REMOTE SENSING APPLICATIONS IN FORESTRY

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SCHOOL OF FORESTRY AND CONSERVATION
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA

A Coordination Task Carried Out in Cooperation with
The Forest Service, U.S. Department of Agriculture

For

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

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REMOTE SENSING OF CHANGES IN MORPHOLOGY AND PHYSIOLOGY OF TREES UNDER STRESS

by

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Annual Progress Report 30 September, 1970

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ABSTRACT

This is the fourth annual progress report describing results of continuing studies of forest trees subjected to varying types of stress. Both greenhouse and field studies are included, and four studies were active during the year.

Greenhouse work with tree seedlings exposed to varying levels of NaCl and $CaCl_2$ in the soil indicated that, in the initial stages, palisade cells shrink and the amount of air space in the leaf increases. As the severity of damage increases, the cells of the spongy mesophyll shrink and flatten, and the amount of air space in the leaf decreases.

Statistical analysis of foliar reflectance and associated moisture content data led to a series of regression equations for predicting foliar moisture content from reflectance data. Equations were calculated for three species, yellow birch (*Betula alleghaniensis* Britton), sugar maple (*Acer saccharum* Marsh.) and white ash (*Fraxinus americana* L.) having multiple correlation coefficients of 0.98, 0.94 and 0.93 respectively.

Interpretation of multispectral imagery of the Ann Arbor Forestry Test Site (NASA Site 190) provided evidence that infections of *Fomes annosus* can be detected in the early stages. Infections of two needle cast diseases were also detected in conifer plantations in the test site.

A study of automatic interpretation of multispectral scanner imagery using the University of Michigan Spectral Analysis and Recognition Computer (SPARC) for tree species recognition provided encouraging results. When training sets were selected which included only the sun-lit portions of tree crowns, the SPARC recognition maps correctly

identified approximately 85 percent of the individual trees, and successfully separated two species of oak with an accuracy approaching 70%.

ACKNOWLEDGEMENTS

The research described in this report was conducted as part of the Earth Resources Survey Program in Agriculture/Forestry sponsored by, and with financial assistance from, the National Aeronautics and Space Administration (Contract No. R-09-038-022). The work was a cooperative undertaking of the Forest Service, U. S. Department of Agriculture and the University of Michigan, School of Natural Resources.

The generous support of Dr. Warren H. Wagner, Jr., Director of the University of Michigan Botanical Gardens, and the entire staff of the Botanical Gardens, is gratefully acknowledged.

The assistance of the University of Michigan, Willow Run Laboratories in processing the multispectral data was invaluable. Without this assistance several phases of the work could not have been completed.

Special thanks are also extended to Mrs. Barbara Wagner and Tim Gregg for their assistance in data collection and processing.

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INTRODUCTION

Early detection of stress in vegetation is one of the keys to correcting the condition causing that stress. Modern remote sensors offer considerable promise for early detection of plant stress when the energy relationships associated with such stress are understood.

Controlled studies of reflectance and emittance characteristics of foliage on trees subjected to varying kinds and severity of stress have been conducted at the University of Michigan for several years (Weber and Olson, 1967; Olson and Ward, 1968; Olson, Ward and Rohde, 1969). This report summarizes work done on four studies during the period from 1 October 1969 through 30 September 1970.

STUDY I: EFFECTS OF SALINITY ON REFLECTANCE AND EMITTANCE PROPERTIES OF TREE SEEDLINGS (Study Leader - J. M. Ward)

During 1968 and 1969 several groups of sugar maple (*Acer saccharum* Marsh.) seedlings were grown in the greenhouse with different concentrations of NaCl or $CaCl_2$ in the soil. Methods used were described in our 1968 Annual Report (Olson and Ward, 1968) and observed changes in foliar reflectance were summarized in the 1969 Annual Report (Olson, Ward and

Rohde, 1969). Work during the 1969-70 reporting period was confined to analysis of anatomical changes in the foliage of the salt-treated plant.

Preparation of leaf cross-sections has been completed and quantitative analyses of changes in the mesophyll tissues begun. Preliminary data indicate that salt damage is associated with increasing volume of air space in the mesophyll during the early stages, but that the volume of the air spaces decreases if the damage becomes more severe. The initial change results from shrinkage of the palisade cells, while the latter change results from severe shrinkage of the spongy mesophyll with a general flattening of the cells in a plane parallel to the epidermis.

Future Plans

This study was temporarily discontinued during the 1970 growing season to permit full utilization of available personnel in support of overflights of the Ann Arbor Forestry Site (NASA Site 190). The anatomical studies should be completed during the 1970-71 project year.

STUDY II: THE RELATIONSHIP BETWEEN LEAF REFLECTANCE AND LEAF WATER CONTENT (Study Leader - W. G. Rohde)

Existing data indicate a close tie between leaf reflectance and water stress, and between leaf reflectance and water content. Work in previous years has concentrated on the relationship with water stress, but the current year's work has provided a closer examination of the relationship between reflectance and moisture content.

Methods

Twelve tree seedlings each of yellow birch (Betula alleghaniensis Britton), sugar maple (Acer saccharum Marsh.), and white ash (Fraxinus *americana* L.) were grown in four-gallon containers in the greenhouse. After the leaves had flushed and reached full size, half of the trees of each species were placed under severe moisture stress while the remainder were watered regularly. Reflectance measurements and leaf water content data were obtained at regular intervals from each group of trees. A Beckman DK-2a spectrophotometer was used for all reflectance measurements and data were recorded for the wavelength band between 0.5 and 2.6 micrometers (μm).

