PANORAMIC AERIAL PHOTOGRAPHY FOR MAPPING HARDWOOD DEFOLIATION BY GYPSY MOTH IN THE NORTHEASTERN UNITED STATES

by

William M. Ciesla
USDA Forest Service
Forest Pest Management Methods Application Group
Fort Collins, Colorado, USA

ABSTRACT

Color-IR panoramic aerial photography was used to map forested areas defoliated by gypsy moth, Lymantria dispar L., in the northeastern United States. In addition, effectiveness of aerial sprays applied to protect foliage could be assessed.

An operational multistate demonstration of this technology was conducted in 1983. States included in this demonstration were all or portions of Delaware, Maryland, New Jersey, and Pennsylvania. Mission planning, photo acquisition, film processing, duplication, and annotation was a cooperative effort involving three Federal agencies; the Forest Service, NASA and EPA. Photo interpretation and data transfer to a map base was done by personnel from state agencies responsible for gypsy moth pest management programs.

All aspects of this project were successfully completed. However, photo acquisition was too early for appearance of peak hardwood defoliation in the mountainous regions of the project area. This points out the need for definition of two or more photo acquisition biowindows over a project area of this magnitude. Cost of photo acquisition, film processing, and duplication for the 180,236 km^2 project area was U.S. $0.61 per km^2.

INTRODUCTION

The gypsy moth, Lymantria dispar L., is a hardwood defoliating insect that was introduced into North America from Europe. From an initial accidental introduction in 1869 in Massachusetts, it has expanded its range to encompass vast areas of hardwood forests in the Northeast with isolated infestations having appeared throughout much of the United States. For example, during 1981, approximately 5.2 million hectares of eastern hardwood forests experienced varying degrees of damage (USDA 1982).

The insect feeds on over 300 species of plants, including hardwood shrubs, and trees and conifers. It prefers oaks, Quercus spp., particularly members of the white oak group.

Gypsy moth has attracted considerable public attention because of the extensive damage caused by feeding larvae and the controversies associated with direct control by aerial and ground spraying of chemical insecticides. Direct control efforts have been concentrated in urban and forested communities and developed recreation sites within some of the most densely populated regions of the United States.

The extent and intensity of defoliation is mapped annually within the general area of infestation in the Northeast. This is usually done by personnel from state forestry agencies using small aircraft and aerial sketchmap techniques. These surveys provide data to monitor the spread and status of infestations and identify sites which might be considered for direct control the following season.

Aerial sketchmapping is a means of rapid data acquisition over extensive areas of forest at relatively low cost. However, sketchmapping is highly subjective, accuracy of resultant data is dependent upon observer competence and the conditions under which it was obtained (Klein et al. 1983). Large or medium scale 23 cm. format color and color-IR aerial photographs provide considerably greater mapping accuracy. Acquisition costs of this photography is high however, and usually prohibitive for continuous area coverage for a single purpose application such as mapping vegetation damage. This approach is generally considered cost-effective only when the attribute being mapped can be sampled, such as tree mortality caused by coniferous bark beetles (Ciesla, et al. 1967; Klein et al. 1979; and Wert and Roettgering 1968).

Recent testing and evaluation of aerial photos taken with an optical bar panoramic camera shows that high resolution images capable of resolving vegetation damage can be obtained from high altitudes (ca. 20,000 meters above mean sea level). These camera systems, mounted in reconnaissance aircraft, are capable of covering large areas of land rapidly and can acquire continuous photo coverage over entire outbreak areas (Ciesla et al 1982; Klein 1982; Dillman and White 1982; and Caylor et al. 1982). Characteristics and geometry of the camera system and photography are described by Liston (1982).

In 1981 work was begun to evaluate the use of panoramic aerial photography for mapping gypsy moth defoliation in the Northeastern United States. This work consisted of three phases:

1 - Evaluation of panoramic aerial photography for mapping defoliated hardwoods over extensive areas of forest land.

2 - Use of panoramic aerial photography to evaluate effectiveness of aerial sprays applied to protect foliage.

3 - A multistate demonstration of this technology in an operational environment.

DEFOLIATION MAPPING

A method for mapping hardwood defoliation was developed on a 7,170 km^2 test site in central Pennsylvania. The area included portions of Centre, Clinton, Cumberland, Franklin, Huntingdon, Juniata, Mifflin, Perry, Snyder, and Union Counties, and contained a significant area of hardwood forests suffering feeding damage.

