DETECTION OF MOUNTAIN PINE BARK BEETLE DAMAGE BY REMOTE SENSING WITH COLOR FILMS

by

DENNIS DALE KUHR

B.S., Dana College, 1972

A MASTER'S REPORT

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Crop Protection Curriculum

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1981

Approved by:

Hugh E. Thompson
Major Professor

TABLE OF CONTENTS

INTRODUCTION

The forest manager needs to monitor and record the status of the forest resource for changes which have occurred, and those changes that are likely to take place. Knowledge about forest insect damage may affect decisions on the amount of allowable cut, plans for the orderly harvest of timber, salvage operations of dead or damaged material, and the control of insect outbreaks.

Because timber mortality is typically scattered in erratic fashion over vast and often inaccessible areas, monitoring insect damage is usually a difficult and expensive task. Often, high costs can be avoided by using aerial photography, which covers ground more quickly and cheaply than fieldwork, yet provides a permanent record of damage.

Information gained from aerial photography includes detecting, locating, estimating damage, and estimating the capacity for future damage.

This report concentrates on the use of normal color films in aerial photogrammetry primarily because it has been the most used and reliable method to detect mountain pine beetle damage (Wear, Pope, and Orr, 1966).

Chapter 1

HISTORY AND USES OF REMOTE SENSING IN FORESTRY

The term remote sensing, defined by Parker (1962) as the collection of data about objects which are not in contact with the collecting device, was first used in the United States about 1958. In forestry practice, the term is restricted to the collection of information from a space-platform such as fixed-wing aircraft, helicopter, or satellite (Howard, 1976).

In 1887, a balloon was used to take aerial photographs of forests containing beech, spruce, and pine and the technique was advocated in 1919 to inventory our national forests. The value of aerial photography for forest sketch-mapping was established by the beginning of World War II using black-and-white panchromatic film with a minus-blue filter which minimized light scattering at shorter wavelengths. Historically, lenses with a focal length of 152 mm and 205 mm have been used widely for forest photo-interpretation, and currently universally used with a 23 cm format. Occasionally, lenses of 254 mm or 305 mm focal length are preferred.

Remote sensing in forestry involves a wide variety of equipment and techniques, including multi-band or single-camera photography, and infrared black-and-white, infrared color, normal color, and panchromatic black-and-white film. Other methods involve optical mechanical scanners such as our Landsat and Earth Resources Technological Satellite; these utilize thermal infrared imagery and Side-Looking Radar (SLAR/SLR) measuring the microwave part of the electromagnetic spectrum.

Because in many cases the insects have left the tree by the time damage becomes visible from the air, aerial photography was not developed to detect initial damage (previsual damage) or evaluate size of insect populations. Aerial photos often are used to estimate tree mortality, determine damage locations, detect damage trends from insect species such as the gypsy moth, spruce budworm, tussock moth, and southern pine beetle, and determine the need for or results of insect control measures.

Chapter 2

THE MOUNTAIN PINE BARK BEETLE

The mountain pine bark beetle, Dendroctonus ponderosae, Hopkins, has plagued the Front Range of Colorado for the past several years. Several thousand pines are killed each year by this bark beetle and the fungi it carries; and the epidemic shows no signs of abating.

The beetle's range as described by McCambridge and Trostle (1972) covers a wide area from the Pacific Coast eastward through the Black Hills of South Dakota and from northern British Columbia to northwestern Mexico. Its habitat varies in altitude from 2,000 feet in the northern latitudes to 11,000 feet in southern California.

In Colorado the insect attacks mainly ponderosa and lodgepole pines; but western white, sugar, whitelark, limber, pinyon, bristlecone, and foxtail pines are additional known hosts. Although broods are not produced in spruce and fir, they may be occasionally attacked and killed during outbreaks. Beetle attack alone may kill the host tree, but these beetles frequently carry a blue-stain fungus belonging to the genus Ceratostomella which also contributes to the death of trees. Sapwood of infected trees turns blue as a result of a chemical reaction between the wood tissue and the toxin produced by the fungus. Salvaged wood may be less valuable because of this blue stain. Epidemics occur every 20 to 40 years within a specified pine forest and may last six to eight years.

