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Detecting Tree Moisture Stress

Although thermal infrared sensors were successful in detecting stress, the stress was also detected with conventional cameras.

(Abstract on next page)

INTRODUCTION

REMOTE SENSING has many possible applications in forestry. One of the more promising is the detection and appraisal of damage resulting from insect and disease attacks. Early detection of this damage is one key to preventing epidemic conditions and is essential if control cost and damage losses are to be minimized.

Many workers have demonstrated that aerial photographic techniques can provide significant assistance in detecting and mapping insect and disease attacks (Taubenhaus, 1929; Fowler, 1951; Colwell, 1956; Heller, 1959; Roth, 1963; and Rishbeth, 1966). Recent advances in remote sensing techniques appear to provide improved detection capabilities. Infrared line scanners and multispectral scanning systems offer considerable promise.

Many insect and disease attacks cause disruption of the water metabolism of host trees by plugging or severing the water and solute conducting tissues. Trees subjected to such attacks become less vigorous and their foliage develops higher moisture tensions than unaffected trees. Weber and Olson (1967) found that trees under high moisture stress were consistently warmer, by 2° to 5°C, than control trees under low moisture stress. In several instances, the difference between light reflectance of the stressed trees and that from the control trees was great enough to permit detection. Olson and Ward (1968) reported differences between drought injury and salt damage to foliage of sugar maple (*Acer saccharum*, Marsh), suggesting that careful analysis of the pattern in which symptoms occur may permit inferential determination of the probable causative agent.

Laboratory data gathered by many workers indicate that differences in reflectance and emittance characteristics of stressed and unstressed trees are great enough to permit detection by airborne sensors. This paper describes the first of a series of continuing field tests of the relative capabilities of line scanning and photographic systems in detecting differences in moisture stress in forest stands. The test was conducted at the Rose Lake Wildlife Research Center, in lower Michigan, during the spring and summer of 1968.

LOCATION AND DESCRIPTION OF THE STUDY AREA

The Rose Lake Wildlife Research Center is located approximately 12 miles northeast of Lansing, Michigan. Many pot-holes and small marshes are scattered throughout the rolling moraines and sandy ridges. Ring-porous oak (*Quercus* spp.) and hickory (*Carya* spp.) are the most common upland species with diffuse-porous elm (*Ulmus* spp.) and red maple (*Acer rubrum* L.) dominating the lowland forest types. Scattered clones of trembling aspen (*Populus tremuloides* Michx.) and balsam poplar (*Populus balsamifera* L.), also diffuse-porous, are common among the native hardwoods. Numerous pine plantations are interspersed throughout the area.

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FLIGHT PARAMETERS

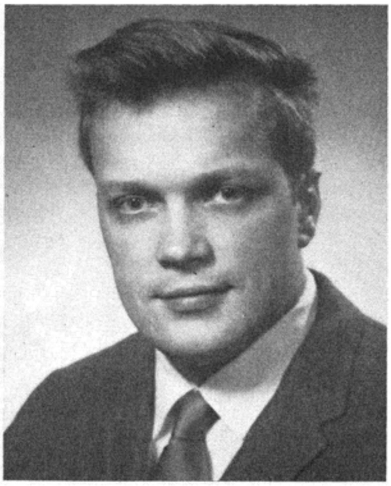
Flight parameters were largely controlled by a wetlands mapping study, conducted concurrently. Day and night flights were scheduled on 6 May and 17 July. The University of Michigan C-47 was the primary aircraft and carried an infrared line scanner with a mercury-doped germanium detector having an instantaneous 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 70 mm, P-2 cameras. One camera was equipped with panchromatic film and a Wratten 22 filter, another with an 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. During the afternoon of 17 July, an aircraft from Bendix Aerospace Systems Division also made data runs over the Rose Lake test site. This aircraft carried a Bendix thermal mapper filtered to the 4.5 to 5.5 micrometer band.

During both day and night flights in May and 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 photographs were obtained with all four cameras during the runs at 2,500 and 4,000 feet.