The Itek IRIS-II[1/] panoramic camera was used for this test. This was the first time the IRIS-II was deployed for a vegetation damage mapping application. Characteristics of the IRIS-II are similar to the KA-80-A, used in earlier work (Ciesla et al. 1982), except that the normal field of view for the IRIS-II is 140 degrees instead of 120 degrees and resolution has been significantly improved through structural changes in the camera, use of a new rigidized pallet system in the aircraft, and introduction of an advanced design optical window.

Aerial platform was a NASA ER-2 based at the Ames Research Center, Moffett Field, California, flying at ca. (20,000 meters) above mean sea level. Expected nadir scale was ca. 1:31,000. Film used was Kodak High Definition Aerochrome Infrared (SO-131), a slow speed, high resolution, color-IR reversal film.

Forested areas were classified into the three classes used by the Pennsylvania Bureau of Forestry when conducting aerial sketchmap surveys for gypsy moth:

- No aerially visible defoliation.
- Moderate and Widespread - pure host type with first noticeable defoliation visible from aerial observation (generally 30-60% defoliation).
- Heavy and Widespread - pure host type with total loss of host foliage (generally >60% defoliation).

Photo interpreters examined every other photo frame monoscopically on a portable light table (Fig. 1). Each interpreter classified only that portion of the photo that fell within ±40 degrees of nadir. Areas of defoliation were classified by intensity class and sketchmapped as polygons of infestations onto 1:24,000 scale USGS 7-1/2 minute topographic maps (Ciesla and Acciavatti 1982).

1/Use of trade names throughout this paper is for convenience only and does not imply endorsement by USDA and its cooperators.

