REMOTE SENSING APPLICATIONS IN FORESTRY

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

By
Charles E. Olson, Jr.
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School of Natural Resources
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Annual Progress Report 30 September, 1968

A report of research performed under the auspices of the
FORESTRY REMOTE SENSING LABORATORY,
BERKELEY, CALIFORNIA—
A Coordination Facility Administered By
The School of Forestry and Conservation,
University of California 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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ABSTRACT

This is the second annual progress report describing results of continuing studies of forest trees subjected to varying types of stress. Greenhouse work with tree seedlings exposed to varying concentrations of NaCl and $CaCl_2$ indicates that the oak species tested were more resistant to salt injury than aspen, tulip poplar, maple, or willow; and that salt tolerance of these species decreased in the order listed.

No consistent differences in foliar reflectance or moisture tension between salt-treated and control plants were observed until leaf mortality occurred. Radiometric temperatures for seedlings subjected to heavy salt concentrations were between 0.5 and $1.0^{\circ}C$ higher than for control plants.

Drought conditions in sugar maple seedlings, created by varying the frequency of watering, were accompanied by increasing foliar reflectance of the stressed plants at all wavelengths from 0.5 to 2.5 micrometers. Radiometric temperatures for stressed plants averaged nearly $2^{\circ}C$ higher than for control plants. During this study, it was observed that leaves began to wilt when foliar moisture tensions exceeded 200 lb./sq.in., and leaf margins became dry and brittle after moisture tension exceeded 350 lb./sq.in.

Previsual detection of drought or salt-stress was not achieved using color or infrared-color photography in the laboratory.

Field tests of infrared scanning systems for detecting moisture stress in mature trees were also begun during this reporting period. Girdled oaks were successfully detected in daytime imagery obtained from altitudes up to 4,000 feet above mean terrain. The girdled trees showed clearly in aerial photographs on panchromatic, infrared-aerographic,

normal color, and infrared-color films; and on infrared imagery in the 8-14 micrometer wavelength band obtained in mid-afternoon. Detection was unsuccessful from any altitude when the infrared imagery was obtained at night.

ACKNOWLEDGMENTS

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INTRODUCTION

Early detection of insect and disease attacks is one of the keys to preventing epidemic conditions, but is difficult to achieve over large areas using ground methods. Recent advances in aerial reconnaissance techniques appear to provide improved detection capabilities.

Many insect and disease attacks cause disruption of the water metabolism of host trees by plugging or severing the water and solute conduction tissues. Trees subjected to such attacks become less vigorous and their foliage develops higher moisture tensions than unaffected trees. Reduced vigor and increasing moisture stress are found in trees subjected to drought as well as in trees attacked by organisms, however. Careful analysis of the pattern in which symptoms occur may permit inferrential determination of their probable cause.

Several workers have shown that the reflectance and emittance characteristics of tree foliage vary dynamically during the growing season. These variations result in equally pronounced variations in the appearance of the trees on imagery obtained from any of the electromagnetic remote sensors. Despite this, there is increasing evidence that differences in moisture stress can be detected in natural and

planted vegetation (Weber, 1965; Olson, 1967b; Weaver, Butler and Olson, 1968).

Carefully controlled studies of changes in reflectance and emittance characteristics of foliage on trees subjected to different levels of moisture stress were begun at the University of Michigan in 1965. Results of work completed through the 1967 growing season were described by Weber and Olson (1967). The present report summarizes additional work performed through September 1968.

OBJECTIVES

Three primary objectives governed the work done during the year ending on 30 September, 1968. These were:

1. To enlarge the laboratory work to include investigations of the specific effects of nutrient imbalance and some common disease organisms.

2. To prepare for field tests of those remote sensing systems which the laboratory data indicate offer most promise of successful early detection of tree vigor decline.

3. To investigate possible differences between ring-porous and diffuse-porous species in their response to moisture stress.

To meet these objectives it was necessary to design three relatively discrete, but related studies. The objectives, procedures, results and conclusions reached to date will be described for each study in turn.

STUDY I: INVESTIGATION OF CHANGES IN FOLIAR REFLECTANCE AND EMITTANCE OF TREE SEEDLINGS EXPOSED TO VARYING SALINE TREATMENTS

Trees growing in many areas are exposed to organic and inorganic wastes of man. In the northeast, and in the Lake States, frequent use

of salt for removing winter ice from roads and streets exposes roots of adjacent trees to high levels of salinity. Significant increases in injury to, and mortality of, such trees have been observed in recent years. This study was begun in an attempt to determine whether remote sensing techniques offer a rapid means of assessing the extent of such injury before the damage becomes severe.

The current work was designed to provide information bearing on the following questions:

1. Does salt accumulation alter the reflectance properties of foliage?

2. If salt accumulation does affect reflectance properties, are the changes continuously progressive and is there a threshold level at which changes first become noticeable?

3. If changes in reflectance properties are observed, do these changes result from increased moisture stress similar to drought, osmotic action, or blockage of vessels in the xylem tissues?

4. Does exposure to high salinity increase susceptibility to Verticillium wilt infection?

Pilot Study

Preliminary studies of the salt tolerance of several tree species to $CaCl_2$ and NaCl were conducted to aid in design of more detailed studies. One to three year old seedlings of quaking aspen (*Populus tremuloides* Michx.), tulip poplar (*Liriodendron tulipifera* L.), red oak (*Quercus rubra* DuRoi), black oak (*Q. velutinia* Lam), willow (*Salix* sp.), and sugar maple (*Acer saccharum* Marsh.) were used. All sugar maple

seedlings were collected from natural reproduction in the Ottawa National Forest in Iron County, Michigan. All other seedlings were grown in the University of Michigan greenhouses for other studies completed previously. Early in January, 1968, all plants were placed in four inch pots containing a soil mixture consisting of one part sand, one part screened peat, and two parts loam. Mean oven-dry weight for the soil in the past was 477.38 grams, plus or minus 20 grams.

After potting, the seedlings were kept in the greenhouse under artificial lighting and air temperatures of approximately 25°C to bring them out of dormancy and maintain growth. Measured amounts of salt were applied to the surface of the soil in the pots to give concentrations of 100, 1,000, 10,000 and 100,000 parts of salt per million parts of soil. The salt was carried into the soil by downward percolation of distilled water applied regularly to the soil/salt surface. A summary of the salt treatments is shown in Table I.

Initial salt applications were made on January 12, 1968. By January 17, foliage on plants treated with 100,000 parts per million was severely wilted, discolored and quite brittle, but there was little evidence of marginal burning. Tulip poplar receiving the 10,000 parts per million treatment showed some discoloration in the vein areas and the leaves had begun to wilt. The 10,000 parts per million treatment of aspen produced less yellowing and the leaves were not wilted, although marginal burning was evident.

