R. L. Talerico
Northeastern Forest Experiment Station
Hamden, CT 06514
J. E. Walker
Calspan Corporation
Buffalo, NY 14221
T. A. Skratt
Northeastern Forest Experiment Station
Hamden, CT 06514

Quantifying Gypsy Moth Defoliation*

The Scene Color Standard (SCS) technique, when employed with color-infrared photography, provided a correlation of measurement of defoliation with ground observations of 0.78.

Introduction

Defoliation by insects can reduce the growth of trees, increase their susceptibility to secondary organisms, and contribute to their mortality. Over large areas, defoliation often results in widespread mortality and subsequent changes in species composition, and can disrupt forest-management plans.

The long-term effects of defoliation are difficult to predict, and monetary losses caused by insects such as the gypsy moth (*Lymantria dispar* (L.)) are difficult to document. Any change in growth increment or in branch or crown dieback depends on the intensity and duration of an attack.

The gypsy moth is an introduced defoliator of most forest vegetation. In the Northeast, the gypsy moth is univoltine, overwintering in the egg stage. Eggs hatch in late April or May, depending on location and aspect; larvae are present for about two months. The amount of foliage consumed

Abstract: *Currently, estimates of gypsy moth* (Lymantria dispar*(L.)) defoliation are subjective judgments of the amount of foliage that has been removed from a tree or a forested area. These estimates can be made by observers on the ground or in aircraft, or from aerial photographs. A precise, objective method for measuring and mapping insect defoliation from aerial photos is the use of color-infrared film (at a scale of 1:31,640) with the Scene Color Standard (*scs*) analysis. This photo-derived defoliation measure includes terms for* IR/R *reflectance, green reflectance at maturity, and average red, green, and infrared reflectance of the crown. The correlation of measurements by the* scs *analysis with ground observations of defoliation was* $R^2 = 0.78$. scs *technology also can be used in monitoring spray programs for uniformity of application and effectiveness in protecting foliage.*

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during their development is considerable; most of this defoliation can be attributed to the larger, late-instar larvae.

The impact of the gypsy moth on nontimber values is even more difficult to assess. However, it is known that visitor use of scenic and recreation areas decreases sharply during and after defoliation.

Currently, estimates of defoliation are subjective judgments of the amount of foliage that has been removed from a tree or forested area. Defoliation is estimated as light, medium, or heavy, or is expressed as a percentage. But there is no standard method of estimating defoliation, so individual experience is the only guide. Differences in estimates among individuals vary from year to year and can be great. Standards for estimating defoliation of conifers have been suggested by Benjamin (1955), Heller and Schmiege (1962), and Waters *et al.* (1958).

Because of these difficulties, foresters and entomologists need a reliable method for quantifying the extent and severity of insect defoliation. Reliable estimates also are needed to project insect population trends and to plan additional ground surveys and suppression projects.

Besides estimating defoliation from the ground, aerial sketch mapping, aerial flights in which operations recorders are used, and photographs and satellite imagery have been used to detect, categorize, and delineate large areas of defoliation. Ground surveys for extensive areas of defoliation are time consuming and require a large trained work force; and many changes in canopy conditions can occur during the survey. Aerial surveys also require considerable time, skilled observers, and good weather. Both methods are costly and their accuracy depends on the observer's training, motivation, and subjective judgment of the amount of foliage present or absent. Aerial surveys are more complicated than ground estimates; they are limited by technical and personal difficulties such as variation in sun angle, poor visibility, and adverse flight conditions, i.e., cramped seating, motion sickness, or long periods of boredom. The observer may also have navigation or tracking duties, and he often is required to make decisions on crown condition instantly.