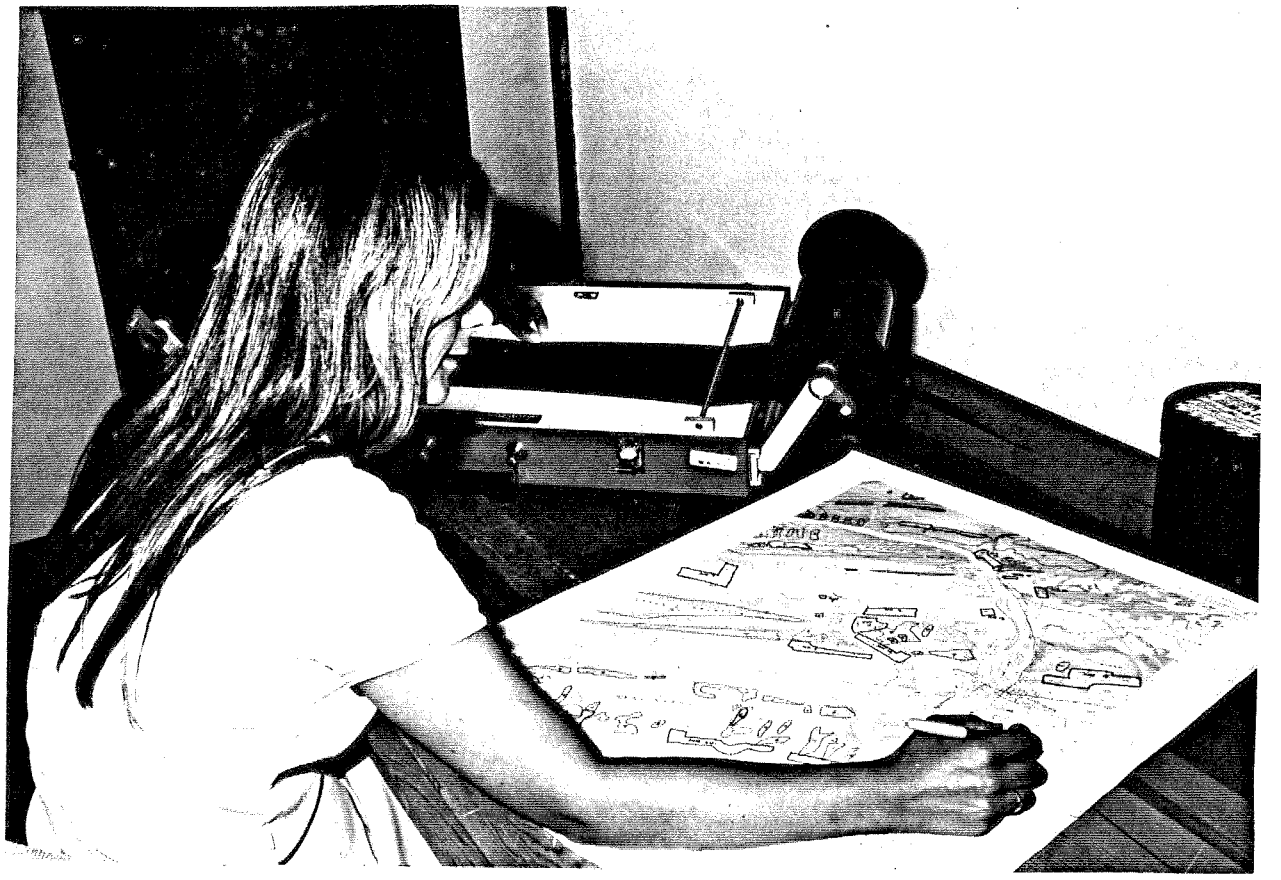


Figure 1 - Photo interpreter classifying gypsy moth defoliation on panoramic aerial photos and transferring data to USGS 7½-minute topographic maps.

EVALUATING EFFECTIVENSSS OF AERIAL SPRAYS

Color or color-IR aerial photos at large to medium scales (1:4,000 - 1:15,000) have been shown to be effective for assessing foliage protection achieved by aerial application of chemical or microbial insecticides against a number of defoliating forest insects (Ciesla et al. 1971; White et al. 1978). Foliage protection is assessed by comparing intensity of defoliation in treated areas to that in adjoining areas of similar forest cover type, topography, and target insect population density or untreated check plots. The panoramic photography taken in 1981 over the central Pennsylvania test site provided the opportunity to evaluate its utility in assessing effectiveness of aerial sprays in protecting foliage from damage by gypsy moth.

Areas treated for gypsy moth suppression during 1981 in Mifflin County, one of the counties in the test site, were selected for evaluation. They consisted of 45 irregularly shaped spray blocks ranging in size from 2.5 to 107 hectares. Thirty-nine spray blocks were included in the evaluation. As

is typical of gypsy moth control programs in the Northeasterm United States, spray blocks consisted of forested communities, scenic corridors, forest recreation sites, and some areas within the general forest. Blocks were treated by helicopter with the insecticide trichlorfon during the period May 21-26, 1981.

Two methods were used to assess foliage protection in the spray blocks; a defoliation map/spray block overlay and detailed photo interpretation.

The defoliation map/spray block overlay approach indicated that 7 of the 39 spray blocks showed some differences in damage intensity when defoliation within the block was compared to surrounding untreated areas. Of the remaining 32 blocks, 11 occurred in areas either completely surrounded by fields, cropland, or other non-forest type, or where no visible hardwood defoliation occurred either in the block or in surrounding stands of hardwoods. These spray blocks did not lend themselves to this type of an evaluation. Defoliation appeared to occur more or less independently of the spray block boundaries in the remaining 21 blocks.