On March 4, 1968, a second application of $CaCl_2$ was made to the oak, willow and maple seedlings using the same concentrations as in the first application, except that the 100,000 parts per million treatment was

Salt Used	$CaCl_2$	$CaCl_2$	$CaCl_2$	$CaCl_2$	$CaCl_2$	NaCl
Species	Tulip pop.	Aspen	Oak	Willow	Maple	Maple
Date Treated	Jan 12	Jan 12	Mar 4	Mar 4	Mar 4	Mar 4
None	x	x	x	x	x	x
100 ppm	x	x	x	x	x	x
1,000 ppm	x	x	x	x	x	x
10,000 ppm	x	x	x	x	x	x
100,000 ppm	x	x				

Table I. Summary of the species, type and concentrations of salt used during a pilot study on the effect of salt uptake on light reflectance properties of tree foliage conducted in 1968.

omitted. An additional group of maple was treated with NaCl in the same concentrations as with $CaCl_2$. The first spectral reflectance curves were obtained on March 15 and additional curves obtained at weekly intervals through March 29, 1968. In all cases reflectance measurements were made without removing the leaves from the seedlings. After a reflectance curve had been obtained, the leaf was removed and placed in a fixing solution preparatory to microscopic examination of the leaf tissues. Leaves picked for microscopic examination were placed in a fixing solution made up of 75% Chromic Acid-1%, 5% Glacial Acetic Acid, and 20% Formaldehyde-40% Aqueous. Leaves were placed in individual screw top vials just large enough to accommodate single leaves, covered with fixing solution and sealed with masking tape. Microscopic examinations of these materials have not yet been completed. By March 29, all trees treated with 10,000 parts of salt per million parts of soil showed severe burning, discoloration and wilting of the foliage. Of those treated with 1,000 parts per million, the oak appeared least affected with slight burning of the spines and tips of lobes, while willow was least tolerant and there was discoloration over entire leaves. The maple foliage was also damaged extensively; however, damage did not appear as severe as in willow. Comparison of the sugar maple seedlings treated with NaCl and $Ca\ Cl_2$ indicated no difference in visual appearance or in the reflectance curves, suggesting that under present test conditions there is no significant difference in toxicity of the salts to the seedlings. Based on data now available, oak appears to be more resistant to the chloride salts than all other species tested. Aspen, tulip poplar, maple and willow showed decreasing tolerance to

the salt, in that order.

The Current Study

Following the pilot study, two hundred sugar maple seedlings (9 to 15 inches tall) were purchased from the Forest Nursery Company of McMinnville, Tennessee. These seedlings were placed in six inch pots containing uniform volumes of the soil mixture previously described. The total number of trees was divided into two groups, one for subjection to drought conditions by withholding water and the second for salt treatment.

A. Drought

The group of trees selected for the drought treatment was divided into two sections. In one section the young trees had leafed out during the previous week, while in the other they leafed out shortly after the treatment began. In each section half the trees were watered twice weekly with 150 ml of distilled water, and the other half received 150 ml of distilled water once a week. Twice weekly, photographic impressions of selected leaves were made for leaf area determination, and the lengths of the lamina and petiole on newly formed and expanding leaves were measured. The rate of stem extension on the new season's growth also was measured. A control group of plants was watered adequately every day with distilled water. Measurements of leaf area and lamina length, and petiole and stem extension were made twice weekly on these plants.

Light reflectance measurements (0.5 to 2.6 micrometers) were made at intervals on each tree. Repeated reflectance measurements were made on each plant over a period of two months or until the tree died.

At the end of this period these leaves were removed from the seedlings, their moisture tension determined in a Scholander pressure cell, and the leaves prepared for microscopic examination of selected cross sections. A Barnes IT-3 radiometer was used in obtaining radiometric temperature data from leaves near the top, and leaves near the middle, of the crown of each seedling.

B. Salinity

Trees assigned to the salinity test were randomly divided into twenty groups of seven trees each. Ten groups were treated with NaCl and ten groups with $CaCl_2$. In each group trees were randomly assigned to one of seven salt concentration treatments. Concentrations of 0.0, 0.05, 0.10, 0.25, 0.50, 1.0 and 2.0 percent salt (by weight) in distilled water were used. During the initial salt application, each plant was watered to excess with the appropriate solution and allowed to drain. Each pot was placed on a plastic saucer, and any further liquid that drained out was discarded. Thereafter, each pot was watered regularly with a sufficient amount of distilled water to allow a little to drain out into the saucer. This liquid was placed back in the pot a few hours later. It is believed that this procedure kept the concentration of salt in the soil solution nearly constant. Since each pot was maintained at field capacity, any moisture tension developing in the leaves should not be the result of insufficient water.

Measurements of petiole and lamina extension were made during the first month after treatment began. Ten of the twenty seedling groups were randomly chosen for these measurements; five treated with Ca Cl_2

and five treated with NaCl. Throughout the first six weeks after treatment began, four groups were chosen randomly each day and reflectance measurements obtained from selected leaves on each plant. Each selected leaf was tagged for identification so that subsequent reflectance measurements could be made on the same leaves. Since four groups out of twenty were randomly chosen each day, the interval between consecutive reflectance measurements on any one group of seedlings varied from group to group.

Additional reflectance measurements were made at hourly intervals on 3 July for four plants treated with 0.0, 0.1, 0.5 and 1.0 percent NaCl. Daily reflectance measurements were obtained for four groups of seedlings from 5 to 15 August. Two groups were treated with $CaCl_2$, and two with NaCl, and all four groups were maintained at field capacity during this period.

Reflectance measurements were obtained at intervals from two leaves from selected plants and the leaves detached from the seedling and prepared for microscopic examination. One leaf in each pair was one of the tagged leaves from which repeated reflectance measurements had been obtained, and moisture tension was determined for that leaf before it was prepared for sectioning.

Radiometric temperatures of individual leaves near the top, and near the base, of the crown of each seedling were determined with a Barnes IT-3 radiometer on 1, 3 and 5 July.

Photographs of all, or part, of each seedling in eleven groups were obtained on 11 July and 22 August. Kodachrome II and Aerial Ektachrome IR (Type 8443) films were used on both occasions.

The soil in the pots of all surviving plants is being maintained at field capacity at the same salt concentration as during the study. These trees will be repotted in soil infected with the Verticillium wilt fungus, to determine whether the salt treatments increased the susceptibility of the seedlings to attack by this organism.

Results

Since data collection continued through August 1968, data reduction and analyses are incomplete. However, a preliminary analyses of the data provide clues as to the probable nature of the results.

A. Drought Treatment

1. Leaf extension. Measurements of lamina and petiole extension under different frequencies of watering indicate that leaf size increased as watering frequency increased (Table II).