Because of the wide distribution of the beetle, there are wide variations in its life history. Normally there is one beetle generation annually in most of its range. Two and a partial third generation may develop in warmer climates below an altitude of 7,000 feet. In the coldest areas of its range the life cycle may require two years.

Adult female beetles attack new trees from June to September by boring through the bark to the cambium area, then tunnelling upwards along the inner bark, scoring the sapwood slightly as they form galleries from 12 to 30 inches long. The male beetle enters the partially completed gallery and mates with the female. The female continues to bore upward, laying eggs in individual niches along each side of the gallery. After about two weeks, a yellowish-white larva hatches from each egg. The larvae, which have four instars, feed on the inner bark (phloem) in individual tunnels which generally extend at right angles to the egg galleries. When the larvae are fully developed they excavate shallow oval cells, where they pupate and later change into adults. Mature beetles are about 5 mm long. They emerge either from these cells or from interconnecting cavities by boring through the outer bark surface and fly to attack new trees to begin another generation.

While the beetles have been developing in the bark of the dying pine tree, the fungus has been growing, producing vegetative growth and asexual spores in the galleries of the beetles. When the adult beetle leaves the tree in which it developed, it may be carrying spores of this fungus and will introduce them into the new host it successfully attacks. This starts a new infection.

Beetle attacks are concentrated from near ground level up to where the main trunk is reduced to a four inch diameter. Some older trees may be attacked on the larger limbs. The first evidence of attack are the presence of pitch tubes on the trunk marking entrances and boring dust around the base of the tree or in bark crevices. Two types of pitch tubes exist: the dry hit, small and brownish from the low quantity of pitch with the boring dust and usually indicates a successful attack by a female beetle; and the pitchout, larger and mostly creamy-white in color. The second type indicates a higher pitch content and in this case the tree may remain healthy by repelling the insect from the abundant flow of pitch. All pitch tubes are from one-quarter to more than one inch in diameter.

Within a few weeks after a successful attack, the blue stain in the wood caused by the toxin produced by one of the fungi in the genus Ceratostomella, carried by the beetles appears just under the bark. The tunnelling of the beetle in conjunction with the toxic effect of the fungi cause the death of the trees (Roe and Amman, 1970). The foliage of infested trees begins to fade from green to yellow to reddish-brown, usually in the spring following an attack the previous summer. It is this color change which is observed in aerial color photographs. A sufficient number of beetles from each infested tree can successfully attack three to five new trees (Pollock and Pollock, 1977).

Infestations normally occur in trees over six inches in diameter at breast height; however, smaller trees may be killed under heavy infestations (Pollock and Pollock, 1977).

During an epidemic, tree mortality increases from about 0.5 trees/acre initially, to a peak of over 25 trees/acre in three or four years, and then declines to less than 0.5 trees/acre during the next two or three years. The losses range from 60 percent of the 12-inch class to about 90 percent of the trees which are eighteen inches or larger. Total stand mortality may average 33 percent.

During the 1960's, in the Pacific Northwest, outbreaks of 80,000 acres occurred annually. In 1973 an estimated 440,000 trees were killed in the Black Hills of South Dakota.

Outbreaks of mountain pine beetle rarely develop suddenly. Starting first as scattered small groups, successive beetle generations kill neighboring trees, thus enlarging the patches of dead trees over several years until as many as 1000 adjacent trees are killed per year (Sartwell and Stevens, 1975).

Control techniques may involve the felling, burning, and salvaging of infested trees, thinning to reduce stand density and promote growth, and the use of pesticides such as lindane, ethylene dibromide, and cacodylic acid.

Chapter 3

AERIAL PHOTOGRAPHY

Aerial photography is catagorized as vertical or oblique. Vertical photography is taken with the optical axis of the lens in a vertical or near vertical position at the time of the exposure, and is the method normally used when remote sensing for mountain pine beetle damage. When the optical axis of the lens is intentionally tilted slightly horizontal with the ground surface it is called oblique photography.

The two types of scales common to aerial photography are scale fraction and representative fraction. Scale fraction uses linear units in the photograph to represent other linear units on the ground, i.e. S = 6'/" and is read "scale equals six feet per inch".

Representative fraction scales express the ratio between the number of units in the photograph and the number of the same units on the ground, i.e. 1:7000 means 1 inch on the photograph represents 7000 inches on the ground.