ABSTRACT: *During 1968, several oak* (Quercus *spp.*), *red maple* (Acer rubrum) *and balsam poplar* (Populus balsamifera) *within test plots on an upland forest site were girdled with a chain saw to create locations of known moisture stress. Day and night thermal infrared imagery in the 8 to 14 micrometer region was obtained in May. In July, day and night thermal infrared imagery was obtained in the 8 to 14 and 4.5 to 5.5 micrometer regions. Color and black and white photographs, both panchromatic and infrared, were also obtained in July. Girdled plots were detectable on all infrared imagery obtained in July. However, girdled trees on upland sites would not have been detected on any nighttime thermal infrared imagery if their exact locations had not previously been known.*

FIELD PROCEDURES

An examination of the field site on 1 May 1968 disclosed that few deciduous trees had leafed out. A one-acre patch of balsam poplar was the only stand with nearly full foilage and approximately one-half of this stand was stem girdled with a chain saw on the afternoon of 1 May. It was expected that severe moisture stress would develop in the foliage prior to 6 May.



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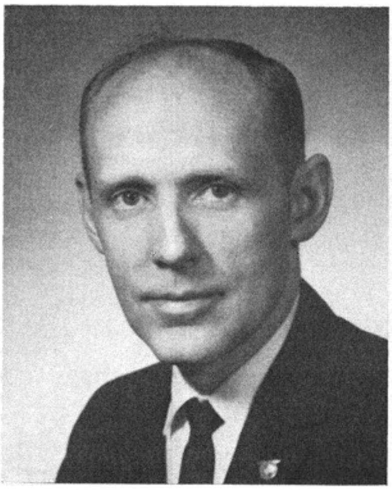

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Ground data collection began approximately two hours before the scheduled first overflight at 1400 on 6 May. Measurements of environmental data similar to those described by Wilson (1968) were made of several targets at one location before, during, and after both the afternoon and evening flights.

Three additional plots, each approximately one-half acre in size, were girdled on 9 and 10 July. Two plots were located in pure upland oak stands. A tree in the center of one plot (plot 2) was left ungirdled. The third plot was in a mixed stand of oak and red maple. Ground data were collected before, during, and after the afternoon and evening flights on 17 July.

RESULTS

The girdled portion of the balsam poplar stand (plot 1) was not visibly different from the ungirdled trees at the time of the overflights on 6 May, or on 17 July. No evidence of moisture stress was detected in this plot on any of the photography or thermal infrared imagery obtained on any flight.

Foliage on girdled oak trees in each of the other three plots had wilted prior to the July overflights. The oak-red maple plot (plot 3) girdled on 9 and 10 July was not detectable on any nighttime imagery and would not have been detected on the daytime thermal imagery had its exact location not been known. This plot was detected on all four sets of aerial photographs (Figure 1). The two upland oak plots (plots 2 and 4) were detectable at all altitudes used in this study and were easily detected on all photographs and in both the 4.5 to 5.5 and 8 to 14 micrometer imagery obtained during the daytime (Figures 2 and 3). Except for a small electronic spike in the vicinity of plot 2 on one set of imagery, stressed trees were not detected on any nighttime imagery.

The relative tone of the stressed trees as compared to the healthy surrounding vegetation varied from sensor to sensor during the test. The stressed trees were lighter toned on the panchromatic film, and darker toned on the infrared aerographic film, than adjacent healthy trees. On the Aerial Ektachrome film, healthy foliage was bluish green (color chip 163 from *Manual of Color Aerial Photography*) and the stressed trees imaged as yellow gray (color chip 93). On Aerial Ektachrome IR film, healthy foliage was light purple (color chip 222) and the stressed trees imaged as a light greenish blue (color chip 172). The results indicate an apparent shift in the color balance of the Aerial Ektachrome IR film. This color shift was not the fault of the Eastman Kodak Company for the film was old and had been stored improperly. It was used only because it was the only roll available at the time.

DISCUSSION

The imagery obtained during this study indicates that gross differences in moisture stress can be detected with infrared sensors under certain conditions. The girdled ring-porous oak species were readily detectable on the daytime imagery, but girdled diffuse-porous species were not distinguishable from healthy trees. It is possible that the girdling of the balsam poplar and red maple was not deep enough to completely sever the wide zone of water conducting tissues common to diffuse-porous species.

