DETERMINATION AND DEMONSTRATION OF REMOTE SENSING CAPABILITIES IN DETECTING AND MONITORING DEFOLIATION, MORTALITY AND DISTURBANCES OVER FORESTED LANDSCAPES

T. Evan Nebeker
Department of Entomology and Plant Pathology
Mississippi State University

In cooperation with
David L. Evans
Department of Forestry
Mississippi State University

EXECUTIVE SUMMARY

Fieldwork for 2000 began with the establishment of experimental plots at a privately owned cottonwood plantation in Leflore County, Mississippi. Small plots, consisting of a block of four trees, and large plots, consisting of a block of 16 trees, were installed on May 9, 2000. In total, we installed 15 small plots and 12 large plots. Plot corners were marked and mapped with a GPS unit. Individual trees within plots were also tagged and numbered. A total of 252 trees were tagged.

Trees in treatment plots were subjected to 25%, 50%, or 75% defoliation. We maintained undefoliated plots as controls for comparison. In addition, within our small plots, we established singletree plots that consisted of one representative of each treatment level (1 25%, 1 50%, and 1 75%) and control. Treatments were applied randomly to both small and large plots with treatments and control replicated three times for each plot size.

Artificial defoliation treatments were applied May 25, 2000 and again on September 15, 2000. Defoliation of trees within experimental plots was carried out using an instrument we designed that roughly mimics the sort of damage feeding CLB inflict on cottonwood terminals and leaves. The instrument consists of a 3.5 ft pvc pipe with four 1.6 ft. nylon cords tied at the top. At the end of each nylon cord wad tied a four-tined treble hook. A total of 184 trees were artificially defoliated.

Multispectral images of this area were captured on June 6, 2000 at an altitude of 4500 ft and on June 7 and June 24, 2000 at an altitude of 12,000 ft. Images of the area were again captured during the fall at 6000 ft. We had requested the plots be flown at 3,000 ft. for this first year of investigation. Reflectance data was also collected from randomly selected trees within all treatment and control plots using a hand-held multispectral radiometer. Radiometer data was collected one, two, and three weeks post-treatment during each treatment period.

In our preliminary analysis, wavelengths 760 nm and 810 seemed the most reliable in differentiating controls from defoliation treatments. In most cases, reflectance for control trees was significantly higher than for defoliated trees. Differentiation among the individual defoliation treatments was somewhat less clear. Overall, the 75% defoliation treatment typically exhibited significantly lower reflectance values than the other treatments. Lower levels of defoliation generally grouped together. These investigations will be intensified during 2001.

INTRODUCTION

A recent report from the National Research Council (1990), FORESTRY RESEARCH: A MANDATE FOR CHANGE emphasized the need for a basic understanding of the biology and ecology of forests. The report placed strong emphasis on determining important genetic and physiological mechanisms vital to the growth and development of economically valuable tree species and key forest organisms, especially in terms of their responses to stress and changing environments. A basic understanding of hybrid poplar, *Populus* spp., cultural systems and associated organisms certainly meets part of this mandate.

The demand for fiber, fuel, and other products derived from wood have led to serious economic interests in plantation culture (fiber farms) of hybrid poplar, such as eastern cottonwood (*P. deltoides*), in the United States and Canada (Ranney et al. 1987; Cuelemens 1990). Their ease of regeneration following harvest, wood properties, rapid growth rate, as well as receptivity to genetic engineering through biotechnology (Bauer 1997) makes hybrid poplar an ideal candidate in meeting these increased demands. Hence, a new and expanding forest landscape is emerging nationally, as well as internationally.

However, hybrid poplar is not without its pest problems and is subject to attack by a variety of insects and diseases. Hybrid poplar plantations being involved in the intensive production of fiber, rotational periods are very short, with harvest of marketable trees occurring in less than 10 years. Target dates of seven to eight years being ideal for genetically improved varieties of hybrid poplar. As a consequence of these short rotational cycles, the impact pest organisms may have on tree growth, development, and mortality can be magnified. With increased pest impact on harvest production, the need to manage specific pest infestations quickly and efficiently is also heightened.