Information gathered by the Remote Sensing Research Work Unit at the Pacific Southwest Forest and Range Experiment Station has found that with the mountain pine bark beetle color infrared and normal color are comparable at scales of 1:15,840 or larger in detecting infestations; however, color infrared is better when smaller scales are used. If single trees need to be detected, normal color or color infrared at the 1:8000 scale should be used. The most efficient scale to use, if small infestations can be overlooked, is a scale of 1:32,000. Although previsual detection can not be determined with normal color or color infrared, epidemic trends and progress can be mapped annually (Heller, 1974).

Image movement (due to the motion of the aircraft when at high speeds or low altitudes) is not usually a factor of remote sensing for mountain pine beetles because of the small scales used.

Chapter 4

REMOTE SENSING METHODS WITH COLOR FILM

One of the first attempts to use color photographs to determine mortality from mountain pine bark beetles was done by Heller (1968). Combining color photos with infrared color photographs and optical mechanical scanning imagery, Heller tried to obtain previsual detection of ponderosa pine tree mortality. Ground measurements were also taken of beetle populations, numbers of infested trees, foliage color, foliage internal temperatures, needle moisture tensions, transpiration, solar radiation, soil moisture, air temperature, humidity, and wind velocity.

All aerial photography was taken with two 70 mm Mauer, KB-8A, cameras equipped with 150 mm Schneider Xenotar lens. The two cameras, impulsed simultaneously by an Abrams CP-3 intervalometer, gave identical photo coverage of the two films. Photography, at a scale of 1:1584, was performed from an Aero Commander 500B airplane flying at 100 miles per hour with a 60 percent overlap for stereoscopic coverage. Shutter speeds were 1,000th second or faster to reduce image motion. Kodak Ektachrome and Anscochrome D/200 color films were used.

Photographs were taken from May through August. May was the earliest any reliable interpretations could be made on color films. Earlier detection of infested trees is needed for control programs to be most effective. Because color changes were more evident as the season progressed, interpretation errors decreased during the photographing period.

In 1970 Klein (1973) used 35 mm color film at a 1:5000 scale and later Klein, Bennett, and Young (1979) used a 1:6000 scale to determine mountain pine beetle-killed estimates.

During Klein's 1970 project all photographs were taken from a Cessna 182 fixed-wing aircraft using a Nikon F with an Auto-Nikkar 85 mm lens and Nikkar L1A filter. The projects conducted by Klein, Bennett, and Young (1979), Hostetler and Young (1979), and Heller and Wear (1969) used the Aero Commander or Cessna 180 fixed-wing aircraft with a Zeiss RMK 21/23 aerial camera with scales of 1:6000, 1:6000, and 1:8000 respectively. Film used in the above projects were either Ektachrome 50-397, Kodacolor-X, or Anscochrome D/200.

Other methods of evaluating insect damage should be used simultaneously with remote sensing surveys to determine credibility of data. Ground truth observations should be taken to calculate a sampling error at a selected confidence level, usually twenty-five percent at one standard deviation. Ground checks should be built into damage assessment whether they are made from large-scale color photographs, visual observations (sketch mapping), or on-site visits. Various successful techniques have been reported by investigators which include visual observation, aerial photography, risk-rating vegetation, multi-stage sampling, and double sampling.

Multi-stage sampling is the use of coarse resolution imagery at the first stage and finer resolution imagery in succeeding stages. This concept was first developed in 1968 (Wert and Roettgering 1968, Heller and Wear 1969) at the Pacific Southwest Forest and Range Experiment Station, Berkeley, California. The first level of information is from satellites, high-flight aircraft, or sketch maps made by visual observers. Data from sketch maps may then be used to stratify the infested area into blocks of light, moderate, and heavy damage. Multi-stage sampling is not intended to be used for early detection of new single tree infestations.

Heller and Wear (1969) used the multi-stage sampling method in the Black Hills of South Dakota. Sketch mapping was done during visual flights with low-flying aircraft. However, plotting accuracy was fairly low, about fifty percent from small infestations.

The second stage consisted of one by ten mile photo strips with three ground checks per strip. Stratum were identified as: few infestations with no control, many infestations with some control, and many infestations with no control.

Ground crews used the color transparencies in the woods for navigation to the infestation. The number of affected trees and their volumes were measured.

