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Spruce Budworm Damage Evaluations Using Aerial Photography

Mortality could be discerned in mature trees when viewing 2640 ft/in. scale color photography at 7X magnification.

Abstract: *The spruce budworm (Choristoneura fumiferana, Clem.) infestation is continuing at epidemic levels throughout northeastern North America's spruce-fir forest. This article describes research to identify at what minimum scale aerial photography can be used to assess budworm damage. Color and color-infrared imagery taken at several times of the year and interpreted by using several viewing methods have been evaluated to find if new infestations, tree mortality, and stands requiring spraying to prevent excessive future mortality can be identified.*

Color photography obtained in the summer at the height of needle browning was best for interpreting current moderate or heavy budworm feeding. Early summer or fall photos taken when the currently fed needles were not on the trees were most suitable for evaluating past feeding and overall tree condition. Mortality was best identified on color-infrared early summer or fall imagery.

Scale and viewing method greatly influenced interpretation accuracy. Individual tree detail could be observed at scales of 825 feet-per-inch and larger. Tree and stand condition were most accurately interpreted by using a 7X monocular viewer on the backlighted, outer portions of the frame. Mortality counts were equally-accurate using two, four, or seven power stereoscopic and seven power monoscopic viewing at scales of 2640 feet-per-inch and larger.

Introduction

The spruce-fir forest in northeastern North America contributes greatly to the region's economy. In Maine, where the work reported in this paper was undertaken, more than 40 per cent of the forest land is in this type, and the income from timber, recreation, and related industries on all forest land provides more than 30 per cent of the State's income. In 1974, the forest industries alone produced 43 per cent of all manufactured goods by value.

Over the past 200 years the spruce-fir forest has been devastated periodically by the spruce budworm (*Choristoneura fumiferana*, Clem.)[2]. In 1974 and 1975 more than 100 million acres in the northeast and nearly all of Maine's seven million acres of spruce-fir forest were defoliated to some degree[6,7].

Spray programs of gigantic scale have

Photogrammetric Engineering and Remote Sensing,
Vol. 42, No. 10, October 1976, pp. 1265-1272

been undertaken on a regular basis to prevent tree mortality. For 1975 in Maine over 2.2 million acres were sprayed of the 3.5 million acres recommended for treatment to prevent excessive timber loss[10]. However, the residual population and inflights from unsprayed areas are continuing the infestation at epidemic levels.

The State's Bureau of Forestry has several entomologists who spend much of their time assessing the infestation and coordinating the spray program. Presently field checks are made at various times of the year to determine predicted population levels. Aerial observation flights to sketch map areas of current feeding are also made in the summer when the insect clipped needles have turned brown[11].

The work described in this article was undertaken in 1974 and 1975 to find if aerial photography could be used to evaluate budworm damage. The approach offers the possibility of accurately extrapolating ground observations of damage over large areas and of delineating precisely current defoliation[1]. Unlike the observation flights, the photos also could provide a record for future reexamination of current and previous year's damage.

Several investigators have examined the use of remote sensing techniques to assess insect damage. Large-scale color photography has been shown to be useful in delineating budworm and other insect damage[1, 8, 11]. The added economy of using smaller-scale photography has led some researchers to evaluate its application[1, 4]. Attempts to use U-2, color-infrared imagery at a scale of 1:127,000 for identifying western spruce budworm damage were not successful[5]. However, color-infrared photos at scales as small as 1:140,000 have been employed in locating forest areas with extensive stands of budworm-caused mortality and severe defoliation in eastern Canada[3]. Even the potential use of LANDSAT imagery, at a scale of 1:1,000,000, and digital processing of Landsat MSS data has been demonstrated by the successful detection and mapping of extensive areas of severe feeding by the Gypsy Moth (*Porthetria dispar*, L.)[9,12].

The research reported here was concerned with identifying the minimum scale at which spruce budworm damage could be successfully evaluated. The specific objectives were to determine the minimum scale and the season of the year when color and color-infrared films could be used to

- Identify forests requiring spraying or other control measures to prevent excessive tree mortality and timber loss from budworm attack,
- Determine the location and amount of mortality caused by the spruce budworm, and
- Accurately map areas currently under budworm attack.