Water content of the leaves was determined gravimetrically. Each leaf was weighed immediately after it was removed from the plant, and again after the reflectance curve was obtained. The greatest difference between the results of these two weighings was 0.009 grams and the average of the two weights for any one leaf was considered to be its weight at the time the reflectance was measured. After the second weighing, the leaves were oven-dried at 85°C and reweighed. Moisture content is expressed as a percentage of the oven-dried weight of the leaf, calculated as:

$$\frac{\text{fresh weight - oven-dried weight}}{\text{oven-dried weight}} \times 100$$

Detailed step-wise regression analyses were used to obtain equations relating foliar moisture content with leaf reflectance at specific wavelengths. Several forms of data transformations were investigated as well.

Results

Maximum leaf moisture contents observed for white ash, yellow birch and sugar maple were 460, 260 and 163 percent of the oven-dried weight, respectively. Average oven-dry weights varied from 0.1165 g for white ash leaflets to 0.274 g for sugar maple leaves.

Although significant reflectance differences between leaves of maximum and minimum moisture contents were observed at wavelengths from 0.50 μm to 0.80 μm, variation in reflectance within and among trees and leaves masked differences recorded for other levels of foliar moisture content. At wavelengths longer than 0.80 μm, reflectance increased with decreasing moisture content with the largest differences within and between species occurring at wavelengths between 1.30 and 2.60 μm.

Step-wise regression analyses indicated that data transformations were necessary. Several were tried, and the three optimum variables seem to be:

$$A = R(1.00)$$

$$B = \left[\frac{R(2.00) + R(2.19) + R(2.30) + R(2.60)}{R(1.64) + R(1.75) + R(1.78)}\right]$$

$$C = \left[\frac{R(1.64) + R(1.75) + R(1.78)}{R(0.80) + R(0.90) + R(0.96) + R(1.00)}\right]$$

where R ( ) is the reflectance at the wavelength indicated in the parenthesis.

Based upon the three variables above, the calculated equations for predicting foliar moisture content from foliar reflectance are:

Sugar Maple ($r = 0.94$)

$$\log M.C. = 8.4181 - 3.1378 \log A + 1.9490 \log B - 1.7609\ B^2$$

Yellow Birch ($r = 0.98$)

$$\log M.C. = 1.5872 + 7.6537\ B^2 + 67.8304\ C^2$$

White Ash ($r = 0.93$)

$$\log M.C. = 7.5649 - 2.6119 \log A - 0.6581\ B^2 - 1.4915\ C^2$$

where M.C. = leaf moisture content

r = multiple correlation coefficient

(Note: These equations differ slightly from those included in our Quarterly Report for the period 1 April to 30 June 1970.)

We know of no biological reason for the log transformations on all linear terms. Review of plotted residuals from the regression analyses indicated that the homogeneity of variance assumption on which regression models are based was not satisfied without the log transform.

Future Plans

The equations presented are significant, and may provide a useful non-destructive test applicable to other studies. These transformations are not easily performed with existing multispectral data processing equipment, however. In addition, the species dependence of the equations limits their usefulness in remote sensing of mixed stands. Additional work is underway using data transforms which are more compatible with existing multispectral data processors. An attempt will also be made to derive a prediction equation independent of species.

STUDY III: MULTISPECTRAL REMOTE SENSING OF VEGETATION STRESS (Study Leader - W. G. Rohde)

Laboratory data indicate that multispectral sensors and spectral discrimination techniques can provide early (previsual) detection of plant stress. Sequential coverage may permit both stress detection and identification of the causative agent. Remote sensing overflights of the Ann Arbor Forestry Test Site (NASA Site 190) by the NASA RB-57F and the University of Michigan C-47 aircraft were obtained during 1969 and 1970 to test the applicability of the laboratory data.

The Ann Arbor Forestry Test Site

The Ann Arbor Test Site is located approximately 40 miles west of Detroit, Michigan. The site is located on morainal topography and includes upland and lowland areas supporting a diverse mixture of natural and planted forest stands for which substantial amounts of ground data exist. Data on growth and land use date back to 1903 for some parts of the test site. Active infections of a number of tree diseases are present in the test area.

Intensive study has been concentrated at three locations which lie between latitudes 42° 10' and 42° 27' N, and longitudes 083° 47' and 084° 13' W. These three areas are:

1.	Sharonville	42° 11' N, 084° 10' W
2.	Stinchfield Woods	42° 24' N, 083° 55' W
3.	Saginaw Forest	42° 16' N, 083° 48' W

The Flight Program

Original plans called for six overflights by the University of Michigan C-47 during calendar year 1969, and six overflights during 1970. Four flight altitudes were requested: 1500, 3000, 6000 and 9000 feet above mean terrain. These overflights were supplemented by high altitude overflights by the RB-57F. One high flight flown in September 1969 for another project (Mission 103) included coverage of Test Site 190. Three additional overflights were requested during the 1970 growing season. Adverse weather and lack of aircraft availability prevented adherence to the plan and several additional problems contributed to delays experienced in receipt of data after overflights were completed.

A summary of the planned flight program, flights actually completed, and date of receipt of imagery is included as Table 1.

The C-47 aircraft carried the University of Michigan multispectral scanner (MSS) as its primary remote sensor. Four 70 mm cameras were also carried and these were usually loaded with panchromatic film (2402) and a Wratten 22 filter, infrared film (2424) and a Wratten 25a filter, normal color film (2448) and a Wratten 1A filter, and color infrared film (8443) and a Wratten 12 filter. On some occasions a K-17 camera was substituted for two of the 70 mm cameras.