Based on discussions with individuals associated with the emerging industry of fiber farming the key insect pest this effort should be directed towards is the cottonwood leaf beetle (CLB), *Chrysomela scripta* F. The CLB is considered to be the most widespread defoliator of hybrid poplar in the United States, and can act as a limiting factor in the establishment of plantations or to the economic accumulation of biomass in the first few years of growth (Caldbeck et al. 1978; Reichenbacker et al. 1996). In areas of the southeastern United States, where hybrid poplar is intensively cultivated one or more insecticide applications are applied annually in an attempt to control the CLB. Yet, guidelines for monitoring CLB populations at the landscape level have not been developed. Information concerning the distribution of CLB over large areas (plantations) are lacking except for some preliminary work by Nebeker (unpublished data). Nor have adequate criteria been established as to when to spray, hence the entire field is treated. From my preliminary work entire plantations are not affected. Instead, often only a portion of the planted area is affected by insect defoliation, with the size of the area being dependent upon CLB population size. Yet, when infestations do occur the entire area of the plantation is sprayed both infested and uninfested. Cost savings could be recognized if only the infested portion of the plantation was treated.

Traditionally, aerial surveys have been a long-standing method of monitoring the impact of insects and disease on forest health. Most federal and state forest health monitoring programs mandate the use of detection flights over forested land and a great deal of airtime is required to conduct these surveys. As levels of insect or disease infestation increase in forest stands there is a concomitant increase in the need for more intense survey flights. As a result, most agencies involved in forest management have access to aircraft and pilots.

A logical extension of visual census from aircraft's has been the addition of cameras to provide a permanent record of the ground scene for analysis at a later date. Damage to individual tree crowns in forest stands can then be assessed in terms of defoliation and discoloration exhibited on aerial photos. One of the first indicators of physiological stress to trees from insects or disease is discoloration of leaves. Changes in leaf structure and color can provide a guide to the most severely affected areas. The detection of insect and disease damage can, therefore, be aided by the use of remotely sensed data, such as aerial photographs. Such an approach has been used to detect and monitor damage to forest stands by insects such as the southern pine beetle, *Dendroctonus frontalis* Zimm., (Ciesla, 1967; Carter et al., 1998) in the southern United States, the western pine beetle, *D. brevicomis* LeConte, (Everitt et al., 1997) in the western United States, and the jack pine budworm, *Choristoneura pinus pinus* Freeman, (Hall et al., 1998) in Canada.

In particular, color infrared photography has become a commonly used technique to monitor forest health in both North America and Europe (Stanley et al., 1996). In these images, changes in the spectral reflectance of tree foliage in relation to infrared wavelengths are used as indicators of plant health or vigor (Barrett and Curtis, 1982). Healthy, green foliage of trees exhibits a strong response in the near infrared and typically appears bright red, whereas unhealthy or damaged vegetation tends to deviate from the red coloration. In many cases, these changes in infrared reflectance appear before visual changes or symptoms manifest themselves (Stanley et al., 1996). However, deviations in spectral reflectance may not always be due to changes in tree health or vigor, but instead, may occur as a result of variations in foliage area, density, and orientation. Limbs, branches, and non-living ground cover exposed through a sparse crown will tend to exhibit color differences, in terms of their spectral reflectance, from that of healthy vegetation.

Cognizant of that fact, images from color infrared photography can also be interpreted in terms of reductions in foliage that occur as a result of insect-feeding. Such reductions would be accompanied by increases in non-foliage reflectance, and should be lower than that exhibited by healthy, full crowns. Insect defoliators, such as the CLB, represent good model organisms in which to apply remote-sensing technologies to measure and monitor the intensity and severity of insect feeding in terms of both physiological stress and foliage loss from affected trees.