Aerial (Ciesla *et al.,* 1971) and satellite imagery (Rhode and Moore, 1974) provide a permanent synoptic visual record of defolia-

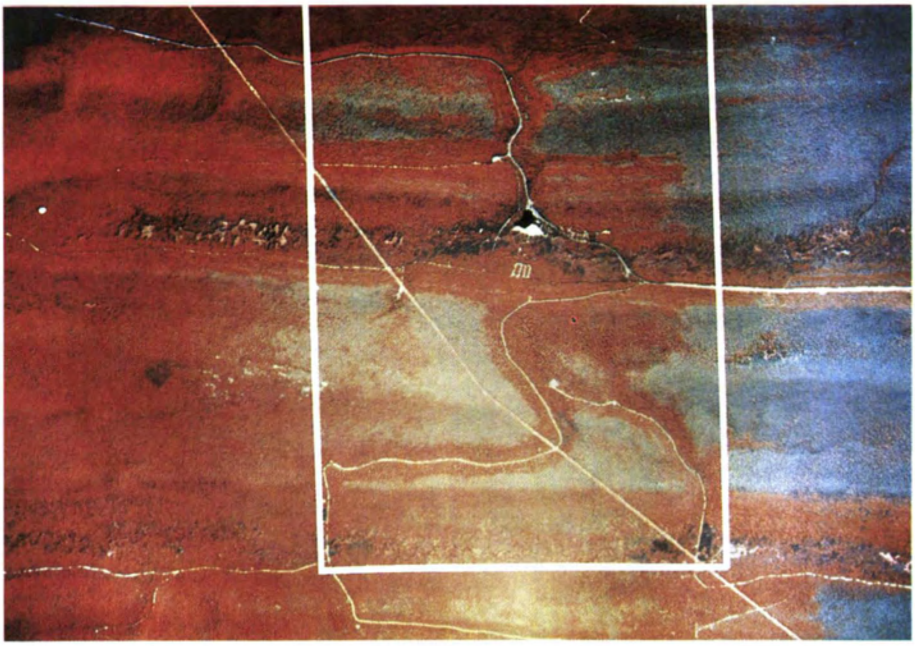

PLATE 1. Color-infrared photograph taken over Raymond B. Winter State Park on 1 July 1975, at scale of 1:31 680. Outlined area denotes the location of infrared-to-red ratio mask area shown in Plate 2. The sketch map (Figure 2) covers all but the extreme western and southern areas in this scene. Foliage patterns along major roads are the result of spray treatments to maintain foliage for aesthetic value.

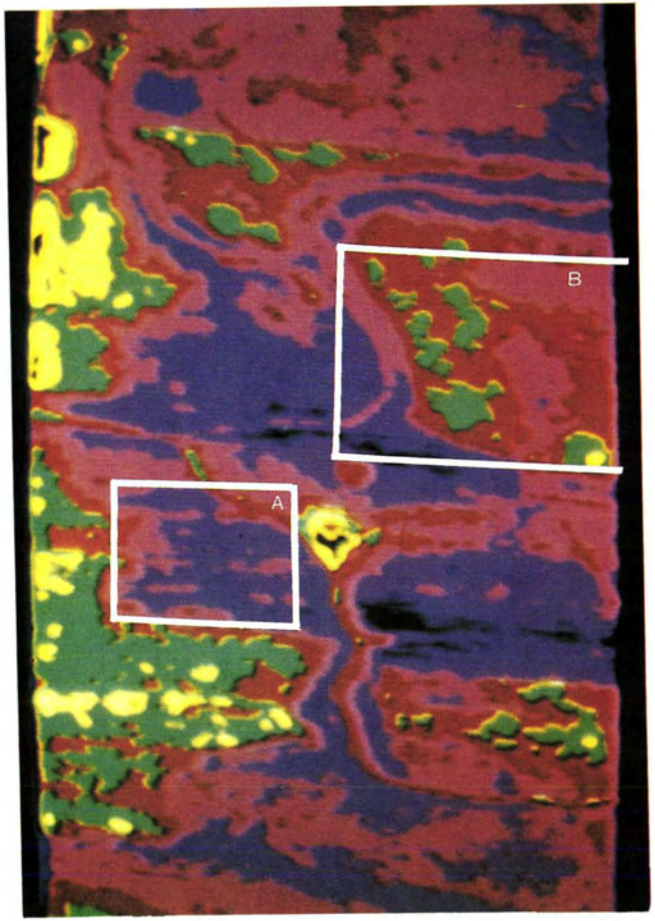

PLATE 2. Color-coded infrared-to-red ratio mask of 6.4 by 12.9-km area around Halfway Lake. Area A is the sprayed area southwest of Halfway Lake; Area B is a treatment block northeast of the lake. Color codes rank defoliation from light to heavy in this order: (1) blue, (2) pink, (3) red, (4) green, and (5) yellow. Refinement of this technique will eliminate false returns such as the black areas and the "island" in the lake.