This project is continuing by examining other remote sensing techniques, such as multispectral photography, to achieve these same objectives.

Data Collection

Color and color-infrared aerial photography, laboratory, and ground verification data were collected to find how well vertical aerial photos could be used to resolve the objectives of the project. The aerial photography was obtained in 1974 and 1975, summer and fall, at several scales, and over areas having different degrees of damage or recovery from spraying (Table 1, Figure 1). The study areas have generally been softwood or mixed-wood stands with a major spruce-fir component. Balsam fir (*Abies balsamea*, L.) needles are the preferred food of the budworm. White spruce (*Picea glauca*, Voss) and red spruce (*Picea rubens*, Sarg.) are also favored hosts.

The majority of the 1974 study sites had heavy to severe current year feeding. In most areas feeding prior to the 1974 (present) growth occurred. In 1975, coverage of a variety of feeding conditions was obtained. Included were a range from light to severe current year feeding.

The summer photos were flown when the clipped needles retained in the budworm's webbing on the branches were at the height of browning. The fall photography was taken after these needles had fallen from the webbing, leaving only live foliage where feeding did not occur and bare twigs where it did.

Color film (Kodak type 5257) was used only in 1975. Color-infrared film (Kodak type 2443) was flown both years. Scales of 2640, 1650, 1320, 825, 382, and 223 feet-per-inch were obtained in 1974 and scales of 5280, 2640, 1320, and 825 feet-per-inch in 1975. In order to avoid haze problems the color film was used only at the three latter scales.

Hasselblad 500EL cameras with 50 and 80 mm focal-length lenses were used to take the photography (Figure 2). The color film was used without any filter and the color infrared film with the equivalent of a Wratten 8 filter. The film was processed and returned in transparency form. All film was airmailed for processing and the time from film exposure

TABLE 1. STAND CONDITION AND AERIAL PHOTOGRAPHY SCALE COMBINATIONS.

Timing of Photography	Condition of Spruce-Fir Foliage, if Damaged	Scales of Photography For Each Flight	
		Feet/Inch	Representative Fraction
Summer	Height of Browning of Insect Clipped Foliage. Needles Still Retained on the Tree	2640 1650 1320	1:31680 1:119800 1:15840
Fall	After Clipped Needles Have Fallen, Only Bare Twigs and Undamaged Foliage Remaining	825 382 223	1:9900 1:4584 1:2674

to return was usually from three days to a week.

Low-altitude oblique ektachrome-X color slides were also taken. This photography was flown within a few days of the vertical imagery and was used to document the forest condition at that time.

Photo-interpretations of stand and tree conditions were made in the Forest Resources Remote Sensing Laboratory (Table 2). Selected stands and individual trees were identified for intensive study and their location fixed on transparent overlays covering the aerial film (Figure 3). The laboratory interpretations were made as soon as possible after the photography was flown.

Using the vertical photography, oblique slides, and the annotated overlays from the laboratory study, the stands and trees of interest were located and their condition was noted for comparison with the laboratory evaluations. Factors identified in the field were the degree of current year defoliation, past feeding, or recovery over different portions of the crown. For example, it might be noted that a tree had severe current feeding over the upper one-half of the crown and moderate past feeding on the upper one-quarter. Tree status, whether living or dead, and the length of bare top from complete defoliation, were also recorded.

A detailed laboratory study of how well mortality could be located at each scale on the color-infrared photos was also undertaken. Counts of dead tops were made on nine 2.5 hectare blocks identically located for each site and scale (Figure 3). Summer and fall photography at scales of 5280, 2640, 1320, and 825 feet-per-inch were examined.

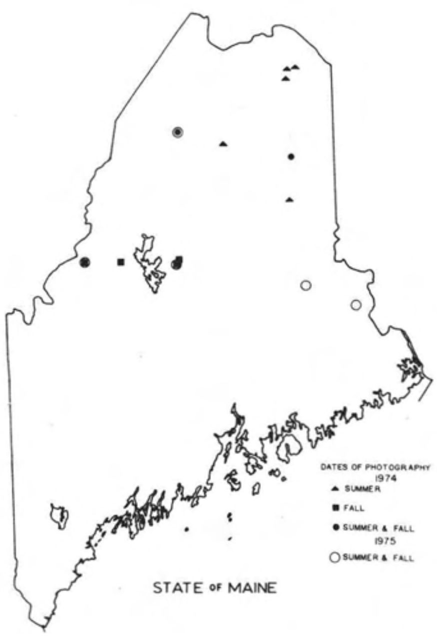

FIG. 1. Aerial photographic sites for the evaluation of spruce budworm damage.