The RB-57F aircraft carried two Wild RC-8 cameras with six inch focal length lenses and a Zeiss RMK camera with a 12 inch lens as the primary sensors. One RC-8 camera was loaded with normal color film (S0397). Both the second RC-8 and the RMK were loaded with color infrared film (8443 or 2443). Six 70 mm cameras were also carried by the RB-57F. Film-filter combinations for this cluster usually included:

Panchromatic (2402)/Wratten 12	Color Infrared (2443)/Wratten 15
Panchromatic (2402)/Wratten 58	Infrared (2424)/Wratten 25a
Normal color (S0356)/Wratten 2A	Infrared (2424)/Wratten 89B

Analysis of the Imagery

All imagery received was examined with conventional photographic interpretation techniques. All detected tonal anomalies indicative of plant stress were recorded and field-checked to determine the probable cause of the anomalous condition. Comparative interpretation of the aerial photography and MSS imagery led to recommendations for subsequent processing of the data with the University of Michigan special purpose digital and analog computer equipment (see Study IV).

Table 1. Summary of aircraft flights over NASA Test Site 190 during calendar years 1969 and 1970.

Flight Date		Imagery Received	Remarks
Planned	Actual		
A. C-47 in 1969			
1-15 Apr.	--	--	Aircraft not available.
1-15 Jun.	--	--	Aircraft not available.
16-31 Jul.	4 Aug.	24 Apr. 1970	Mission 6M. Cloud shadows in much of imagery. MSS data fair. Poor color balance in photography.
16-31 Aug.	13 Aug.	24 Apr. 1970	Mission 7M. Good data obtained over most of test site.
16-31 Sep.	--	--	Aircraft not available.
16-31 Oct.	26 Nov.	24 Apr. 1970	Mission 8M. MSS data noisy but usable. Photography fair due to shutter malfunctions.
B. C-47 in 1970			
1-15 May	--	--	Adverse weather. Mission not flown.
1-15 Jun.	8 Jun.		Mission 15M. Data not received as of 30 Sep. 1970.
16-31 Jul.	6-7 Jul.		Mission 15M. Data not received as of 30 Sep. 1970.
16-31 Aug.	5 Aug.		Mission 20M. Data not received as of 30 Sep. 1970.
16-31 Sep.	29 Sep.		Mission 24M. Data not received as of 30 Sep. 1970.
16-31 Oct.	16 Oct		Mission 26M.
C. RB-57F in 1969			
--	12 Sep.	29 Jan. 1970	Mission 103. Data available for review at the Willow Run Laboratories.
D. RB-57F in 1970			
1-15 Jul.	5 Jul.	3 Sep. 1970	Mission 132. Clouds masked part of the test site. Color balance good except on SO-387, which is quite blue.
1-15 Sep.	--	--	Mission 144 (not flown).
1-15 Oct.			To be flown as part of Mission 145.

Sharonville Test Location

Natural infections of the root-rotting fungus Fomes annosus were discovered in pine plantations at this location in 1968. The disease is spreading, but to less than 2 percent of the trees per year. Recently attacked trees were easily detected on color infrared photography at scales of 1:48,000 and larger. On color infrared photography the openings created by dying trees are generally black or deep-blue in color, whereas the dead stems are light blue-green in color and are easily distinguished from the characteristic "red" appearance of foliage of healthy trees.

Detection was also accomplished with normal color, and both panchromatic and infrared black-and-white films at scales of 1:24,000 and larger. The attacked trees appeared lighter toned on panchromatic film and darker toned on infrared film. Old killed trees imaged darker toned on both black-and-white films, presumably due to the low reflectance of wood and bark. Many stems were shaded by nearby trees, also contributing to darker tones in the imagery. After attacked trees have died, dark toned openings in the crown canopy develop which mask the dead stems.

Analysis of the MSS imagery indicated that infection centers resulting from Fomes annosus are easily located in virtually any spectral region. In several cases, individual attacked trees were also detected.

Attacked trees were detectable on thermal imagery from the 13 August 1969 overflight, but not on imagery from the 26 November 1969 overflight. Transpiration is quite low in November and differential moisture stresses may not develop between healthy and attacked trees. Previous laboratory data indicate that thermal differences between healthy and attacked trees are closely related to differences in moisture stress. If this is the explanation for our failure to detect attacked trees on the 26 November 1969 imagery, then thermal sensors should not be used for detection of moisture stress phenomena in conifers in late fall or winter.

Stinchfield Woods Test Location

Photographic and MSS imagery of this location were used to monitor an infection of the Swiss needle cast fungus on Douglas fir (*Pseudotsuga menziesii* [Mirb.] Franco var. *menziesii*) and another needle cast disease on Scots pine (*Pinus sylvestris* L.). Widespread defoliation, stunting and mortality resulting from these diseases pose serious threats to forest nurseries and Christmas tree plantations.

The Douglas fir trees are five to ten feet tall and surrounded by tall weeds and brush. Early symptoms of the disease develop in the lower crown and are easily masked by the tall weeds and brush. Although recently attacked trees have not been detected on any of the imagery examined, old killed trees were successfully detected on large scale color photography.