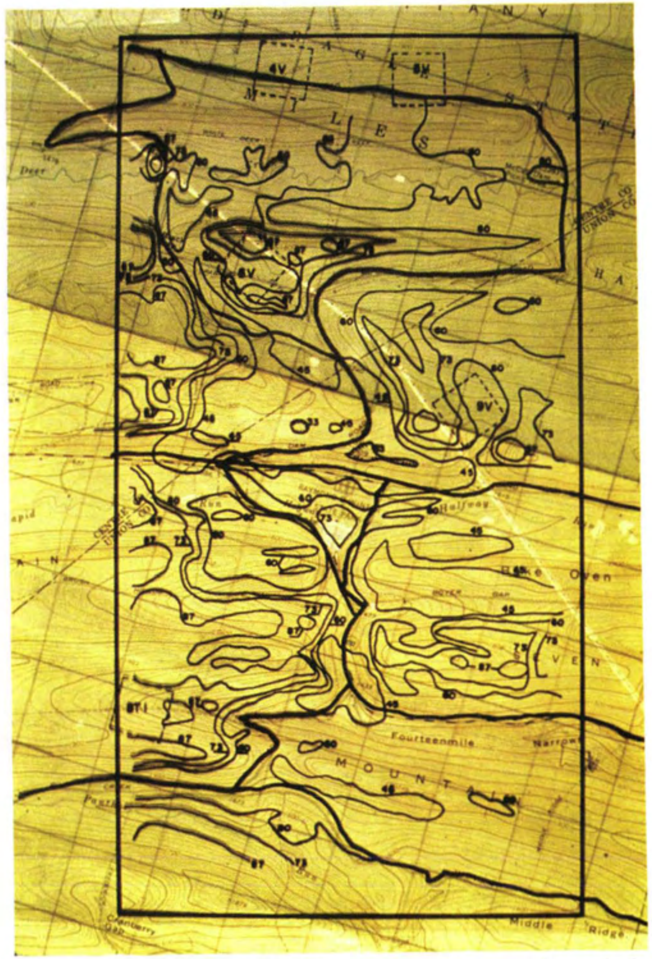

PLATE 3. Map overlay of Halfway Lake environs with isopleths designating the effect of defoliation, in percent.

tion. Levels of defoliation are distinguished by changes in brightness, tone, and texture on aerial photographs. A judgment of the severity of defoliation is then made by the photointerpreter. However, the effect of combinations of film, filter, altitude, and sun angle on viewing and categorizing the defoliation of hardwoods has not been determined.

Because of the limitations inherent in all of these methods, we sought a more objective way of rating insect defoliation. Thus, we investigated the Scene Color Standard (SCS) technique (Piech and Walker, 1971, 1972) for analyzing aerial color film.* In the SCS analysis, absolute reflectance measurements that can be related over time are produced from sequential aerial photos. In using SCS, we wanted to (1) develop a quantitative index for defoliation based on photo-derived reflectance measurements, and (2) produce map overlays of the effect of defoliation from this index. A location in central Pennsylvania was selected for this study because—

- A healthy, vigorous gypsy moth population was present in large areas of continuous forest where varying degrees of defoliation could be measured,
- Ongoing work enabled us to share data such as egg-mass counts and ground estimates of defoliation, and
- The State was seeking an alternative to current sketch-mapping methods.

The aerial photos and ground data for this study were obtained during the spring and summer of 1975. A total of five photo missions were flown in May, June, and July.

