REMOTE SENSING APPLICATIONS IN AGRICULTURE AND FORESTRY

A REPORT OF RESEARCH
by the
Institute of Agriculture
Remote Sensing Laboratory
College of Forestry
University of Minnesota
St. Paul, Minnesota

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APPLICATIONS OF AERIAL PHOTOGRAPHY AND ERTS DATA
TO AGRICULTURAL, FOREST AND WATER RESOURCES MANAGEMENT

by

Personnel of the
University of Minnesota
Institute of Agriculture Remote Sensing Laboratory

Annual Progress Report
NASA Grant NGL 24-005-263 1 July 1973

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PERSONNEL

Since the $25,000 grant provided this project by NASA's Office of University Relations was applied in its entirety to equipment purchase, travel, overflights, image processing and general operations, the involved salaries of the following personnel were contributed to the development and execution of the project by the University of Minnesota Institute of Agriculture and the U. S. Department of Agriculture:

Project Leaders

Dr. D. W. French, Professor of Plant Pathology
Dr. A. C. Mace, Head, Department of Forest Biology
Dr. M. P. Meyer, Director, Institute of Agr. Remote Sensing Laboratory
Dr. R. H. Rust, Professor Soil Science

Cooperating Investigators

Dr. H. C. Chiang, Professor of Entomology
Dr. D. K. Barnes, Res. Geneticist, USDA, ARS
Dr. R. W. Douglass, Ass't Prof. of Forestry, The Penna. State Univ.

Graduate Students, Technical Assistants

John C. Clausen, Graduate Student (Dept. of Forest Biology)
Bruce H. Gerbig, Graduate Student (Dept. of Forest Resources Devel.)
George Hudler, Instructor (Dept. of Plant Pathology)
Mark Jensen, Jr. Scientist (IARSL)
Greg R. Johnson, Jr. Scientist (IARSL)
Michael M. McCorison, Graduate Student (Dept. of Forest Biology)
Victor Odenyo, Graduate Student (Soil Science Dept.)

Clerical/Stenographic

Ms. Kathleen K. Stephens

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Chapter 1

FOREST DISEASE DETECTION AND CONTROL

D. W. French, Robert W. Douglass and Merle P. Meyer

ABSTRACT

Dwarf mistletoe infection centers 1/10 acre in size were visible on infrared color film at scales as small as 1:118,000. Detection of 1/10 acre centers was easily accomplished at scales of 1:31,680. Individual aspen trees killed by the hypoxylon fungus were detected with relative ease at scales of 1:6,000. Armillaria root rot in red pine was detectable only after the trees had died and the foliage had turned from green to brown.

INTRODUCTION

To control forest tree diseases it is first necessary to detect these diseases and know where to apply the control efforts. In that forests are extensive and access can be a problem, it is obvious that aerial photography is one approach to locating diseased trees. The objective with this study, which began in 1970 (1, 2, 3), was to develop information on the best methods of detecting dwarf mistletoe in black spruce, Hypoxylon canker on aspen, and Armillaria root rot on red pine (Figure 1). In addition, aerial photography has been evaluated for detection of oak wilt and Dutch elm disease. The results of studies involving these latter diseases will be presented in a subsequent report.

Eastern dwarf mistletoe

Eastern dwarf mistletoe, *Arceuthobium pusillum*, was selected for vigor loss detection studies because of its importance, geographic range, and its potential for detection. It is an economically important pathogen occurring over the range of black spruce. While it is in most cases parasitic on black spruce, it does cause losses in other spruce species and in eastern larch. It has been estimated that seven percent of the 2,250,000 acres of black spruce forest type in Minnesota are infected with dwarf mistletoe. (Figure 2).

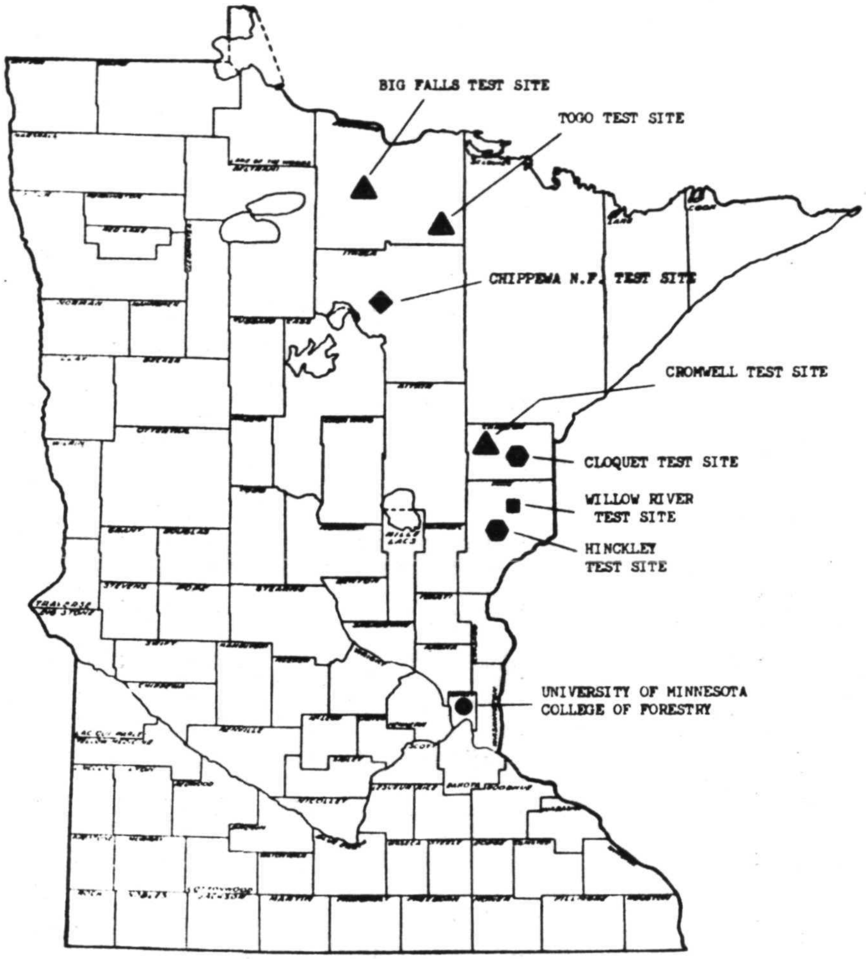

Figure 1. Location of the tree disease test sites in Minnesota.

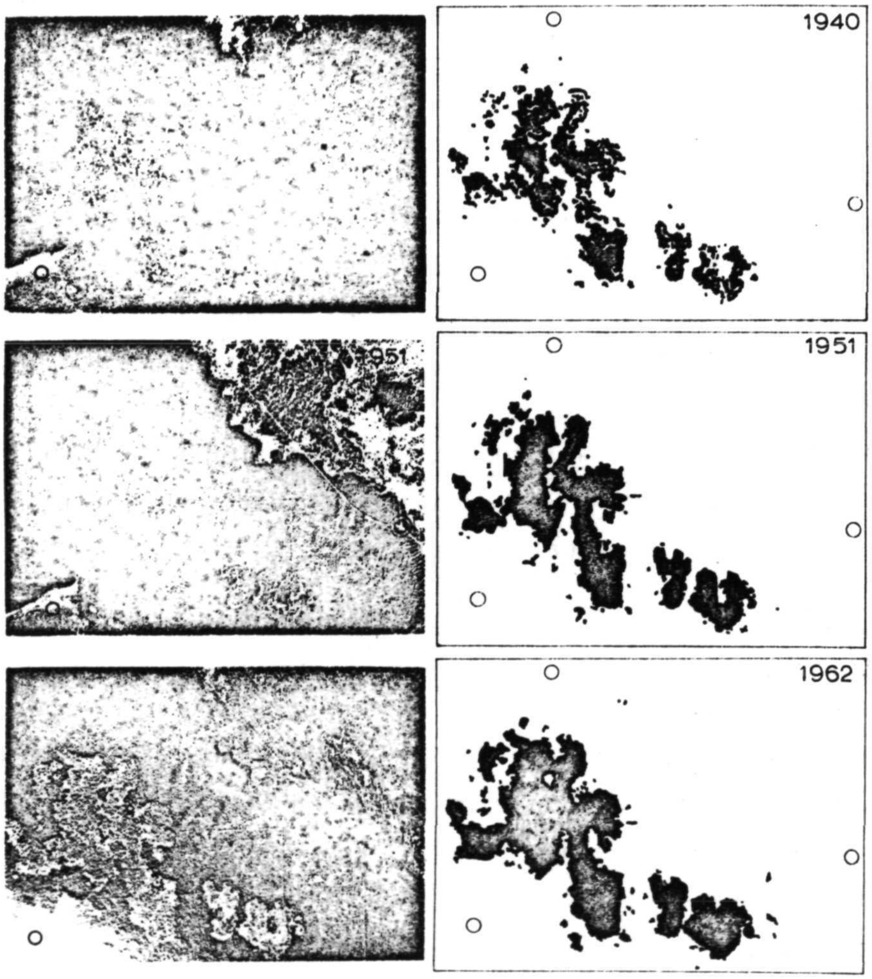

Figure 2. Aerial photographs and trace maps which show progressive increase in the size of the dwarf mistletoe infections during a 22-year period.

This pathogen is well suited for a study in remote sensing in disease detection for the following reasons:

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 evenaged and generally uniform in height so as to be very suitable for aerial photography 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 followed by prescribed burning of the cutover land. Since a control is known, a technique for location, detection, and monitoring becomes a necessity to a successful control program.

Study sites were established at two locations in Northern Minnesota. A fixed tower-tramway site was established near Cromwell in Carlton County and an extensive survey area was delineated north of Togo in Koochiching County.

Hypoxylon Canker

Hypoxylon canker is the most important disease affecting aspen. The causal organism, *Hypoxylon mammatum*, girdles and kills the tree in 3 to 10 years. The infections appear more endemic than epidemic in that the dead trees occur singularly rather than in concentrated centers as is the case with diseases such as dwarf mistletoe.

Aspen trees killed by the Hypoxylon fungus retain the brown leaves even into the winter months. This is a phenomenon which allows the disease to be detected by aerial survey. The foliage of girdled trees turns brown in the summer and is in sharp contrast with the healthy green leaves.

Approximately twelve percent of the aspen trees in the 21,000,000 acres of aspen forest type in Minnesota, Wisconsin, and Michigan are infected. Of significant importanct is that while hypoxylon canker is endemic to the Lake States and Canada, it has not been reported in Alaska. The aspen type is one of only four in Alaska. The 2,400,000 acres of aspen forests in Alaska represent a major resource. A system of detection of hypoxylon canker would enable mapping the disease's range and its pattern of spread from Canada into Alaska.

The site selected for this study was adjacent to Interstate 35 just north of Hinckley in Pine County.

Armillaria Root Rot

Armillaria root rot, Armillaria mellea, is caused by a fungus which is distributed worldwide on many species of trees. The disease is most common in forest plantations where unusually high levels of inoculum may be present in old root systems. Some plantations of red pine within Minnesota have lost as many as 55 percent of the trees to this disease. Ten percent mortality due to Armillaria root rot is common. A part of a plantation management program calls for replanting where losses have been extensive. An economic detection system, perhaps airborne, would provide the manager with the information to plan on replantings or if necessary to change, tree species. Red pine plantations in Pine County were selected for the Armillaria study.

STUDY DESIGN, DATA COLLECTION

Dwarf Mistletoe (Intensive study area-tower tramway)

At the Cromwell 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 in that the normal foliage of partially infected trees gave no spectral indication of stress that registered in the tramway photography (Figure 3).

The parasite 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 approximating 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 tried using several combinations of colored filters on the three

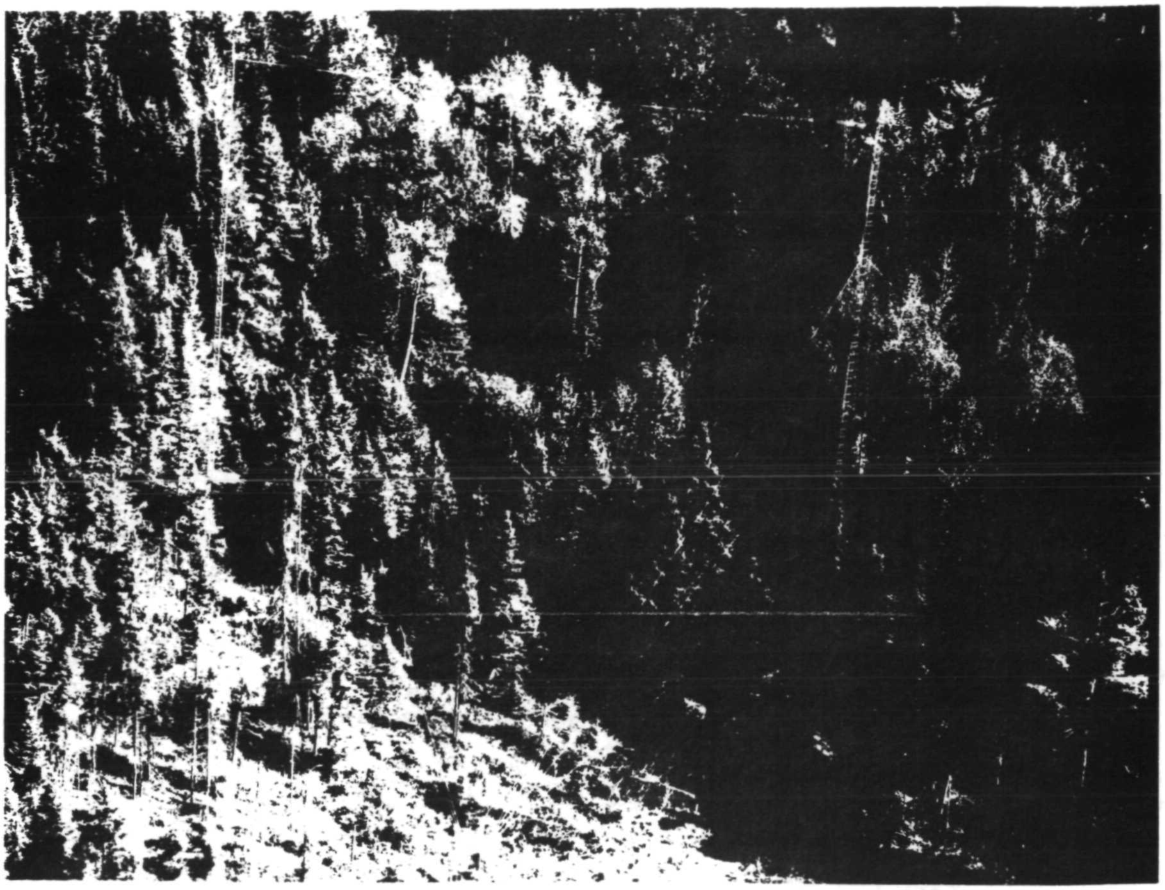

Figure 3. The tower-tramway system used for the intensive study site aerial photography at Cromwell, Minnesota.

projectors. The color enhancement approximating color 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 the photograph taken on panchromatic film 2402 with Wratten 58 filter did not add detail to the projected image.

The tower-tramway 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 was a factor that interfered with exact registration. In certain cases, the images being superimposed were not simultaneous because of exposure bracketing and photograph selection procedures. 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 50mm lens is used. Rephotography of the combined image done with the same system resulted in poor reproduction because of the light fall-off problem.

Dwarf Mistletoe (Extensive study area)

The field checking in Section 33 at Togo, Minnesota was successful in locating dwarf mistletoe infection centers occurring both as openings and as clusters of standing, but infected, black spruce trees. Some single infected trees were found in scattered locations. However, dwarf mistletoe is so slow in killing a tree that single infected trees may have large amounts of healthy foliage. Most single dead trees however, when checked on the ground, were found to have been killed by some cause other than dwarf mistletoe. Many single dead trees were found to be balsam fir.

Most of the ragged openings were due to dwarf mistletoe. Two of the openings were not caused by dwarf mistletoe and did serve as comparative areas. On two infection centers all of the infected trees were still standing. The two openings not caused by dwarf mistletoe were covered by a stand of 8 to 10 feet tall speckled alder, Labrador tea, and sphagnum moss. These openings were approximately 20,000 square feet in area, whereas the mistletoe centers were less than 10,000 square feet. In many of the infection centers of long standing speckled alder was present, but was not found in new centers.

Large scale photo interpretation. Simultaneous 70mm 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 a Wratten 12 filter (See Figure 4), and also 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" were generally in openings where they were contrasted to the deciduous or herbaceous ground cover. The two large 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 appeared brown while the dead trees without foliage were grey. Plot 5 was clearly detectable but not plot 4. Plot 5 contained more dead trees and thus was more easily identified than plot 4. No tonal differences were apparent between the dead spruce of the non-mistletoe and mistletoe 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-mistletoe openings were the exceptions because they were interpreted as being dwarf mistletoe centers.
Ektachrome infrared film. The dead spruce foliage had 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. 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.

