerial photography, ed. by John T. Smith, Jr. Falls Church, American Society of Photogrammetry. p. 3-11.

Swanson, Lawrence W. 1968. Forward. In: Manual of color aerial photography, ed. by John T. Smith, Jr. Falls Church, American Society of Photogrammetry. p. v.

Wear, John F. 1969. Research Forester, U. S. Forest Service, Pacific Southwest Forest and Range Experiment Station. Personal communications.

Wear, J. F., R. B. Pope, and P. G. Lauterbach. 1964. Estimating beetle-killed Douglas-fir by aerial photo and field plots. Journal of Forestry 62:309-315.

Wear, John F. and H. H. Bynum/ 1969. Unpublished study on detecting dwarfmistletoe on mature ponderosa pine with color infrared photography. U. S. Forest Service, Region Six Offices.

Wert, Steven L., Paul R. Miller, and Robert N. Larsh. 1969. Detecting and evaluating air pollution effects to forest trees with large-scale color aerial photography. Unpublished paper presented before the ASP-ACSM fall convention, Portland, Oregon.

Wert, Steven L., Bruce Roettgering. 1968. Douglas-fir beetle survey with color photos. Photogrammetric Engineering 34:1234-1248.

APPENDICES

APPENDIX I

Determination of Limiting Scale

The percent of overlap between photographs was set at 80 percent in order to reduce height parallax in the large scale photographs. Too much parallax would hinder interpretation because of the inability of some people to "fuse" a stereo pair with too much parallax.

The minimum safe speed of the aircraft is 70 miles per hour, or 100 feet per second. The fastest cycling time is one picture per second with the Hasselblad cameras set for automatic action. The size of the picture from 70 mm film is 2.25 inches square.

(100%-80%)(2.25 inches)	=	.55 inches of "new" area per picture.
(100'/sec.)/(1 pic./sec.)	=	100 feet/picture or 100 feet of "new" ground area per picture.
.55 inches on photograph	=	100 feet on the ground
1 inch	=	181.81 feet
1 foot	=	2181.8 feet

This can be rounded off to 1/2000.

APPENDIX II

Table 1. Calculated flying heights for different scales and flight lines.

Flight Line	Scale	Flying Height (H)
North-South	1/2000	5477'
	1/4000	6462'
East-West	1/2000	5574'
	1/4000	6558'

Flying Height Calculation

Average ground elevations taken from topographic maps were:

North-south flight line = 4492 feet

East-west flight line = 4590 feet

From photogrammetry:

Scale = f/(H+h)

f = Focal length of camera.

h = Elevation of ground.

H = Flying height.

Example: East-west flight, 1/4000 scale.

H = f/Scale +h

H = 5.9055"/(1/4000) + 4590 feet

H = 1968.5 feet + 4590 feet

H = 6558 feet

APPENDIX III

Table 1. Number of trees in each classification for each scale.

	Classification						
Scale	0	1	2	3	4	5	6
1/4000	53	2	4	11	14	10	11
1/2000	62	2	4	11	14	10	11
1/1000	37	7	7	23	14	6	4

APPENDIX IV

Four Factor Analysis of Variance

A = Film

B = Interpreter

C = Scale

D = Classification

Source	D. F.	S. S.	M. S.	f[a]
A	1	53.907	53.907	.126 N. S.
B	2	792.245	396.122	.925 N. S.
C	2	17.829	8.914	.021 N. S.
D	3	3264.870	1088.290	2.541 N. S.
AxB	2	148.505	74.253	.173 N. S.
AxC	2	471.312	235.656	.550 N. S.
AxD	3	256.232	85.411	.199 N. S.
BxC	4	727.173	181.793	.424 N. S.
BxD	6	4738.711	789.785	1.844 N. S.
CxD	6	999.877	166.646	.389 N. S.
AxBxC	4	149.797	37.449	
AxBxD	6	487.379	81.230	
AxCxD	6	753.183	125.531	
BxCxD	12	1464.047	122.004	
AxBxCxD	12	745.314	62.120	
Total	71	15070.381		

[a]The three and four factor interactions were combined to give an Error M. S. of 428.323 with 40 D. F.

APPENDIX V

Three Factor Analysis of Variance

A = Interpreter

B = Scale

C = Film

Source	D. F.	S. S.	M. S.	f[a]
A	2	11.177	5.588	.188 N.S.
B	2	280.204	140.102	4.704 N.S.
C	1	.087	.087	.003 N.S.
AxB	4	575.694	143.923	4.833 N.S.
AxC	2	9.593	4.796	.161 N.S.
BxC	2	6.744	3.372	.113 N.S.
AxBxC	4	119.123	29.781	
Total	17	1002.621		

[a] The three factor interaction was used as Error.

APPENDIX VI

H = Healthy L = Light M = Medium Hv = Heavy

Table 1. Key for the trees in Figure 11.

Number	Level of Infection	Number	Level of Infection
1	H	11	Hv
2	M	12	Hv
3	H	13	Hv
4	M	14	M
5	M	15	H
6	L	16	H
7	H	17	M
8	L	18	M
9	M	19	M
10	H	20	Hv

APPENDIX VI (Continued)

Table 2. Key for the trees in Figure 12.

Number	Level of Infection	Number	Level of Infection
1	Hv	26	M
2	M	27	L
3	M	28	L
4	M	29	Hv
5	M	30	M
6	M	31	Hv
7	M	32	Hv
8	M	33	M
9	M	34	L
10	Hv	35	L
11	M	36	M
12	Hv	37	Hv
13	M	38	Hv
14	M	39	Hv
15	M	40	M
16	H	41	M
17	H	42	M
18	L	43	M
19	H	44	M
20	L	45	M
21	H	46	M
22	H	47	Hv
23	H	48	M
24	M	49	M
25	M		