METHODS

STUDY AREA

The 182-km² study area was located about 14.5 air km northwest of Mifflinburg, Pennsylvania. The approximate center was Raymond B. Winter State Park, including Halfway Lake. The overstory in this area is primarily northern red oak (*Quercus rubra* L.), black oak (*Q. velutina* Lam.), scarlet oak (*Q. coccinea* Muenchh.), chestnut oak (*Q. prinus* L.), and white oak (*Q. alba* L.). The understory is mostly red maple (*Acer rubrum* L.) and mountain-laurel (*Kalmia latifolia* L.). Eastern hemlock (*Tsuga canadensis* L. Carr) is found on the moister northern exposures; there also is some white pine (*Pinus strobus* L.) mixed with oaks. Characteristic overstory trees in this area range from 10 to 30 cm in diameter at breast height (dbh), and from 12 to 18 m in height; the basal area ranges from 14 to 16 m²/ha.

DATA COLLECTION

Within the study area, two sites were monitored intensively during each photo mission. We collected data on (1) reflectance, (2) changes in soil moisture, (3) tree conditions, (4) the status and development of insects, and (5) defoliation. For this study, a site was a 0.4-ha area on which the data recorders were centered. These data were taken to help explain any anomalies that might develop during the analysis of the photographs.

Site 1, located near the western boundary of the area, had 5,091 gypsy moth egg masses per ha in the spring of 1975. Site 2, about 8 air km east of Site 1, represented an undefoliated forest canopy. No egg masses were found on this site in the spring of 1975, but Site 2 was similar to Site 1 in species composition, aspect, and previous management.

GROUND ESTIMATES

Ground estimates of defoliation of overstory trees are made within a specified small area, and are expanded to a hectare figure. For analysis, our ground estimates at Sites 1 and 2 were augmented by ground estimates on thirty 14.2-ha plots that had been sprayed with a bioinsecticide. The treated plots were within the area photographed and were easily located.

Before each mission, two 2.4 by 2.4-m target boards—one light gray and one dark gray—were placed in an open field. These target boards were used as reflectance references during the SCS analysis.

PHOTOGRAPHY

We wanted to record the entire defoliation process on Aerochrome MS true color (TC) film 2448, and on Aerochrome color infrared (CIR) film 2443 at weekly intervals throughout the period of larval development, but adverse weather and cloud conditions disrupted this sequence. The TC and CIR films were not exposed simultaneously, but they were exposed on the same day.

Photographs were taken from a Forest Service Aerocommander 500B by employing a Wild Heerbrugg RC-10 camera with a 150

* The Scene Color Standard was developed by the Calspan Corporation, Buffalo, N.Y. 14211. Calspan also provided technical assistance and facilities for analysis of photographs.

mm focal length lens. The TC film was exposed through a clear antivignetting filter; the CIR film was exposed through a Wratten number 12 filter. Camera settings for both films varied slightly with the mission, but were usually f/8 at 1/250 of a second. All photo flights were made between 1000 and 1500 hours. Sensitometer wedges were placed on the TC and CIR films before each flight.

Altitudes were selected to provide normal photographic mapping scales of 1:15, 840 and 1:31, 680. In addition, Sites 1 and 2 were photographed at a scale of 1:4, 000. Standard 60 percent overlap was obtained at all scales to allow stereoscopic viewing. The film was processed commercially; a second set of sensitometer wedges was added to detect changes on the films from the time the first set was added until the films were processed.

After the flights, the camera lens and filters were photometrically calibrated by Calspan personnel for light transmission and falloff. This provided exposure correction factors for targets on the film regardless of where they fell on the 22.9 by 22.9-cm film. However, targets that fell within the outer 2.5 cm of the film were excluded from the analysis.

CALIBRATION OF FILM

After processing, the film from each flight was sent directly to Calspan for inspection, calibration, and analysis. A quick scan of the film verified that the exposure settings were acceptable and that coverage of the area was adequate. Details of film calibration for the SCS technique were described by Piech and Walker (1971, 1972).

ANALYSIS

Because defoliation was defined more clearly on the CIR film than on the TC film, we eliminated the latter film from the analysis. We hypothesized that the degree of defoliation could be related to a stress ratio for vegetation expressed as the mean infrared reflectance divided by the mean red reflectance ($\overline{R}_{IR}/\overline{R}_R$). Sites 1 and 2 and the 30 treatment plots provided a total of 96 data points on the CIR film exposed in May, June, and July. However, 25 points were eliminated because of inaccurate mapping, cloud cover, or because locations fell in the outer 2.5 cm of the film.