Along with the CLB, other insects such as the cottonwood borer, (*Plectrodera scalator* F.), cottonwood twig borer, (*Gypsonoma haimbachiana* Kft.), and the cottonwood clearwing borers, (*Paranthrene dolli* Neum. and *P. tricinta* Harris) are also of concern in hybrid poplar plantations and can cause trees to respond in different ways that may be detected through remote-sensing. Use of this technology would be far more desirable and efficient than the current individual tree assessment that must now take place. As these and other pest species are encountered during the course of this research effort the database concerning hybrid poplar plantation health will be extended.

As the fiber farm system becomes more common and widespread, new insect and disease associations may develop as this new type of forest begin to dot the landscape. For example, during the summer of 2000 we discovered a root-feeding aphid in the genus *Pemphigus* causing mortality to hybrid poplar during their first growing season (Nebeker, personal observation). This had not be observed nor reported before. We are at a new frontier, with many questions and limited data to base sound pest management prescriptions on. Hence, it is essential that we begin an intensive research effort to assess the potential of new technologies to assist in the development of sound pest management programs to protect forest resources of interest. It is critical that a monitoring system be developed for this emerging industry. Especially during the first year when replanting might be necessary due to early season mortality caused by the CLB.

The ultimate goal of this effort is to provide a methodology that can be used to document forest health disturbances (insects, disease, and storm damage) at the landscape level that is timely and cost effective. It is also a goal that this can be tied to forest inventory, and can become part of the inventory process of each user. Users have a need to know the extent of defoliation in the case of the CLB to determine how much of an area needs to be treated. The selected system, hybrid poplar, for this demonstration is also unique. Within the settings in which this research effort will be conducted, only hybrid poplar will be growing and the major defoliating organism will be the CLB. Principle periods of defoliation occur during March through the end of June and again in September and October. Subsequently, in this simple system there are few extraneous complicating factors to deal with when analyzing and interpreting the data.

METHODS/RESULTS

Objective 1. The fiber farms and plantations to monitor were selected in connection with our industrial partners – Van Development (Fitler, MS), Westvaco (Timberlands Division, Wickliff, KY), International Paper (Rincon, GA), and Crown Vantage (Vicksburg, MS). Each of these companies are extremely interested in technology that can assist in monitoring and evaluating insect/disease activities over various levels of resolution (individual tree, small plot and large acreage's). They also represent a core group, along with state agencies such as the Mississippi Forestry Commission, that would represent potential investors in the technology given it proves effective in detecting and monitoring insect/disease activity. Each of these companies, as well as others in the region represents a significant land holding base for future monitoring.

The primary study area, ca. 1,000 acres, was a cottonwood plantation on a farm near Greenwood, MS. The secondary study area was an established cottonwood plantation, ca. 20,000 acres, near Fitler, MS. Critical flight periods were during the spring and fall to coincide with the primary destructive periods of the CLB.

Trees were defoliated mechanically to represent different intensities of defoliation. This was to ensure that different levels of defoliation were present in the study area. Defoliation rates of 0%, 25%, 50% and 75% was achieved by removing the Leaf Plastochron Index leaves 1 – 10's to establish a baseline for comparison. Trees, n=16 (4x4) for each defoliation rate and replicated three times, were defoliated mechanically to simulate CLB defoliation. The GPS location of each tree was recorded. White sheets, 36 inches x 36 inches, were placed at a variety of locations in the study area as reference points.

Flights were requested for the year 2000 at 3,000 to 3,500 ft for three periods that followed each of our treatment defoliations at approximately 1-meter resolution. Theses dates were May 29 – June 2, June 5 – 9, and June 12 – 16, 2000. The second set of flights was September 18 – 22, September25 – 29, and October 2 – 6, 2000. Flights over the study area took place on June 6, 2000 at 4,500 ft, June 7, 2000 and June 24, 2000 at 12,000 ft. Flights also occurred on September 26, 2000 and October 23, 2000 at 6,000 ft. This imagery is still being evaluated to determine if we can gain anything from it. During the first year of this project no requested hyperspectral data was obtained.