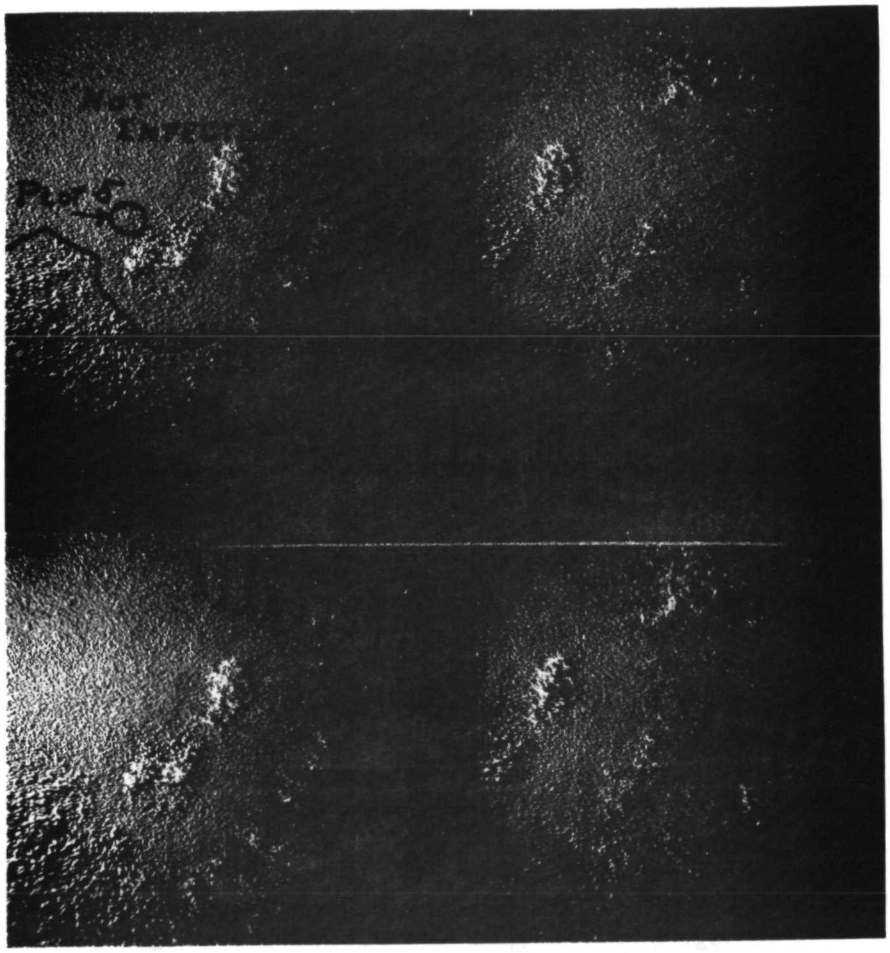

Figure 4. 70mm stereograms of Ektachrome MS/2A and Ektachrome infrared (8443)/12 film-filter combinations (scale of 1:8,000) showing areas of black spruce infected with dwarf mistletoe and openings not related to dwarf mistletoe.

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.

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 photo interpretation. 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 infection centers with standing trees 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 to detect on the scales smaller than 1:63,360.

The August overflight of the NASA RB57F did not include any small scale photography. A twelve inch focal length Zeiss camera provided 1:59,000 scale 9x9-inch color infrared 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 Zeiss positive transparency provided resolution that is superior to the equivalent scale of 70mm photographs; however, it provided less intelligence 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.

Very small scale photo interpretation. RB57F overflights on August 6 and September 29, 1971, provided photographs taken with the six inch focal length Wild RC-8 cameras from a flying height of 59,000 feet. On both flights, the superiority of infrared color film over color for high altitude photography was demonstrated. Scene brightness and atmospheric penetration were 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 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 chain (i.e. 66 feet) were detectable on the infrared color film taken during both overflights. The summer photograph presented a much brighter scene with the alder, sphagnum, and labrador tea infrared reflectivity at a high level. This made the location of the one-chain diameter 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.

Microscale photo interpretation. Direct interpretation of the microscale (1:462,000) RB57F 70mm photography indicated that the moth-eaten pattern of extensive dwarf mistletoe infestations could be located under certain conditions. The location of the affected 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.

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 (2.3) revealed some of the pattern. Panchromatic film type 2402 with a Wratten 25A 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.

Optical recombining. The three spectral slices contained on the NASA Hasselblad imagery were combined optically into one false color image. This was done on the I^2S Addcol viewer by projecting the combined picture onto the backlit screen at approximately ten-power magnification. This enlargement enabled detailed study of the scene; however, rephotographing had to be done to obtain a permanent record. While in theory the three spectral slice recombination is supposed to be superior to a triemulsion photograph, it has not in fact proven to be so in all cases. Nothing could be detected by using the optical recombining that did not show on the triemulsion at the 1:118,000 scale; however, the recombined photograph produced a color enhanced scene superior to any of the single images.

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) projector at a 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 filter on different projectors, the overall infection area could be highlighted. The use of red and green projectors provided the scene needed to locate these areas.

Masking. Several masking combinations were used for locating 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 were as follows:

Mask 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

Mask number 1 creates a harsh black 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 were visible including the chain diameter plot when the mask was viewed on the light table. However, none of the infected plots with standing trees were evident. 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 interpretative 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. More of 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 high altitude disease survey.

Density level slicing. The color enhanced density separations present an impressive appearance, but do not provide any more information to this study than is available on the infrared color transparency of that scene. This would agree with the findings at the Cromwell site where no distinct spectral signature could be determined for infected black spruce trees. In this situation, no density level separation represented infected trees or the dwarf mistletoe openings.

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. The test area as it appears when all sixteen density slices are stacked together is illustrated in Figure 5.

The Digicol electronic image enhancer 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. However, these density differences were unrelated to dwarf mistletoe. Density differences related to the disease were detectable on the photograph.

Hypoxylon Canker

No film-filter combination showed an advantage for detecting hypoxylon canker over the others for interpretation at the 1:6,000 scale. However, the true color films (Ektachrome MS and Ektacolor) were more suitable for use in locating landmarks and diseased trees on the ground. The use of the Wratten 21 filter with the 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 present 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 6)

Figure 5. Photograph resulting from "stacking" 16 color-enhanced density separation transparencies of the Togo infection centers.

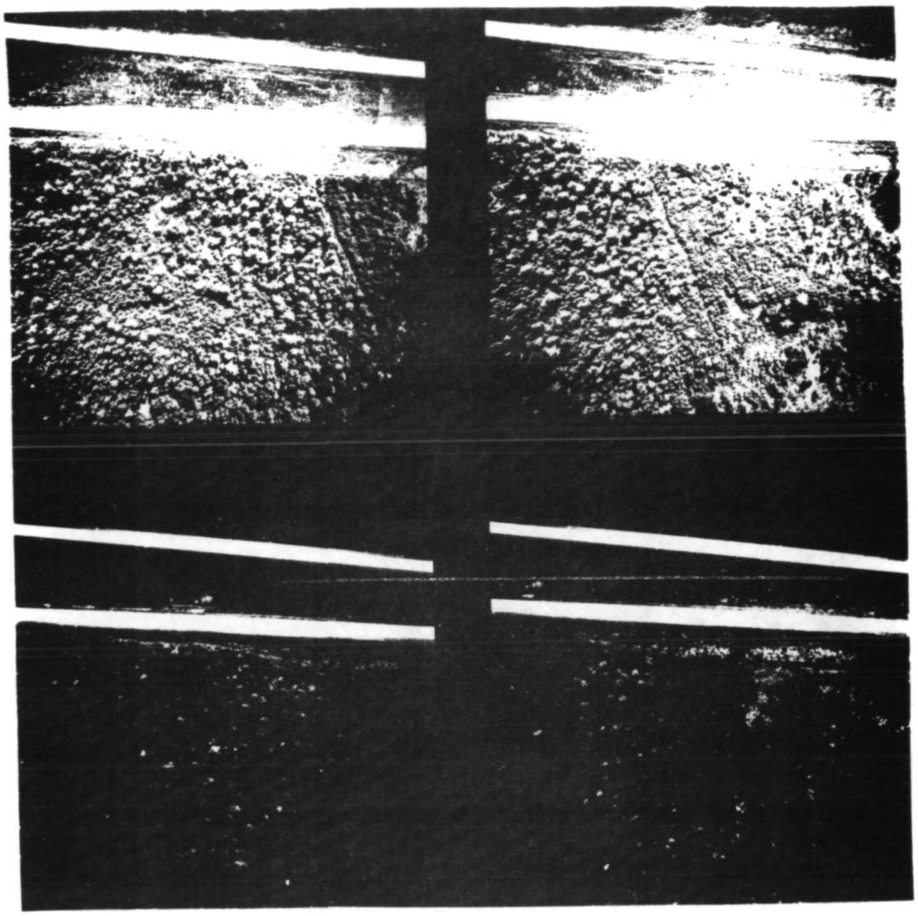

Figure 6. 70mm stereograms of Ektachrome MS/2A and Ektachrome infrared (8443)/12 film-filter combinations (1:6,000 scale) of the Hinckley area showing aspen trees killed by Hypoxylon canker.

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

On the basis of observations on the ground every one of the hypoxylon-killed overstory trees had been detected by photo-interpretation. Trees under two inches in diameter and infected living trees were not evident on the photography.

Those trees detected on the photographs as being dead or partially dead were all aspen; however, they were not all victims of hypoxylon canker. Three trees were victims of some combination of *Nectria*, *Fomes igniarius* heart rot and over maturity. Of the 25 trees marked for having hypoxylon, 17 were detected on the large scale photographs. The eight undetected, infected trees were under 2 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

The 309 trees examined on the ground and located on the photographs were classified as follows:

Class	Number of Trees
1. Healthy	265
2. Died in 1968	5
3. Died in 1969	11
4. Died in 1970	13
5. Currently dying	15

On the July 8, 1971 photography, 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. These latter trees had lost most of their foliage. Trees which died in early 1971 were detected with considerable difficulty and none of those trees which died later in 1971 could be detected on either of the two film types, Ektachrome MS and Ektachrome IR (Figure 7).

SUMMARY, PRACTICAL IMPLICATIONS

Dwarf Mistletoe Detection

Summary. No spectral signature for dwarf mistletoe-related stress on black spruce 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 "motheaten" pattern associated with dwarf mistletoe infections was detectable on all photograph 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.

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

Color contrasts between 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

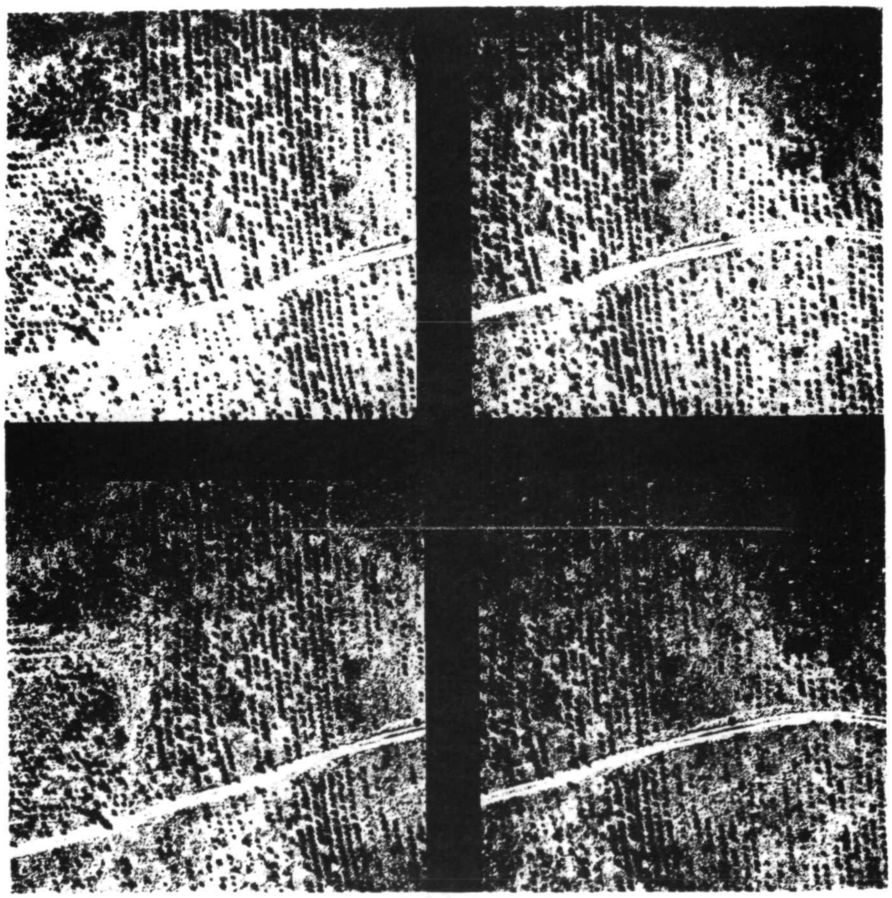

Figure 7. 70mm stereograms of Ektachrome MS/2A and Ektachrome infrared (8843)/12 film-filter combinations (1:2,000 scale) of the Willow River study area showing Armillaria root rot of red pine.

associated with dead, defoliated trees on infrared color was present at scales greater than 1:63,360.

Practical Implications. Based on the findings of this study, a multistage sampling project could be designed using 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 recombining process. Everything that was visible on the color enhanced scene was also visible on the spectral slices and on the triemulsion films.

Although two masking combinations were given high ratings for dwarf mistletoe pattern detection or location, 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 informational return related to dwarf mistletoe in this study.

The photographic density level slicing and color coding did not prove to be 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 this study. In light of the success, although very limited, of the electronic image enhancer further studies should be made in the area.

Hypoxylon Canker Detection

Summary. 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 present year's mortality are detectable because of the persistant 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

Summary. 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.

LITERATURE CITED

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Chapter 2

EVALUATION OF PEATLAND WATER TABLE ELEVATION AND WATER QUALITY INDICATORS

Arnett C. Mace, Jr.

ABSTRACT

The need for an economically and technically feasible system for monitoring water table elevation of peatland areas for flood prediction and water quality changes prompted this study. Density values of color infrared photography were significantly correlated with water table elevation. Correlation of film density with water table depth was not significant due to the undulating surfaces of peatlands.

Results of identification of aquatic vegetation and population by image enhancement and density level-slicing was not successful although sufficiently encouraging to modify sampling techniques. Large scale photography (1:3,000-6,000), precise location of sampling points and time of sampling are modifications which should improve results.

INTRODUCTION

Organic soils or peatlands are normally associated with high water tables and have the capacity to store large volumes of water. Consequently, numerous individuals have suggested that these areas (15 million acres in Minnesota, Wisconsin and Michigan) serve as a temporary storage area for spring snowmelt water thereby reducing spring floods. Numerous research results indicate that water table elevation determines storage capacity and the role of peatlands in reducing spring floods.

An increasing interest is being given these areas as a possible disposal site for additional physical, chemical, and biological treatment of secondary effluent. Potential use of these areas for this purpose and treatment effectiveness will be determined indirectly by water table elevation since it will regulate effluent residence time.

The second part of this study relates to the use of aquatic vegetation species and population as indicators of water quality, particularly nutrient concentration. It is widely recognized that increased nutrient levels enhance aquatic vegetation productivity in terms of population or concentration and diversity of species. Consequently, identification of population and species by remote sensing techniques would provide an economically feasible monitoring system for water quality status and trends due to recreational, industrial and municipal discharge and numerous land use practices.

STUDY AREA LOCATION, CHARACTERISTICS

Both phases of this study were conducted on Chippewa National Forest sites located approximately 20 miles north of Grand Rapids, Minnesota (Figure 1). Site One was used for evaluation of peatland water table elevations and is located on Watershed S-1 of the U. S. Forest Service's Marcell Experimental Forest. This perched peatland watershed, which is 20 feet in depth, is 20 acres in area surrounded by silt loams overlying glacial till. Black spruce [*Picea mariana* (Mill.) B.S.P.] is the dominant vegetation ranging in age from 60 to 80 years. This area was clearcut in alternating strips 100 feet in width oriented perpendicular to the drainage in 1969 (Figure 2).

Study Site Two consisted of Burnt Shanty, Burrows and Lost Moose Lakes located in the same area (Figure 1). These lakes are surrounded by both organic and mineral soils of varying depths and vegetation cover types such as northern hardwoods, aspen, spruce-fir, red and jack pine, open farmlands and low shrubs.

STUDY DESIGN, DATA COLLECTION

Overflights of the two study areas were made on September 8, 1972, with the following film/filter combinations:

Plus-X/Wratten 58 (.5-.6 Microns)
Plus-X/Wratten 25 (.6-.7 Microns)
Aero Infrared/Wratten 89B (.7-.9 Microns)
Aerochrome Infrared/Wratten 15 (.5-.9 Microns)

Simultaneous ground truth measurements of ground water elevations and aquatic vegetation (surface and submergent) were conducted.

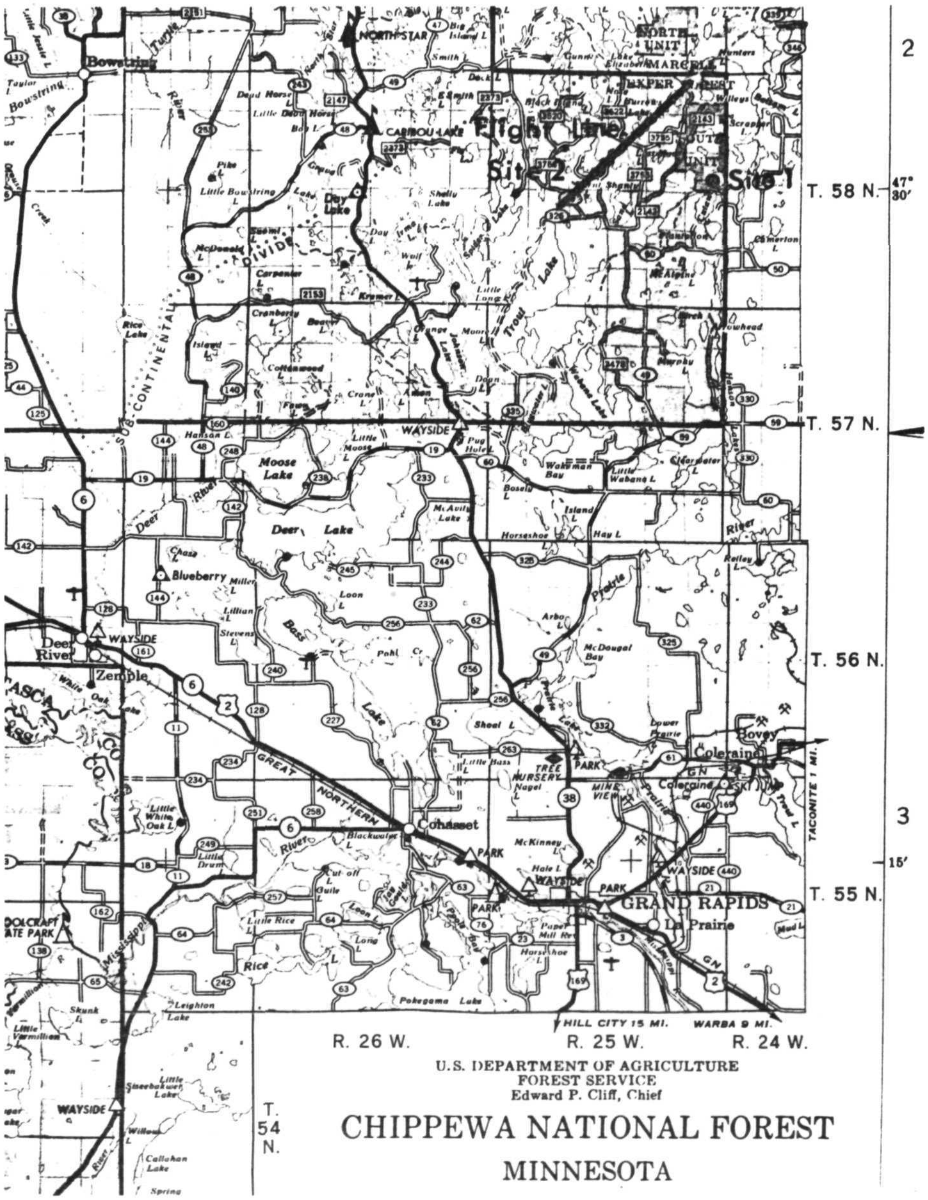


Figure 1. Location of two test sites for the September 8, 1972, overflight.