Heller and Wear (1969) also conducted controlled tests near the same area using identical 70 mm Maurer cameras with color and color infrared film at six decreasing smaller scales from 1:8000 to 1:174,000. In the two years of testing no advantage in using infrared color film instead of color film was discovered. More mistakes were made on the false color film.

Multi-stage sampling and double sampling with regression were techniques used by Klein, Bennett and Young during 1979 in the Targhee National Forest, Idaho and by Hostetler and Young in the Black Hills, South Dakota.

Double sampling with regression analysis is an efficient way of combining photo and field plot information into an estimate of mortality or damage. This method employs a sample within a sample. The first sample consists of photo plots where the mortality and volume, if desired, is calculated on each plot. Ground checks from a portion of the aerial photos are compared with the results obtained from the photo plots. The photo and field data provide the basis for computing a linear regression expressing the relation between the photo and field measurements. This regression is used to adjust the data from the photo sample to obtain the final estimate of the mortality or damage.

It is probably not better to use a double sample survey with aerial photos if the photo plots are not substantially cheaper than the field plots, or if the relation between the photo and field measurements is poor.

The method of double sampling with regression when estimating tree mortality consists of the following steps: (1) defining the area to be sampled; (2) determining size and shape of plots; (3) estimating numbers of plots needed; (4) establishing locations of plots; (5) obtaining aerial photos; (6) measuring the mortality or damage on the photos; (7) field checking a portion of the plots; and (8) calculating the estimate for the total amount of mortality or damage.

The decision on what area to be sampled is a two-phase procedure: boundary delineation of the general area, and determination of what specific areas within the boundary are sampled.

Boundary delineation is best done from an airplane or helicopter. The area boundaries are sketched on a map, or if the area is not too large, they can be marked on aerial photo prints. Ground checks should be conducted to insure the damage or mortality is the type to be surveyed. If substantial damage is outside of the boundaries, the boundaries should be revised. Plot location should be only where damage or mortality could occur.

The end result of the above two-phase procedure should be a detailed map which shows the boundary, photo plots, and field plot survey locations. To assure a relationship between the photo and field measurements of mortality or damage the plots must be identical in size, shape and location.

Klein (1973) in his 1970 project used nineteen ground checks in areas ranging from 0.3 to 4.0 acres.

Hostetler and Young (1979) selected photo plots of 90, 62.5, and 40 acres for light, intermediate, and heavy strata respectively. Square acetate templates were used to represent 90 acres on a range of scales (1:5400 - 1:6600). Each template was divided into 36 squares each representing a 2.5 acre subplot.

In the above study faders were recorded for all 2.5-acre subplots for the light stratum photo plots. Twenty-five and sixteen subplots were counted in the intermediate and heavy strata respectively.

Twenty 2.5-acre ground check plots were randomly selected (without replacement) from the photo plots of each stratum in the Hostetler and Young project.

In the project by Klein, Bennett, and Young (1979) there were twenty photo plots in the heavy stratum (more than 3.5 faders/acre), fifty photo plots in the medium stratum (2.0-3.5 faders/acre), and sixty photo plots in the light stratum (less than 2.0 faders/acre). Each photo plot was forty acres (20 x 20 chains) in size, and subdivided into sixteen 2.5 acre subplots. Acetate templates with the plot and subplot boundaries, with a range of scales (1:5400 to 1:6600) were also used.

Ground truth correlations were established by using twenty 2.5 acre randomly selected plots within each of the three strata.

Photo and ground plots may be selected randomly or with a systematic grid pattern.

An easy method of random selection is by using random numbers to pick a township and then a section within it. The plot location is the center of the section. Discard those plots that are not to be sampled. The process is repeated until the numbers of required photo plot locations have been selected. Numbers one through thirty-six should still be used for those townships having less than thirty-six. No plot is used if the selected section does not exist.

A systematic grid of plot locations should be used if many plots are to be selected or if the area to be sampled is only a small portion of the gross area within the survey boundary.

A systematic grid is made by dividing the desired number of photo plots into the total acreage of the areas actually to be sampled to get the area represented by each plot. Gridline spacing is then chosen so the squares they bound contain this number of acres. For example, a gross area within the survey boundary is a million acres, but the total acreage to be sampled is only 750,000. If one hundred photo plots are to be located, each will represent 7,500 acres.