The Scots pine plantation is approximately 30 feet tall and has a nearly continuous crown canopy. The needle cast on these trees was easily detected on all photography at scales of 1:24,000 and larger. Infected trees were also detected on smaller scale photography but many attacked trees were missed. This Scots pine plantation is located near a natural stand of mixed broadleaved species, primarily oak (*Quercus* spp.). The high altitude color infrared photography from the RB-57F shows a distinct contrast between the red tones of the broadleaved species and the dark blue-green tones of the conifers (Figure 1). The infected Scots pine stand (indicated by the arrow) has a lighter, somewhat yellowish, cast when the positive transparencies are viewed over a 5500°K light source.

The tone difference between broadleaved and coniferous species, so conspicuous in the high altitude photography, is not present in the low altitude photographs (Figure 2). As shown, the disease was more severe in 1969 than in 1970, but individual attacked trees can be detected in the color and color infrared photographs from both years.

Infected Scots pines were also detected in several channels of the MSS data. Combination of one visible, one near infrared and one thermal infrared channel may increase detection accuracy. Further study is planned.

A small area of white pine (*Pinus strobus* L.) near the Northwest corner of the Stinchfield Woods property contains several trees with abnormal tonal renditions in the photographic and MSS imagery. This may prove to be a case of ozone damage, and continued study is planned.

Saginaw Forest Test Location

This area includes many different tree species with no known active infestations of insects or diseases and provides a relatively homogeneous area suitable for tree species recognition studies*. The area is

* Our present study deals only with the species identification of *healthy* trees, whereas the title of our report focuses attention on *stressed* trees. However, stress symptoms, as recorded by remote sensing, are known to vary with tree species. Hence, the identification of healthy trees, by species, was considered to be an important first step toward one ultimate objective.

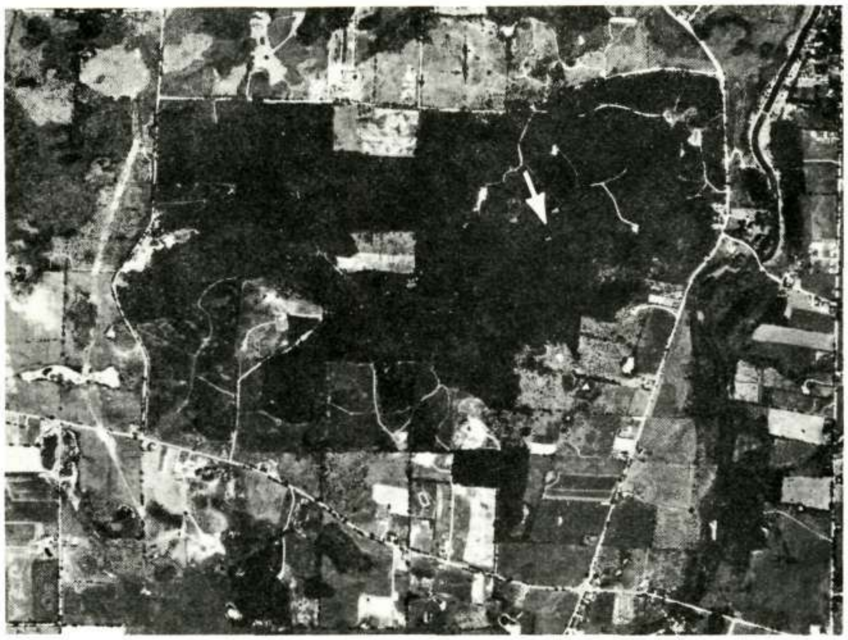


Figure 1. Color infrared photography obtained from approximately 42,000 feet above ground on 5 July 1970. The tip of the arrow is near the center of the Scots pine stand which was severely infested by the Swiss needle cast disease in 1969.

Scale of the original	-	1:42,000
Scale of this print	-	1:35,000

A B C

Figure 2. Color and color infrared photography obtained from approximately 3,000 feet above ground on 4 August 1969 (A) and 6 July 1970 (B and C). The yellow-brown trees in A are severely infested with the Swiss needle cast fungus. The attack was less severe in 1970 but individual attacked trees are visible in both B and C.

The color infrared image (C) shows no obvious color difference between the broadleaved trees in the lower left corner and the pines in the rest of the photograph. This is not true of the high altitude photograph shown in Figure 1.

Approximate photo scale - 1:4,400

described in considerable detail under Study IV. This discussion is included to provide a qualitative summary of the species recognition work performed with conventional photo interpretation techniques.

Color infrared photography provided excellent color contrast between broadleaved and coniferous species from high altitude but no color contrast between the same species at altitudes below 10,000 feet. Black-and-white infrared film provided excellent tone contrast between broadleaved and coniferous species at all altitudes, however.

Combined interpretation of the normal color and color infrared photographs provided the best separation of the various conifer and broadleaved species at scales up to 1:36,000. Several tree species could be distinguished at scales as small at 1:72,000.

Species separation was also accomplished from MSS imagery in the visible and photographic infrared channels. The thermal infrared data were useful in separating broadleaved trees from conifers, but were not particularly useful in separating the several species of either group. Conifers were consistently lighter toned on the positive thermal imagery than were the broadleaved trees.

Future Plans

Several combinations of the MSS data give promise of improved detection, and possible previsual detection, of disease and stress in forest stands. Thermal contouring of infected stands may also assist in previsual detection. Both approaches will be explored.

Preparation of various types of "false-color" imagery assembled from different spectral bands, including reflective infrared channels in the 1.5 to 2.0 micrometer region, is planned. Laboratory data and visual interpretation of the MSS data indicate that such combinations hold considerable promise for enhancement of damage symptoms.