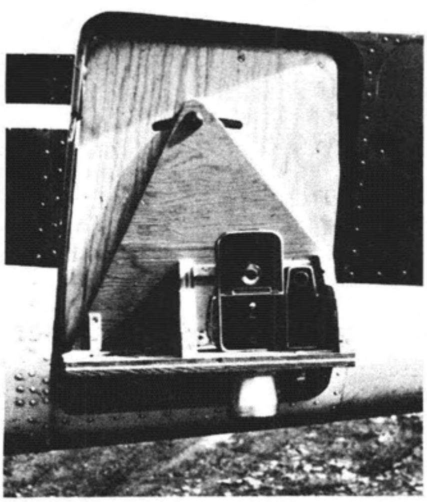

FIG. 2. Dual camera mount with one Hasselblad 500EL in position for vertical photography.

TABLE 2. CATEGORIES OF DEFOLIATION USED BY INTERPRETERS IN THEIR STUDY OF SPRUCE BUDWORM DAMAGE.

	Amount of Defoliation	
Category	Current Year	Previous Years
Trace-light	Less than 20 per cent	Some evidence of feeding in past year(s). Less than 20 per cent of last year's or 40 per cent of past two year's growth fed upon. Top not bare.
Moderate	Between 21–50 per cent of current foliage fed upon.	Defoliation evident on at least two years previous growth. 41 to 70 per cent of this foliage removed by feeding, crown appearing thin with a short bare top.
Heavy	Between 51–80 per cent of current foliage fed upon.	Pronounced defoliation on two or more year's growth. Greater than 70 per cent of this foliage removed. Crown thin and greyish with more than 2 feet of bare top.
Severe	Greater than 80 per cent of current foliage fed upon.	
Mortality	Tree completely defoliated, crown completely bare.	

Most of the data collected were for forest stands with a high proportion of balsam fir. These areas are suffering the greatest damage and are in the most need of study.

METHODS OF ANALYSIS

The laboratory analyses were made using several types of equipment and interpretive techniques. Stereoscopic and monoscopic evaluations of the photography at several magnifications were made with an Abrams 2-4× pocket stereoscope and a Bausch and Lomb Zoom Stereoscope to find which provided the most reliable interpretations. Viewing methods included two, four, and seven power stereo and seven power monoscopic optics (Figure 3). The Zoom Stereoscope was used for both the 7× stereo and monoscopic studies.

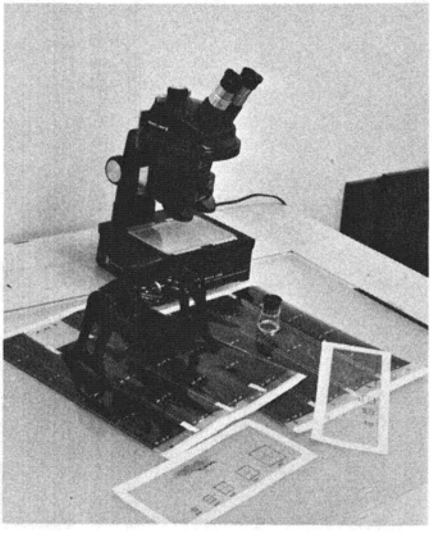

FIG. 3. Transparencies enclosed in acetate overlays. Also shown are the 2-7× viewing devices and the 2.5 hectare overlay grids at several scales.

The imagery was also examined to find what solar illumination conditions and relative image position (i.e., distance from the principal point) gave the best damage and mortality estimates. Trees and stands with all degrees of direct, fore, and backlighting at positions varying from the center to the edges of the transparencies were studied.