Watering Frequency	Number of Plants	Number of Leaves Measured	Average Leaf Length
Once weekly	10	62	7.0 cm
Twice weekly	10	67	8.6 cm
Daily	10	57	10.7 cm

Table II. Average length of lamina plus petiole for sugar maple leaves developing under varying frequencies of water application.

Leaf area data have not yet been reduced to reportable form.

2. Moisture tension. All plants undergoing drought treatment developed moisture tension in excess of 200 lb./sq. in. before leaf

wilting occurred. As drought was prolonged the effects became more severe and leaves began to dry around the edges, but not until moisture tension exceeded 350 lb./sq. in. (the limit of the pressure gauges on the Scholander Pressure Cell used). Moisture tensions remained low throughout the period and active oozing of sap from the cut end of the leaf petiole was common, for the control plants. Occasional leaves cut from plants watered twice weekly had moist petiole surfaces, but in most cases pressure was required before moisture appeared. Freshly cut ends of leaf petioles were dry for all leaves from plants watered only once weekly.

3. Reflectance. All leaves showed generally increasing reflectance over time at all wavelengths from 0.5 to 2.5 micrometers (Figures 1, 2 and 3). Reflectance increases were greater at long, than at short wavelengths; with greatest increases observed near 2.2 micrometers. The magnitude of these increases is indicated in Table III.

Watering Frequency	Wavelength	Reflectance Increase[1/]	Plant Condition At End of Period
Once Weekly	1.0	5.6%	Dead
Twice Weekly	1.0	5.5%	Living
Daily	1.0	4.2%	Living
Once Weekly	2.2	9.9%	Dead
Twice Weekly	2.2	5.0%	Living
Daily	2.2	3.6%	Living

1/ % Reflectance at end minus % reflectance at start.

Table III. Typical data for reflectance increases at 1.0 and 2.2 micrometers for sugar maple foliage from seedlings watered at varying intervals.

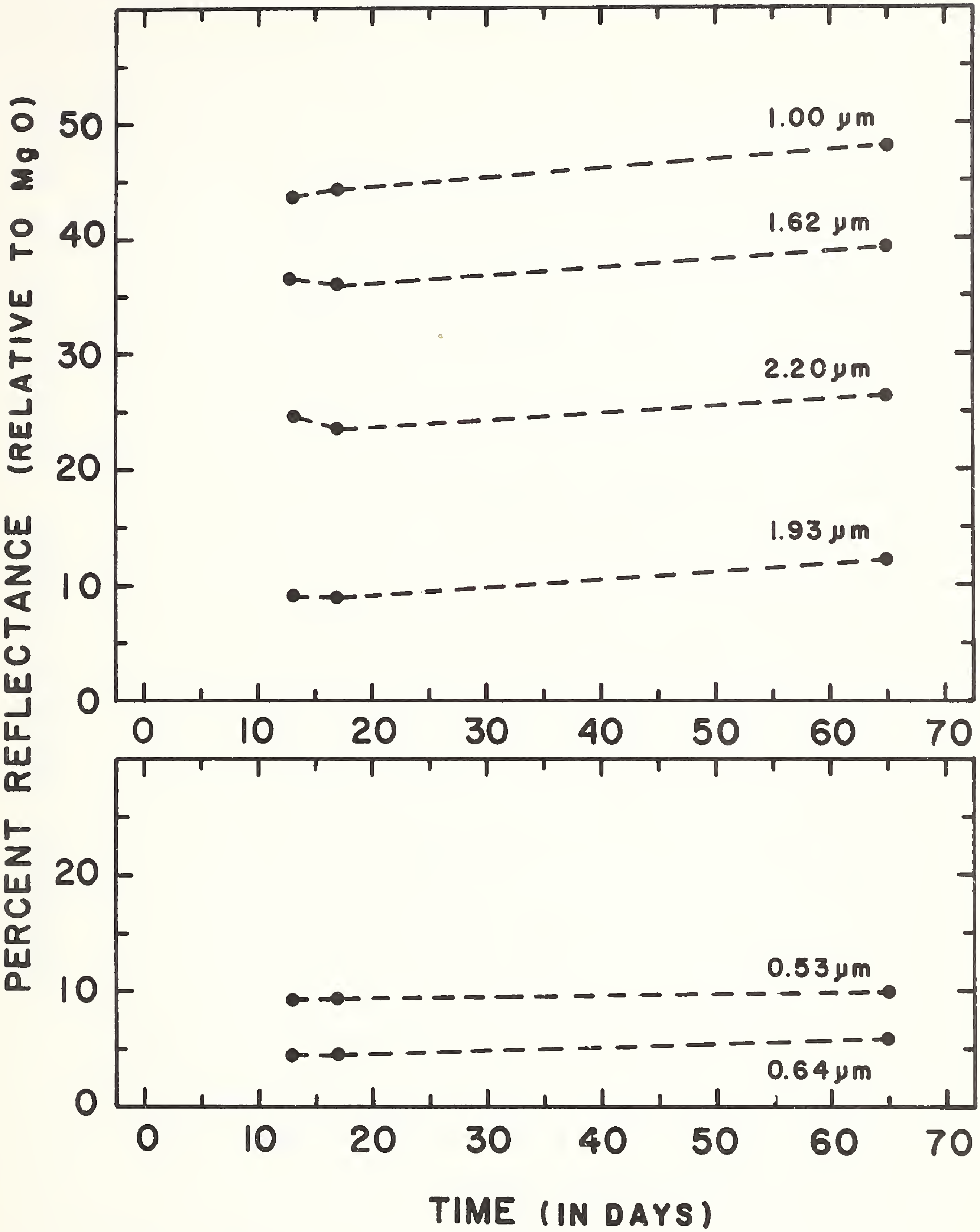


Figure 1. Apparent change in reflectance over time at six wavelengths for a typical leaf on a well-watered sugar maple seedling (leaf C05A).