STUDY IV: AUTOMATIC RECOGNITION OF FOREST TREE SPECIES FROM MULTISPECTRAL DATA (Study Leaders - C. E. Olson, Jr. and W. G. Rohde)

Remote sensing techniques are extremely useful for rapid monitoring of dynamic environmental parameters, many of which provide valuable information about landforms, soil type, drainage, land use and subsurface features. When multispectral data are available, differences in spectral signatures often permit recognition of specific rock units, soil conditions or plant species. Laboratory studies reveal consistent differences in spectral signatures of tree foliage. Analyses of laboratory data indicate that narrow band multispectral sensors may provide better species discrimination than broader band sensors, including color and color infrared photography.

Computer processing of narrow band multispectral data has been successfully used to map hydrobiological features and to discriminate between healthy and insect attacked pine trees (Kolipinski and Higer, 1969; Heller, et al., 1969). Improvements in data collection and data processing techniques offer considerable promise for rapid recognition of ecological communities and identification of plant species.

This study was begun to investigate possibilities for automatic recognition of forest tree species from narrow band multispectral scanner (MSS) data based on existing knowledge of spectral signatures of tree foliage.

Study Area

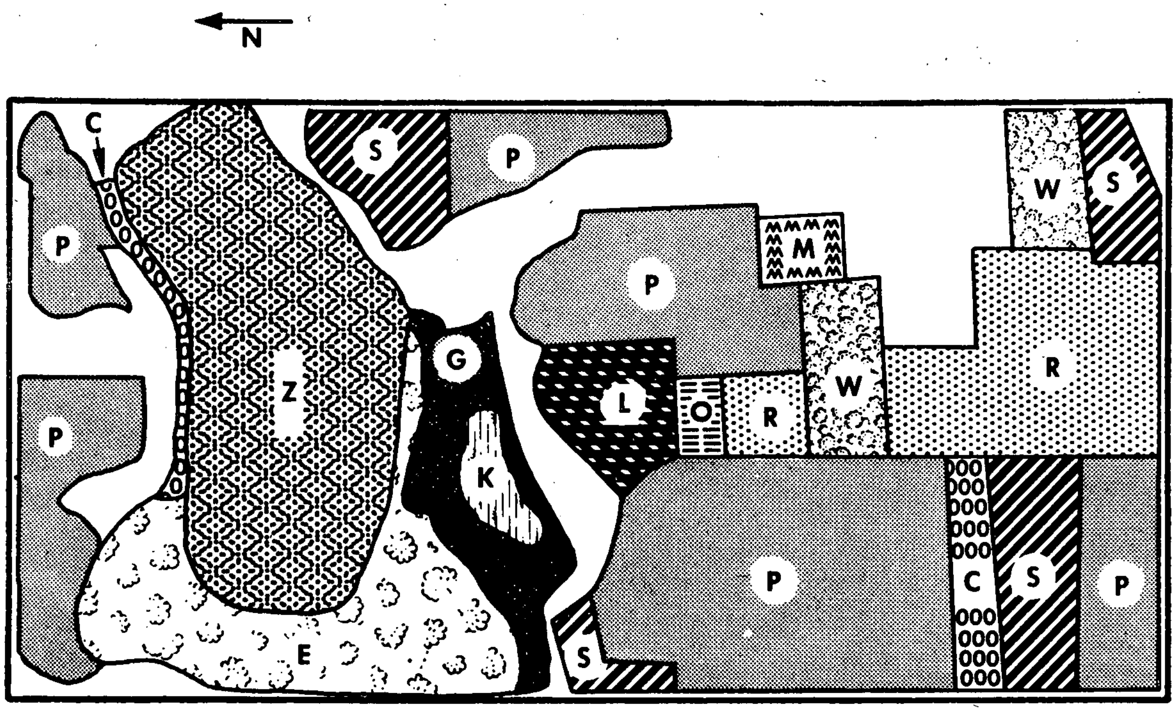
The University of Michigan's Saginaw Forest, an 80-acre tract of forest plantations approximately two miles West of Ann Arbor, was selected as the study area. Saginaw Forest lies completely within NASA Test Site 190 and is located on morainal topography including both upland and lowland sites. The property was an active farm with small areas of residual forest on steep and wet areas when it was given to the University for forestry purposes in 1903. Tree planting began the same year and was largely complete by 1935. The area now supports a diverse mixture of coniferous and broadleaved forest plantations as well as cutover remnants of natural broadleaved forest (Figure 3).

Data Collection

The MSS data used for this study was obtained at approximately 0930 on 4 August 1969. Data runs had been made at altitudes of approximately 1500, 3000, 4500 and 9000 feet above mean terrain. Since clouds and cloud shadows obscured part of the Saginaw Forest property during the higher altitude runs, the 1500 foot data were selected for computer processing.

Data Processing

Data processing was performed with the University of Michigan Spectral Analysis and Recognition Computer (SPARC) by personnel at the University's Willow Run Laboratories. Tape recorded data from six spectral channels in the 0.4 to 1.0 micrometer wavelength region were used to separate coniferous from broadleaved species, and to differentiate among tree species within each of these two broad groupings. Channel selection was based upon laboratory and field reflectance measurements, and on an analysis of the imagery from all ten channels shown in Figure 4. The 0.58 to 0.62, 0.62 to 0.66, 0.72 to 0.80 and 0.80 to 1.0 micrometer channels were used in each recognition attempt. Slight changes in channel selection in the blue and green



C - Cottonwood, Aspen, Willow
E - Elm, Red Maple
G - White Cedar
K - Swamp
L - Black Locust
M - Sugar Maple
O - White Oak
P - Pine
R - Red Oak
S - Spruce
W - Black Walnut
Z - Lake

Figure 3. Distribution of tree species at the University of Michigan Saginaw Forest property near Ann Arbor, Michigan.