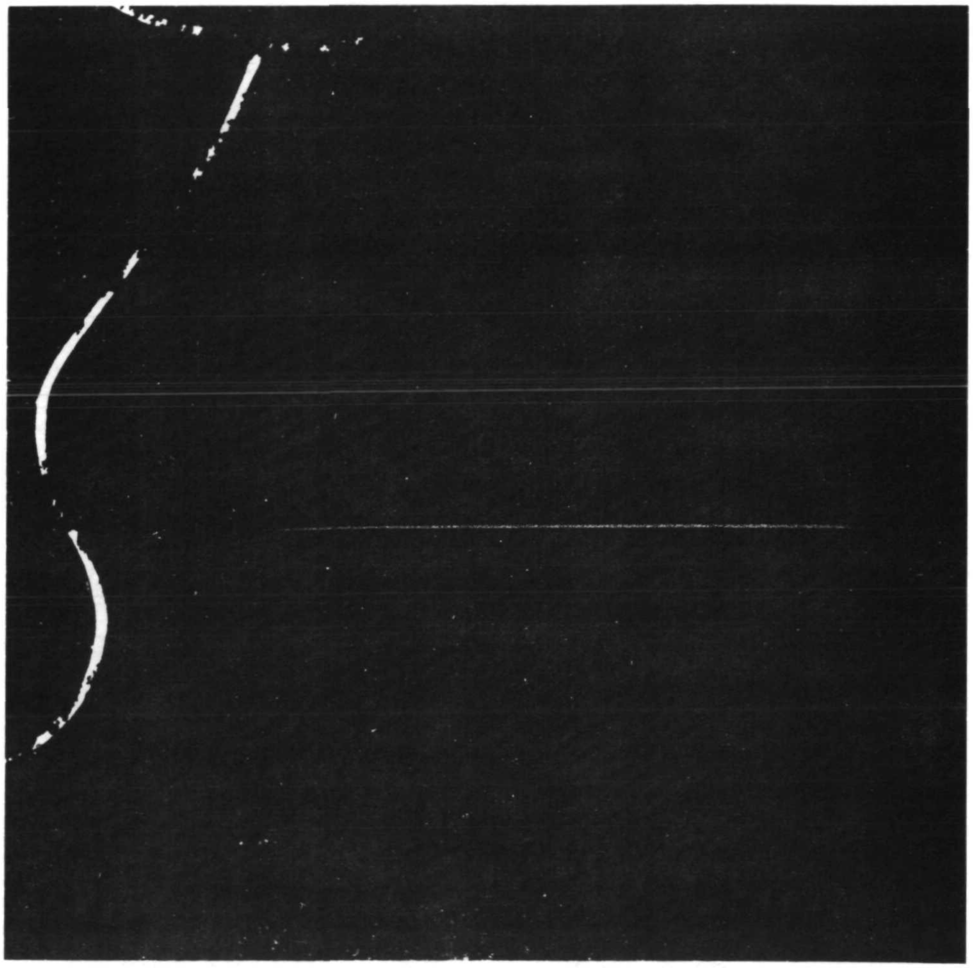


Figure 2. Color infrared photograph (original scale = 1:12,000) of peatland area study site for ground water elevation.

Ground water elevation measurements were made by personnel of the U. S. Forest Service's North Central Forest Experiment Station located at the Northern Conifer Laboratory, Grand Rapids, Minnesota. A minimum of three measurements were taken in permanent ground water wells located in each clearcut strip.

Twenty-three, thirty and fifty sampling points were located on Lost Moose, Burnt Shanty and Burrows lakes, respectively. Algal samples and percent surface cover by species of surface vegetation were mapped for each sampling point. Algal populations were determined from liter samples collected at grid points and fixed with Lugol's solution. Microscopic examination of each sample provided identification and concentration of organisms using a Sedgewick-Rafter cell. Surface aquatic vegetation was mapped on a grid system using counts per unit area.

DATA ANALYSIS, RESULTS

Data analysis relating water table elevation to color infrared photography was accomplished through linear correlation. The density at thirty, randomly-located points in each clearcut strip was determined by VP-8 density level-slicing and correlated with water table elevation.

Image enhancement techniques were employed to identify aquatic vegetation species on Burrow Lake to train the interpreter. Specific attention was first given to monoculture sites of similar densities determined on the ground (Figure 3). Density level-slicing was then utilized to differentiate variation in density within and between species.

Significant correlation was found between water table elevation of the peatland site photographed on September 8, 1972, and the color infrared film density (Figure 4). The high coefficient of determination of 0.974 indicates that a high degree of correlation exists when the water table is near the surface as existed during this overflight. Correlation of film density with water table depth was not significant due in part to the presence of numerous hummocks and depressions in peatland areas. These characteristics preclude an accurate measure of water table depth of peatlands for the purpose of correlation with film density. Larger scale photography and/or marking ground water well sites prior to overflights may also enhance correlation between film density and groundwater table depths.

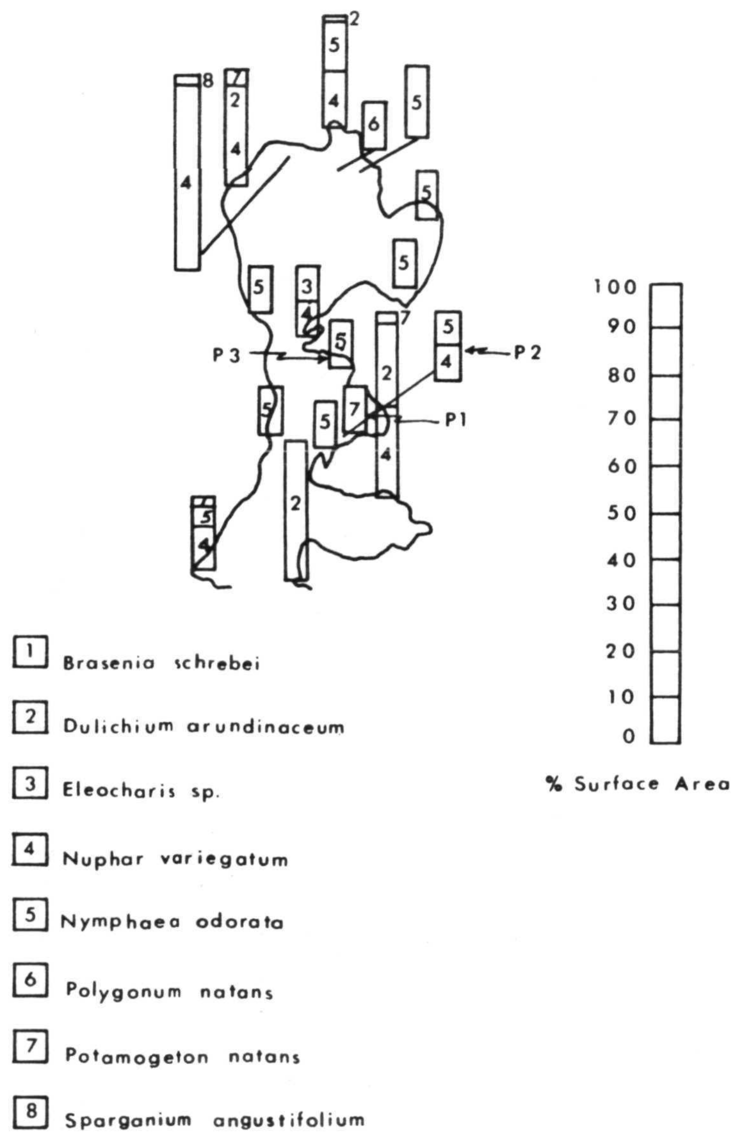


Figure 3. Aquatic vegetation of a portion of Burrow Lake indicating location, species and cover density at the time of overflight. Points 1, 2 and 3 correspond to those in Figure 5.

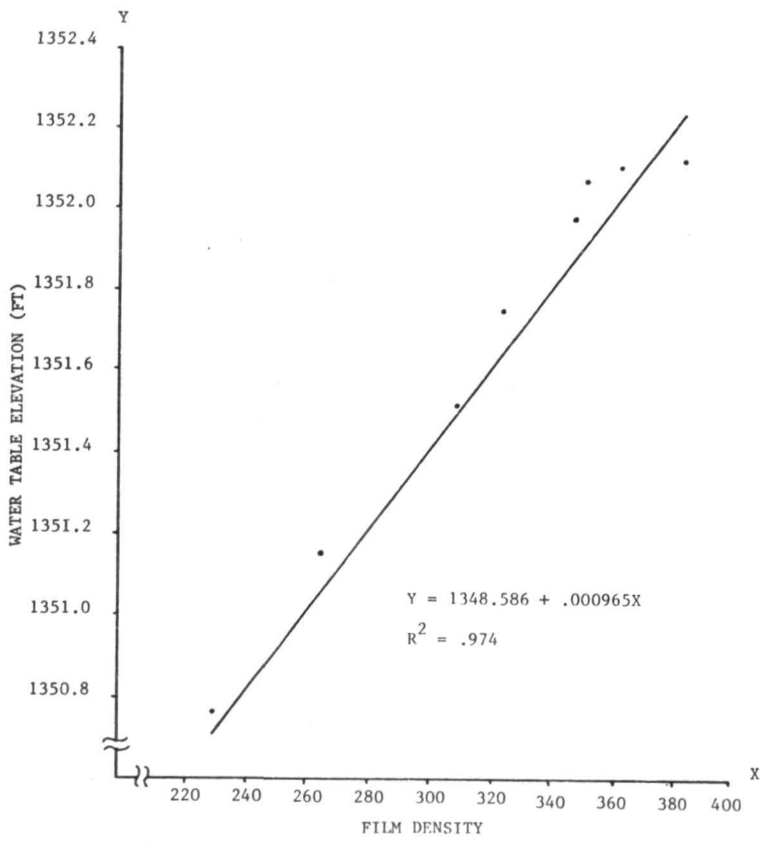


Figure 4. Linear correlation between density of Ektachrome IR/Wr 15 film/filter combination and water table elevation. Overflight made September 8, 1972, at a scale of 1:12,000.

Although it was not the specific objective of this study and measurements were not taken, vegetation types occurring in peatland areas can be readily identified using either image enhancement or density level-slicing techniques.

Identification and determination of concentrations of aquatic vegetation by image enhancement and density level-slicing presented more difficulties than were initially anticipated. Two factors which may have contributed to these problems were that the overflight occurred during a decline in aquatic vegetation production and the scale was too small. Phytoplankton production during this overflight was minimal and, consequently, was not detectable. More precise ground truth sampling locations will also augment present sampling procedures in that precise areal delineation is required rather than mean vegetation cover density.

The VP-8 Image Analyzer was used to separate density values of color infrared film and generate color signals to a color television monitor. Figure 5 depicts this visual display for a portion of Burrow Lake showing the different color scales useful in identifying aquatic species. Points 1 and 3 represent monocultures while point 2 represents a composite of species. Image enhancement did not increase the ability of the interpreter to identify species above that of the unenhanced color infrared film/filter combination.

Density values taken on various film/filter combination was, in general, unsuccessful due to VP-8 electronic drift being larger than the standard deviation of the sample points (Table 1). More precise location of sample points will reduce the standard deviation in addition to a larger scale. Also, the electronic drift may be reduced with additional adjustment by the manufacturer of the VP-8 Image Analyzer.

Although results from this overflight were not as successful as anticipated, modification in techniques and sampling location and time should enhance the potential for using remote sensing techniques for aquatic vegetation indicator of water quality trends and status. This tool will provide management and regulatory agencies with a desired economically feasible method of monitoring water quality.

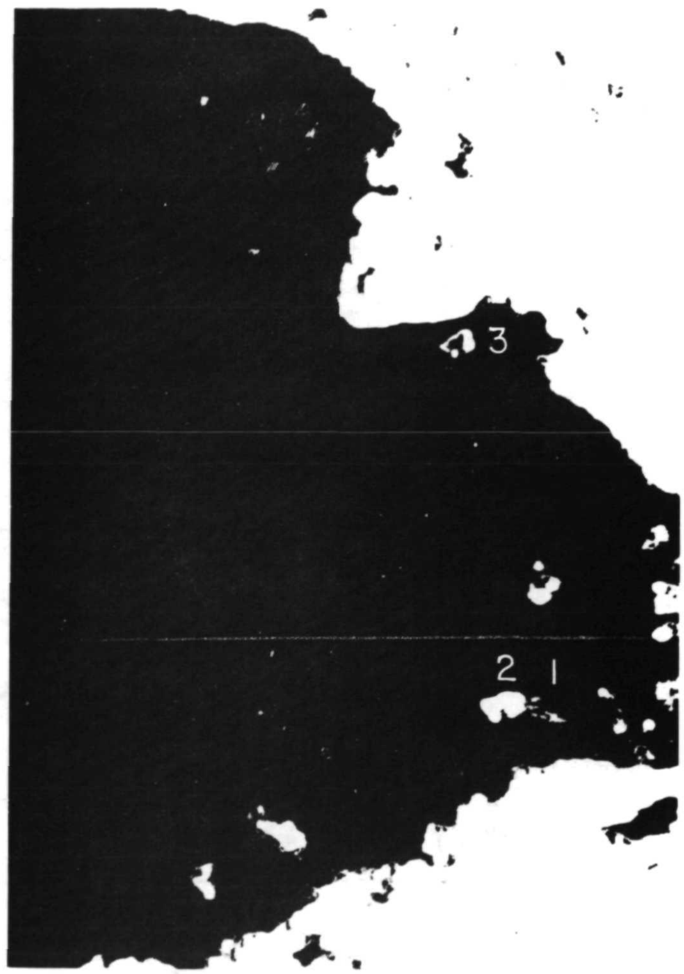


Figure 5. Example of 1:12,000 scale (original) 70mm Ektachrome IR/Wr 15 image of aquatic vegetation taken on Burrow Lake. Points 1, 2 and 3 represent ground truth data shown in Figure 3. Scene enhanced by VP-8 Image Analyzer.

Table 1. VP-8 density level-slicing readings for four sites and associated standard deviations and electronic drift. Water base levels have been subtracted from these values.

Site	Species	Cover Density (%)	VP-8 Density	Standard Deviation	Drift
19	White & yellow water lilly	5	43.8	15.3	18
20	White & yellow water lilly	7.5	50.0	26.2	30
21	White water lilly	10	88.9	29.6	12
22	White water lilly	5	7.5	6.7	23

SUMMARY, PRACTICAL IMPLICATIONS

Summary

1. A high correlation ($R^2 = 0.974$) was found between density of EKTA-IR/15 film/filter combination at a scale of 1:12,000 and water table elevation of a perched peatland area. Low correlations existed between film density and mean water table depth which was attributed to the undulating surface of peatland areas.

2. Image enhancement did not increase the interpreter's ability to identify aquatic vegetation beyond that of unenhanced color infrared photography. The low density of surface vegetation and small concentrations of phytoplankton present precluded expected results of identification at a scale of 1:12,000. Overflights will need to be made during peak productivity and at larger scale (1:3,000-6,000), if aquatic vegetation indicator identification can be used to evaluate water quality status.

3. Differentiation between species and cover density by density level-slicing was not significant. Larger scale photography and more precise location of ground truth sampling points should improve these relationships.

Practical Implications

Flood forecast models are an important hydrologic tool for predicting peak flows during the spring flood season in the upper Midwest. Accurate forecasts assist in reducing economic and loss of human life during this period as well as floodplain deliniation for land use planning. One prerequisite for better forecast is better and more input information of various hydrologic parameters.

Peatland areas may serve as a storage area for snowmelt runoff; but, the storage capacity is dependent upon ground water elevation of the previous fall. Ground water elevations are measured only on a few experimental sites in the Lake States region due to the abundance of small peatland areas and economics of the multitude of necessary measurements.

It was the purpose of this study to determine the potential of remote sensing techniques for determination of water table elevation and subsequent water storage capacity. This information is directly applicable for data input into forecast models used by the Corp of Engineers and River Forecast Centers.

Numerous federal, state and local agencies are faced with the task of monitoring water quality for a variety of purposes. At this point in time, most monitoring is accomplished by obtaining water samples and subjecting them to a series of tests to ascertain the concentration of specific parameters. This procedure is extremely expensive and many agencies cannot obtain sufficient funds to sample water systems adequately on either an areal or temporal basis.

Aerial photography of water systems provides a means of covering large areas on a periodic basis at a fraction of the costs of surface sampling. Equipment and technical requirements are normally less than those required by surface sampling and testing methods. In addition, this technique can provide an integration of the chemical and biological components of the water system with greater ease than surface sampling methods.

It is obvious that remote sensing is not feasible for monitoring all water quality parameters, but aquatic vegetation is a function of its environment and will serve as an indicator of the composite of water quality conditions.

A possible significant reduction in monitoring costs and efforts facilitates increased action programs to enhance the quality of water systems. For example, a 20 percent savings in monitoring will permit a 20 percent increase in funding for implementation of pollution abatement.

This study suggests that medium scale, 1:12,000, color infrared photography can be utilized to monitor water elevation for input into flood forecast models to reduce flood damage, possible loss of human life and location of floodplain zones. Large scale color infrared photography offers a potential for aerial and temporal monitoring of water quality status and trends which would permit considerable cost savings over present systems.