Ground surveys were conducted to assess the physiological state of the trees and degree of insect activity at the time of each flight. This included sampling to determine percent defoliation. During 2000 very little natural defoliation (<1%) by the CLB occurred in the study area. The extended drought that was experienced may be one explanation. There was a slight increase during the later summer but was insignificant.

Reflectance of defoliated and control trees were measured on the ground using a hand-held multispectral radiometer (Cropscan Model MSR87). A bubble-spirit level mounted on the support pole of the radiometer was used to set up the sensors to the appropriate angle. This instrument measures reflectance across eight narrow wavelengths (460, 510, 560, 610, 660, 710, 760, and 810nm). Reflectance was measured approximately every two weeks from May 30 to July 14, 2000 and September 30 to October 30, 2000 (Tables 1 – 12). Reflectance values were expressed as a percentage of the voltage value for the radiation divided by the voltage values obtained for incident radiation. Average reflectance was obtained from each sample tree (100 trees in the small plots and 120 trees in the large plots). Reflectance measurements were obtained between 0830 and 1600 hrs from a height of 3 - 4 m above ground level during near cloud-free periods.

In our preliminary analysis, wavelengths 760 nm and 810 seemed the most reliable in differentiating controls from defoliation treatments (Tables 1-12). In most cases, reflectance for control trees was significantly higher than for defoliated trees. Differentiation among the individual defoliation treatments was somewhat less clear. Overall the 75% defoliation treatment typically exhibited significantly lower reflectance values than the other treatments. Lower levels of defoliation generally grouped together. These data are subject to further analysis.

Objectives 2 and 3. An economic evaluation is to be performed to determine the feasibility of utilizing this technology in relation to the value of the crop over various rotation periods. Economic opportunities and associated costs need to be considered and factored in to determine the economic opportunity of utilizing this emerging remote sensing technology in this setting. Data are being generated to provide this economic evaluation and for a basis for part of the dissertation of the graduate student associated with this project. It is also our intent to propose as simple as system as possible and we are in communication with various individuals and groups to explore these ideas.

We are appreciative of the time taken by NASA personnel to review this project, in person, twice during the first year. Comments and suggestions have been noted and will be followed up on as suggested. We also appreciate the efforts of Michael Warriner (Research Assistant II), William Jones (under grad), Steven Tucker (under grad), and Gensheng Shi (Ph. D. student) for their efforts in association with this first years efforts.

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DATA

Number followed by letters indicates significant difference at p = 0.05.

Table 1. Average percent reflectance of defoliation treatments and controls across eight wavelengths (large plots – May 30, 2000)

Treatment	band460	band510	band560	band610	band660	band710	band760	band810
Control 0%	2.978	4.092	7.874	6.985	5.898	12.817	30.462	34.418
Defoliation 25%	2.910	3.953	7.916	6.704	5.394	12.373	31.719	36.167
Defoliation 50%	3.096	4.192	7.948	7.100	5.927	12.912	29.541	33.514
Defoliation 75%	3.131	4.210	8.126	7.104	5.854	12.918	29.695	33.823

Table 2. Average percent reflectance of defoliation treatments and controls across eight wavelengths (small plots– May 30, 2000)

Treatments	band460	band510	band560	band610	band660	band710	band760	band810
Control 0%	4.187 B	6.079 B	12.619	10.741AB	8.484 B	20.903	50.491A	56.837 A
Defoliation 25%	4.372 B	6.243 AB	12.452	10.991AB	9.001 AB	20.869	47.340AB	53.570AB
Defoliation 50%	4.248 B	5.973 B	11.591	10.392B	8.680 B	19.235	42.741BC	48.447BC
Defoliation 75%	4.828 A	6.693 A	12.359	11.597 A	10.037A	20.603	41.140 C	47.123 C

Table 3. Average percent reflectance of defoliation treatments and controls across eight wavelengths (large plots – June 14, 2000)