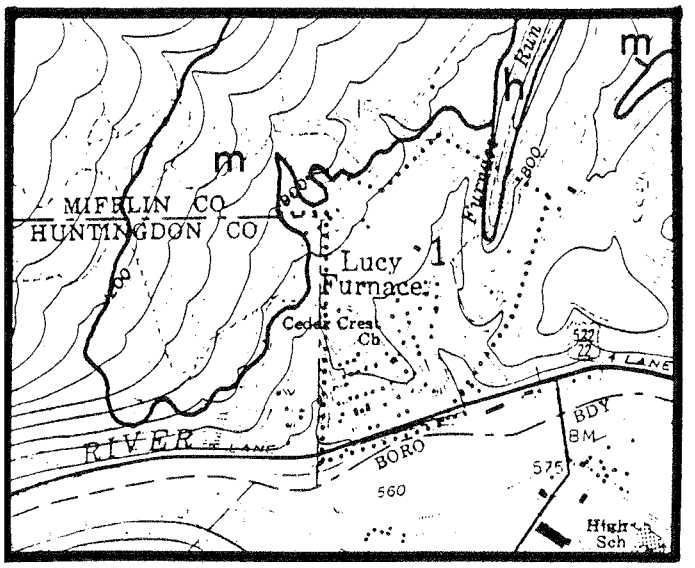
Detailed photo interpretation, on the other hand, revealed that 26 spray blocks had some apparent treatment effect. This was significantly higher than the defoliation map/spray block overlay (Chi square=23.6 %1 d.f; reject H_o:PI=Overlay in favor of H_1:PI> overlay at the .05 level of probability). Careful re-examination of each spray block and the area immediately surrounding the block revealed a number of instances where boundaries of defoliated areas roughly coincided with spray block boundaries. Often a sharp line of demarkation was observed with heavy defoliation occurring just beyond the spray block. In other cases additional areas of localized moderate defoliation were detected that were not previously mapped. This was especially true in areas from ±20 to 40 degrees of nadir where image distortion and some atmospheric haze tend to make photo interpretation more difficult. In three instances, significant errors in location of defoliation boundaries were made on the original interpretation of the panoramic photography. When defoliation boundaries were replotted, an apparent treatment effect could be seen (Fig. 2).

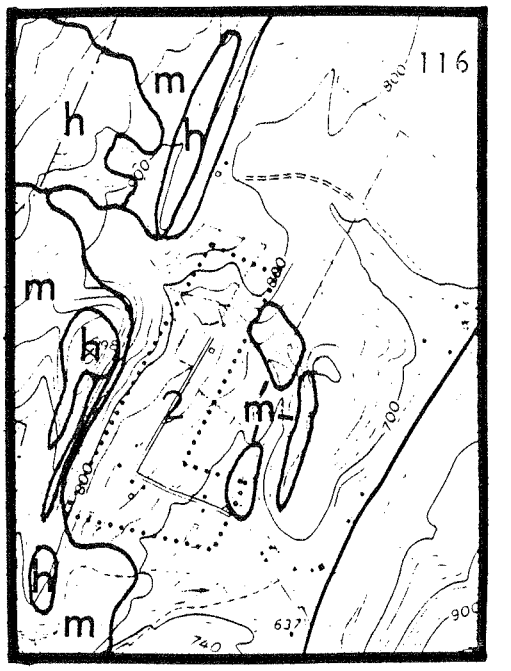
This work showed that high altitude color-IR panoramic aerial photographs can be used to assess hardwood foliage protection achieved by aerial sprays directed against gypsy moth, provided that:

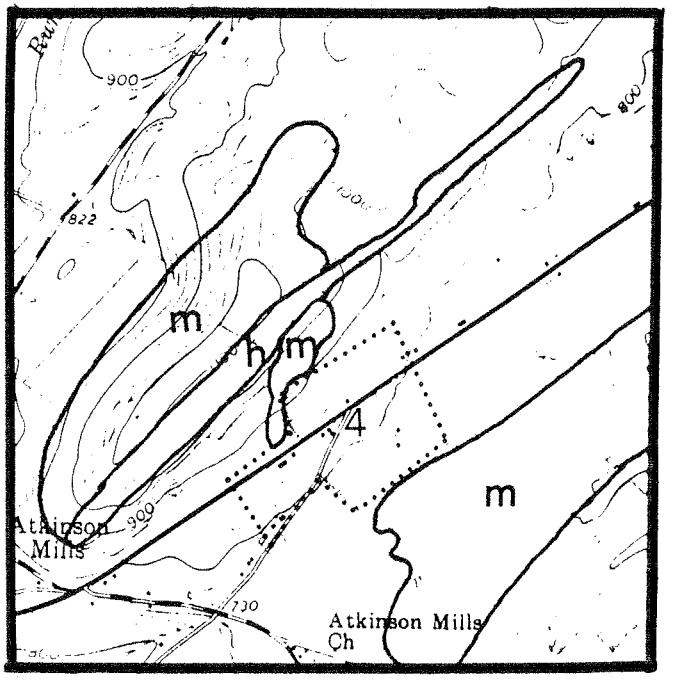
1. Surrounding areas of the same forest cover type occur beyond the spray block boundaries; AND