Chapter 3

FOREST VEGETATION CLASSIFICATION AND MANAGEMENT

Robert W. Douglass and Merle P. Meyer

ABSTRACT

Since vegetation classification is basic to most forest land management decisions, a study was made of the applicability of very small scale aerial photography. Practicing professional foresters were able to classify vegetation species to an 85% level of accuracy on 1:120,000 color infrared fall photography. 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 first stage (and, in some cases, second stage) multistage forest vegetation classification and sampling was very obvious. Significant savings in aerial photo procurement and interpretation costs are indicated for certain uses of very small scale aerial photography in lieu of conventional (larger) scales of forest photography.

INTRODUCTION

Thirty-seven percent of Minnesota's total land area (50,745,000 acres) is forest land. Historically of great economic and aesthetic importance in terms of forest products, water, minerals and recreation, this area is destined to become even more important in view of the rapidly increasing demands for the use and exploitation of its resources in the future. It is essential, therefore, that better systems of vegetation and land use survey and evaluation be developed - particularly those which apply to large forest areas. For certain purposes, conventional ground (and aerial photography) assessment techniques are too expensive and too detailed for the types of information required. For example, the ability to locate, and broadly map, the black spruce forest stands of Minnesota in this manner may be totally adequate for broad planning purposes or to serve as a sampling base for either inventory or a survey of the amount of mortality due to such agencies as the dwarf mistletoe.

The purpose of this project, therefore, was to determine, on a pre-ERTS launch basis, the applicability of very small scale aerial photography to the first stage level of resource classification: i.e., forest cover types. Should it be possible to successfully detect basic vegetation types on a consistent basis, such information would provide the sampling base in those cases where more detailed information would be required - and suffice, as in others.

The Marcell Ranger District of the Chippewa National Forest in Itasca County served as a study site location, and was used to test levels of difference in ability to interpret major forest vegetation cover types on NASA-provided very small scale photography. Studies by Aldrich indicate that the use of Apollo 9 reduced the sampling error by 58 percent in a multistage forest inventory in the Lower Mississippi Valley. Also, satellite imagery provides the advantage of synopic views which combined with the new probability sampling theories, enable designs including several levels of sampling to achieve greater informational gains (1).

To what extent can the upper stage of the sample, the satellite or (in this case) 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, an analysis was made of the ability of skilled photography interpreters of various professional disciplines in the forest management field to interpret the same major forest cover types in northern Minnesota.

STUDY AREA LOCATION, CHARACTERISTICS

The Chippewa National Forest Study Area is approximately thirteen miles by fourteen miles in size and lies astride the subcontinental divide approximately twenty miles north of Grand Rapids, Minnesota (Figure 1). 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 diversity of landscape helps to produce a variety in vegetation cover types on the test site (aspen, spruce-fir, red pine, jackpine, northern hardwoods, shrublands, marsh, grass and croplands).

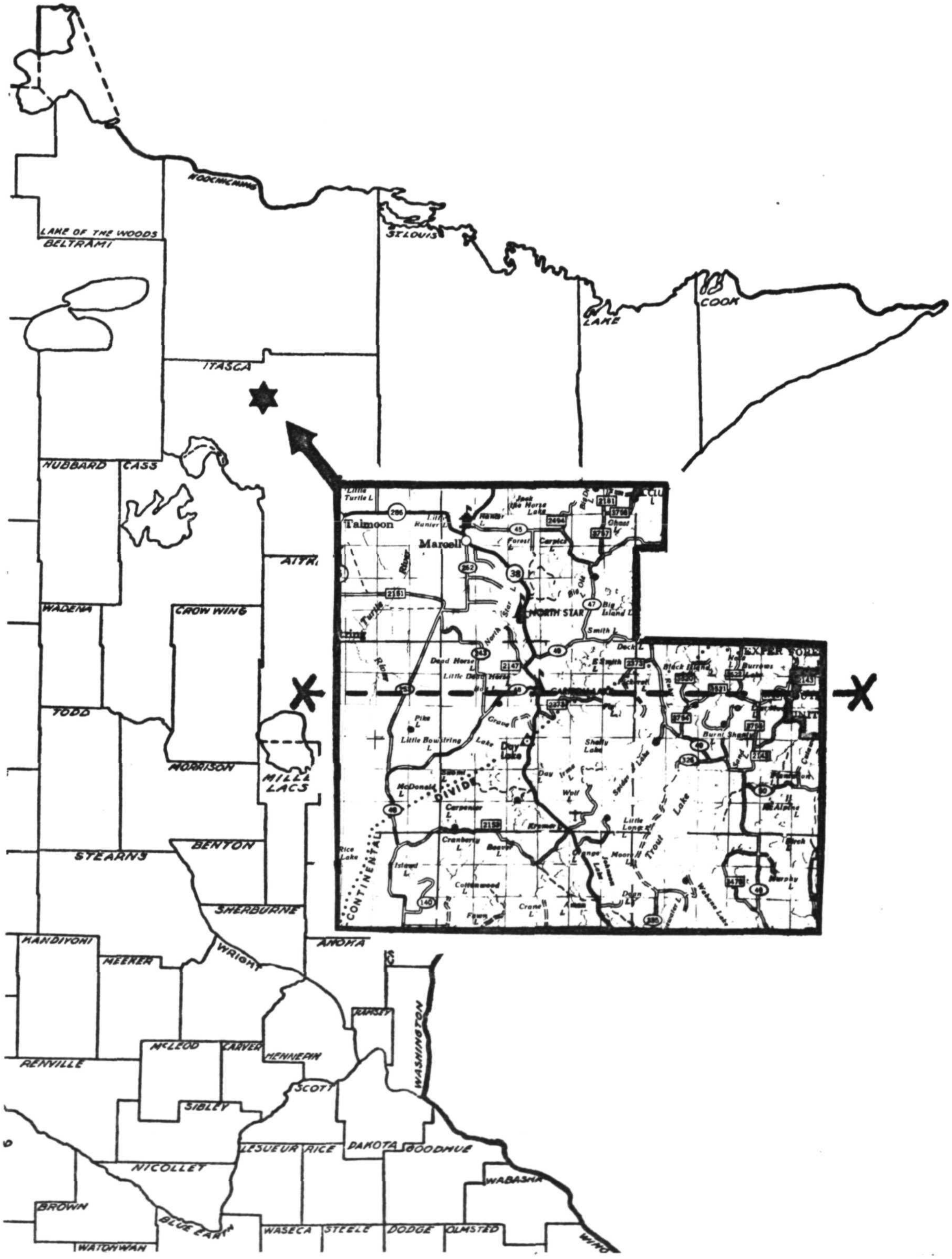


Figure 1. Location and nature of Chippewa National Forest Test Site. The flight line of the RB57F is located on the enlarged insert map of the test site.

STUDY DESIGN, DATA COLLECTION

The types of aerial photography provided by NASA for this test are listed in Table 1. The photographs used (prepared in sets according to scale, film type, and season of the year) involved the sets listed in Table 2. All seven sets were photographed by the NASA RB57F flying at 60,000 feet above mean sea level along the flight line indicated in Figure 1. Positive transparency duplicates prepared by NASA-Houston were used in all seven sets. Selected samples of the imagery are portrayed in Figures 2, 3 and 4. Stereoscopic viewing was accomplished on a Richards portable light table. Although a variety of stereoscopes were available for use, all five interpreters elected to use the folding Abrams CF-3 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 were the high altitude aerial photographs available to foresters on a working basis.

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.

The five interpreters each 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 stereopair 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

Table 1. Photographic coverage of the Chippewa National Forest Test Site provided by the NASA RB57F Aircraft.

Flight Date	Camera	Focal Length	Film	Filter Wratten	Data
August 6, 1971	RC8	6 in.	2443	15	Ekta IR
	RC8	6 in.	S0397	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.	S0397	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&W
	Hasselblad	40 mm	2402	58	B&W

Table 2. Films, scales and dates of photography used in the forest vegetation classification test on the Chippewa National Forest Test Site.

Set	Film		Scale	Date
	Emulsion	Size		
1	color IR	9x9-inch	1:60,000	9/29/71
2	color IR		1:120,000	8/6/71
3	color IR		1:120,000	9/29/71
4	color		1:120,000	8/6/71
5	color		1:120,000	9/29/71
6	color IR	70mm	1:460,000	9/29/71
7	color		1:460,000	9/29/71

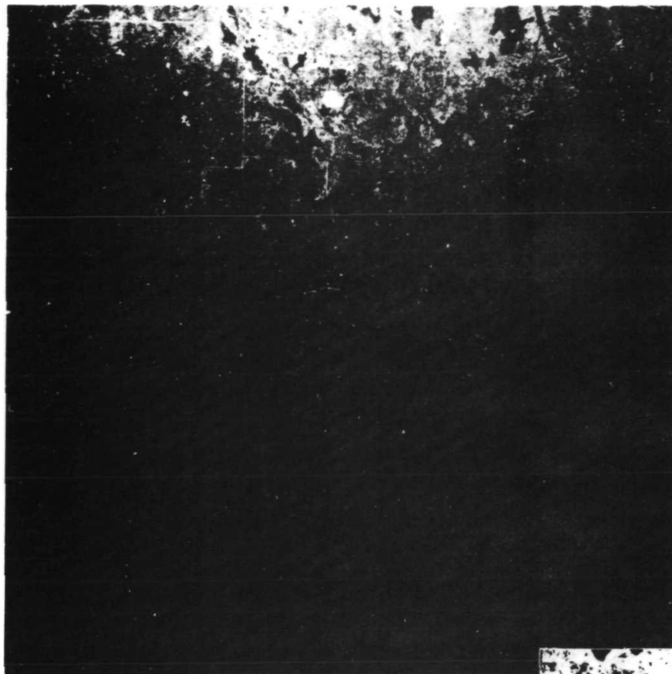
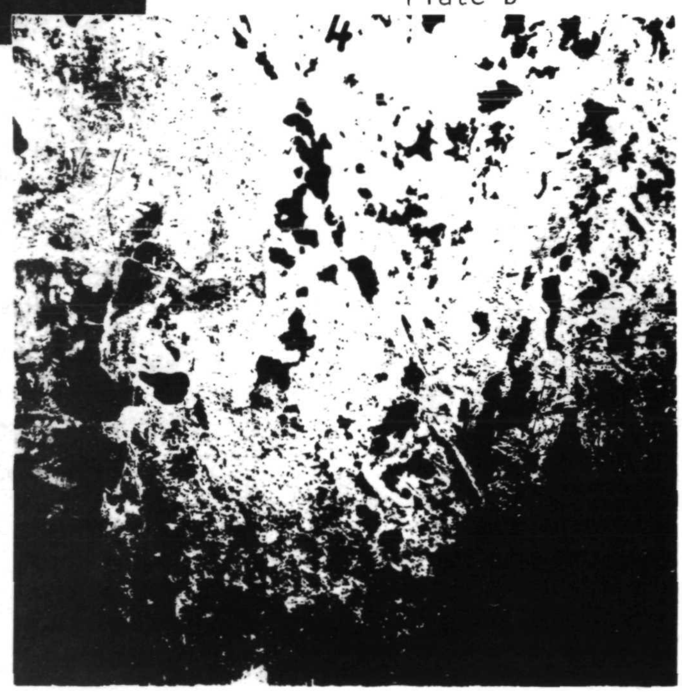


Plate A

Plate B



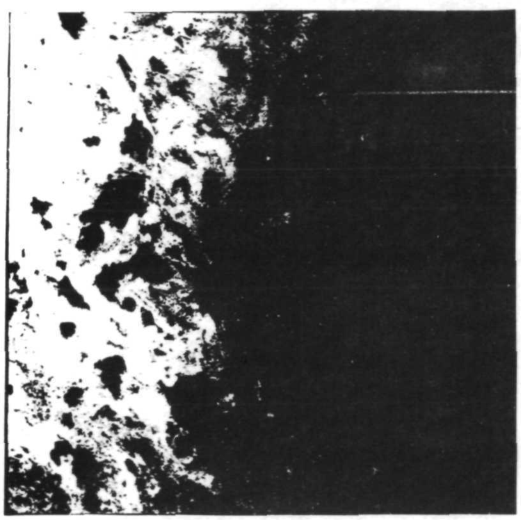


Plate C

Figure 2. Examples of 1:460,000 original scale 70mm RB57F imagery of the Chippewa National Forest Test Site, flown September 29, 1971. Plate A = Ektachrome MS; Plate B = Color infrared; Plate C = color-combined rendition of the B&W multispectral (Plus-X/Wr58 + Plus-X/Wr25 + Aero infrared/Wr89B). Plates A and B shown 1.6X original scale.

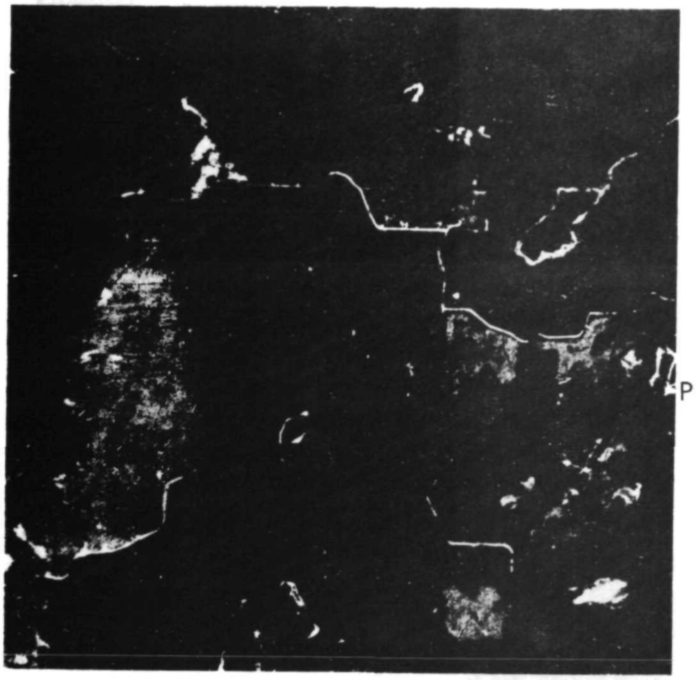


Plate A

Plate B

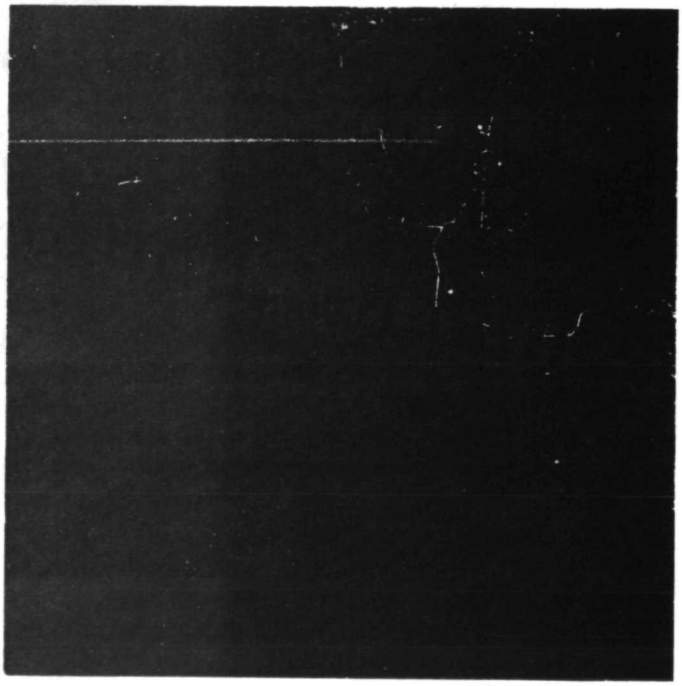


Figure 3. Examples of portions of RB57F 1:120,000 original scale 9x9-inch format Ektachrome (color) photography of the Chippewa National Forest Test Site. Plate A = Exposed on August 6, 1971 - shown 1.65X original scale; Plate B = Exposed on September 29, 1971 - shown 1.65X original scale.

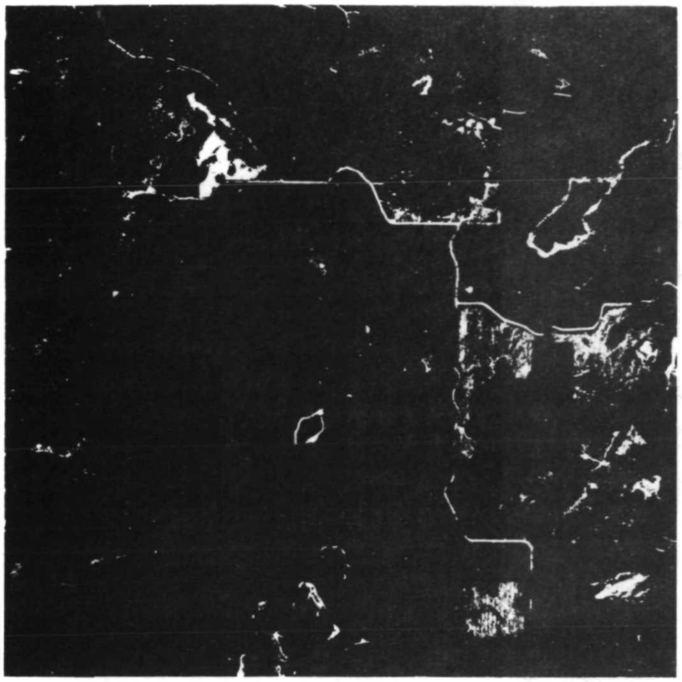


Plate A

Plate B

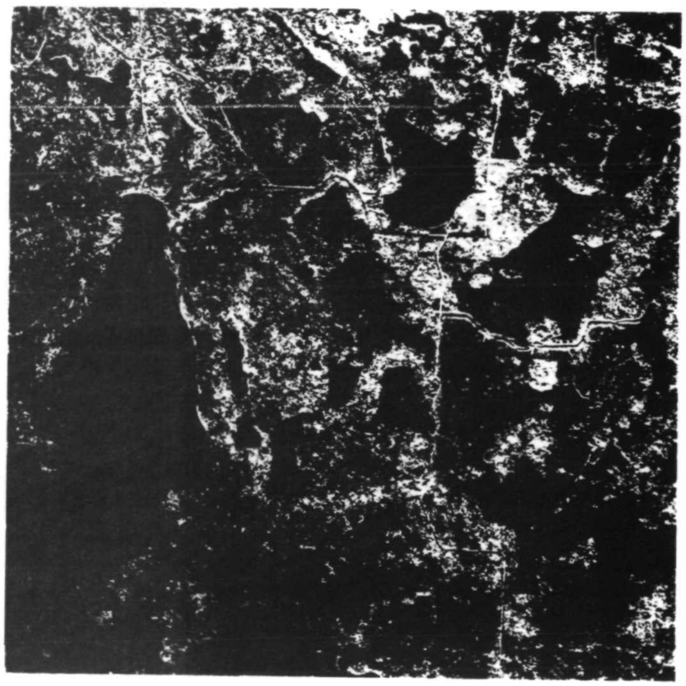


Figure 4. Examples of portions of RB57F 1:120,000 original scale 9x9-inch format color infrared photography of the Chippewa National Forest Test Site. Plate A = Exposed on August 6, 1971 - shown 1.65X original scale; Plate B = Exposed on September 29, 1971 - shown 1.65X original scale.