Treatment	band460	band510	band560	band610	band660	band710	band760	band810
Control 0%	2.836 B	3.867 B	8.102 B	6.645 B	5.018 B	13.383AB	39.275	44.567 A
Defoliation 25%	2.915 B	3.943 B	8.197 B	6.636 B	5.037 B	12.969 B	39.501	42.478 B
Defoliation 50%	2.993 B	3.968 B	7.851 B	6.620 B	5.149 B	12.681 B	36.654	39.755 B
Defoliation 75%	3.513 A	4.626 A	8.743 A	7.466 A	6.139 A	14.069 A	37.459	41.325 B

Table 4. Average percent reflectance of defoliation treatments and controls across eight wavelengths (small plots – June 14, 2000)

Treatments	band460	band510	band560	band610	band660	band710	band760	band810
Defoliation 0%	3.357 C	4.538 B	9.335 AB	7.656 B	6.089 B	14.744 B	40.622 A	50.047 A
Defoliation 25%	3.551 BC	4.799 B	9.414 AB	8.071 B	6.689 B	15.144 AB	37.951 B	45.619 B
Defoliation 50%	3.722 B	4.892 B	9.319 B	8.151 B	6.764 B	15.196 AB	38.391 AB	47.232 AB
Defoliation 75%	4.098 A	5.364 A	9.905 A	8.861 A	7.658 A	15.749 A	36.222 B	44.315 B

Table 5. Average percent reflectance of defoliation treatments and controls across eight wavelengths (large plots – July 14, 2000)

Treatments	band460	band510	band560	band610	band660	band710	band760	band810
Defoliation 0%	2.226 B	3.222 B	7.737 B	5.920 B	4.105 B	12.593 B	43.344 B	50.246 C
Defoliation 25%	2.400 AB	3.539 AB	8.858 A	6.703 A	4.416 AB	14.217 A	46.875 A	57.400 A
Defoliation 50%	2.508 A	3.678 A	8.944 A	6.820 A	4.608 A	14.568 A	46.165AB	52.090BC
Defoliation 75%	2.341 AB	3.407 AB	8.428 AB	6.371 AB	4.268AB	13.808AB	45.323AB	54.793AB

Table 6. Average percent reflectance of defoliation treatments and controls across eight wavelengths (small plots – July 14, 2000)

Treatments	band460	band510	band560	band610	band660	band710	band760	band810
Defoliation 0%	2.810	4.042	9.211	7.179	5.249	14.688	41.198	47.163
Defoliation 25%	2.780	4.017	9.117	7.263	5.272	14.547	39.936	47.559
Defoliation 50%	2.821	4.045	9.079	7.281	5.445	14.822	39.659	45.348
Defoliation 75%	2.896	4.191	9.415	7.549	5.643	15.149	39.103	44.811

Table 7. Average percent reflectance of defoliation treatments and controls across eight wavelengths (large plots – September 28, 2000)

Treatments	band460	band510	band560	band610	band660	band710	band760	band810
Defoliation 0%	3.541 AB	4.692 A	9.432 A	8.143 A	6.177 B	15.694 A	38.194 A	48.633 A
Defoliation 25%	3.346 B	4.332 B	8.199 B	7.092 B	5.775 B	12.879 B	33.357 B	42.919 B
Defoliation 50%	3.687 A	4.820 A	9.419 A	8.241 A	6.656 A	15.590 A	36.694 A	43.321 B
Defoliation 75%	3.314 B	4.340 B	8.185 B	7.264 B	6.027 B	13.645 B	31.692 B	38.740 B

Table 8. Average percent reflectance of defoliation treatments and controls across eight wavelengths (small plots – September 28, 2000)