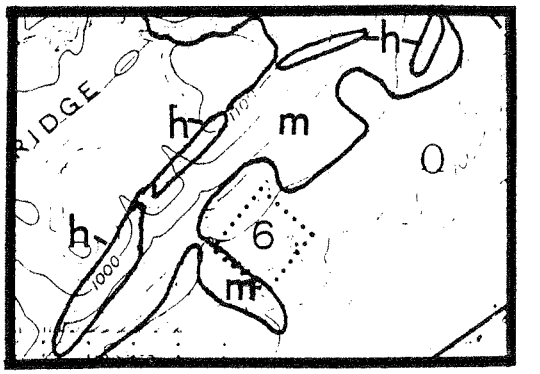
2. Prior to treatment both sites contain similar populations of the target pest; AND

3. Populations of the target pest are capable of causing aerially visible defoliation (approximately 30 percent or more of the foliage removed) (Ciesla 1983).









igure 2 - Examples of patterns of hardwood defoliation relative to location of areas treated with aerial insecticide applications for control of gypsy moth as determined by interpretation of panoramic aerial photos; m = moderate defoliation; h = heavy defoliation (approximate scale = 1:24,000).

1983 OPERATIONAL MULTISTATE DEMONSTRATION

Methods

In 1983, a cooperative multistate demonstration of panoramic aerial photography involving personnel of the USDA Forest Service, NASA, EPA, and four state agencies was conducted. The objective of this project was to demonstrate the feasibility of integrating this technology into an operational pest management program for defoliation mapping and post treatment evaluation.

The target area comprised all or portions of Delaware, Maryland, New Jersey, and Pennsylvania. Delaware and New Jersey were included in their entirety. Planned coverage of Pennsylvania and Maryland extended west to 79° longitude. Flight plan called for 14 north-south flight lines spaced at 17 mile intervals. Two flight lines were extended into the Finger Lakes Region of western New York to provide photo coverage for a cooperative USDA/Pennsylvania Department of Agriculture study on detection of golden nematode infestations in potatoes (Fig. 3).

The camera system used was once again the Itek IRIS-II panoramic optical bar camera. A modified version of this camera with a 90° field of view was used as opposed to the 140° field of view camera used in the 1981 test. An ER-2 high altitude reconnaissance aircraft was deployed to Wallops Island, Virginia, for this demonstration. Biowindow for photo acquisition was timed to coincide with estimated peak defoliation by gypsy moth which was estimated to occur within ±10 days of July 1, 1983.

All aerial film acquired in conjunction with this demonstration was processed by the EPA, Environmental Photographic Interpretation Center (EPIC), Vint Hill Farms, Warrenton, Virginia. Original film and one duplicate copy was processed. The duplicate copy was used for photo interpretation and the original was archived at the USDA Forest Service, National Forestry Applications Program (NFAP) in Houston, Texas.

Film was annotated by Forest Service personnel at the EPA - EPIC Laboratory, and distributed to state agencies responsible for conducting gypsy moth surveys for photo interpretation. Photo interpreters were state personnel (foresters, entomologists, or technicians) familiar with terrain features and forest cover types representative of the Northeastern United States and gypsy moth defoliation.

Photo interpreters were provided formal training in the nature and properties of color-IR aerial photography, geometry of panoramic aerial photography, photo scale determination and annotation procedures, classification of hardwood defoliation, and transfer to a map base. Interpretation procedures used were identical to those developed by Ciesla and Acciavatti (1982).

Cost for photo acquisition, film, processing and duplication was estimated at U.S. $0.78 per km^2, based on a similar project; an inventory of mountain pine beetle losses in the Front Range of Colorado using panoramic aerial