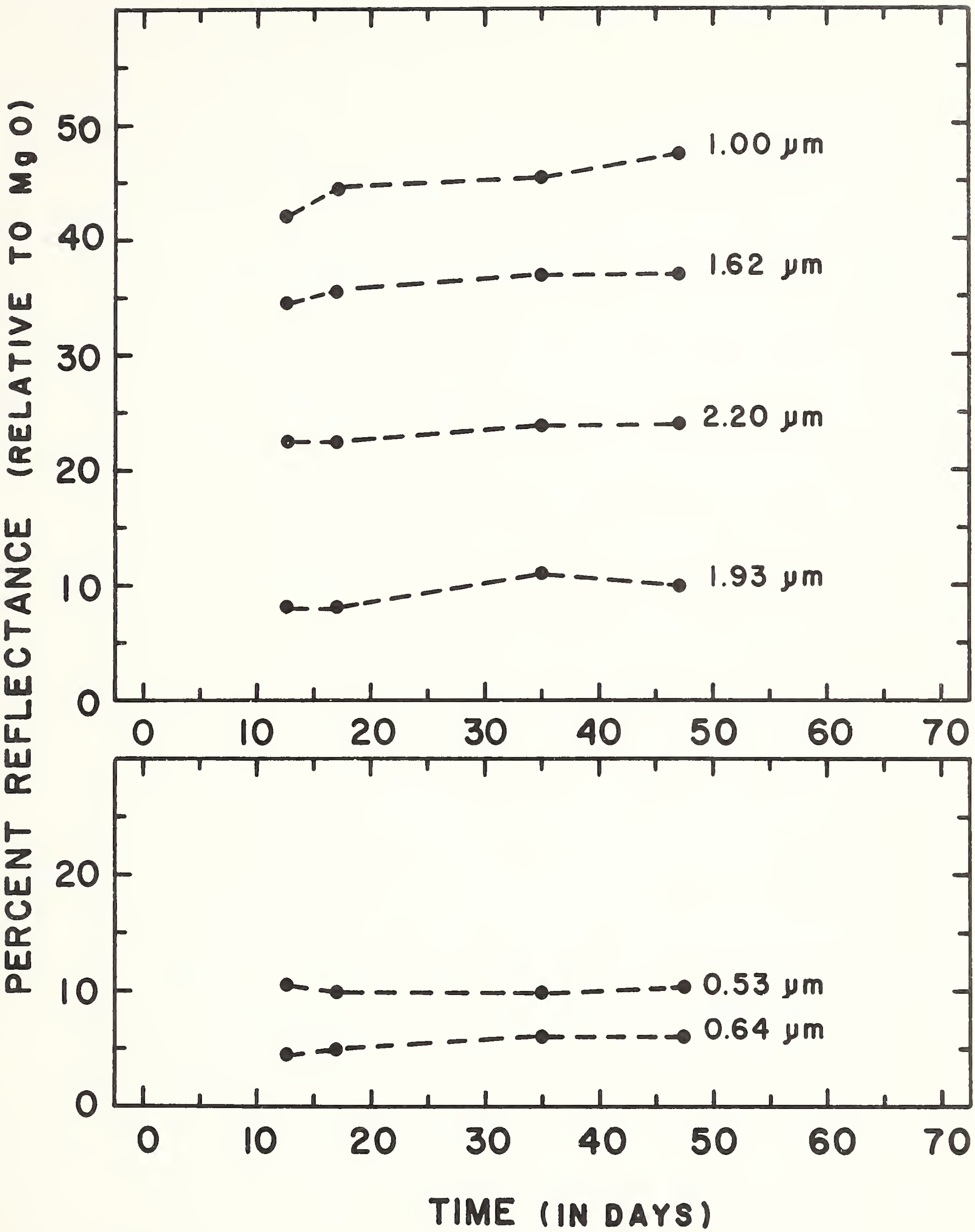


Figure 2. Apparent change in reflectance over time at six wavelengths for a typical leaf on a sugar maple seedling watered twice weekly (leaf DI07B).

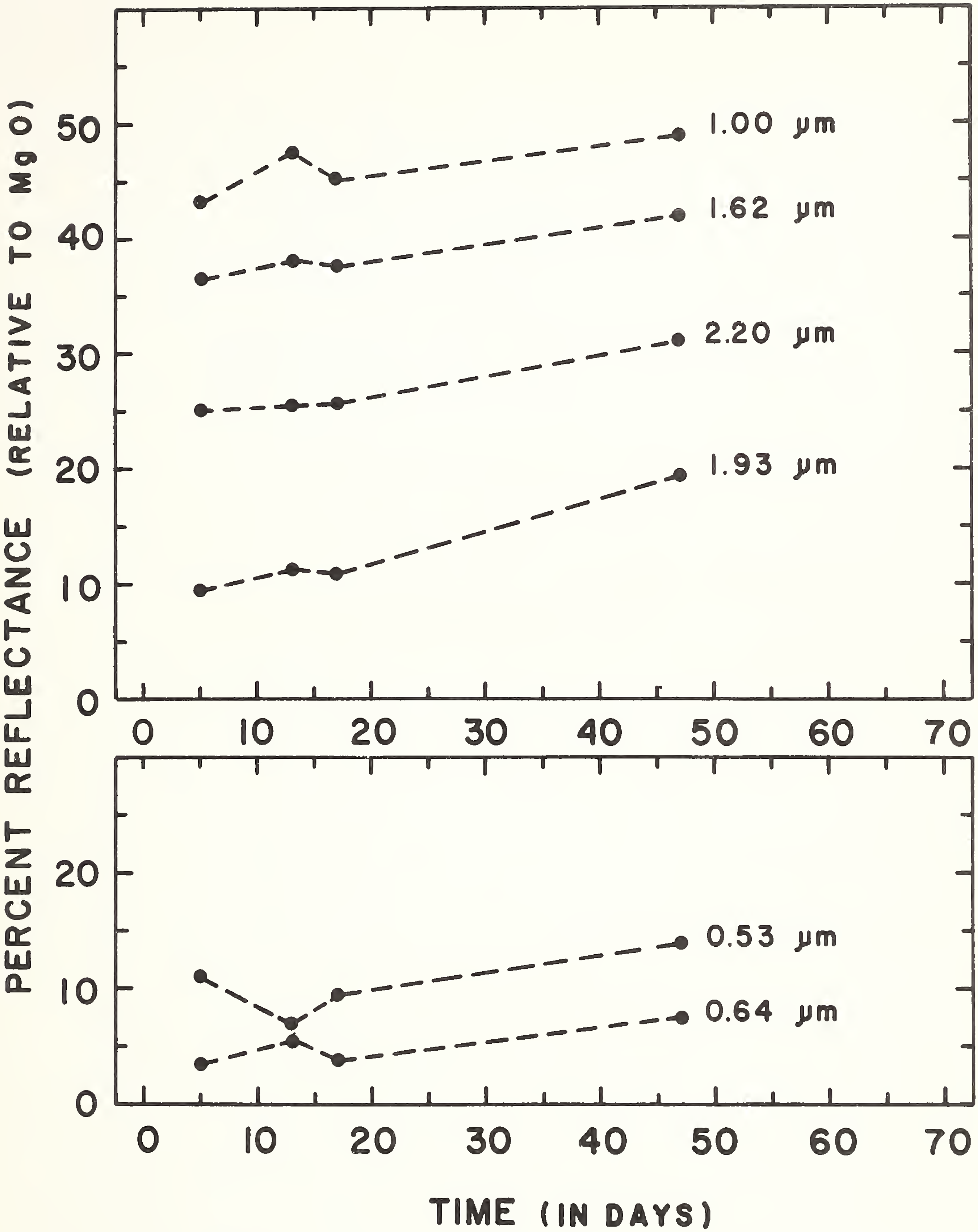


Figure 3. Apparent change in reflectance over time at six wavelengths for a typical leaf on a sugar maple seedling watered once weekly (leaf D101A).