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 of the Marcell Ranger District and numbering the grid intersections. The grid numbers were then selected by using a table of random numbers. All of the plot selection was completed on the vegetation cover map supplied by the Chippewa National Forest (see Figure 5) 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 fifty-six plots that each observer was to interpret.

Test administration. Eight numbered plots were marked on each set of photographs with india ink. An answer form with the corresponding numbers were 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.

DATA ANALYSIS, RESULTS

Approach, Methods

Result analyses were accomplished through the use of factorial designs to test for significant differences related to scale, film, type, cover

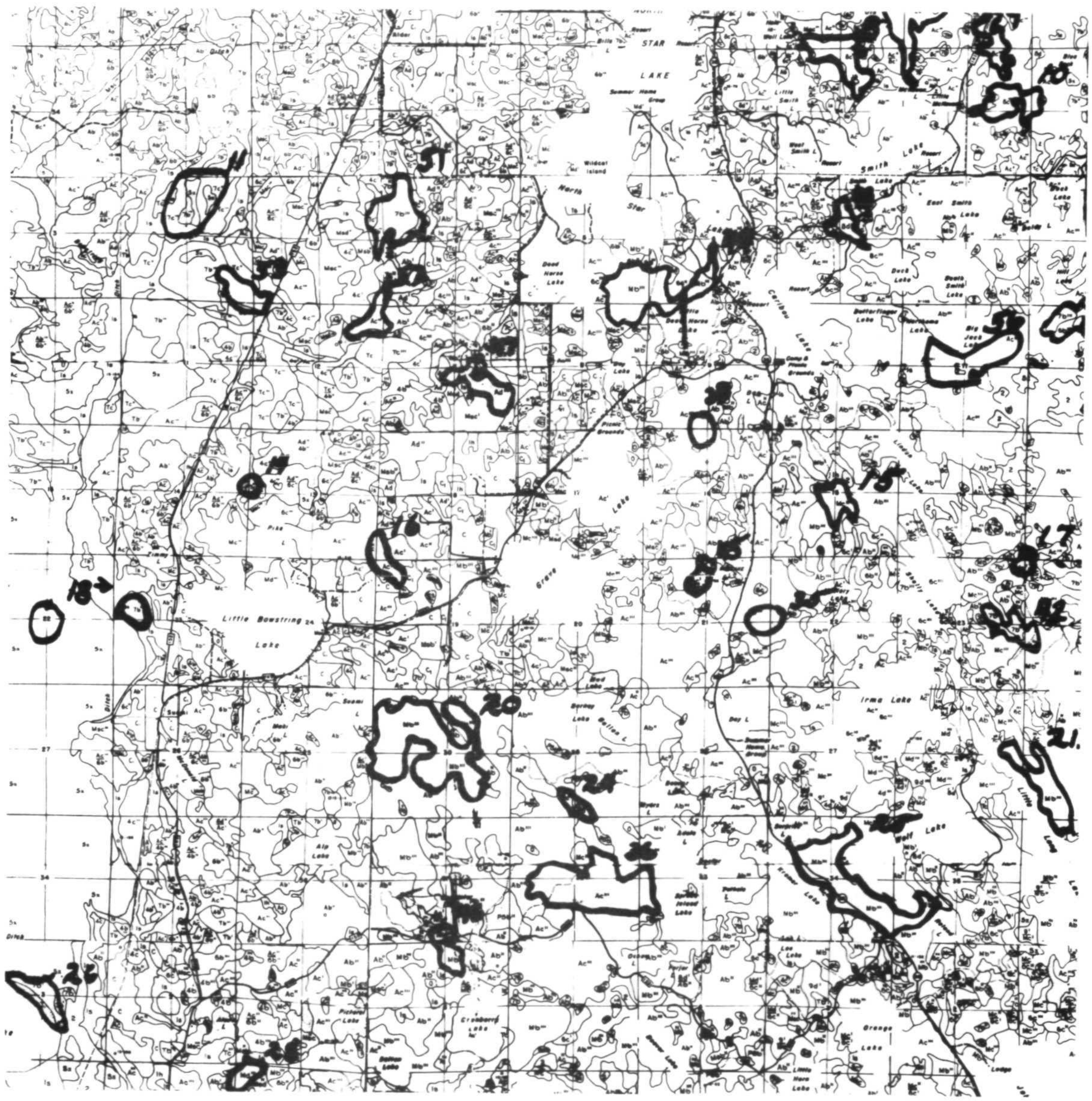


Figure 5. Chippewa National Test Site cover type map and plot locations.

types and interpreters. 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 analysis of variance to test the following null hypotheses:

> 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 2x2x4 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).

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

A 3x4 factorial was used in this test of s gnificant difference. The main effects were photo scale (3 levels) and timber type (4 levels).

> 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 to be used to determine if the observer's scores are significantly different from one another.

The questionnaires were hand-scored and the score 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 (3).

Statistical Investigation Results

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 photography taken on August 8 and September 29, 1971, at a scale of 1:120,000 was used in this analysis.

Film effect was significant at the ninety-five percent level while season effect was significant at the ninety-nine percent level. Vegetative cover type did not significantly influence the scores at the ninety-five 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 to summer photography by a score of 66 to 51. No significant difference in vegetative cover type identification was shown in this experiment.

Interaction between the film type and the season proved to be highly significant (99% level) while the other first order interactions were not significant. The second order interaction of film, season, and cover type was significant at the ninety-five percent level. Based on the significance of the interactions, Null Hypothesis I_B must be rejected (see Table 3).

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

Null Hypothesis II (scale, cover type). 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 1:60,000, 1:120,000 and 1:460,000 were used in this test.

The effect of photograph scale was significant at the ninety-nine percent level. Vegetation cover type did not have a significant effect at the ninety-five percent level. Null Hypothesis II_A should be rejected because of the significance shown in the Analysis of Variance summary in Table 4. Since no significance can be attached to the effect of interactions, there is no basis for rejecting Null Hypothesis II_B.

Scores of 38, 32, and 27 out of a possible 40 were made, respectively, on 1:60,000, 1:120,000, and 1:460,000 scale of photography (see Table 4).

Null Hypothesis III (interpreters). A one-way classification was made to test for differences among the interpreter's 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 5).

No multiple comparison procedure was performed on the data because the F-ration showed no significant difference in the scores. Steel and Torrie recommend against making multiple comparison tests when the F-ratio is not significant (3).

Interpreter Reactions

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 9x9-inch format 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 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 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 based upon their feeling of ease of interpretation. The results of this ranking are given in Table 6.

Table 3. 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 4. 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		

Table 5. 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	2.3333	
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

Table 6. Results of interpreters' ranking of the film/filter/season combinations in the vegetation classification tests and the test scores obtained.

Interpreter's ranking of film/filter/season combinations		Test score ranking of film/filter/season combinations	
(best)	Color infrared-fall	Color-fall	34[1/] (highest)
	Color-fall	Color infrared-summer	32[1/]
	Color infrared-summer	Color infrared-fall	32[1/]
(worst)	Color-summer	Color-summer	19[1/] (lowest)

[1/] Score out of a possible 40 points.

SUMMARY, PRACTICAL IMPLICATIONS

Summary

1. The scale of the photographs had a very significant effect (0.010 probability) on the interpreter's ability to identify the vegetation cover types. Scores of 38, 32, and 27 out of a possible 40 were made on 1:60,000, 1:120,000, and 1:460,000 scale photography, respectively. However, the interpreters commented that they had no preferences for any of the scales that they had used in the sub-study.

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

3. The observers' comments were mostly concerned with the season that the photographs were taken. The season did have a very 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.

4. Color infrared film produced the highest score with 64 correct plots out of a possible 80 plots (Table 7). 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 season/film combination produced the poorest results in this sub-study.

Practical Implications

That there is a direct cost relationship between relative photo scale and related costs of photography procurement and information extraction is obvious. For example, it takes half the flight lines and half the exposures in each flight line to obtain photography of a given area at a scale of 1:100,000, as compared to the coverage of the same area with 1:50,000 scale. It is also obvious that it will cost considerably more to interpret the 1:50,000 scale photography since it will involve the handling of four times as many individual prints as is the case with the 1:100,000. Achievement of the savings possible, however, is dependent upon an ability to derive the information required from the smallest scale. It was the purpose of

Table 7. Degree of success achieved in discrimination of 4 basic forest cover types by 5 trained Chippewa National Forest photo interpreters using NASA RB57F color infrared photography. Note that the detectability of northern hardwoods increased from 50% for the 1:120,000 scale 8/6/71 photography to 80% for the 1:460,000 scale 9/29/71 photography (*). This was due to the more highly visible fall coloration of the northern hardwoods in September, as compared to the photography flown in August prior to fall coloration.

Cover type	Color infrared photo scale		
	1:60,000[1/]	1:120,000[1/]	1:460,000[2/]
	-percent interpretation success achieved-		
Aspen	100%	100%	80%
No. hardwoods	90%	50%*	80%*
Spruce-fir	90%	80%	60%
Pine	100%	90%	50%
All hardwoods	100%	100%	95%
All conifers	100%	100%	80%

[1/] Flown August 6

[2/] Flown September 29

this study to determine the possibility of achieving first-stage (vegetation) classification with small scales of aerial photography - and, if so, what particular film/filter/season/scale combination would best be suited to the task.

Although medium scale (1:15,000 to 1:24,000) resource aerial photography is generally available, and in intensive use, on almost all forest areas, there is increasing interest in classification, planning and management of large land units representing broad vegetation types, land uses, physiographic and soil provinces. Since it is slow and costly to arrive at these broad definitions with available ground methods and/or medium scale photo coverage, there is broadening interest in very small scale aerial photography (and space imagery) to achieve the broader resource definitions necessary to large-area planning. What is being suggested is that land managers will ultimately require two or more levels of imagery to accomplish the overall tasks of resource assessment and management.

Where resource management is concerned, aerial photo coverage is normally a relatively small portion of the total management cost picture. By shifting all possible large area-related information extraction functions from currently-available large to medium-scale photo coverage, considerable savings can be achieved in terms of the time and effort required to obtain the necessary information. The results of this study very strongly substantiates the work of Ulliman and Meyer (4) which showed it possible to accomplish certain information-gathering functions with smaller scales than are now being utilized and with considerable savings.

In summary, this study suggests that very small scale, 1:100,000 to 1:120,000, fall or summer color infrared forest aerial photography can be an economically important source of management information. Both in terms of economy and efficiency, it will serve best as a first-stage sampling and classification medium when used in conjunction with more conventional medium scales of resource photography on a large-area management unit such as national or state forests, counties or major private holdings.

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Chapter 4

DETECTING SALINE SOILS IN THE RED RIVER VALLEY, MINNESOTA, BY REMOTE SENSING TECHNIQUES

Richard H. Rust and Bruce H. Gerbig

ABSTRACT

In this study the use of several kinds of photo imagery is evaluated for detection and delineation of saline-affected soil areas in a portion of the Red River Valley of Minnesota. Two ten-mile transects crossing the common range of soil conditions were monitored. Ground truth consisted of mapping the soils in the saline-affected area at a 1:20,000 scale and making conductivity measurements in selected small grain and fallow fields in saline and non-saline affected areas. Kodachrome 35mm imagery was used to broadly outline affected areas. Density level-slicing techniques were employed on color infrared imagery in a qualitative analysis. After separation of cultural patterns, identification of saline-affected areas was greatly facilitated by image analysis. The effort is directed toward providing the county assessor with information to use in rural land assessment.

INTRODUCTION

The use of remote sensing techniques for the detection of saline soils is a comparatively recent development. Previous work has centered on determining the effects of saline soils on plant growth and the use of remote sensing techniques for general soil mapping and the detection of plant disease conditions. A survey of the available literature reveals few sources that directly relate the application of remote sensing techniques to the detection and delineation of saline soils. Such studies were done using vegetative cover conditions as being indicative of the saline properties of the soil. In this study an alternate approach is also being investigated for mapping saline soils in the Red River Valley. In this attempt, efforts are being made to relate soil spectral characteristics to the saline properties of some Kittson County soils.

Soil salinity in the Red River Valley has been noticed for some time. According to Sandoval (1), Jensen and Neill recognized an "alkali" problem in North Dakota as early as 1902 that was associated with gypsum. They also noted high sulfate concentrations in the soil and high quantities of chlorides in artesian waters.

Nikiforoff (2) was the first to report on soil conditions in Minnesota's Red River Valley area. In his report he surveyed the glacial history, climate, and farming practices of the area and outlined the soil types found in the area. He noted that saline conditions were present, with most of the problem occurring in the northeastern corner of Traverse County and in the eastern part of Wilkin County, mainly the southern end of the Agassiz glacial lake plain.

AREA LOCATION, DESCRIPTION

Topography. The Red River Valley occupies the axial depression of a vast plain which ranges from 40 to 50 miles wide at the south to 80 to 90 miles at the north and is about 300 miles long, extending from Lake Traverse to Lake Winnipeg.

The greater part of the area was covered in geologic history by Glacial Lake Agassiz. This area is very flat and is characterized by lacustrine sediments over glacial drift. The remaining part belongs to the extensive uplands surrounding the ancient lake bed. These areas are gently undulating to rolling.

Slopes range from two feet to about one-half foot a mile towards the north and range from over 15 feet per mile in the eastern part of the valley to less than three feet per mile in the west.

Climate. U. S. Weather Bureau records indicate that the climate of the area is subhumid, being characterized by long cold winters and relatively hot summers. Mean winter temperatures range from 4.3° F to 13.7° F and mean summer temperatures range from 64.8° F to 68.9° F. Soine (3) reports an average April-September temperature of 59.2° F and Oct.-Mar. temperature of 20.2° F. About 75% of the annual precipitation occurs in the April through October months, with the rest occurring as snow. Annual precipitation ranges from a high of about 23 inches to a low of about 19 inches.

Geologic History. The Wisconsin glaciation left a nonuniform drift ranging in thickness from less than 100 to several hundred feet covering the entire Red River Valley (2). From the melting of the ice to the formation of the present soils, the surfaces of the drift deposits were modified by many geological processes and these processes produced several types of parent material.

Most of the region, including Kittson County, was covered by glacial lake Agassiz, following the recession of the glacier. This lake eventually drained southward by means of Glacial River Warren. As the glacier receded, it left a series of recessional moraines. By the time it had retreated to the area between Moorhead and Crookston, the water back of it was 200 feet deep in the Fargo region and it began to flow back through Glacial River Warren (4). It later flowed into northern Minnesota by an eastern outlet.

On account of this lowering and changing of outlets, several beach ridges were established as wave action worked and reworked the sediments. This wave action also accounts for the gradual sorting of materials with the sands and gravels to the eastern edge of the old lake basin, and the clays and silts to the middle of the basin. As the lake gradually decreased in size, the strength of the wave action also decreased, and this also decreased the carrying capacity of the water. In the last stages, sediments from tributary sloughs and rivers were added to the already sorted lacustrine deposits.

Land Use Patterns. Present land use patterns in the initial study area indicate a diversity of land uses, with agriculture being dominant. Figures from the U. S. Dept. of Commerce (5) show that, of 718,976 acres of land in Kittson County, farms occupied 544,575 acres in 1969, with this being further divided into 436,902 cropland acres, 57,801 woodland acres and 49,872 acres of other land use. The major crops by area are wheat, other small grains, and hay. These crops occupied 230,988 of 266,457 acres actually cropped in 1969.

Soil Salinity. The saline phases of soils in the Red River Valley are commonly associated with the extensive soils such as the Bearden, Ulen, and Foxhome series, with an occasional saline phase of the heavier Fargo series. Nikiforoff (2) stated that these phases occur in poorly drained areas, often occurring within the gravelly ridges. These ridges block the surface drainage and evaporation brings the soluble salts close to the surface. The salts are mostly carbonates and sulphates of calcium and magnesium, with gypsum being common. Sandoval (1) reports that for similarly affected areas of North Dakota, the saline areas can be characterized by an undulating microrelief, with the salts being concentrated on the ridges. Salt accumulations there are apparently due to a comparatively greater upward than downward movement of soil moisture. Allison (6) states that waters increased in salinity from east to west within the valley, with the highest figures from those areas underlain by Cretaceous beds. The study area, besides being underlain by these Cretaceous deposits, also has an artesian head of 10 to 25 feet in the western part of the county. Salt water escaping from the subjacent rocks percolates upward through the drift very generally and even issues as salt water seepages, with salinity readings ranging to 57,224 parts per million.

Interpretation of Imagery. Richards (7) indicates that a field of crop plants growing on saline soil usually has (1) barren spots, (2) stunted growth, (3) considerable variability in size, and (4) deep blue-green foliage. He further notes that these are not invariable indicators, because these conditions can also be caused by other things.

Previous studies that have involved the use of remote sensing techniques have always used plants as indicators of saline conditions that occur below the soil surface. Myers' (8) work involved the use of cotton plants as indicators relating salinity in the 0-5 ft. soil profile at selected points where salinity was known to a number of prediction sites where salinity ranges were predicted from plant growth and vigor conditions. An earlier study by Myers (9) had shown that healthy vegetation from non-saline soils had a higher infrared reflectance than the vegetation from saline areas. With this principle, he used color infrared aerial film to photograph test sites that had varying salinity readings. The cotton plants that were affected by salinity appeared as darker shades of red, and, when seriously affected, nearly black. This is compared to bright red for healthy plants. Results showed that five salinity groups could be delineated and significance at the 5% level was achieved.