A grid with the chosen interval is then constructed and laid in a random position over the map showing the areas to be sampled. Each grid intersection that falls on an area to be sampled becomes a photo plot location; the rest are rejected.

The best large-scale or recent small-scale photos should be used to mark the photo plot locations for orienting the photo crew. Locations on existing aerial photo prints provide positive identification.

After establishing, photographing, and interpretating the photo plots, the field plots are selected. Field plot selection may be random or systematic, but it is best to follow the same method used in the selection of photo plots. Systematic selection of field plots is obtained by dividing the number of photo plots by the number of field plots for the sampling fraction. Then choose a random number between one and this number as a starting point. Take the remaining plots at intervals of the sampling fraction from then on. For example, to choose twenty field plots from one hundred photo plots, stand with the random number between one and five, then select every fifth plot thereafter. The field plots should be marked on maps or photos for field crew guidance (Wear, Pope, and Orr, 1966).

For a more complete description of double sampling with regression and the formulas involved, the reader may refer to the work done by Wear, Pope, and Orr (1966), by Klein, Bennett, and Young (1979). and by Hostetler and Young (1979).

"The interpreter should be able to orient photos for proper viewing, see the stereo image easily, and be able to distinguish tree species. Experience in forest insect damage recognition is desirable.

"If sample plots are off-center or near the edge of the photos, simply shift the plot location to the center of the photos", (Wear, Pope, and Orr, 1966).

In general, it is easier to separate dead from live trees with color films than panchromatic prints. On the other hand, color prints are more expensive than panchromatic film and panchromatic film is easier to use stereoscopically in the field than are color transparencies.

Dead trees tend to photograph much lighter than live trees with panchromatic film. If dead trees have yellow, orange, or red foliage an orange filter used with panchromatic film emphasizes the tone difference and the distinction between live and dead trees is made easier.

The detection and identification of tree damage and mortality is usually more reliable in one of the color films such as Anscochrome, Ektachrome, and Ektacolor which show objects in their natural colors. It is easier to separate the yellow to reddish brown color changes shown by mountain pine bark beetle damage from the greens of healthy trees than to distinguish the color variations as shades of gray on panchromatic prints.

"Photographs produced from color films come in two forms. Anscochrome, Ektachrome, (and Ektachrome Infrared) films become positive transparencies which must be viewed by transmitted light. Ektacolor film is transformed into a negative transparency with colors that are complementary to the actual colors of the objects photographed. From this negative it is possible to make color transparencies, color prints, or black-and-white prints.

"This feature of Ektacolor, besides making it versatile, has several other advantages. Color prints are more convenient to interpret than transparencies. Moreover, in the process of making a color print, it is possible to exert some control over the general color balance and density. On the other hand, color prints, besides being very expensive, don't seem to have quite the sharpness or color saturation of transparencies.

"Color prints are interpreted with either a pocket or mirror type stereoscope. Color transparencies must be viewed on a light table.

"An Old Delft scanning stereoscope with variable magnification and a series of controllable lights on the light table is an excellent setup for interpreting transparencies.

"A grid placed over the transparencies reduces the chance of error.

"The appearance of dead or damaged trees varies somewhat, although fairly consistent patterns for color film types show:

a) Tree conditions in their actual colors

b) Needleless trees as purple

c) Trees without small twigs as gray and thin

d) Trees after the loss of small branches as snaglike" (Wear, Pope, and Orr, 1966).

Sartwell and Stevens (1975) reported that color aerial photographs taken over natural and thinned stands of ponderosa pine in the Black Hills, South Dakota, illustrated the effectiveness of silviculturally reducing the basal area of dense stands. Invariably, thinned ponderosa pine stands were free of mountain pine beetle attack while in the natural stands many infestations showed up on the photos, often to the very edges of the thinned stands. Replicated visual evidence like this convinces the forest manager that thinning is the proper management action to keep his ponderosa pine stands free of this pest problem.

Chapter 5

MORTALITY COMPUTATIONS

The procedures and formulas for determining the mortality estimate, sampling error determination, correlation coefficient, sample size, and double sampling for stratification are covered by Wear, Pope, and Orr (1966).

Additional information for estimating the relationship between ground and photo counts, the average volume per tree, the total volume loss, and standing dead volume is found in Klein, Bennett, and Young (1979).