Statistical tests were made to find if there were significant differences in mortality counts on the color-infrared imagery between scales, viewing methods, and interpreters. The data were collected over several sites, both summer and fall imagery, on 2.5 hectare blocks. These areas were located on the imagery by lining up obvious site landmarks on the transparencies with orientation marks on the block overlay shown in Figure 3. The blocks were viewed sequentially from the smallest scale to the largest to prevent, as much as possible, interpreter bias from the increased familiarity with the location of dead trees at the larger scales.

The data were divided into two sets. The first group included counts made by two interpreters on four sites at four scales (5280, 2640, 1320, and 825 feet-per-inch) using all four viewing methods. These figures were used to examine if there were significant differences in counts between scales. The second set included data from five additional sites for only the three larger scales by the same interpreters. This group of counts was used to find if there were significant differences between viewing methods, interpreters, or any of the interactions between the three main factors of scale, viewing method, and interpreters. The general model used was

$$Y = S_i + V_j + I_k + SV_{ij} + VI_{jk} + \text{error}$$

where Y = mortality count, S_i = scale, V_j = viewing method, I_k = interpreter, and the others are interactions.

The reasoning for the two sets was to gain more data for the second test series. Not all of the sites had photography at all four scales.

A field analysis was undertaken to provide a comparative basis for the accuracy of the laboratory interpretations. The study trees or stands were located on the ground by referencing their marked locations on the laboratory overlays to a road system, stream, or other easily identifiable ground feature appearing on the frame being studied. Using these entities for starting points and relative orientation, the exact stand or tree was found by locating and walking between identifiable forest features such as large hardwoods and pine standing out of the overstory. A 7× hand-held magnifier was used to view the transparencies on a portable field viewer as an aid in picking out the reference points and the exact study areas (Figure 4). Once at the desired site, 7×-35 binoculars were utilized to help in assessing the actual tree or stand conditions. General observations and notes taken from very low-altitude fixed-wing and helicopter flights were also used to supplement this ground data.

FIG. 4. Field viewing of transparencies to locate specific damage sites.

RESULTS AND DISCUSSION

Viewing technique, season, film type, and scale all were determinants in how well the spruce budworm damage could be assessed. Except where excessive shadow existed, monocular viewing with a 7× magnifier gave the best feeding evaluation results. Interpretations also were more accurate when made on the outer portion of the pictures on the backlighted side of the frame. Here radial relief displacement had tipped the trees so that the crown profile could be viewed and the shadow background in the top of the tree accentuated the outer periphery of the crown where most of the feeding had taken place. On a few of the study areas the photos were obtained either early or late in the day with a low solar elevation and a large amount of resulting shadow. Under this condition, stereo viewing at any of the magnifications was found to give better, more accurate results. Possibly the more direct lighting on one frame psychologically compensated in part for the excessive shadow.

Mortality interpretations were made on the color IR transparencies and were equally accurate using any of the viewing methods. The analysis of variance to test for differences between viewing techniques, interpreters and the interactions between scale, viewing method and interpreters indicated no significant differences ($\alpha = 0.01$). This analysis is shown in Table 3.

Seasonal differences were found to influence interpretation ability. Field checks verified that current moderate and heavy defoliation was identifiable on the summer imagery taken at the height of browning of budworm clipped needles. Except in the

TABLE 3. ANALYSIS OF VARIANCE OF FACTORS INFLUENCING MORTALITY COUNTS ON AERIAL PHOTOGRAPH.

Source	Degrees of Freedom	Mean Square	F Value
scale (S)	3	581.05	48.26**
viewing method (V)	3	17.40	1.45
interpreters (I)	1	1.32	0.11
SV interaction	9	5.70	0.47
SI interaction	3	3.80	0.32
VI interaction	3	5.78	0.48
Error	104	12.04	—

** Significant at the 1 per cent level ($\alpha = 0.01$).

case of heavy to severe top feeding, present year defoliation could not be detected on the fall photography taken after the clipped needles had fallen. Further complication arose from the similar appearance of severe past feeding and dead branches on the top few feet of the crown.

On the summer photography a heavy cone crop appeared similar to heavy or severe current feeding on balsam fir. However, at scales of 1320 feet-per-inch and larger the interpreters were consistantly able to identify trees with cones using the color IR film, because of their distinct white coloration. The current feeding was more of a dull grey to greenish-brown. Where cones and feeding occurred on the same tree and the defoliation was only in the top few feet of the tree, the conation masked the feeding.