Figure 4. Multispectral imagery collected over Saginaw Forest on 4 August 1969. Six spectral channels were selected for computer processing. Aircraft altitude was approximately 1,500 feet.

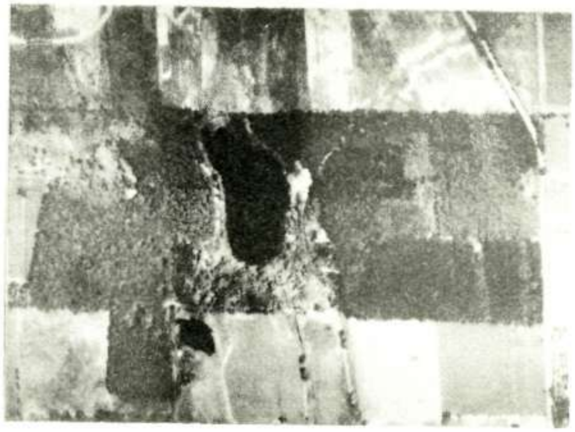
regions facilitated separation of coniferous and hardwood species. The 0.46 to 0.48 and 0.52 to 0.55 micrometer channels were used when discriminating between coniferous species and the 0.40 to 0.44 and 0.55 to 0.58 micrometer channels were used when discriminating between broadleaved species.

Spectral signatures of objects to be recognized were entered in the computer using training locations for which explicit ground data are available. From the tape-recorded MSS data, the computer determined the mean and variance of signal intensity in each selected channel, and the covariance between channels, for each object to be recognized. Subsequent discrimination between objects was accomplished in the computer for each resolution element by comparing the spectral signatures from the training locations. In operation, a separate analog plot of all resolution elements recognized as a given object class is printed on photographic film for each object of interest (Figure 5). These recognition "maps" can be color-coded, superimposed, and rephotographed for display purposes. More detailed descriptions of SPARC processing of multispectral data have been issued by Marshall (1969), Nalepka (1970), and Holter (1970).

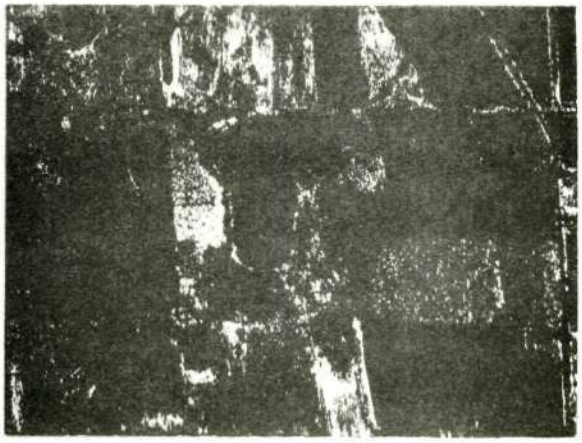
Results

As expected, black-and-white infrared photography (Figure 6) provided excellent tonal contrast between coniferous and broadleaved trees. Consistent discrimination between tree species was not possible with any single set of photography obtained during the mission.

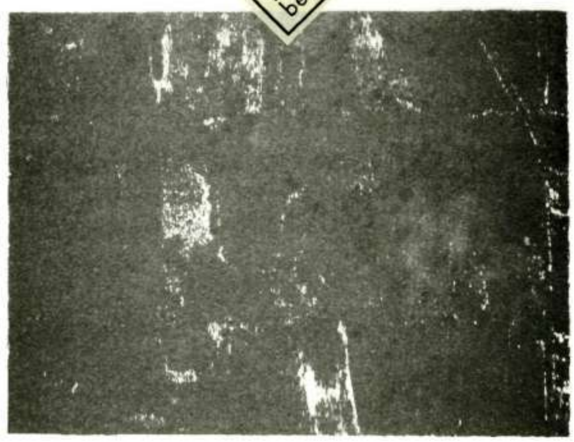
Results of SPARC processing were substantially better. Separation of coniferous from broadleaved trees was as accurate as with any combination of photography. Separation of coniferous species was more successful than with any of the photography, and discrimination between pine (<u>Pinus</u> sp.)



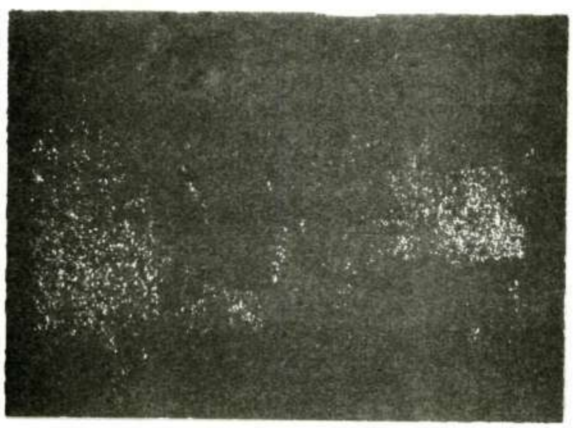
video print 0.72 - 0.80 micrometers



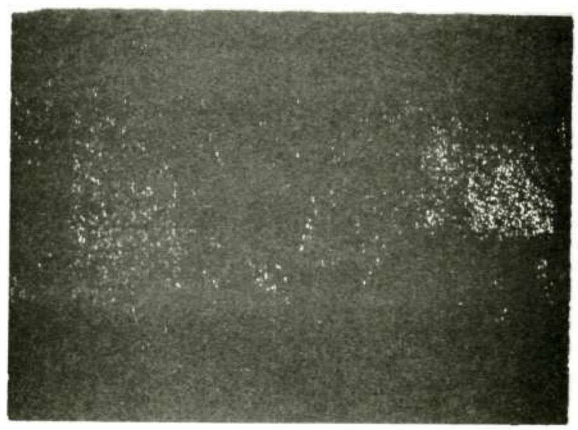
White pine recognition map
Threshold - 1.50