Gausman (10) was to show later that cotton plant leaves from a highly-saline soil appeared higher in chlorophyll content than leaves from a low-saline soil area. Leaves with higher chlorophyll concentrations induced a darker red tone on color infrared film than low chlorophyll content leaves because of the reduced visible light reflectance. A lower reflectance over the approximate wavelength interval of 600 to 700 nm results in a greater saturation of the magenta positive image, which contributes the most to the viewer's subjective impression of darkness on an EIR transparency.

STUDY DESIGN, DATA COLLECTION

Kinds of Imagery Obtained. Photography of the Kittson County test site was obtained on Oct. 23, 1972. A 70mm quadricamera system developed by the University of Minnesota, College of Forestry (11) was used with the following film/filter combinations: Plus-X/58, Plus-X/25A, Aero IR/89B, and Aerochrome IR 2443/15 and 15 + 20C, and was flown at scales of 1:20,000 and 1:64,570. An additional set of coverage was obtained on 35mm Aerochrome IR 2443 with a No. 15 filter at a scale of 1:184,440. These film/filter combinations correspond to the multispectral scanner imagery provided by the ERTS-A satellite that was launched on July 23, 1972. Other aerial photography resources from the A.S.C.S. and S.C.S., U.S.D.A., are also being utilized.

Progress of Investigation. In the Red River Valley significant areas of soils have a problem of excess salinity. The condition has been increasingly recognized in the course of detailed soil surveys over the past two decades and indicated even earlier by a reconnaissance survey in the 1930's.

The problem has been, and remains, to be able to delineate the saline, or near saline, areas with good definition. There is some indication that the nature of the areas, their size and the severity of the saline condition are related to the annual weather pattern. There appears to be a more severe inhibition of yields from salts in a drier than normal year.

In respect to the commonly grown field crops in the area wheat shows the effects of a saline soil condition more readily than barley or oats and the manifestation of growth reduction is most clearly evident at time of "maximum green" - i.e., last week of July through mid-August, depending on the growing season. Thus it was felt that remote imagery taken at this time would be most helpful.

Two east-west transect lines 10 miles long were selected in the western half of Kittson County (Figure 1). The transects were selected in areas believed to have extensive salinity; also across a range of soil types ranging from the very clayey soils nearer the Red River to medium (loamy) soils and to some sandy soils on the eastern end of the transects. The salinity condition occurs in the total range of these soils but is generally more serious in the clayey soils of Kittson County.

Due to adverse flying conditions in the area, the planned imagery was not obtained until mid-October, 1972. By this time a major portion of the landscape is customarily plowed. Under this condition the best indication of a saline soil condition is in the lack of stubble, or dry residue, i.e., the bareness of the plowed land becomes an indication of a saline situation. In the extremely saline areas no wheat will grow or only minimal growth occurs (Figure 2).

Sample fields were selected in which wheat or barley was growing in 1972. Some fallow fields were selected also. Since almost 20 percent of the land is kept in fallow and since farmers frequently choose the more saline areas to put into fallow (idle), relatively higher percentages of these fields will have some salt problem.

Soil samples were taken in selected fields along the 10 mile transect. The samples were taken in N-S or E-W linear transects across areas believed to represent saline and non-saline areas. Samples were taken of the surface as well as subsurface horizons and conductivity measurements made. Table 1 gives the results of samplings in the south (Davis) transect and Table 2, results in the north (Clow) transect. Conductivity values of four (mmhos) or higher are associated with commonly visual symptoms of plant stress in wheat.

On August 12, 35mm Kodachrome II imagery was obtained from an aircraft flying at about 1000 feet over the presumed saline-affected areas. This photography consisted mostly of oblique views taken from either north-south or east-west flight lines. Figure 3 is an example of a view of about a one square mile area in a Fargo soil area. With the aid of this photography a general delineation of the saline areas is being developed on a one inch to mile aerial photomosaic of about one half of the county area. About 300 Kodachrome images were studied.

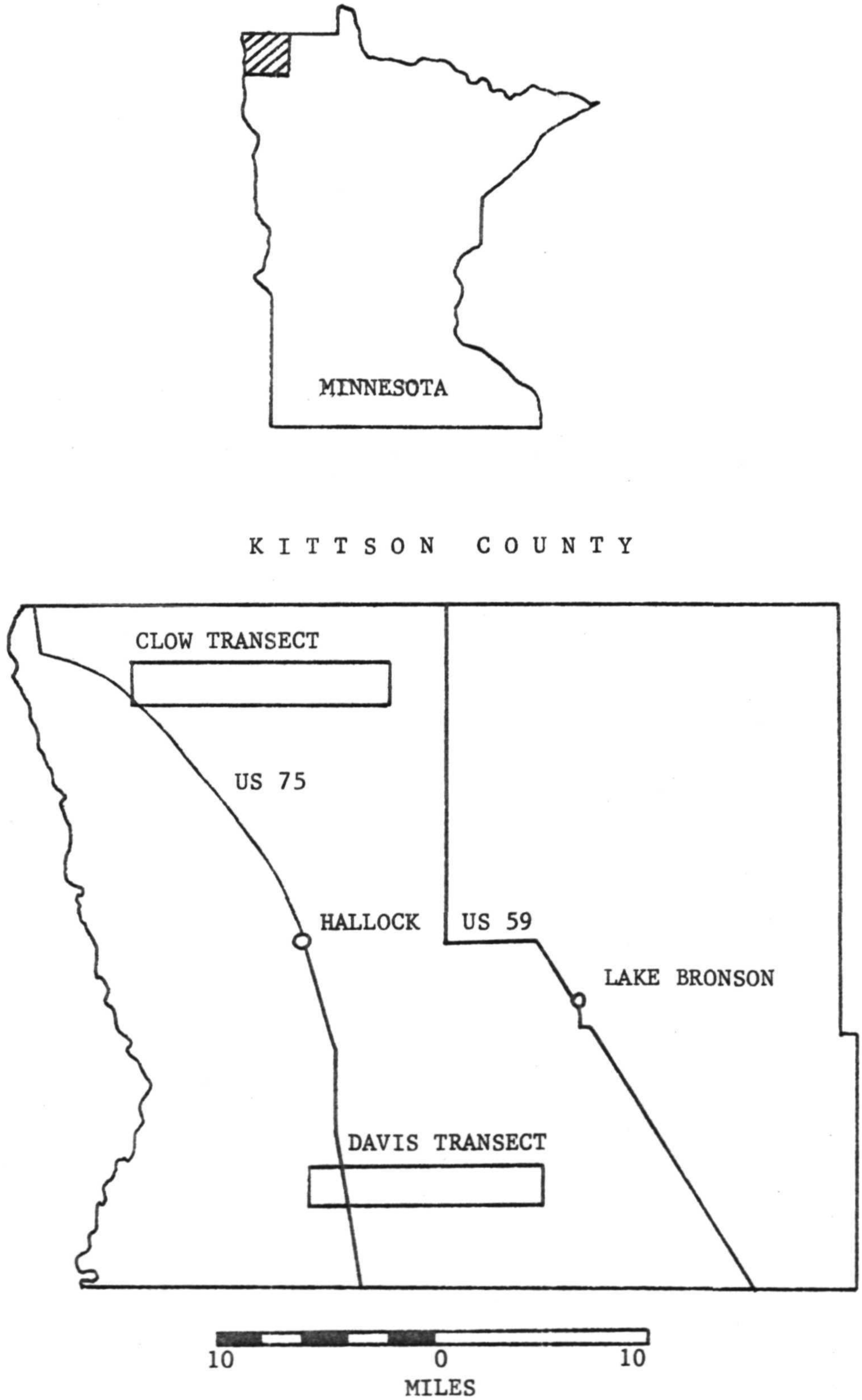

Figure 1. Location of test areas within Kittson County, Minnesota, for aerial photography and field study of saline soil conditions.

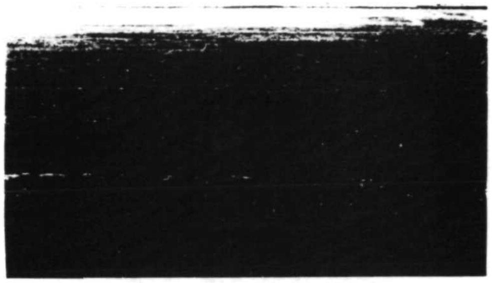

Figure 2. A field of barley showing significant crop loss from saline soil conditions. (Field A2, Davis Transect, August, 1972).

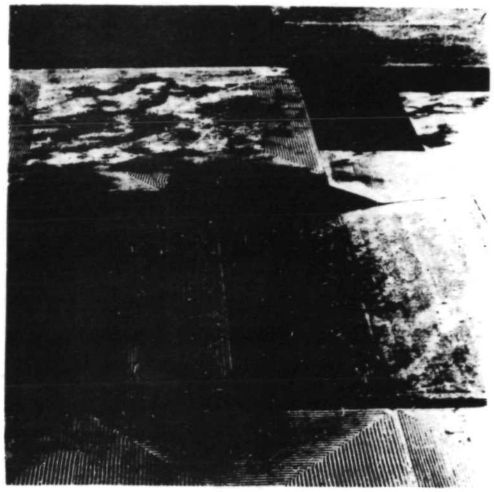

Figure 3. Oblique view of saline-affected area (Fields A1, As and A3 in south half, Sec. 8, Davis twp; Kodachrome II, August 12, 1972).

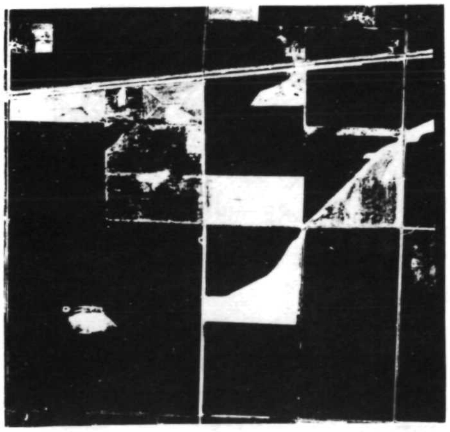

Plate A

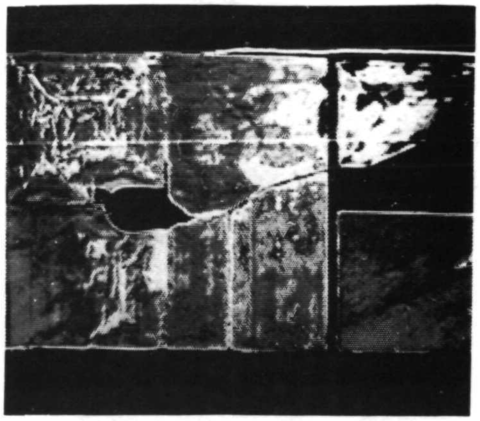

Plate B

Figure 4. Correlation of color infrared imagery to its density level-slice rendition. Plate A illustrates the CIR imagery obtained on October 20, 1972. Plate B depicts the color rendition created with density level-slicing techniques.

Table 1. Conductivity measurements on surface and subsurface soil samples taken in fields along north (Clow) transect in Kittson County, Minnesota, in 1972.

	Fields							
	F-1		F-2		F-6		M-2	
Site*	Surface	Sub-surface	Surface	Sub-surface	Surface	Sub-surface	Surface	Sub-surface
	mmhos/cm							
1	4	2	7	12	<1	<1	2	<1
2	4	4	3	8	<1	<1	1	1
3	4	8	7	9	1	1	1	2
4	2	2	<1	9	1	1	<1	<1
5	8	4	1	3	1	<1	<1	<1
6	8	4	5	10	1	<1	<1	1
7	4	8	1	2	1	<1	2	4
8	4	4	2	5	1	1	1	1
9	4	4	1	1	1	2	1	6
10	6	6	<1	7	1	<1	2	1
Crop:	Wheat		Wheat		Fallow		Fallow	
Soil:	Fargo-Hegne		Fargo-Hegne		Fargo-Hegne		Norliss	

* Sites about 100 feet apart.

Table 2. Conductivity measurements on surface and subsurface soil samples taken in fields along south (Davis) transect in Kittson County, Minnesota, in 1972.

	Fields																			
	A		A1		A2		A3		A5		5		K		L		M		H	
Site*	Surf	Sub	Surf	Sub	Surf	Sub	Surf	Sub	Surf	Sub	Surf	Sub	Surf	Sub	Surf	Sub	Surf	Sub	Surf	Sub
	mmhos/cm																			
1	8	8	4	2	15	20	18	20	13	13	8	8	4	2	1	1	1	<1	4	8
2	12	12	4	4	18	18	3	5	2	2	2	0	2	3	<1	<1	1	<1	12	12
3	12	12	8	4	9	18	12	13	5	6	8	8	4	2	<1	<1	1	<1	12	8
4	8	8	2	4	15	14	5	12	1	<1	8	9	4	2	1	<1	3	2	12	6
5	16	12	12	8	16	16	8	11	1	1	12	12	4	6	<1	<1	<1	<1	12	8
6	4	4	8	8	16	16	7	10	2	4	10	10	4	8	<1	<1	<1	<1	2	4
7	9	12	4	8	12	13	25	20	2	3	8	12	4	6	1	<1	<1	<1	4	4
8	4	4	4	8	9	9	12	14	1	5	8	8	4	4	<1	<1	1	1	2	3
9	-	-	8	8	10	15	15	16	1	<1	12	2	4	4	1	<1	-	-	2	2
10	-	-	4	8	4	8	24	17	1	1	4	8	4	6	2	1	-	-	2	2
Crop:	Barley		Fallow		Barley		Fallow		Wheat		Barley		Fallow		Fallow		Wheat		Barley	
Soil:	Fargo		Fargo		Fargo		Fargo		Fargo		Bearden		Bearden		Wheatville		Wheatville		Wheatville	

* Sites about 100 feet apart.

On October 23, 1972, additional imagery along the selected transect lines was obtained as indicated by items 4-8 in Table 3.

Also on October 10, imagery from ERTS-A MSS bands 4, 5, 6 and 7 was obtained. ERTS imagery on other occasions during the period August through October was of poor quality due mostly to cloud conditions.

Interpretation and Analysis of Imagery.

1. Panchromatic (1:15,840). This imagery has been used in the course of the presently conducted detailed soil survey of Kittson County. Light and dark toning is mostly related to occurrence of calcareous surface horizons (light tones) and to depressional soil areas (darkest tones). The occurrence of saline areas is not established with any confidence using this photography.

2. Panchromatic (1:90,000). This imagery which was flown in 1969 on a state-wide basis has been useful in composing an aerial photo mosaic for that portion of Kittson County in which the saline soil areas occur. On a mosaic scale of 1:63,360 (one inch equals one mile) a general delineation will be made of soil areas believed to be salt-affected.

3. Kodachrome (35mm, oblique views). This imagery, uncontrolled, was taken to assess the value of color imagery taken of the crops at a time when maximum expression of salt damage is most evident. Figure 3 is an example of this photography. The poor stand of small grain is largely related to salt damage.

4. The Plus-X/58, Plus-X/25A, and Aero Infrared/89B film/filter combinations taken on October 23 were intended to approximate ERTS-A's MSS bands 4, 5, and 6. After some study, it was decided that the Aerochrome IR 2443/15 film/filter combination approximates a combination of these MSS bands and, with the use of the image analyzer, afforded the best correlation with observed and measured saline conditions. Figure 4 (Plate A) is an example of this imagery (also of approximately the same areas as the previous Figures 1, 3, and 4). A number of the sample fields (Tables 1 and 2) were studied using this color IR imagery and evaluating density with the ISI VP8 Image Analyzer.

Figure 4 (Plate B), which is taken of the display on the SL-14 Color Monitor, is of the south half of Section 5 and all of Section 8, Davis township. The majenta area in the center of Section 8 is a depressional

Table 3. Imagery obtained and available for study of saline soil areas in Kittson County, Minnesota in 1972.

Kind of film	Filter	Date of photography	Scale	Use
Panchromatic (9x9")	12	7/16/66	1:15,840	Soil Survey
Panchromatic (9x9")	12	May, 1969	1:90,000	Compose mosaic
Kodachrome (35mm)	--	8/12/72	about 1000 feet altitude, oblique	Crop condition
Plus-X (70mm)	25A	10/23/72	1:20,000, 1:64,570	Soil & Crop analysis
Plux-X (70mm)	58	10/23/72	1:20,000, 1:64,570	Soil & Crop analysis
Aero IR (70mm)	89B	10/23/72	1:20,000, 1:64,570	Soil & Crop analysis
Aerochrome IR 2443 (70mm)	15+20C	10/23/72	1:20,000, 1:64,570	Soil & Crop analysis
Aerochrome IR 2443 (35mm)	15	10/23/72	1:184,440	Soil & Crop analysis
ERTS-A Bands 4,5,6,7 (70mm bulk product)	--	10/10/72	1:3,369,000	Soil & Crop analysis

area having some marsh grass cover, but lacking strong green color (late October). Field A, a portion of the SW quarter, Section 5, appears mostly in cyan and blue. The cyan colored area correspond closely to the more saline areas. On October 23 this field was plowed. The field on the opposite side of the drainage ditch, magenta in the color slice, was unplowed and covered with barley stubble and some quackgrass. Field A1, northwest quarter, Section 8, appears in cyan, green, and orange. The cultural condition was slightly different, having been fallow throughout 1972. The orange areas corresponds to the more saline conditions. The southeast quarter, Section 8, was also fallow in 1972 and much of the area appears in orange and yellow suggesting extensive saline areas. This remains to be field checked.

Figure 5 correlates the image analysis with the ground truth. Plate A illustrates the location of the transect and sample plots on the density slice rendition of the Aerochrome IR imagery while Plate B is the graph of the conductivity readings found along the transect. Note how the various colors correspond with different conductivity values. The principle complicating factor in this comparison is the nature of the ground surface. While a majority of the small grain fields have been plowed, or otherwise tilled, by late October, there are number of fields remaining in stubble or as new legume seedings. These fields require a different interpretation of the density, e.g., salt-damaged crops will have less stubble residue in the affected areas, will appear darker on the color IR transparency and will be in the red end of the red to magenta (8-level) color slicing. On most of the fallow fields the higher conductivity areas appear in the orange slice of an 8-color image slice (red, yellow, orange, green, violet, cyan, blue, magenta).