Ten Macbeth densitometer readings were made for three spectral bands—red, green, and infrared—within each measured site or block, and were averaged to produce a density value for that data point. These values were then converted and adjusted to reflectance data by using the SCS technique.

The initial regression of the $\overline{R}_{IR}/\overline{R}_R$ ratio to ground defoliation estimates (GDE) showed a very low degree of correlation ($\overline{R}^2 = 0.35$). A plot of these data showed that values for each coverage date were clustered in fairly distinct groups, but the May data did not correspond to those for June and July. A reexamination of photographs of the instrumented sites for all coverage dates revealed that the forest canopy was much denser on the June and July photos than on those taken in May. We reasoned that some factor was needed to account for leaf expansion and maturity of the crowns of the trees.

A second ratio was selected to modulate the $\overline{R}_{IR}/\overline{R}_R$ ratio throughout the period of defoliation. This ratio was the observed green reflectance value for a given measurement location divided by the green reflectance value for the undefoliated forest canopy of Site 2 at maturity (June 10). This product of ratios was again regressed and plotted against GDE, but no improvement was noted in the correlation ($R^2 = 0.34$). Most of the May data blended in with those for June and July. But this approach doubled the spread of the aerial photography gypsy moth defoliation index (APGMDI), so another factor was sought to temper this product ratio.

An examination of the photographs showed that the brightness level on the May photos at Site 2 was much greater than that for the other dates. A third product ratio describing the average of the measured red, green, and infrared reflectance was combined with the APGMDI and regressed against GDE. A linear model did not seem proper for describing the data, though the correlation was high ($R^2 = 0.74$). A third order polynomial produced a more reasonable description of the data at the extremes (Figure 1) and an even higher correlation ($R^2 = 0.78$). For this reason we prefer the third order polynomial to describe the relationship between the APGMDI and the GDE. Tests of the residual sum of squares for each model indicated that the polynomial coefficients were adding significant information to the function.

The mathematical equation that related ground estimates of defoliation to the reflectance defoliation index (in percent) on CIR at 1:31,640 with the SCS technique is—