White pine recognition map
Threshold - 1.65

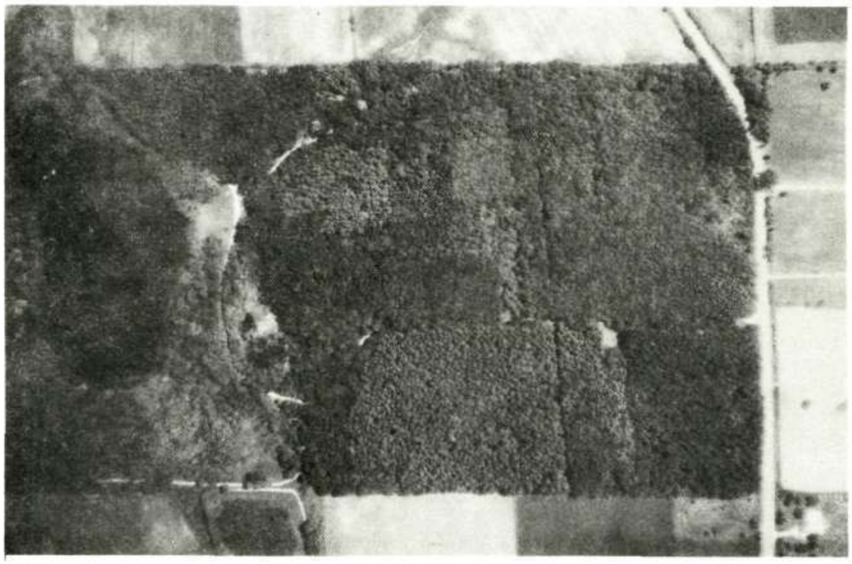


Red oak recognition map
Threshold - .70



Red oak recognition map
Threshold - 1.50

Figure 5. Recognition maps of white pine and red oak at two thresholds. Higher thresholds result in fewer commission errors.



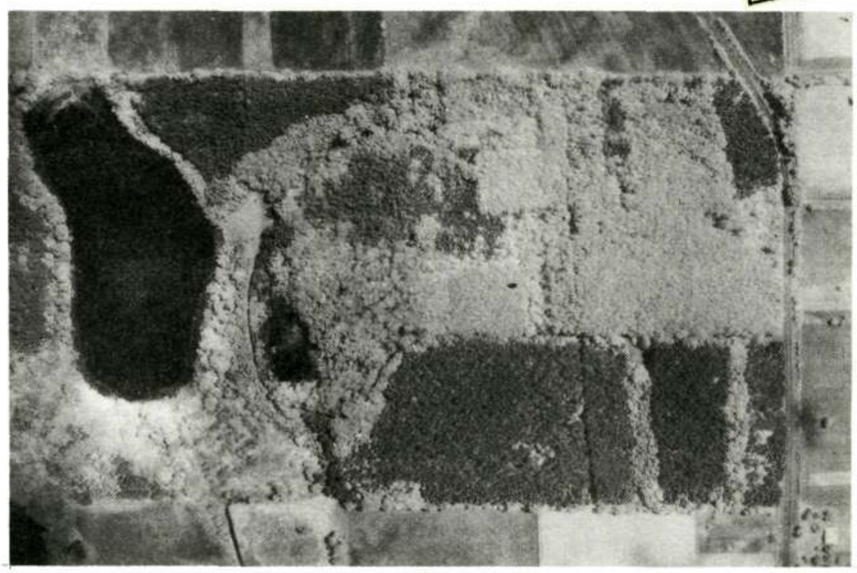


Figure 6. Panchromatic (top) and black-and-white infrared (bottom) photographs obtained from approximately 3,500 feet above the ground in Saginaw Forest on 4 August 1969. Broadleaved species are lighter toned than conifers on the infrared photograph, but neither photograph provides consistent discrimination between species within these two broad tree groups.

and spruce (Picea sp.) was particularly successful. The discriminant capability of the SPARC is best illustrated by the results of the broad-leaved species recognition, however. Red oak (Quercus rubra Du Roi), white oak (Q. alba L.), Black walnut (Juglans nigra L.), black locust (Robinia pseudoacacia L.), sugar maple (Acer saccharum, Marsh.), other broad-leaved trees, conifers, and water were the eight object classes recognized (Figure 7). Approximately 85 percent of all trees within the Saginaw Forest property were correctly identified. The greatest number of errors were failures to separate red from white oaks, but even this separation was performed with an accuracy of approximately 70 percent.