Increasing reflectance at wavelengths shorter than 1.2 micrometers for trees under stress is contrary to results published by several authors including Colwell (1956), but in agreement with a more recent report by Olson (1967a). Differences in species may be a factor and the fact that earlier authors had worked with picked foliage may also be important.

4. Radiometric temperatures. In all treatments, apparent temperatures determined with the Barnes radiometer were nearly the same for leaves from the upper and lower parts of the crown. The control plants, watered daily, gave apparent temperatures with averages approximately 2°C lower than the treated plants. Differences between plants watered once, or twice weekly were less than 0.5°C.

B. Salinity Treatment

The first visible effect of the salt treatments was usually a slight yellowing of the leaf near the margin, particularly at the tips of the lobes. As the yellowing increased, the tips died and turned a light yellow-brown, or fawn color. The area of dead, fawn-colored, material per leaf increased as the study progressed. Color, and false color, photographs of typical plants are shown in Figures 4, 5 and 6.

Visible effects began to appear in plants subjected to the highest salinity (2.0%) on the sixth day after treatment began. All of the high salinity treatment plants showed visible symptoms after 34 days. Most plants receiving the second highest salinity treatment (1.0%) showed definite symptoms after 23 days, but half of the trees treated with the 0.5% salt solution showed no visible symptoms, and weaker salt treatments had produced no visible symptoms, after 77 days. No differences

Kodachrome II/no filter

Ektachrome-IR/Wratten 12 filter

Figure 4. Normal color (top) and infrared color (bottom) photographs of a single, full-sized leaf on a sugar maple seedling from the control group (leaf 18C74B).

Upper Photographs Taken on 11 July 1968

Kodachrome II/No filter

Ektachrome IR/Wratten 12 filter

Lower Photographs Taken on 22 August 1968

Figure 5. Normal color and infrared color photographs taken on two dates of the foliage on a sugar maple seedling watered regularly with a 1.0 percent solution of $CaCl_2$ in distilled water (plant 08C16).

Upper Photographs Taken on 11 July 1968

Kodachrome II/No filter

Ektachrome IR/Wratten 12 filter

Lower Photographs Taken on 22 August 1968

Figure 6. Normal color and infrared color photographs taken on two dates of the foliage on a sugar maple seedling watered regularly with a 2.0 percent solution of $CaCl_2$ in distilled water (plant 08C27).

in symptoms were observed between plants treated with the two salts used.

1. Leaf extension. Most of the leaves formed in a single flush of growth at the time the seedlings were placed in individual pots. Leaf expansion was completed before salt treatment began. Since sugar maple is one of the few diffuse-porous species that do not flush continuously during the growing season, measurement of leaf extension was not practicable during the study.

2. Moisture tension. Measurements obtained with the Scholander pressure cell for plants treated with salt seldom exceeded 100 lb./sq.in., even in plants exhibiting visible damage symptoms. No correlation is apparent between moisture tension and the salt concentrations used.

3. Reflectance. Data for foliar reflectance showed no obvious differences between leaves from control plants and leaves from plants subjected to any treatment until leaf mortality occurred. However, all reflectance measurements were made at a point near leaf center, the last area to be affected by the yellowing, and then fawn coloration, as salt effects become more severe. Short term variations in reflectance measured at hourly intervals were greatest in a control plant, but did not exceed 2 percent at any wavelength. Of those plants for which reflectance data were obtained at daily intervals near the end of the study period, reflectance changes were greatest in two of the trees treated with the highest salinity (2.0%), but results were sufficiently variable that no obvious trend is evident from our preliminary analysis of the data.

4. Radiometric temperatures. Apparent temperatures measured with the Barnes radiometer indicate an average temperature of leaves in the

upper part of the crown that is approximately 0.5°C higher than for leaves lower down. The plants receiving the two highest concentrations of either salt gave apparent temperatures between 0.5 and 1°C higher than the control plants.

DISCUSSION

The work undertaken proved overly ambitious for the personnel and equipment available. Breakdown of the DK-2a spectrophotometer, and erratic performance of the digital readout components prevented sampling as often as desired. The defects in the digital readout have also increased the time needed to reduce the reflectance data.

Our preliminary analyses of the data are inconclusive but seem to indicate that high salinity does not produce the same physiologic effects as drought. This tentative conclusion is based on the moisture tension measurements made with a Scholander pressure cell. While this is a reliable means of determining moisture tension, some abnormalities were observed with the sugar maple leaves.

When using a Scholander pressure cell a leaf is cut from the plant and immediately placed in a thick-walled, sealed container with only the cut end of the petiole protruding through an air tight gasket. Inert nitrogen gas is bled from a high-pressure tank into the cell until the pressure in the cell is just high enough to force water out of the cut end of the petiole. The pressure inside the cell at this instant, and the pressure at which the water film on the cut end of the petiole disappears as the pressure inside the cell is slowly reduced, are averaged to give a measure of the moisture tension inside the leaf.

When sugar maple leaves were subjected to pressure in this manner, the initial oxygenation of water was obscured by the formation of a foam, or froth, which solidified in air and could not be sucked back into the leaf by reducing the pressure in the cell. This was observed in almost all cases when pressures over 100 lb./sq.in. were required. In such cases, the pressure at the time foam first appeared was recorded as the leaf moisture tension. When a water film appeared at lower pressures, it was sometimes, but not always, accompanied by foam formation. It was not clear whether the foam formed from the contents of the xylem or phloem but the foam may result from the sugary sap characteristic of sugar maple.

It was mentioned above that control plants for the drought treatments actively oozed water from the cut end of the petioles on many occasions. This occurred both when leaves were held in the hand and when they were laid gently on the bench. The appearance of water without application of pressure indicates negligible moisture tension, or possible positive pressure inside the leaf. Oozing of moisture from cut petioles was also observed with 69 of 84 plants in the salinity test, and was noticed for leaves from all concentrations of either salt. The possibility that the sugary sap of the maple lessened the osmotic gradient between internal water and external salt solutions may be a factor in our inability to detect high moisture stresses in the plants subjected to saline conditions. On the other hand, salinities of 2 percent or less in the soil solution may not be sufficient to creat an osmotic gradient that will bring about physiologic drought in sugar maple.

It was interesting to observe the differences in visible stress symptoms between plants subjected to drought and salt treatments. The

sequences for the two groups can be summarized as follows.

<u>Drought treatment</u>. The first visible symptoms of drought were wilting of the leaves and progressive distal bending of the leaf petioles. This was followed by drying of the leaves and withering of the petioles. Finally, the leaves turned fawn-colored and abscission occurred.