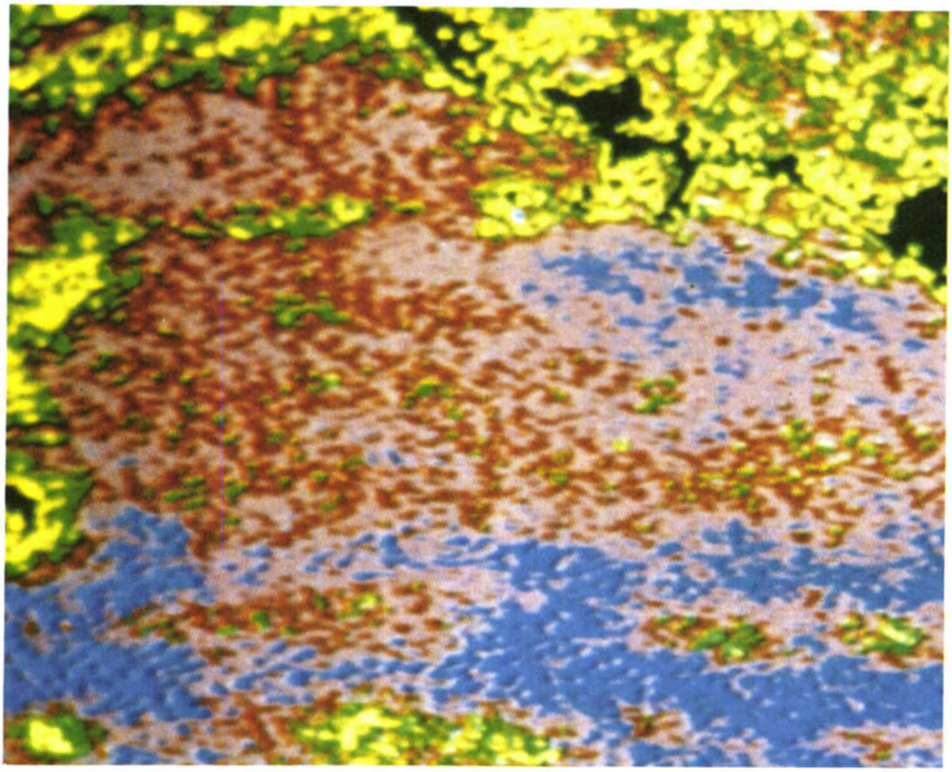

PLATE 4. Enlargement of sprayed area southwest of Halfway Lake (Area A, Plate 2). Various levels of foliage protection are evident. The linear pattern in the bottom two-thirds of the photo indicates the east-west flight plan of the spray aircraft, and shows how spray "skips" can be detected. (Color code is the same as in Plate 2.)

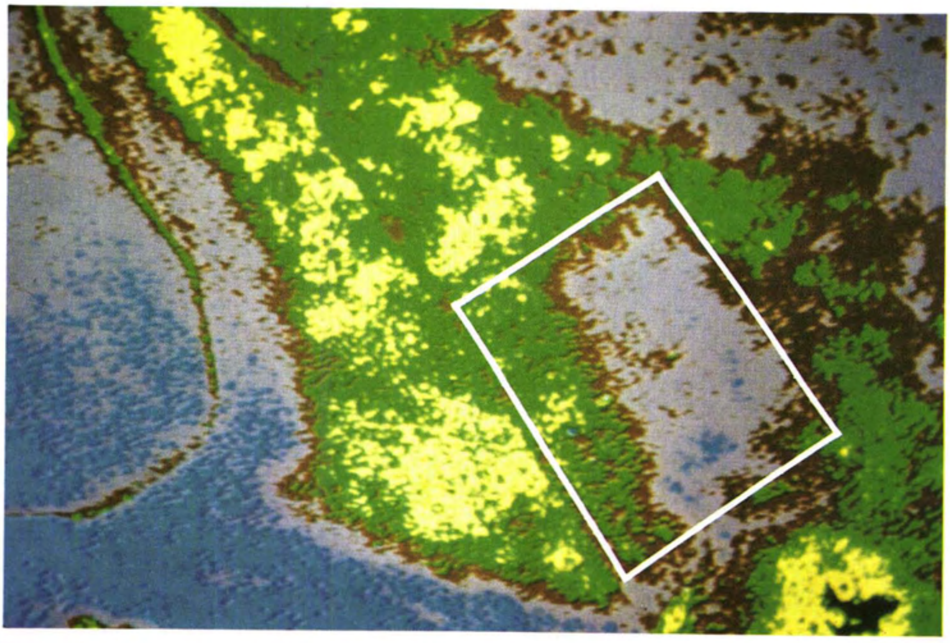

PLATE 5. Enlargement of treatment block northeast of Halfway Lake (Area B, Plate 2). Differences in foliage protection within the block are evident. The southwestern third of the plot was not sprayed.

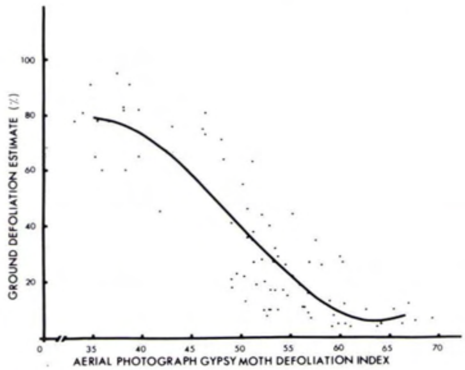

FIG. 1. Third order polynomial regression line showing relationship between the APGMDI and GDE defoliation estimates.