Discussion

The recognition accuracies cited above are not as definite as we would like. Differences in the spectral signatures for the sunlit and shaded portions of individual tree crowns complicated both SPARC recognition and evaluation of the results. To minimize recognition problems, training cells were selected that included primarily sun-lit portions of tree crowns. This resulted in many shaded portions of tree crowns being ignored (i.e., treated as not any of the eight target classes). When crowns of two or more trees overlap or intertwine, it is often impossible to be certain that all trees have been recognized. This precludes definite accuracy statements at this stage of our work.

Restricting training cells to the sun-lit portions of tree crowns reduced the variation in the spectral signature for each object class. In addition, the amount of variation about any spectral signature accepted by the computer as belonging to any one object class can be controlled by changing the recognition thresholds (Figure 5), and it was found that raising threshold

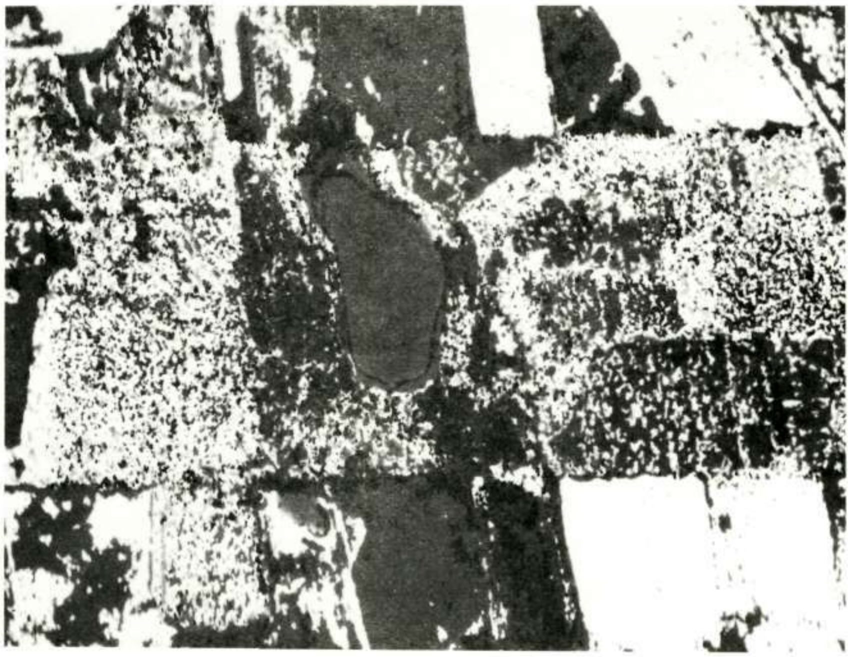


Figure 7. Color-coded recognition map of Saginaw Forest generated by the University of Michigan Spectral Analysis and Recognition Computer. Conifers are shown in green, red oak in red, white oak in orange, black locust in gold, black walnut in light blue, and sugar maple in pink.

levels reduced commission errors (inclusion of incorrect targets in the class being recognized during any particular run). At low threshold levels all broadleaved species merged into a single class.

Training cells were not located in any of the agricultural fields surrounding the Saginaw Forest property. In several cases these fields were identified as one of the forest classes, indicating that spectral signatures of these non-forest types fell within the limits established by the computer from the training cells actually utilized. Comparison of the computer generated recognition maps with the aerial photography obtained during the same flight, provided a simple means of correcting this type of error.

The results described in this report were obtained using MSS data from narrow wavelength bands selected to provide discrimination of tree species. Differences in rooting habit, foliar surface area and structures of water conducting tissues between species are known and have contributed to the successful recognition of tree species. These results are especially significant for they were obtained in an area with varying topography and soil profiles (Figure 8). It should be pointed out, however, that results were poorest on the steepest slopes.

Future Plans

This study will be continued as time and funding permit. Additional tests as Saginaw Forest are planned to determine the consistency with which species recognition can be accomplished. Extension of the study to natural forest areas in the vicinity is also planned.

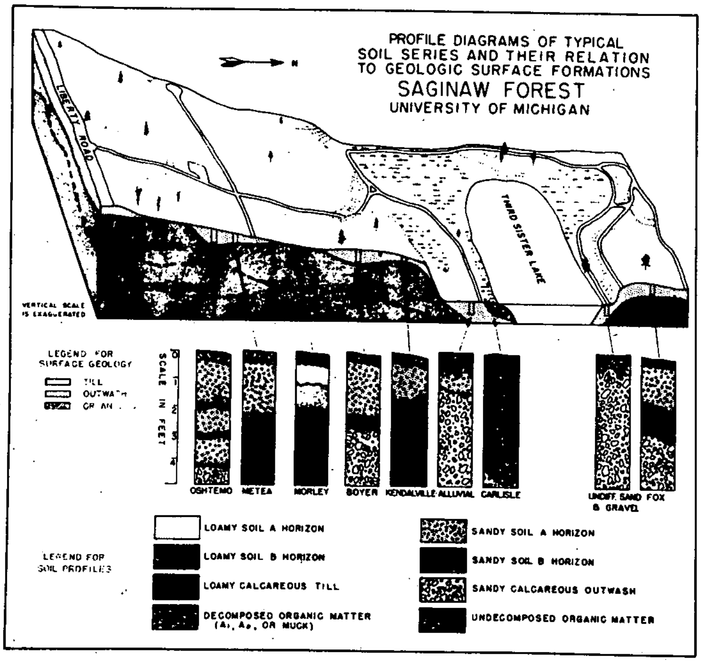


Figure 8. Soil and topography profile of Saginaw Forest showing variations in slope, aspect, and soil type (from Ladrach, 1964).

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