<u>Salt treatment</u>. Visible symptoms were more numerous and prolonged in salt treated plants, but usually occurred in the following order:

1. Midribs of unfolding leaves bent distally.
2. Tips of unfolding leaves turned black.
3. Tips of full expanded leaves turned fawn-colored, but remained flexible.
4. Interlobate areas turned fawn-colored, but the central portion of the leaf remained a normal green.
5. Entire leaf border turned fawn-colored. Fawn-colored border sometimes dry and brittle, but green center remained turgid.
6. Whole leaf eventually turned fawn-colored and leaf petioles bent distally.
7. Green mold began to form on those fawn-colored leaves that had not dried.
8. Fawn-colored leaves dried and abscission occurred.

It appeared that leaves on plants subjected to drought died because of insufficient water, but that leaves on plants subjected to salt treatments died from other causes. If moisture stress was not significant in plants receiving salt treatments, the lack of observable changes in infrared reflectance from leaves on such plants may not be incongrous.

Microscopic examination of cross-sections through leaves from plants subjected to various levels of salinity has revealed little

difference in structure that can be attributed to the treatment, except in cases where the cross-section included part of the leaf which was dead and dry when sectioned. The absence of observable intermediate conditions in leaf anatomy is probably due to the fact that the leaves were already fully expanded when the treatments began.

Work Currently in Progress

Detailed analyses of the data are underway, and sectioning and microscopic analyses of leaf tissues from various treatments are continuing. In addition, preparations are being made to inoculate surviving trees from each salt treatment with the Verticillium wilt fungus, and to study the effect of the fungus on reflectance and emittance characteristics of foliage from infected trees. This will also provide an opportunity to determine if the salt treatments increase the susceptibility of the treated plants to this organism.

STUDY II: PRELIMINARY FLIGHT TESTS FOR REMOTE SENSING OF MOISTURE STRESS IN FOREST TREES

Previous work (Olson, et al, 1964; Olson, 1967a; Weber and Olson, 1967) indicates that changes in reflectance and emittance characteristics of forest trees are closely related to moisture stress. The differences noted in laboratory studies appear great enough to permit detection by airborne remote sensors. Long range plans call for field testing of the laboratory results during calendar year 1969. Preliminary field testing to gain calibration data for the test site, and to insure that at least major changes in moisture stress can be detected from the air was accomplished in 1968.

Early in the year, the Michigan Conservation Department's Game Research Division proposed a cooperative test of infrared sensors for mapping wetland areas suitable for ducks. By combining our preliminary field testing with the flight program proposed by the State of Michigan, significant cost savings were realized. This required use of a different test area than originally planned.

OBJECTIVES

The cooperative test program was designed to provide data concerning:

1. The accuracy of wetland mapping from infrared imagery obtained in early-May and mid-July, and the accuracy with which swamp dry-up between these dates can be determined from the infrared data.

2. The ability of infrared and photographic sensors to detect gross differences in moisture stress in forest stands.

3. The adequacy of planned ground truth collection to document the important environmental conditions affecting the remote sensor imagery.

Description of the Study Site

The Rose Lake Wildlife Research Center is located twelve miles northeast of Lansing, Michigan, in rolling morainal topography along the Clinton-Shiawassee County line. Small marshes and swampy pot-holes are scattered among sandy ridges and extensive areas of active cultivation are interspersed among the natural vegetation. Pine plantations supplement the native hardwoods in the forest areas. Oak (*Quercus* sp.) and hickory (*Carya* sp.) are the most common trees in the upland stands and

elm (Ulmus sp.) and red maple (Acer rubrum L.) dominate the lowland forest types. Patches of quaking aspen (Populus tremuloides Michx) and balsam poplar (Populus balsamifera DuRoi) are common.

Flight Parameters

Cost and the large size of the Rose Lake Center, precluded complete aerial coverage of the research area. Instead, two flight lines were chosen that crossed some of the most diverse cover conditions in the area.

Day and night flights were scheduled on both 6 May and 17 July. The University of Michigan C-47 was the primary aricraft and all flights were completed on schedule. During the afternoon of 17 July, an aircraft from Bendix Aerospace also made data runs over the Rose Lake test site.

The University of Michigan aircraft carried an infrared line scanner with a mercury-doped germanium detector having an instantaneous field-of-view of 6 milliradians on all flights. The detector was filtered to the 8 to 14 micrometer wavelength band on both daytime flights, but was not filtered at night. During the afternoon flight on 17 July, this aircraft also carried four 70mm, P-2 cameras. One camera was equipped with Panchromatic film and a Wratten 22 filter, another with Infrared Aerographic film and a Wratten 89B filter, a third with Aerial Ektachrome film, and the fourth with Aerial Ektachrome IR (type 8443) film and a Wratten 12 filter.

The Bendix Aerospace aircraft carried a Bendix Thermal Mapper filtered to the 3.5 to 5.5 micrometer band.

During both day and night flights in May, and again in July,

infrared imagery was obtained over the test area from altitudes of approximately 1,000, 2,500 and 4,000 feet above mean terrain. Both direct record and tape record systems were used. During the afternoon flight in July, aerial photography was obtained with all four cameras during the runs at 2,500 and 4,000 feet.

Field Procedures

A preliminary site reconnaissance on 1 May 1968 revealed that most tree species had not leafed out and would be essentially leafless at the time of the over-flights scheduled for 6 May. Three upland stands suitable for creating gross differences in moisture stress later in the year were selected and approved by State Game Division personnel. All three of these stands were located near the centerline of the planned flight track.

On the afternoon of 1 May, a one acre patch of balsam poplar was the only stand available with nearly full foliage. Approximately half of this stand was girdled with a chain saw and severe moisture stress was expected by 6 May. Two charcoal fires, each approximately one square foot in area, were located so that the area of girdled poplars was mid-way between these two hot, point targets.

Field data collection began at noon on 6 May, approximately two hours before the first overflight. A recording hygrothermograph was set up, and apparent and actual temperatures of several background conditions were determined using Stoll-Hardy HF-2 radiometers, a Barnes IT-3 radiometer, and an Alnor Contact Pyrometer. A small, hand-held anemometer of unknown manufacture was used to gather surface wind information. Data

was gathered with each instrument before, during and after the mid-afternoon and night flights. In addition to this data, State Game Division personnel prepared field maps showing the status of wetland habitats along the flight lines.

On 9 and 10 July three additional plots were girdled to produce severe moisture stress. Two plots were located in nearly pure upland stands of oak, and the other in a mixed stand of oak and red maple. Each plot was approximately one-half acre in size and nearly circular. One large tree was left ungirdled near the center of one of the upland oak plots (Plot No. 2).

Ground instrumentation was the same as in May except that an additional hygrothermograph was used, and a pair of black and white panels, three by five feet in size, was placed in the area for additional calibration.