A helpful reference for understanding the statistical formulas used is Snedecor and Cochran, Statistical Methods, 1973.

Chapter 6

OBSTACLES TO GOOD PHOTOGRAPHY

Weather, terrain, and sun angle may prevent photographs from being taken when the damage shows up best and can affect their cost and quality.

The primary weather problem is clouds. Contrasts in colors are reduced by lower light intensity. Photo projects can be delayed by persistent cloud cover. Scattered clouds over photo points delay photography and increase flight time and photo costs. Daily weather forecasts should be checked including weather records for the average number of cloudless days during the survey period.

Visibility can be obscured by smoke or haze from forest fires or slash burning, particularly in valleys or basins where it tends to concentrate.

Turbulence can occasionally hinder aerial photography, primarily at low flying heights when large-scale photos are taken. Turbulence can be caused by air currents over the rough terrain in the mountainous range of the mountain pine bark beetle. By using a larger lens, which permits higher flights, the problem of air turbulence may be minimized.

In addition to the possible turbulence or downdraft problems in mountainous areas, changes in elevation in short distances may be so great that the scale of aerial photography can vary. When these conditions exist, the scale of photography must be decreased to permit safe operation at a higher altitude and an aerial camera with a larger focal length lens must be used to secure the desired photo scale.

Because a high sun angle and minimum shadow result in maximum illumination of tree crowns, thus facilitating color change interpretation on aerial photos, photographs for monitoring mountain pine bark beetle damage should be taken be.ween 10 a.m. and 2 p.m. in late June through early September. Another factor, if the survey area has many northern slopes, is that north-facing slopes in steep terrain are illuminated for shorter periods than other slopes (Wear, Pope, and Orr, 1966).

CONCLUSION

Remote sensing with color films is a useful tool in forestry management to detect damage caused by the mountain pine bark beetle.

Because mountain pine beetle damage first occurs in small groups of trees, larger scale normal color photography appears to be the best method for detecting early outbreaks; however, medium scale color infrared photography may be more effective and more economical in detecting outbreaks of epidemic proportions and damage trends.

Medium scale (maximum 1:30,000) high resolution color infrared should be taken, as well as the large scale (1:6000) color photography to test the large format film for use in stratification of different damage intensity classes and direct sampling. This photography method could lower survey costs and amount of time spent conducting the survey. This should reduce population variance and overall lower sampling error.

Photo and plot selection should be made by using the probability proportional to size procedure to reduce the probability of selecting plots which have zero or low counts. Aerial photos and ground plots should then be selected randomly in each strata.

May is the earliest time of year when reliable interpretations can be made with color films. Because foliage color changes are more evident as the season progresses, interpretation errors will decrease later in the year. Weather, terrain, and sun angle must also be taken into consideration for obtaining the most effective photos possible.

LITERATURE CITED

1. Aldrich, R.C. 1971. Space Photos for Land Use and Forestry. Photogrammetric Engineering. pp 389-401.

2. Aldrich, R.C. 1975. Detecting Disturbances in a Forest Environment. Photogrammetric Engineering. 41: 39-48.

3. Aldrich, R.C., W.F. Bailey, and R.C. Heller. 1959. Large Scale 70 mm Color Photography Techniques and Equipment and Their Application to a Forest Sampling Problem. Photogrammetric Engineering. pp 747-754.

4. Ciesla, W.M. 1974. Forest Insect Damage from High-Altitude Color - IR Photos. Photogrammetric Engineering. pp 683-690.

5. Heller, R.C. 1968. Previsual Detection of Ponderosa Pine Trees Dying from Bark Beetle Attack. Fifth Symposium on Remote Sensing of the Environment. Univ. Mich. pp 387-434.

6. Heller, R.C. 1974. Remote Sensing as an Inventory Tool for Forest Insect Surveys. Proceedings of Monitoring Forest Environment Through Successive Sampling. pp 321-343.

7. Heller, R.C. 1978. Case Applications of Remote Sensing for Vegetation Damage Assessment. Photogrammetric Engineering and Remote Sensing. 44: 1159-1166.

8. Heller, R.C., and J.F. Wear. 1969. Sampling Forest Insect Epidemics with Color Films. Proceedings of the Sixth International Symposium on Remote Sensing of Environment. Univ. Mich. pp 1158-1160.