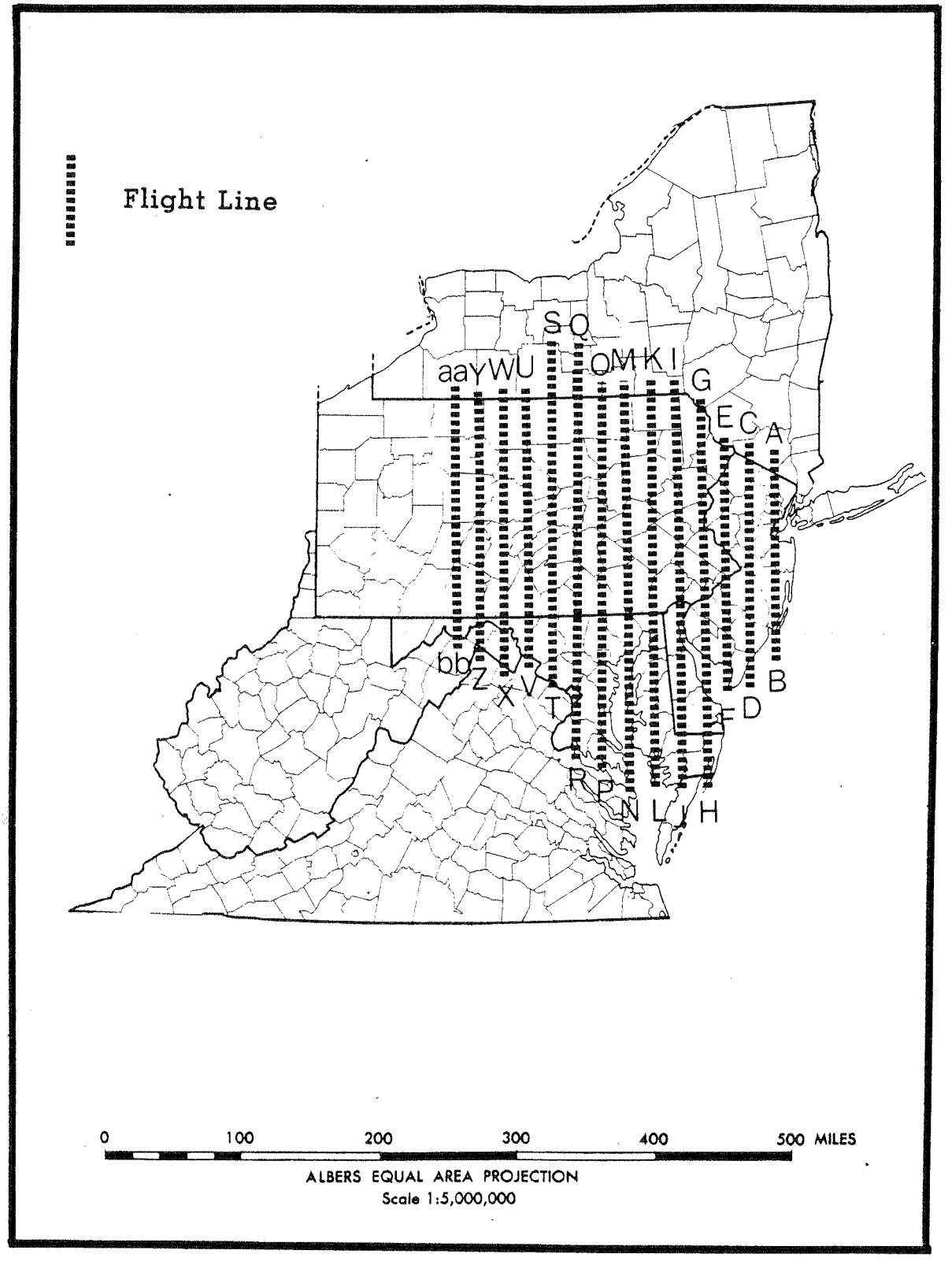


Figure 3 - Area included in multistate demonstration of panoramic aerial photography for mapping gypsy moth defoliation in the Northeastern United States - 1983. Letters at either end of flight line are flight line identifiers.

photography (Dillman et al. 1981). Funding for this project was made available by USDA Forest Service subject to partial reimbursement by cooperating state agencies upon successful execution of this demonstration.

Since the demonstration involved a number of groups within the Forest Service, and several Federal and state agencies, close coordination among cooperators was essential to insure its successful completion. A timetable of critical events was established early in the planning phase and was used to monitor progress (Table 1).

Results

The NASA aircraft arrived at Wallops Island, Virginia, on June 21, 1983. The target area was dominated by a high pressure system following passage of a cold front on June 22 and 23. This provided ideal conditions for aerial photography. Approximately 60 percent of the target area (western and central Pennsylvania) was flown June 22. The remaining area was flown the following day. Approximately 12,000 feet of aerial film was exposed: 2,207 frames (2,128 meters) on June 22; 1,420 frames (1,520 meters) on June 23.