Ground data collection was begun at 0900 on 17 July and continued through 2300. Data were collected at one hour intervals for a designated series of test objects. The recording hygrothermographs provided continuous data on air temperature and relative humidity one foot above ground in a low brushy area, and four feet above ground in one of the upland oak plots.

Results

Preliminary results of the wetlands mapping phase of the study indicate that areas suitable for ducks can be mapped readily from thermal infrared imagery obtained in early May, but obscuration by tree foliage reduces accuracy when the imagery is obtained in mid-July. Image enhancement techniques using the tape recorded signals may facilitate

wetland mapping in both cases. While interpreting the imagery for this phase of the study, much greater tone differences between vegetation types in swampy acres were observed in the night imagery than in imagery obtained during daylight hours. The reverse was true in upland areas.

The balsam poplar stand girdled on 1 May was not visibly different from the ungirdled portion of the same stand at the time of the 6 May flight. The leaves had not wilted, and the foliage on most trees was still green on 17 July. The girdled trees appeared no different than the ungirdled trees on the infrared imagery obtained on any flight, nor was this plot detectably different on any of the aerial photographs obtained on 17 July.

The two upland oak plots girdled on 9 and 10 July were readily apparent on all four sets of aerial photography, and in both the 8 to 14 micrometer imagery obtained by the University of Michigan aircraft and the 3.5 to 5.5 micrometer imagery obtained by Bendix during the daytime (Figures 7 and 8). Both plots were detected at all altitudes used during the test and the plot with the ungirdled tree near the center resembled a small donut in the imagery. Although both of these plots were readily apparent, the oak-red maple plot on lower ground would not have been detectable if its exact location had not been known.

Only one of the plots was detectable on any of the infrared imagery obtained at night (Figure 9). However, this plot would not have been detected if its exact location had not been known in advance.

DISCUSSION

Imagery from the two flights conducted during this study indicate

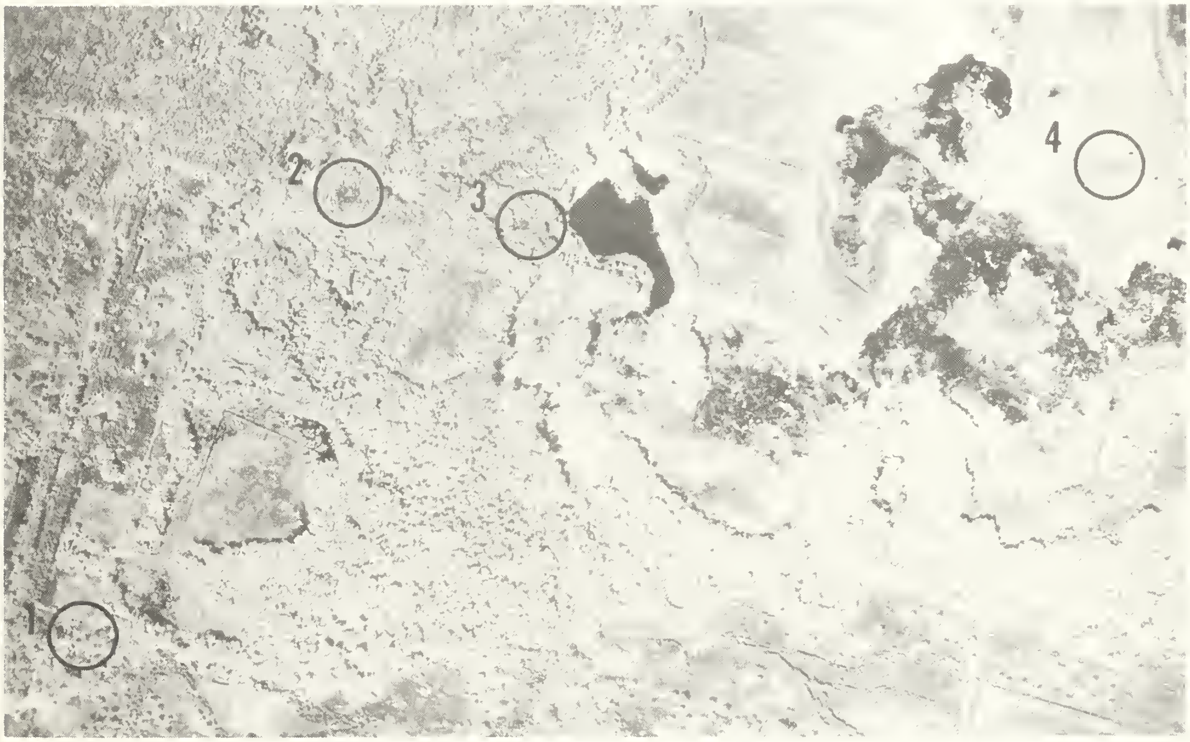
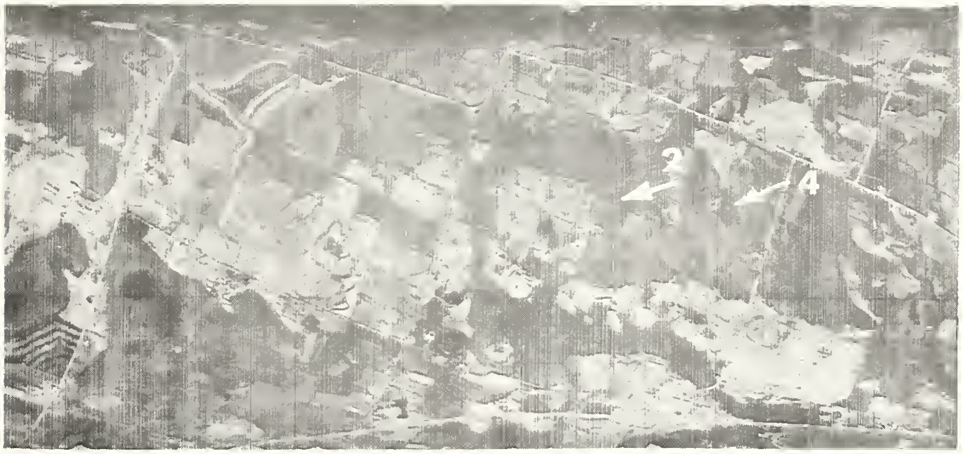


Figure 7. Panchromatic (top) and infrared (bottom) photo-mosaics of a portion of the Rose Lake test site showing the locations of the four plots of girdled trees. Both sets of photographs were obtained simultaneously at mid-afternoon on 17 July 1968.