Overall tree condition and past feeding was best identified when using fall photography. The bare twigs contrasted with the live foliage at that time. On the summer imagery the current feeding tended to mask the status of the tree from previous defoliation.

Mortality could be identified well at either season. The interpreters, however, found the film exposure and lower sun angle of the fall imagery at least subjectively gave them less eye strain and more interpretation comfort. Further, in several cases when using the summer color IR film, it was found that heavy-severe current feeding over most of the visible crown, coupled with a high sun angle, gave, on the first look, an appearance similar to a dead tree. However, with concentrated effort the two tree conditions were separable.

Depending upon the scale and purpose, both film types were advantageous. Current feeding was best interpreted using the summer, color photography. At this time trees with moderate to severe feeding appeared brown. However, at the highest flight altitude much of the photo detail was "greyed out" from haze. Only heavy to severe current defoliation could be detected on the summer, color IR transparencies. For this film and feeding condition the trees had lost their red, unfed look and appeared grey.

Past feeding and overall tree condition were better interpreted on the fall, color-infrared photography. Light past feeding was not interpretable with either film type. Moderate past defoliation was evident only in the color IR photos and heavier feeding was more distinctly seen on this film than on the color imagery.

Mortality was more accurately identified on the color IR photography. The blue-green appearance of the bare, dead tree crowns on these transparencies contrasted more with the reddish-pink of unfed and grey to brown of budworm-fed live trees than the white appearance of these same dead trees contrasted with the green of unfed, brown of current, and grey of past budworm-fed live trees on the color film.

Photo scale also in part determined the degree of accuracy of the budworm damage evaluations for individual trees or stands. Generally individual trees could be examined at the scales of 825 feet-per-inch and larger, and in some instances when the tree was not obscured by the surrounding stand at the 1320 feet-per-inch scale. After examination of the 1974 imagery it was found that the 382 and 223 feet-per-inch scales did not provide any more accurate assessments than the 825 feet-per-inch scale. For reasons of economy the 825 feet-per-inch scale was selected as the largest to use for future study of individual trees.

On the color film at the 825 feet-per-inch scale, the portion of the crown currently being heavily fed upon versus that part lightly fed upon could be determined by the degree or intensity of brown occurring on the crown. The more the browning, the greater the amount of feeding. The color IR imagery at this scale also allowed good delineation of heavy current feeding. However, the interpreters could not separate light or moderate current defoliation from the unfed condition.

The ability of interpreters to categorize either current or past feeding of trees or stands as light, moderate, heavy or severe has not been analyzed statistically. However, the results discussed above have been derived from two years' experience and hundreds of lab-field comparisons of individual tree and stand evaluations. In any given flight, the different emulsion batches, processing, sun angle, and stand characteristics such as density and species mix gave a varying appearance to a given feeding condition. Even with these differences, after a few days of work with a given batch of imagery in the field, the interpretations were consistently correct.

The ability to interpret mortality on the color IR imagery was evaluated statistically. An analysis of variance to test for differences between scales indicated there were significant differences. From Duncan's multiple range test the 5280 feet-per-inch scale counts were significantly different from those on all other scales, as were those for the 2640 feet-per-inch scale. The 1320 and

TABLE 4. AVERAGE MORTALITY COUNT PER 2.5 HECTARE BLOCK ON COLOR IR FILM.

Scale (ft./in.)	Average Number of Dead Trees/Block
5280	1.84
2640	2.66
1320	7.91
825	10.75

825 feet-per-inch mortality tallies were not significantly different.

Although not statistically tested, ground evaluation of the areas where the mortality counts were made gave some interesting results. The average number of dead trees per 2.5 hectare block for each scale is shown in Table 4. The number of dead trees detected obviously increased with scale. The field checks indicated that some trees, even of merchantable size, were being missed at the smallest scale. At the half-mile-per-inch scale, large, overstory merchantable mortality was consistently identified. All groups of more than a few dead overstory trees, even if the individual trees had a small crown area, were also visible. Individual trees missed were those, merchantable or otherwise, with small crowns of less than ten feet in visible diameter. At the two larger scales all merchantable mortality and some smaller size was detectable.