Film was flown from Wallops Island, Virginia, to the EPA-EPIC lab in Warrenton, Virginia, in a chartered Cessna 172. Processing began when the film was delivered to EPA. Original film was processed by June 28, cut and placed on 600 foot spools for duplication. Duplicate copies were available by June 30. Color balance of the duplicated film was adjusted to enhance reds and maximize contrast between defoliated and undamaged areas.

Film annotation was done by marking the location of every tenth to twentieth photo frame on sectional aeronautical charts (scale = 1:500,000). In addition, flight line number, direction of flight, frame number, state and a prominent landmark appearing on each annotated frame were recorded on a data sheet. Airports proved to be one of the most definitive landmarks for annotation. When a flight line crossed a state line, film was cut and a new spool was started. A total of 28 spools of film were prepared and annotated for distribution to the states participating in this demonstration.

Film and photo index maps were delivered to personnel of the four state agencies responsible for photo interpretation during the period July 5-12, 1983.

Overall photo quality was judged to be excellent. Color balance of the duplicated film was optimum for classification of defoliation. Cloud cover was minimal and consisted of scattered cumulus clouds on only a few photo frames.

At the time of photo acquisition, gypsy moth defoliation was nearly at its peak in central and southern New Jersey, Delaware and Maryland. Insect development was considerably later in the mountainous regions of northern New Jersey and central and northern Pennsylvania due to increased elevation and an unusually cool, wet spring. There were serious initial concerns that the flight was made 7 to 10 days too early; preliminary viewing of the film, however, revealed extensive areas of hardwood defoliation in the mountainous

Table 1 - Timetable of critical events, groups responsible, and actual accomplishment dates, 1983 multistate demonstration of panoramic aerial photography for mapping hardwood defoliation.

Event	Unit Responsible	Critical Date	Date Accomplished
Place order for photo mission with NASA	FS - NFAP	Jan 15	Jan 15
Advise EPA of film processing requirements	FS - Engineering	Jan 15	Jan 15
Develop training package	FS - R-8	Jan 30	Jan 30
Finalize cooperative project funding	FS - NA	Feb 15	Feb 15
Light tables delivered	FS - NFAP	Mar 15	Mar 21
Provide training to states	FS - NA & R-8	Mar 30	Mar 22-23
Photo acquisition	NASA	Jun 21-Jul 10	Jun 22-23
All film delivered to EPA	FS - Engineering	Jul 11	Jun 24
Film processing and duplication completed	EPA	Jul 15	Jun 30
Photo interpretation	States	Jul 29	Sep 15
Map products available for review	States	Aug 15	Oct 1
Post project review	FS - MAG	Oct 15	Oct 18
Final report	FS - MAG	Jan 1	Jan 30

regions of western Maryland and southern Pennsylvania. In Pennsylvania, defoliation could be readily discerned as far north as Altoona. From this point north, defoliation gradually became more faint. Despite the timing problem, effective defoliation mapping could be done in all of Delaware and Maryland, the southern two-thirds of New Jersey, and the southern half of Pennsylvania.

The photography was extremely effective for assessment of foliage protection in areas sprayed to suppress gypsy moth defoliation. In several instances a regular pattern of alternating bands of defoliation was observed.

This was indicative of spray aircraft flying too wide a swath interval. The photography provided the opportunity to conduct a detailed assessment by the Maryland Department of Agriculture of all areas treated in the state. Comparisons were made by insecticide used, spray application, and aircraft type. Overall effectiveness of treatment in terms of foliage protection was estimated at 98.3 percent.

Several sources of commission error were reported by photo interpreters and field foresters as a result of ground checks. These included hardwoods damaged by late spring frost or certain conifer stands which had a color similar to defoliated hardwoods. In addition, pockets of tree mortality, which are believed to be the result of several successive years of defoliation by gypsy moth, could be readily discerned. When these occurred in areas that also had current year's defoliation, photo interpreters had difficulty separating the two.

When interpretation for hardwood defoliation was completed, the resource management and regulatory agencies within the four states used the photography for numerous other applications. These included locating pine plantations for sampling of other pest problems, mapping riparian zones, land use surveys, statewide crop inventories, location of chicken farms to inspect for avian flu, inventory of Christmas tree plantations, and location of fields of certain agricultural crops to inspect for diseases.