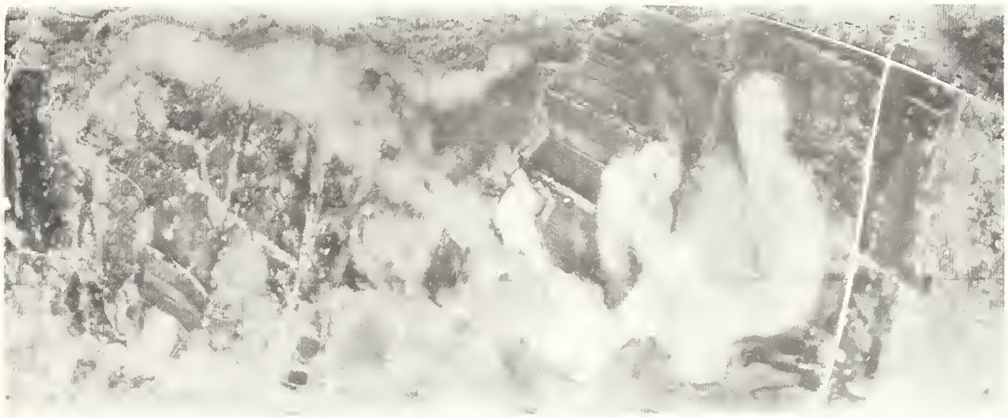
Altitude Above Ground, Approximately 1,000 Feet

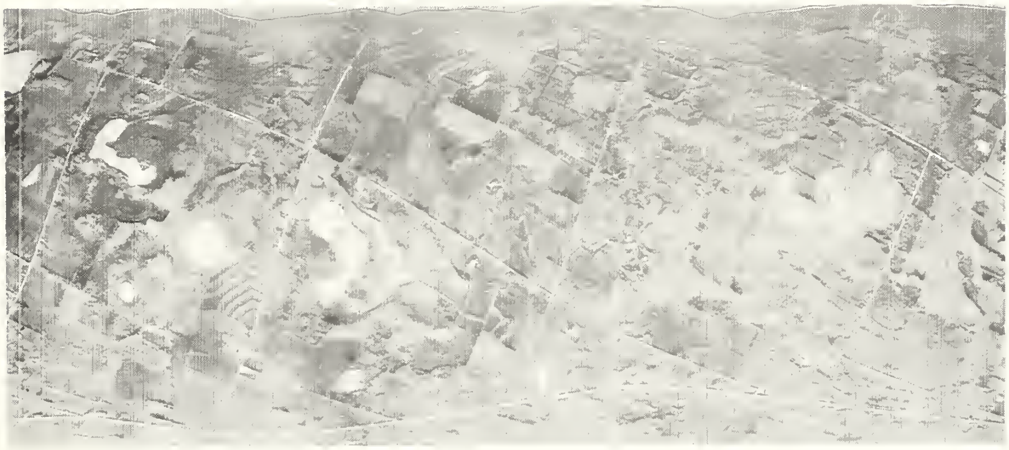


Altitude Above Ground, Approximately 4,000 Feet

Figure 8. Infrared imagery in the 8 to 14 micrometer wavelength band of a portion of the Rose Lake test site obtained in mid-afternoon on 17 July 1968. Girdled trees in plots 2 and 4 are clearly visible in the original imagery from both altitudes.

Altitude Above Ground, Approximately 1,000 Feet





Altitude Above Ground, Approximately 4,000 Feet

Figure 9. Infrared imagery in the 0.7 to 14 micrometer wavelength band of a portion of the Rose Lake test site obtained at 11:00 p.m. on 17 July 1968. None of the girdled trees in any plot are detectable without prior knowledge of their location.

that gross differences in moisture stress can be detected in photographic or line-scan imagery in any of several wavelength bands, at least in some circumstances. Detection of girdled trees was greatest in upland areas with trees having a ring-porous wood structure. Bottomland areas where many trees have diffuse-porous wood structure produced poor results; possibly because the girdles were not deep enough to completely sever the wider band of water conducting tissues usually present in diffuse-porous species as compared with ring-porous species. The results of this test are considered good enough to justify continued field testing to determine the threshold level at which increasing moisture stress first becomes detectable in trees of different species.

Confirmation of the hypothesis that differences between plant species are most readily detected on infrared imagery obtained in the daytime in upland areas, but at night for swampy areas, was not an objective of this study (Weaver, Butler and Olson, 1968). The imagery obtained supports the hypothesis, however.

Work in Progress

Plans are actively underway for continuation of field trials for remote sensing of moisture stress in forest trees. Expansion of the study to include loss of vigor due to root-rotting fungi will be accomplished by including an area of pine plantations infected with *Fomes annosus* in the test site. A request for formal designation of our test area as a NASA test site has been submitted.

STUDY III: INVESTIGATION OF DIFFERENCES IN FOLIAR REFLECTANCE CHARACTERISTICS OF SEEDLINGS OF RING-POROUS AND DIFFUSE-POROUS TREE SPECIES SUBJECTED TO MOISTURE STRESS

Data for tulip poplar (Liriodendron tulipifera L.) seedlings under moisture stress indicate that leaves unfolding under high stress are less reflective than leaves on seedlings with little stress, but that little difference in reflectance characteristics is observed if the leaves unfold and attain full size before the plants are subjected to the stress (Weber and Olson, 1967). If this is also true of ring-porous species, such as the oaks (Quercus sp.), then moisture stress symptoms should be harder to detect in ring-porous than in diffuse-porous species. This hypothesis is based on the fact that ring-porous species usually have only one flush of growth in the spring--while most diffuse-porous species flush continuously during the growing season. Moisture stresses are usually low in the spring but increase later in the growing season. When this is the case, leaves on ring-porous trees would already have attained full size when high stress developed and little change in reflectance would occur. The outer (newer) leaves on the continuously flushing, diffuse-porous trees would be unfolding under increasingly high moisture stress, and this should made the affected trees appear darker than unaffected trees when viewed from above.

Work Completed

Lack of suitable seedlings delayed work on this study. Moisture stress treatments should not be started until the plants to be treated have had sufficient time to recover from any transplanting shock, and

have developed effective root systems. Funding limits prevented acquisition of the needed seedlings until April 1968. At that time, sixteen seedlings between 15 and 24 inches in height, and of each of three species were obtained from the Forest Tree Nursery, McMinnville, Tennessee. The species are: red oak (*Quercus rubra* DuRoi), white ash (*Fraxinus americana* L.) and sugar maple (*Acer saccharum* Marsh.). Oak and ash are ring-porous, and sugar maple is a diffuse-porous species. All seedlings were planted in individual four-gallon containers kept well watered and exposed in full sunshine throughout the 1968 growing season.

Work in Progress

Following bud set in early winter of 1968, the plants will be moved indoors and induced to break dormancy under varying degrees of moisture stress. Measurements of light reflectance and radiant emittance will be determined for foliage on each plant at regular intervals as this foliage develops. Methods will be essentially the same as those described by Weber and Olson (1967).

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