Treatments	band460	band510	band560	band610	band660	band710	band760	band810
Defoliation 0%	4.008A	5.385A	5.385A	9.571A	7.506AB	18.406A	40.174A	44.479A
Defoliation 25%	3.379B	4.520B	8.616BC	8.201BC	6.885BC	15.138BC	30.538B	34.253B
Defoliation 50%	4.085A	5.348A	9.805AB	9.352AB	8.071AB	16.914AB	32.747B	37.365B
Defoliation 75%	3.501B	4.538B	7.980C	7.717C	6.865B	14.148C	28.158B	32.991B

Table 9. Average percent reflectance of defoliation treatments and controls across eight wavelengths (large plots – October 12, 2000)

Treatments	band460	band510	band560	band610	band660	band710	band760	band810
Defoliation 0%	3.379B	4.427B	8.610	7.810AB	6.536B	14.590AB	32.878A	41.933A
Defoliation 25%	3.450B	4.444B	8.137	7.552B	6.449B	13.432B	30.318AB	38.152B
Defoliation 50%	3.818A	4.872A	8.840	8.550A	7.214A	15.469A	31.602A	36.611B
Defoliation 75%	3.67AB	4.627AB	8.018	7.965AB	6.941AB	14.216AB	28.501B	33.270C

Table 10. Average percent reflectance of defoliation treatments and controls across eight wavelengths (small plots – October 12, 2000)

Treatments	band460	band510	band560	band610	band660	band710	band760	band810
Defoliation 0%	4.312	5.629	10.575A	10.146A	8.499	18.115A	34.260A	44.569A
Defoliation 25%	3.991	5.210	9.040B	9.217AB	8.221	15.923B	27.442B	35.898B
Defoliation 50%	3.969	5.124	8.429B	8.899AB	8.356	15.213B	25.388B	32.979B
Defoliation 75%	3.891	4.921	7.964B	8.431B	7.824	14.767B	25.416B	31.509B

Table 11. Average percent reflectance of defoliation treatments and controls across eight wavelengths (large plots – October 30, 2000)

Treatments	band460	band510	band560	band610	band660	band710	band760	band810
Defoliation 0%	4.042AB	5.336AB	10.016A	9.695A	8.475A	17.338A	32.607A	40.863
Defoliation 25%	3.857B	5.047B	8.762B	8.467B	7.691B	14.734B	30.882AB	38.203
Defoliation 50%	4.249A	5.580A	10.155A	9.985A	8.905A	17.633A	33.107A	41.119
Defoliation 75%	3.887B	4.944B	8.256B	8.181B	7.631B	14.359B	28.093B	36.823

Table 12. Average percent reflectance of defoliation treatments and controls across eight wavelengths (small plots – October 30, 2000)

Treatments	band460	band510	band560	band610	band660	band710	band760	band810
Defoliation 0%	4.603	6.053	11.053A	11.066A	9.968	19.329A	33.959A	40.571A
Defoliation 25%	4.368	5.741	9.833B	10.185AB	9.563	17.201B	28.781B	35.315B
Defoliation 50%	4.827	6.072	9.269BC	10.246AB	10.012	16.320BC	24.869C	31.678BC
Defoliation 75%	4.450	5.647	8.509C	9.259B	9.419	15.090C	23.406C	29.292C

LEVERAGING ACTIVITIES

We (MSU/MAFES) are investing in the research effort through salary support, benefits, supplies, contractual, and travel expenses of the principle investigator, research assistant II and one graduate student. At Mississippi State University and in cooperation with Iowa State University a Poplar Pest Management Research program has been established with our industrial associates. The timber companies are supporting the research effort by providing study areas, equipment (for field use), personnel, as well as monetary support (~$16,000/yr). This support is to assist in the development of monitoring programs, evaluate new pest associations and develop new technologies to assist in the management of pests associated with hybrid poplar cultivation in fiber farms and plantations. It is expected that as success is demonstrated that those that are identified as users of the technology maybe applying for small business development grants or soliciting for investors in this technology development. Our cooperators are also furnishing us with study areas at no cost.

PUBLICATIONS ARISING FROM PROJECT

No publications generated at present. All data required for analysis and evaluation has yet to be collected.