Percent Defoliation

$$= [-475.0900 + 41.7470X - 0.9925X^2 + 0.0072X^3]100$$

where X

$$= \frac{R_{IR}}{R_R} \times \frac{R_G}{0.0318} \times \left[\frac{R_{IR} + R_G + R_R}{3}\right]^{-1}$$

On the Macbeth microdensitometer, we examined five aperture sizes ranging from 3 mm to 50 μm to determine the most applicable size for analysis. If the proper size is not used, ground space or void space between crowns may affect reflectance readings at different photographic scales. The use of large apertures (1 or 3 mm) for each altitude that we selected produced almost identical reflectance data for the three spectral bands. For defoliation purposes, the large apertures integrate the densities for crowns and voids to produce average reflectances for the stands measured.

From a frame of CIR photography exposed on 1 July 1975 over Raymond B. Winter State Park (Plate 1) we produced a color-coded infrared-to-red ratio mask (Plate 2) by density slicing. From this mask we prepared a map overlay of the effect of defoliation (in percent) for a 6.4 by 12.9-km area centered on Halfway Lake (Plate 3). This overlay on a topographic map demonstrates the detail that can be achieved. It may be compared to an aerial sketch map of the same general area (Figure 2).

Plots protected by aerial spray treatments are easily discerned on the photographs. In fact, it is possible to detect levels of foliage protection within the plots (Plate 1). Plates 4 and 5 are enlargements of photos of foliage protection in two treatment blocks—a protective spray operation by the State in an area in Raymond B. Winter State Park located southeast of Halfway Lake, and a test spray block adjacent to a powerline that is northeast of the Lake. The color codes for the effect of defoliation are the same as those described in Plate 2.

DISCUSSION AND CONCLUSION

The use of color-infrared film with the SCS technique is an objective method for determining degrees of defoliation by gypsy moths over a forested area. Aerial photographs analyzed by the SCS technique serve as a permanent record of damage, and they

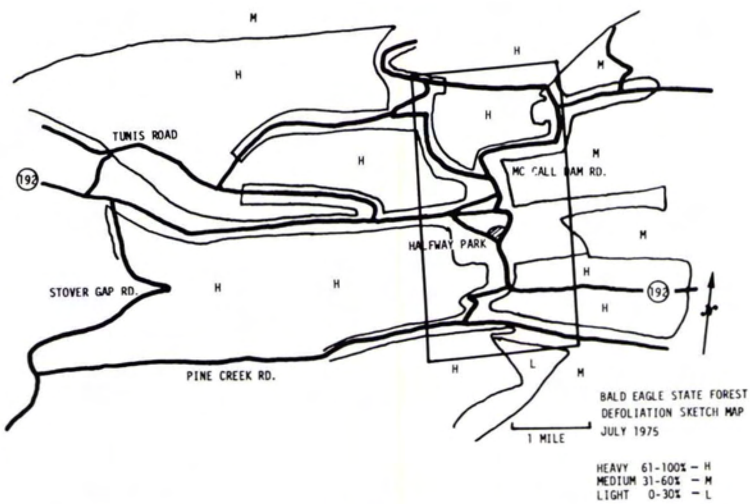

FIG. 2. Aerial sketch map of Halfway Lake and environs.

provide a total picture of ground conditions such as the distribution of stand susceptibility and defoliation patterns.

Sequential photography also can provide a permanent record of changes in insect distribution and defoliation intensity; this record can be used in pest management. This information would be very costly if it were obtained by ground methods. And though we lack cost and time estimates for obtaining these data from aerial photos analyzed by the SCS technique, we would expect savings similar to those reported by others (Heller *et al.*, 1959; Wert *et al.*, 1968).

The SCS technique could be useful in assessing the degree of foliage protection provided by various pesticides. Precise reflectance measurements of forest canopies could be used alone or in conjunction with the gypsy moth egg mass population reduction index to measure the success of a field experiment or control operation. This technique might also be useful in assessing the effectiveness of spray coverage; "skips" or misses in coverage would be easy to document on aerial photographs.

Though we used the SCS method for measuring defoliation by the gypsy moth in an oak-type forest, we believe the SCS technique can be adapted and applied to other forest types and defoliating insects.

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For further information please contact

Dr. Joseph J. Ulliman
College of Forestry, Wildlife and
Range Sciences
University of Idaho
Moscow, ID 83843