9. Hostetler, B.B. and R.W. Young. 1979. A Pilot Survey to Measure Mortality of Lodgepole Pine Caused by the Mountain Pine Beetle in the Black Hills of South Dakota and Wyoming. USDA Forest Service.

10. Howard, J.A. 1976. Development and Role of Remote Sensing in Forestry, Commonwealth Forestry Bureau. 37: 493-501.

11. Klein, W.H. 1973. Beetle-Killed Pine Estimates. Photogrammetric Engineering. pp 385-388.

12. Klein, W.H., D.D. Bennett, and R.W. Young. 1979. A Pilot Survey to Measure Mortality of Lodgepole Pine Caused by the Mountain Pine Beetle. USDA Forest Service. Intermountain Region and Methods Application Group, Forest Insect and Disease Management.

13. Klein, W.H., D.L. Parker, and C.E. Jensen. 1978. Attack, Emergence, and Stand Depletion Trends of the Mountain Pine Beetle in a Lodgepole Pine Stand During an Outbreak. Environmental Entomology. 7: 732-737.

14. McCambridge, W.F. and G.C. Trostle. 1972. The Mountain Pine Beetle. USDA Forest Service. Forest Pest Leaflet 2. pp 1-6.

15. McNeil, G.T. 1953. ABC's of Photogrammetry Part I Fundamentals. Edwards Brothers, Inc., Ann Arbor, Mich.

16. Murtha, P.A. 1976. Vegetation Damage and Remote Sensing: Principle Problems and Some Recommendations. Photogrammetria. 32: 147-156.

17. Murtha, P.A. 1978. Symposium on Remote Sensing for Vegetation Damage Assessment. Photogrammetric Engineering. 44: 1139-1145.

18. Parker, D. 1962. Some Basic Considerations of the Problem of Remote Sensing. Proceedings, 1st Symposium on Remote Sensing of Environment. Univ. Mich. p 7.

19. Pollock, J. and R. Pollock. 1977. The Pine Killer. Colorado Outdoors. 26: 41-44.

20. Roe, A.L. and G.D. Amman. 1970. The Mountain Pine Beetle in Lodgepole Pine Forests. USDA Forest Service. Intermountain Forest and Range Experiment Station.

21. Sartwell, C. and R.E. Stevens. 1975. Mountain Pine Beetle in Ponderosa Pine Prospects for Silvicultural Control in Second Growth Stands. J. Forestry. 73: 136-140.

22. Snedecor, G.W. and W. Cochran. 1973. Statistical Methods.

23. Wear, J.F., R.B. Pope, and P.W. Orr. 1966. Aerial Photographic Techniques for Estimating Damage by Insects in Western Forests. USDA Forest Service. Pacific Northwest Forest and Range Experiment Station.

24. Wert, S.L. and B. Roettgering. 1968. Douglas-fir Beetle Survey With Color Prints. Photogrammetric Engineering. 34: 1243-1248.

REMOTE SENSING WITH COLOR FILMS TO DETECT MOUNTAIN PINE BARK BEETLE DAMAGE

by

DENNIS DALE KUHR

B.S., Dana College, 1972

AN ABSTRACT OF A MASTER'S REPORT

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Crop Protection Curriculum

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1981

The mountain pine bark beetle, Dendroctonus ponderosae, Hopkins, is one of the most destructive forest pests in the western United States.

Aerial photography with color films has been the most used and reliable method in monitoring and recording its damage. Previsual damage of insect populations can not be detected with aerial photography; however, estimates of tree mortality and damage locations and trends can be determined.

The main hosts of the beetle are ponderosa and lodgepole pines, although other pines may also be attacked. Foliage color changes from green to yellow to reddish-brown, usually a year after a successful attack, are observed in the aerial photographs.

The most efficient scale of photography to use if small infestations can be overlooked is a scale of 1:32,000.

Ground truth observations should also be used with remote sensing surveys to determine credibility of data. Successful techniques include visual observation, aerial photography, risk-rating vegetation, multi-stage sampling, and double sampling.

Color transparencies, which are generally cheaper and have better sharpness and color saturation than color prints, are best viewed with an Old Delft scanning stereoscope.

Weather, terrain, and sun angle must all be taken into consideration to insure quality photography and minimal costs.