Figure 6 illustrates a portion of an ERTS-A scene enlarged to illustrate the area of the south (Davis) transect line. This image was produced by color-combining MSS bands 4, 5, 6, and 7 in the I^2S color combiner. While the area illustrated in the previous figures is visible (note irregular shaped field in Section 5 which is light colored from stubble residue not plowed on October 10), the detail is not sufficient to delineate saline areas which often occur as a few acres in a non-saline area. Forty-acre fields are about the smallest recognizable delineation although, at

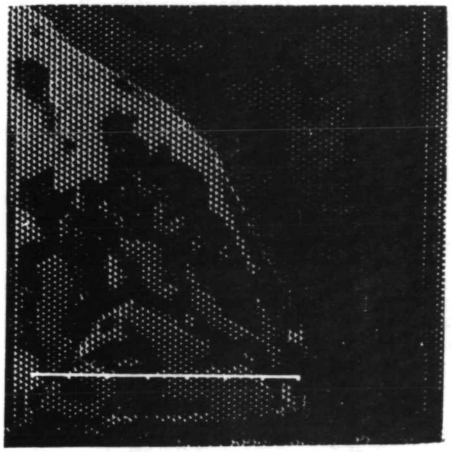

Plate A

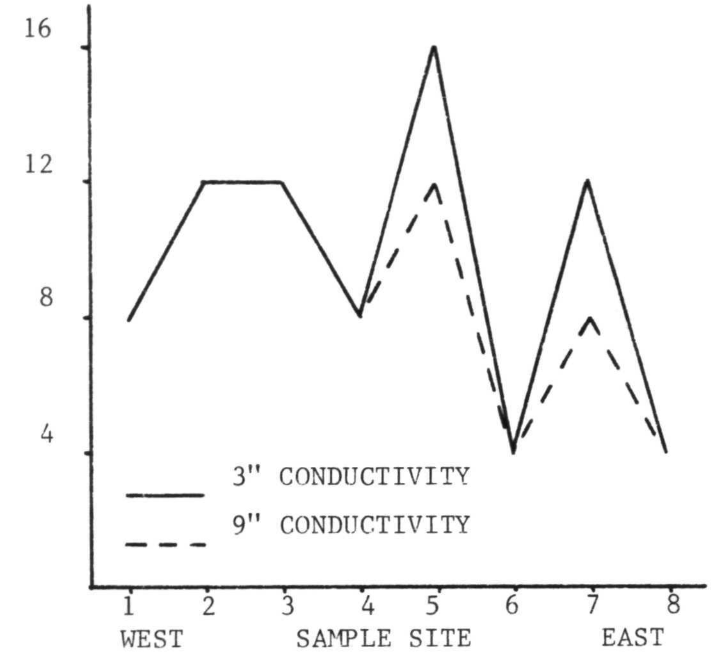

Plate B

Fig. 5. Correlation of image analysis and ground truth. Plate A depicts the location of the sample points and Plate B graphically shows the salinity in terms of conductivity readings. Note how the colors correspond with conductivity graph.

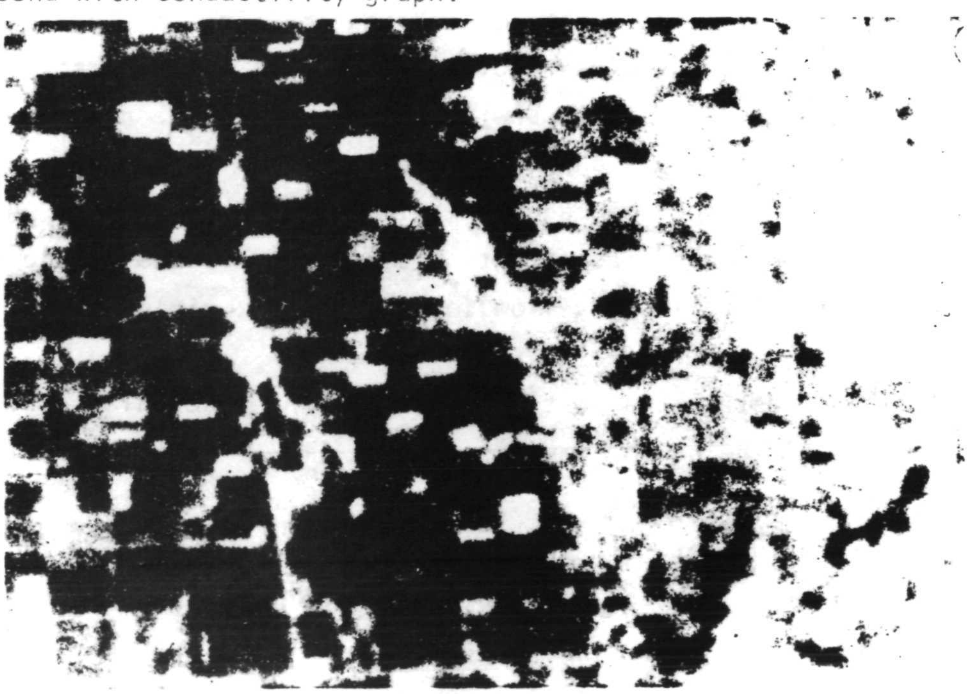

Fig. 6. ERTS scene of October 10, 1972 covering the south (Davis) transect in Kittson County - enlarged to approximately 1:175,000. Image is color combination of MSS bands 4, 5, 6 and 7.

this scale, many cultural features are apparent: plowed or fallow fields; the permanent grass areas at the eastern margin of the glacial basin (sandy soils); and tree vegetation along major water-courses.

SUMMARY, PRACTICAL IMPLICATIONS

Summary

1. In cooperation with field soil scientists and county technical workers areas of significant saline conditions were outlined and transect study lines selected.

2. Conductivity measurements and crop conditions were measured and observed on a sampling of fields along the transect lines.

3. A study of Kodachrome 35mm imagery taken in August indicated that crop conditions and crop density are well shown and can be correlated with saline conditions. Since this was uncontrolled (i.e., oblique views) photography, it was not suitable for accurately mapping saline areas.

4. Color infrared imagery, at a scale of 1:20,000, taken in late October and subjected to image analysis was of some value in delineating saline conditions on essentially bare soils. However, a subsequent attempt (1973) will be made to obtain color infrared imagery (or color) at maximum small grain growth, or just prior to harvest.

5. A principal problem remains in the cultural separation of image analyzed photography. One signature for saline areas may be developed for fallow, or bare, soil but a different signature must be developed where the crop condition is being used as indicator. It is not yet clear which is the more feasible or efficient procedure.

Practical Implications

A principal application of this investigation is to assist the county officials in delineating as precisely as possible, the saline-affected soil areas so that ameliorative procedures may be adopted. Some fairly successful treatments have been developed by research in similar North Dakota situations. A second application will be an assist to the county assessor in his attempts to equalize rural land assessments to reflect reduced productivity on salt-affected soils.

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Chapter 5

CORN DEFOLIATION SURVEYS

H. C. Chiang and Merle P. Meyer

ABSTRACT

Artificial defoliation in corn was used to explore the usefulness of remote sensing in detecting crop-insect infestation. Defoliation of plant tops was easily detected, while that on the base was less so. Aero infrared film with a Wratten 89B filter gave the best results, and morning flights at a scale of 1:15,840 are recommended. Row direction, plant growth stage, and time lapse since defoliation were not important factors. Image enhancement significantly advanced the defoliation recognition threshold, but added a cost factor which may not be acceptable in terms of commercial remote sensing survey techniques.

INTRODUCTION

Armyworm larvae, *Pseudaletia unipuncta* (Haworth), and grasshoppers defoliate corn plants. Information on the amount of leaves destroyed is useful in assessing potential crop losses, and assists in estimating the levels of pest populations involved. To obtain such information by ground checking requires considerable time and labor - and time is particularly crucial because early availability of this information is essential for preparing plant-protection measures.

Aerial photography has been used in various aspects of agriculture (1), forest insects (2, 3, 4, 5), range insects (6), and fruit insects (7). However, no applicable published work on cereal-crop-insect infestations was available until the preliminary trial involved in the initial phase of this project in 1970 (8), and the 1971-72 followup feasibility study (9).

The objective of the overall study was to develop the necessary criteria and techniques for the detection of pest defoliation of corn and to develop from them an economically-feasible survey system. Although the actual over-flights (and related field treatments) were accomplished during the 1970 and 1971 growing seasons, lack of personnel and funding delayed the final (visual) analysis of the imagery until late in 1972 and the optical/electronic analysis until early 1973. This report will concern itself primarily with the latter work and with a discussion of the beginning of a pilot survey system for commercial fields.

The University of Minnesota's College of Forestry 70mm multispectral camera unit was used for all of the aerial photography. The image interpretation and analysis were carried out by the University of Minnesota Institute of Agriculture's Remote Sensing Laboratory (IARSL); and the image enhancement was accomplished by IARSL and International Imaging Systems (I^2S) of California.

STUDY AREA LOCATION, CHARACTERISTICS

Overflights and field work were done on the University of Minnesota Institute of Agriculture's Rosemount Experiment Station.

STUDY DESIGN, DATA COLLECTION

1970 Study Phase (Meyer and Chiang 1971). Three types of 25x25-foot plots were involved: (1) controls (no defoliation), (2) 4 basal leaves removed and (3) 8 basal leaves removed. Two groups of replicated plots were treated on two different dates and flown on August 24, 1970 with the following film/filter combinations at scales of 1:4,000 and 1:12,000:

Plus-X/Wratten 58
Plus-X/Wratten 25A
Aero Infrared/Wratten 89B
Ektachrome Infrared 8443/Wratten 12

The heavy defoliation simulation plots (8 leaves removed) were easily visible on all combinations at all scales. The light defoliation (4 basal leaves removed), however, was not visible - even with enhancement (optical and photographic color combining; density level-slicing).

Overall results were sufficiently encouraging to warrant continuation and expansion of the initial feasibility study for the following reasons:

1. Crop row direction did not affect the results which meant that, under practical conditions, the direction of flight could be in one direction without loss of detectability -

an important consideration because adjacent fields may have corn row orientations up to 90° to each other.

2. Medium scale (and ultimately, perhaps, small scale) photographs could be used - i.e., expensive, large scale coverage is not necessary. An economically-feasible survey system would surely require that medium or small scale coverage be used.
3. Morning photography was the best - usually the most cloud-free daytime period in the corn belt.
4. Image enhancement techniques served to make more easily detectable what was already ocularly visible on the imagery (Figure 2).

1971-73 Study Phase (Chiang, Latham and Meyer 1973). In view of the lack of gain from color combining the three B&W spectral bands in 1970, the 1971 overflights involved the following film/filter combinations in various configurations:

Plus-X/Wratten 8
Aero Infrared/Wratten 89B
Ektachrome Infrared 8443/Wratten 12
Ektachrome MS/Wratten 2A
Ektacolor/Wratten 2A

As before, defoliation was accomplished on several dates during the growing season and, additionally, different levels of defoliation were employed (controls plus 6 treatments):

Controls (no defoliation)
2, 4 and 6 basal leaves, respectively, removed, simulating armyworm damage
2, 4 and 6 top leaves, respectively, removed, simulating grasshopper damage

The different types of photo coverage (3 time lapses and 4 film/filter combinations) were analyzed by 2 specially-trained photo interpreters. A rating system was employed which required the interpreters to identify those plots which they felt were visible and assign each one with a numerical defoliation scale ranking the plots from 1 (lightest) to 4 (heaviest).

Although it is still an economically questionable step in any future survey system, tests of both color combining (Aero Infrared/Wratten 89B + Plus-X/Wratten 8) and density level-slicing (Aero Infrared/Wratten 89B) were accomplished (Figure 1).

DATA ANALYSIS

Comparison of interpreter results with the actual field conditions revealed the following:

1. As before, defoliation in corn was detected with reliability regardless of row direction.
2. Detection was feasible within one day after defoliation; it was not necessary to wait for intensive plant stress.
3. Detection was feasible when plants were at the 11-leaf stage through tasseling.
4. A scale of 1:6,336 gave more reliable detection but, considering cost factors, a scale of 1:15,840 was deemed satisfactory; 1:31,680 scale results were of questionable value.
5. Aero Infrared film with Wratten 89B filter gave the best results among the 7 combinations tested but was closely followed by color infrared.
6. Morning flights produced the best results.
7. Defoliation on top of the plant was easier to detect than that on the basal part of the plant.
8. Enhancement by means of color-combining was of questionable value both economically and in terms of any additional level of information gain.
9. Enhancement by means of density level-slicing, both of Aero infrared/Wratten 89B and color infrared photography, produced an obvious gain in defoliation level detectability. Preliminary tests also indicate that comparative film density readings may be significantly correlated with specific defoliation levels in any particular field situation.

SUMMARY, PRACTICAL IMPLICATIONS

Summary. Simulated armyworm and grasshopper defoliation of corn at levels critical to control programs was found subject to detection and relative assessment by aerial remote sensing methods. Aero Infrared/Wratten 89B and color infrared at a scale of 1:15,840 were judged to be the two

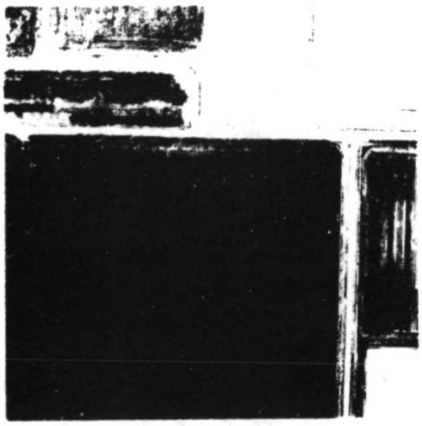

Plate A: Plus-X/Wr 8, scale of 1:6,336, flown 7/20/71.

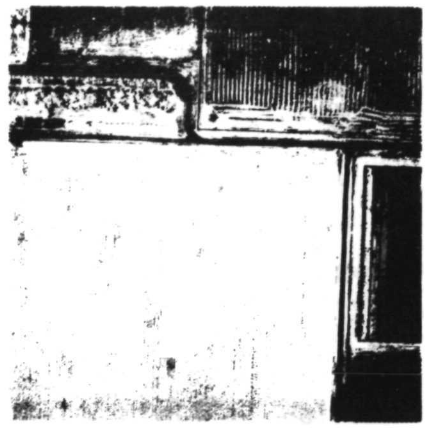

Plate B: Aero IR/Wr 89B, scale of 1:6,336, flown 7/20/71.

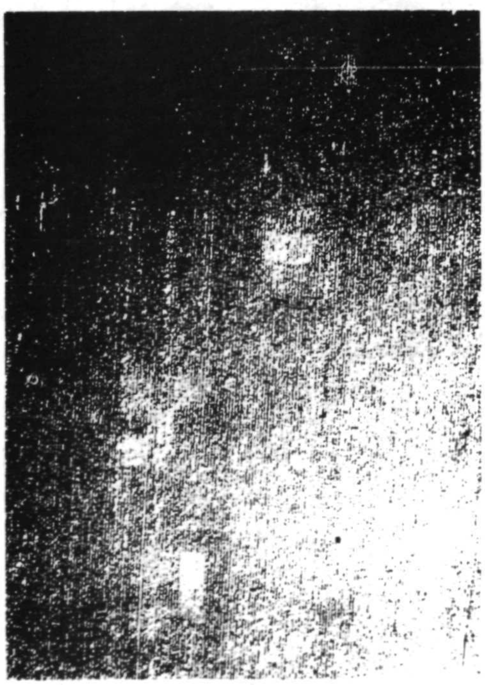

Plate C: Color combined (G+R) rendition of Plates A and B.

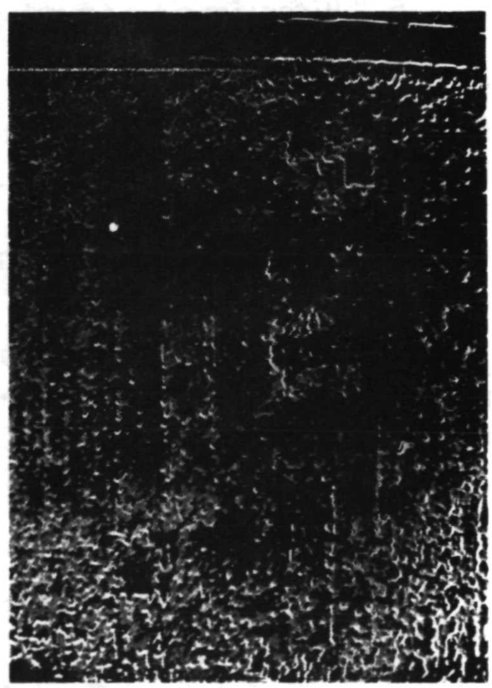

Plate D: Density level-sliced rendition of Plate B.

Figure 2. July 20, 1971, views of corn defoliation test plots.

best film/filter/scale combinations. The basic interpretation task was accomplished through direct viewing of the film aided only by magnification and stereoscopic scene rendition. Color-combining provided no information gain, but density level-slicing aided in discrimination of different levels of defoliation.

Practical Implications. The basic criteria for a practical system of corn-pest defoliation survey are now considered to have been determined:

1. Small-camera imagery (35mm or 70mm) appears to be usable.

2. Purchase and processing of 35mm film is relatively inexpensive and convenient and its use creates little time delay between exposure and analysis.

3. Ordinary film/filter combinations such as B&W infrared/Wratten 89B and/or color infrared/Wratten 12 or 15 are the most productive.

4. Morning photography is deemed the best - a desirable requirement since late forenoon to afternoon cumulus cloud formation is a characteristic of the corn belt in the summer.

5. Directionally speaking, flight lines can be planned so as to get the most convenient, economical coverage of large areas - without being concerned with the corn row orientation, which may vary up to 90° from field to field.

Actual application during the growing season of 1973 is planned on a pilot basis. Using a small-camera system involving a 70mm camera or the 35mm system described by Meyer et al (10), outbreak areas will be flown at a variety of scales upon notification by field cooperators. There is the possibility that natural infestation areas in commercial corn fields may be much more easily detected and assessed than the 25x25-foot simulated defoliation plots used in the original feasibility tests. Should this be the case, it may be possible to reduce costs and time, and increase survey effectiveness, by utilizing higher flight altitudes (smaller scales) and thus reducing costs of photography and analysis. By the same token, the extra dividends in detectability attainable with density level-slicing enhancement techniques may then become economically feasible.