Although considerable research is still needed to determine patterns of changes in reflectance for various tree species, work by Weber and Olson (1967) indicates that the reflectance characteristics of leaves which develop with ample water are not greatly affected by increasing moisture stress; wheras, leaves which develop under periods of high moisture stress are significantly less reflective at all wavelengths than leaves which develop with ample water. This indicates that it may prove more difficult to detect stress in ring-porous, than in diffuse-porous species, because ring-porous species generally flush (produce leaves) early in the growing season. Diffuse-porous species flush continuously during the growing season and the newer, most visible, foliage should exhibit moisture stress symptoms if moisture stress develops in the middle or late part of the growing season.

During the tests described in this report, it is possible that the wilted leaves on the girdled oak trees did not completely obscure the reflectance from dead foliage on the forest floor. If so, the lighter tone of the panchromatic, and the darker tone of the infrared photographs of the girdled trees may be due to increased importance of the reflectance from the dead leaves on the forest floor. There is considerable evidence that dead foliage is more reflective in the visible region, but less reflective in the photographic infrared region, of the spectrum than is healthy green foliage.

Just as leaf geometry affects the reflectance characteristics in the visible and near infrared region of the spectrum (Knipling, 1967), so variations in leaf temperature affect the thermal emittance properties of foliage. One important factor affecting leaf temperatures is transpiration, the process by which leaves

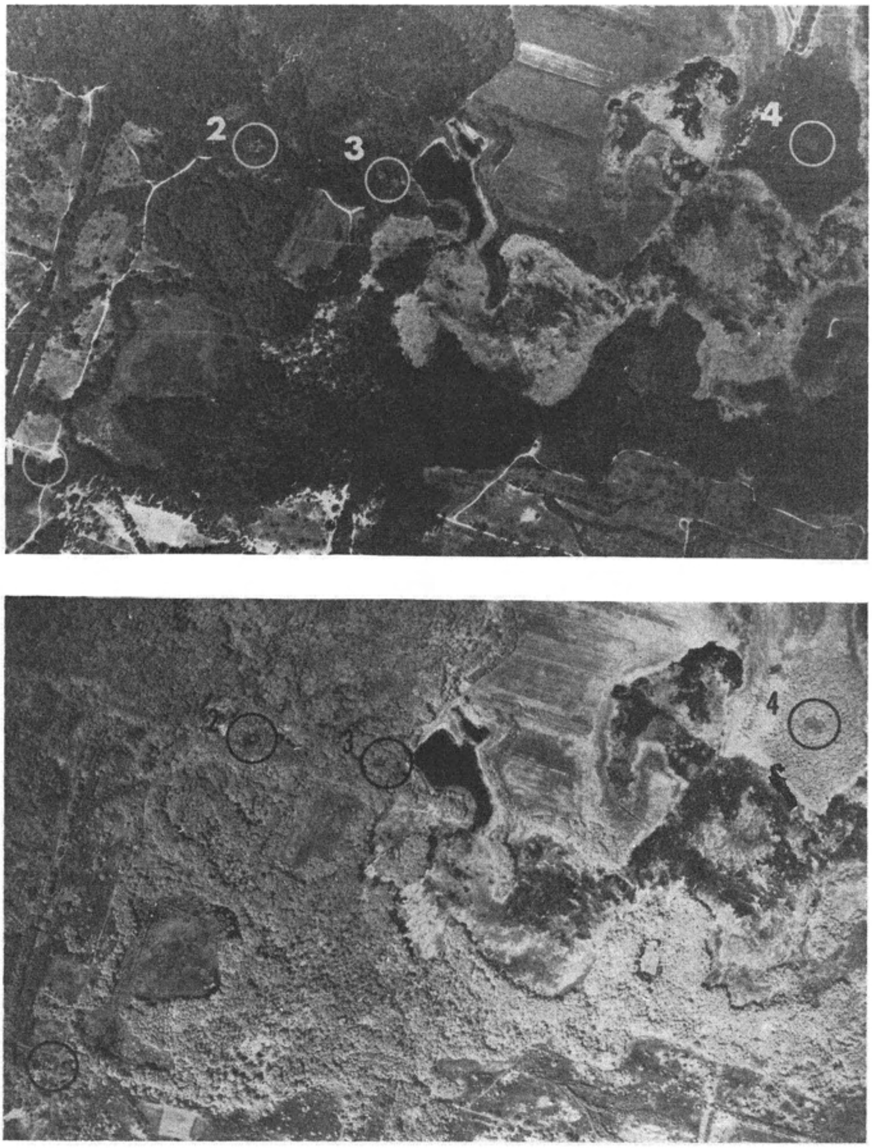

FIG. 1. Panchromatic (top) and infrared (bottom) photo-mosaics showing four plots of girdled trees at mid-afternoon on 17 July, 1968.