The 7× monocular counts in a few instances resulted in insignificant overestimates of the actual dead trees visible on the imagery. In the field it was found that bare ground was sometimes confused with this tree status. From field checks of more than 200 individual trees identified in the lab using a 7× mono-magnifier, more than 95 per cent were correct. For interpreter comfort the authors found two or four power stereo worked best on the four-inch-per-mile and larger scales. Seven power stereo was felt best for smaller scales.

CONCLUSIONS

The results of this study indicate that spruce budworm damage can be evaluated using color and color infrared aerial photography. Color, summer imagery at scales of 1320 feet-per-inch and larger was found best for evaluating current defoliation at the time insect clipped needles were brown and still held within the budworm's webbing on the branches. Color IR fall photography taken when the clipped needles had fallen from the branches was found to be best for evaluating overall tree condition and identifying mortality. It is assumed early summer photography, flown before current feeding is evident, would have a similar result.

The accuracy of the evaluations also depended, in part, upon viewing techniques and scale. Except where excessive shadow existed, the best interpretations of current and past feeding were made during a 7× monocular magnifier and looking at the trees or stands to the outer part and backlighted side of a frame. Individual tree detail could be observed on scales of 825 feet-per-inch and larger and at the 1320 feet-per-inch scale when the tree was standing alone in an opening. Heavy current and past defoliation could be identified at scales of 2640 feet-per-inch and larger. Moderate and light past defoliation could not be detected at any of the scales examined. These ranged from 5280 to 825 feet-per-inch.

Mortality of individual, mature overstory trees with crowns larger than ten feet in diameter could be discerned on the color IR film at scales as small as 2640 feet-per-inch. Mortality was not consistently identifiable at the mile-per-inch scale. All merchantable size dead trees, except those whose crown had broken off, could be located on the 1320 feet-per-inch photography.

Tests indicated no differences in accuracy of mortality counts using stereo or monocular viewing. However, for interpreter comfort stereo viewing with 2-4× magnification is recommended for scales of 1320 feet-per-inch and larger. For smaller scales, 7× stereo viewing is suggested.

It should be realized that aerial photography alone is not enough to evaluate the exact amount of damage. Variations in feeding appearance from year to year for a given degree of feeding and differences in film emulsion batches and processing require that some ground observation comparisons be made to insure the accuracy of interpretations.

Specific recommendations for the aerial photography to achieve the objectives are

(1) Color IR photography at scales at 1320 feet-per-inch or larger should be used to identify forests requiring spraying or other control measures. These photos should be flown in early summer or fall after the clipped needles have fallen. Because of low solar elevation and resulting reduced illumination, the photos should not be flown before mid-May or after mid-September. This imagery will show the amount of past feeding and the overall forest condition, factors necessary in prescribing treatment for the forest.

(2) Color IR photos at scales of 2640 feet-per-inch or larger, flown at the same times as for past feeding should be used to locate large overstory, merchantable mortality. Scales of 1320 feet-per-inch and greater should be used to locate any dead overstory trees whose crowns are more than a few feet in diameter. For unmerchantable, small crowns and broken stems in the overstory or stand openings, use scales of 825 feet-per-inch or larger.

(3) Color photography at scales of 1320 feet-per-inch or larger, flown at the height of clipped needle browning should be used to identify areas of current defoliation.

Further work needs to be done in several areas. The film types and scales best suited to evaluate spray success and recovery need to be studied. Methods of integrating presently collected spot ground measurements of damage on small areas, with photo interpretations of feeding condition over large areas, should be developed. This would provide a potentially more accurate assessment of overall forest condition than is presently obtained by the spot ground and aerial observer check system. The use of enhancement techniques and multispectral photography to accentuate feeding and tree conditions even more than is evident on color or color IR film should also be considered. Even with the work which remains to be done, the authors feel that significant progress has been made in demonstrating that aerial photography can be used to evaluate spruce budworm damage.

ACKNOWLEDGMENT

This project was supported in part by McIntire-Stennis, State Department of Conservation Appropriation 3236.7, and private funds.

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