The final development of such a system would have a considerable impact upon corn crop management and protection and also, ultimately, upon the total yield and related (significant) reduction in costs to producer and consumer alike.

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Chapter 6

ALFALFA CROP PRODUCTIVITY ANALYSIS

Donald K. Barnes and Merle P. Meyer

ABSTRACT

Three years of sequential, ERTS-compatible multispectral, multiscale 70mm aerial photography were accomplished on a study area containing five varieties of alfalfa. The study objective was to determine if aerial remote sensing techniques could differentiate insect and disease injury on alfalfa as compared to pest-free controls.

Preliminary results indicate an association between visual analysis of 1:6,000 to 1:15,000 scale color infrared aerial photography and relative pest injury. There appears to be an improvement in pest injury detection through image enhancement (density level-slicing) of the color infrared. Indications are that there is a correlation between film density readings and crop yields. Both indications are being studied as possible bases for development of an economically-feasible survey system for county-size areas.

INTRODUCTION

Alfalfa is the most important forage crop grown in the United States. It produces more protein per acre than any other agronomic crop. More than 2 million acres of alfalfa are grown in Minnesota and nearly 40 percent of the nation's 27 million acres are grown in Minnesota and the four adjacent states.

It would be desirable from both a scientific and economic crop reporting standpoint if it were possible on a large scale (county or statewide basis) to accurately determine alfalfa acreages, time of harvesting practices, age of stands, density of stands, insect-infestations, disease infections and yield estimates. The conventional ground assessment techniques are too expensive and too limited in scope for most scientific assessment needs and are of limited value in identifying pest infestations.

The purpose of this project, therefore, was to determine the potential application of small scale aerial photography in identifying features within the alfalfa ecosystem throughout a three-year period from seedling establishment through two harvest years. This involves a period from July 1971 through October 1973.

STUDY AREA LOCATION, CHARACTERISTICS

The study area is a nine-acre unit located at the University of Minnesota's Rosemount Agricultural Experiment Station. The area includes 20 1/3-acre plots and is situated on flat to gently rolling agricultural lands just south of Minneapolis and St. Paul.

STUDY DESIGN, DATA COLLECTION

Five varieties were chosen to include those both resistant and susceptible to most major alfalfa pests in the area (see Figure 3). Commencing when seedlings were 2 weeks old (July 1971) fungicide treatments have been applied weekly to part of each plot to control foliage diseases. Weekly treatments were continued until fall freeze-up and started again in spring (1972 and 1973) at first growth. Besides weekly fungicide and insecticide treatments, weekly samples of insect fauna in each plot have been taken. Plants have also been sampled weekly to study disease and plant-growth patterns. Total forage yields have been recorded for each season. Incidence of alfalfa mosaic virus infection, and severity of crown-rot and root-curculio injury are being noted. Climatic data are available throughout the study. The total ground truth data collection is a cooperative effort among Agronomists, Entomologists, and Plant Pathologists of the USDA and the University of Minnesota.

The Institute of Agriculture Remote Sensing Laboratory's (IARSL) 70mm quadricamera unit has been used to monitor changes in this alfalfa ecosystem during the past 3 years. Successful overflights, primarily at scales of 1:15,840, 1:6336 and 1:4,800, were accomplished on 3 dates in 1971, 8 dates in 1972 and will continue throughout the 1973 season (5 overflights already completed). On the basis of the 1971 feasibility tests, the following film/filter combinations have been used in 1972 and 1973:

Panchromatic Plus-X/Wratten 58
Panchromatic Plus-X/Wratten 25A

Aero Infrared/Wratten 89B

Aerochrome Infrared/Wratten 15

Films exposed to date have been prepared for analysis with the IARSL color-additive combiner and VP-8 image analyzer (density level-slicer).

DATA ANALYSIS

A number of the film/filter/scale combinations tested have shown variation in either color or gray scale which appear to reflect differences in past infestations and plant growth. Initially it was felt that Ektachrome MS/Wratten 2A photography showed the greatest potential due to its ability to differentiate the inate difference in green among alfalfa varieties and to identify waterways and weedy areas (Figure 1). However, it was abandoned in 1972 in favor of Aerochrome Infrared/Wratten 15 coverage in view of the latter's better apparent ability to portray differences both with, and without, color enhancement. For example, slight variations in plant growth and plant color due to pest injury that cannot be readily discerned on the ground or from color (Ektachrome MS) film, can be detected visually by means of color infrared, and are even more apparent when enhanced through density-slicing (Figure 2).

It generally has been possible by means of the imagery to differentiate disease free and diseased areas within varieties, to differentiate insect free and insect infested areas within varieties and to relate color density with dry matter yields (Figures 3, 4 and 5) on a particular date within varieties. However, a complete analysis of the imagery will not be possible until the completion of the study in October 1973.

SUMMARY, PRACTICAL IMPLICATIONS

Summary. Three years of sequential, ERTS-compatible, multiscale, multispectral 70mm aerial photography have been accomplished on a study area containing five varieties of alfalfa. The objective of the study is to determine whether the results of the differential treatments of the alfalfa test plots, in terms of insect pests, disease and related controls, are visible (and economically assessable) with aerial remote sensing techniques.

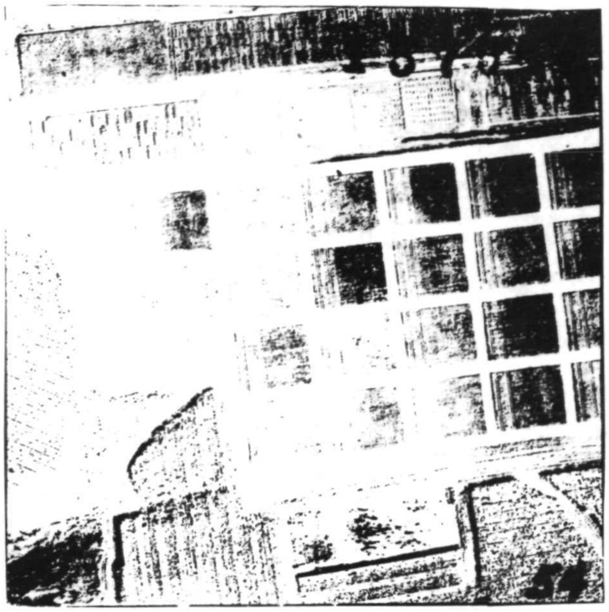

Figure 1. Ektachrome MS/Wratten 2A scene of a portion of the alfalfa study area flown on Oct. 15, 1971, at a scale of 1:6,336.

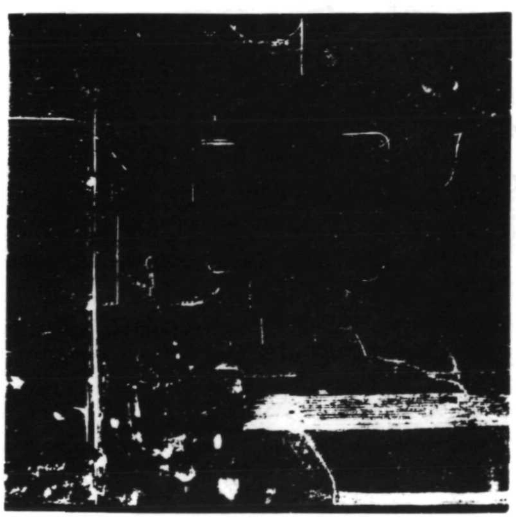

Plate A

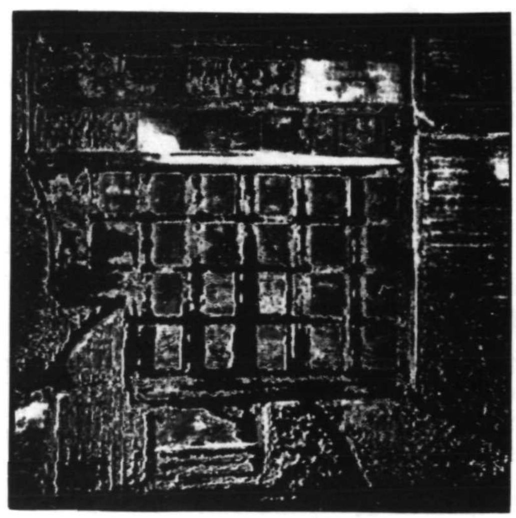

Plate B

Figure 2. Plate A = Example of a color infrared view of the test plots (enlarged from original scale of 1:15,840). Plate B = VP-8 image analyzer enhancement of the scene in Plate A.

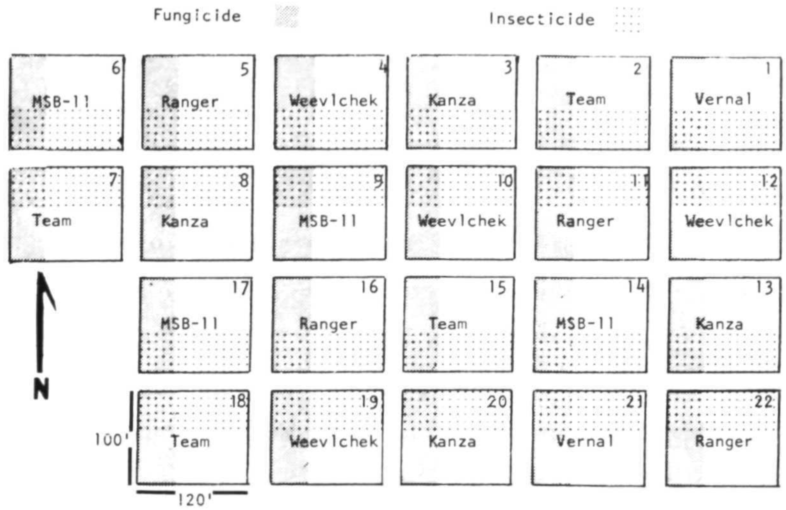

Figure 3. Map of the alfalfa ecosystem showing the different varieties under study and the treatments applied. Density level-sliced enhancements of Plots 13 and 22, as of 6/13/73, are portrayed in Figures 4 and 5 below.

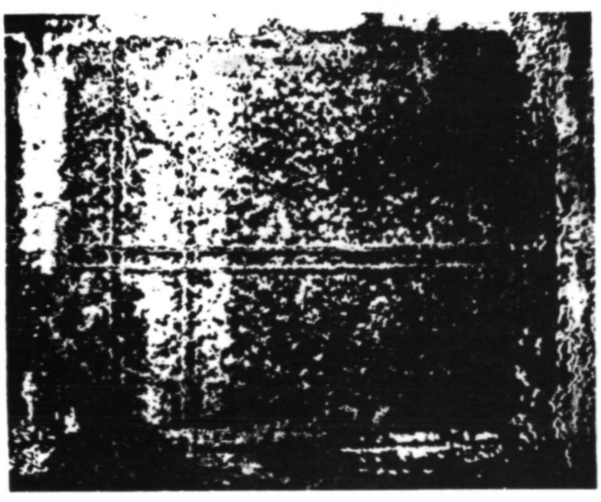

Figure 4. Enhancement of Plot 13 taken from 1:6336 scale CIR photo flown 6/13/73 (see Fig. 4 for treatments).

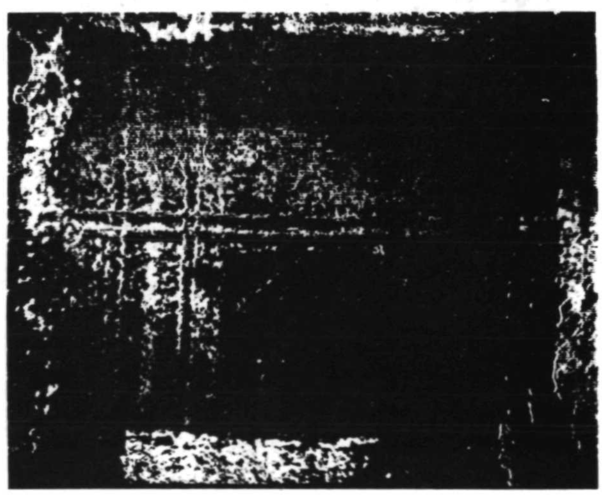

Figure 5. Enhancement of Plot 22 taken from 1:6336 scale CIR photo flown 6/13/73 (see Fig. 4 for treatments).

Preliminary results indicate that a close association exists between forage yields and visual analysis of 1:6,336 to 1:15,840 scale Aerochrome infrared/Wratten 15 photography (1). There also appears to be a possibility of useful improvement of pest injury and yield detection through image enhancement (density level-slicing) of this type of photography. Film density readings may also be used to estimate crop yields. Both of these possibilities are currently being studied as possible bases for a technically, and economically, feasible remote sensing survey system - perhaps involving small-camera techniques such as those developed by Zsilinszky (2) and Meyer (1).

Practical Implications. Alfalfa is the most important forage crop grown in the United States and it is essential, from both a scientific and economic crop reporting standpoint, to determine to an acceptable level of accuracy, its acreages, time of harvest, age of stands, density of stands, insect infestations, disease infections and yield estimates. Since conventional ground assessment methods are very slow, unreliable, and costly, the principle hope for a practical survey method lies in aerial remote sensing. The development of an economically-feasible remote sensing survey system should have an important impact upon production and marketing estimates of this crop and also assist in crop protection programs.

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Chapter 7

WORK PLANS FOR FY1974

D. French, A. Mace, M. Meyer and R. Rust

Due to a 28 percent decrease in the funding from NASA Grant NGL 24-005-263 to the Institute of Agriculture remote sensing applications working group for FY74, the scope of activities of this project series for the coming year will, necessarily, be curtailed. Also, and partially as a result of this reduction, it will not be possible to again generate the very generous FY73 level of matching funds from within the Institute of Agriculture - which was achieved mainly through sacrifices from other funded projects of the involved investigators. As an end result, certain of the projects initiated in 1973 will have to be adjusted, reduced in scope or shifted elsewhere in FY74.

Preliminary FY74 work plans are as follows:

FOREST DISEASE DETECTION AND CONTROL

To provide forest land managers with a practical means of detecting dwarf mistletoe in extensive black spruce stands, we plan on evaluating 35mm photography for this purpose. The same equipment and approach is needed for detecting other disease problems such as Armillaria root rot in pine plantations. We also plan on evaluating 35mm photography for detecting oak wilt and Dutch elm disease. The 35mm photography will be compared with direct aerial observation and on-ground surveys. In all of these applications it will be necessary to study film types, filter combinations, season of year, and scale to arrive at the most economical and effective means of detecting tree diseases - a system that can be used by the practicing land managers.

EVALUATION OF WATER QUALITY INDICATORS

Initial results from this project indicate that timing of overflights and scale may be the two most important factors governing the success of remote sensing techniques for monitoring aquatic vegetation for the purpose of evaluating water quality. Consequently, during FY74, research efforts will concentrate on maximizing these two parameters. First, overflights will be conducted on Lake Minnetonka rather than northern Minnesota lakes to enhance overflights at the peak of phytoplankton production. Second, overflights will be flown at a scale of 1:3,000-6,000 compared to previous overflights with a scale of 1:12,000 and 1:36,000.

The following 70mm film/filter combinations will be used: Plus-X/Wratten 58; Plus-X/Wratten 25A; Aero IR/Wratten 89B; Aerochrome IR 2443/Wratten 15. In addition, 35mm color infrared photography will be utilized to assess its potential.

Image analysis will include both image enhancement through multi-spectral image enhancement of various film/filter combinations and density level-slicing techniques of the most promising scenes. Correlation of density output with ground truth data consisting of aquatic vegetation and water quality data will test the validity and potential of this system.

The product of this research, if positive, will provide monitoring and regulatory agencies with a tool to evaluate changes in water quality as evidenced by aquatic vegetation indicators.

FOREST VEGETATION CLASSIFICATION AND MANAGEMENT

Due to the inability to meet the costs of obtaining necessary high-altitude aerial photographs in the Chippewa National Forest/Itasca County Study Area in the face of reduced FY74 funding, plans for a practical-applications trial of very small scale color infrared aerial photography have been abandoned.

In lieu thereof, a cooperative project with the Minnesota Department of Natural Resources, the Land Commissioner's Association of the 18 forested counties, the U. S. Forest Service and the forest products industries is being supported. This project will assist in the development of a continuing program of medium-scale forest aerial photography for the 18 forested counties of Minnesota. Among the products of the study will be the following: (1) a model set of specifications for medium scale, 1/15,840-1/20,000 scale, forest aerial photography, (2) training of field and management personnel in the procurement and inspection of this aerial photography, (3) assistance in the development of a statewide committee of users to advise on the procurement and use of resource aerial photography, and (4) the development of (possible) new specifications for forest aerial photography which will reduce the future costs of both procurement and interpretation.

The latter will be accomplished at the time of conventional scale overflight in each county through the inclusion of test strips over cooperator-monitored test areas in the county on which experimental coverage (1:24,000 and 1:36,680 scale) will be flown. In the event the smaller scales of photography are acceptable to users, future specifications will be written for the desired scale which will result in significant procurement/user savings.

DETECTING SALINE SOILS IN THE RED RIVER VALLEY, MINNESOTA, BY REMOTE SENSING TECHNIQUES

The activities planned for FY74 include obtaining color and/or color infrared imagery of the same transect strips of agricultural land in Kittson County as viewed in FY73 but with flight time scheduled immediately before small grain harvest. Subsequent ground truth and image analysis work is intended to establish more quantitative delineation of saline areas. A principal product of the study would be a medium scale (1:15,840) map on photo background of selected areas to use in advising county technical workers and to assist the county assessor in agricultural land assessment.

CORN DEFOLIATION

Project activities terminated under NASA Grant NGL 24-005-263 due to the reduction in FY74 funding. The next project phase (practical application, on a pilot test basis, of a small-camera color infrared reconnaissance technique to the monitoring of natural infestations in commercial corn fields) will, however, be continued under sponsorship from other funding sources. Target date for an economically-feasible system of application: 1973 or 1974.

ALFALFA CROP PRODUCTIVITY ANALYSIS

Project activities terminated under NASA Grant NGL 24-005-263 due to the reduction in FY74 funding. The next project phase (development of a working technique for stress and relative productivity assessment applicable to commercial fields) will, however, be continued under sponsorship from other funding sources. Target date for an economically-feasible system of application on county-size units: 1974.