lose moisture through stomatal openings in the epidermal tissues. Gates (1964) states that leaves transpiring readily may be as much as 5°C cooler than nontranspiring leaves. Weber and Olson (1967) found that trees subjected to moisture stress had foliage which was consistently warmer than the healthy foliage of unstressed trees. The warmer foliage of the stressed trees would thus be expected to image lighter toned, or as *hot spots*, on imagery obtained in early-afternoon when transpiration is near maximum. At night the rate of transpiration is minimal, narrowing the temperature range between stressed and unstressed foliage and making it more difficult to detect moisture stress.

Although thermal infrared imagery was obtained in only two wavelength bands, the results of this test indicate that thermal detection of moisture stress is more easily accomplished from imagery obtained in the 8 to 14 micrometer band, than from imagery obtained in the 4.5 to 5.5 micrometer band. In agreement with the theoretical discussion

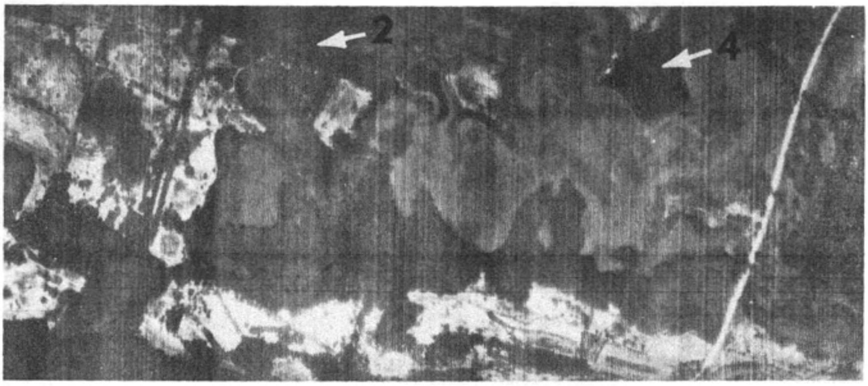

FIG. 2. Infrared imagery in the 8 to 14 micrometer wavelength and obtained at mid-afternoon from approximately 1000 feet on 17 July, 1968. Girdled trees in plots 2 and 4 are clearly visible.

FIG. 3. Infrared imagery in the 0.7 to 14 micrometer wavelength band obtained at night from 1000 feet on 17 July, 1968. None of the girdled trees were detectable without prior knowledge of their locations.

above, stressed trees on upland sites imaged best, and were more easily detected on daytime, than on nighttime, imagery. Additional flight tests have been scheduled for 1969 in an effort to determine the optimum time of day to fly, and the lowest level of stress that can be detected with thermal sensors.

Although thermal infrared sensors used in this study were successful in detecting the areas of moisture stress, detection was also accomplished with conventional cameras. Of the four film/filter combinations tried, the best results were obtained with the infrared aerographic film and a Wratten 89B filter. It should be emphasized, however, that this was not a fair test of the aerial Ektachrome IR (Type 8443) film because of improper storage of the film and the resultant shift in color balance noted earlier.

Some of our colleagues have noted that levels of moisture stress detected during this study were so high that detection came too late to permit effective corrective action. Yet, the ability to detect high levels of stress provides a base from which additional work to determine minimum detectable levels of stress can proceed.

SUMMARY

Flight tests were begun in 1968 to confirm laboratory findings that indicate that moisture stress in forest trees can be detected with thermal infrared sensors. Detection of girdled oak plots was accomplished with infrared line-scanners in the 8 to 14, and 4.5 to 5.5 micrometer bands during the daytime, but not at night. Detection was also accomplished with panchromatic and infrared sensitive photographic systems. Results of these tests do not indicate any particular advantage of infrared line-scanners over conventional camera systems for detecting moisture stress in forest trees.

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