Project Costs

Cost of photo acquisition (aircraft time plus film) was U.S. $86,500. Film processing and duplication was $25,000 which included only the cost of materials. Labor and laboratory facilities associted with processing and duplication were contributed by EPA. Approximately 180,236 km^2 of the earth's surface were covered by the project at a per unit acquisition cost of $0.61 per km^2. This is somewhat less than the $0.78 per km^2 anticipated cost. Lower than anticipated per unit cost is due to additional land area covered by the photo mission.

DISCUSSION AND CONCLUSIONS

This demonstration achieved its objectives in that all critical targets in the planning timetable were met. High altitude panoramic aerial photography is a viable alternative to aerial sketchmapping for mapping hardwood defoliation in an operational environment.

The major problem encountered was the delayed insect development in the mountainous regions in the northern and western portions of the target area due to the unusually cool, wet spring of 1983. The next period of suitable weather for aerial photography occurred over the target area on July 7 and 8. This time period would have been more suitable for the mountainous regions; however, ground examinations on July 7 of areas which imaged as heavy defoliation in central Delaware had already begun to refoliate. Had the photo mission been delayed until this second period, these areas would not have been as readily discerned because of refoliation, and data would have been lost.

The wide range of gypsy moth development times and periods of peak defoliation over the target area points out the need for definition of two or more photo acquisition biowindows when planning and conducting expanded operational surveys of panoramic aerial photography for mapping hardwood defoliation and assessing effectiveness of gypsy moth suppression projects. This need will become more apparent as the insect continues to expand its range southward and westward into regions of warmer climate as well as a greater change in elevation.

A second problem encountered was the presence of commission error; photo interpreters mistaking areas of late spring frost, tree mortality, or pure stands of certain conifers, for hardwood defoliation. This source of error will undoubtedly be minimized as forest pest management specialists in the Northeast gain more experience with the appearance of forest vegetation and damage on color-IR film. This experience will best be gained through a combination of photo interpretation and ground checking of questionable areas.

REFERENCES CITED

Caylor, J., J. Pierce, and W. Salazar. 1982. Optical bar panoramic photography for planning timber salvage in drought stressed forests. Photogrammetric Engineering and Remote Sensing 48:749-753.

Ciesla, W.M., J.C. Bell, Jr., and J.W. Curlin. 1967. Color photos and the southern pine beetle. Photogrammetric Engineering 33:883-888.

Ciesla, W.M., L.E. Drake, and D.H. Wilmore. 1971. Color photos, aerial sprays and the forest tent caterpillar. Photogrammetric Engineering 37:867-873.

Ciesla, W.M. and R.E. Acciavatti. 1982. Panoramic aerial photography for mapping gypsy moth defoliation. USDA Forest Service, Forest Pest Management Methods Application Group, Fort Collins, CO. Rpt. 83-1, 17 pp.

Ciesla, W.M., R.A. Allison, and F.P. Weber. 1982. Panoramic aerial photography in forest pest management. Photogrammetric Engineering and Remote Sensing 48:719-723.

Ciesla, W.M. 1983. Panoramic aerial photography for assessing foliage protection achieved by aerial sprays directed against the gypsy moth. USDA Forest Service, Forest Pest Management Methods Application Group, Fort Collins, CO. Rpt. 83-4, 14 pp.

Dillman, R.D., S.S. Shen, B.B. Eav, and W.B. White. 1981. Operational test of panoramic aerial photography for estimating annual mortality of ponderosa pine caused by mountain pine beetle. Lockheed Engineering and Management Service Company, Inc. Houston, TX. Rpt. No. LEMSCO - 16377, 20 pp.

Dillman, R.D. and W.B. White. 1982. Estimating mountain pine beetle killed ponderosa pine over the Front Range of Colorado with high altitude panoramic photography. Photogrammetric Engineering and Remote Sensing 48:741-747.

Klein, W.H., D.D. Bennett, and R.W. Young. 1979. A pilot survey to measure annual mortality of lodgepole pine caused by mountain pine beetle. USDA Forest Service, Forest Insect and Disease Management Methods Application Group, Davis, CA. Rpt. No. 78-3.

Klein, W.H. 1982. Estimating barkbeetle killed lodgepole pine with high altitude panoramic photography. Photogrammetric Engineering and Remote Sensing 48:733-737.

Klein, W.H., S. Tunnock, J.G.D. Ward, and J.A.E. Knopf. 1983. Aerial sketch-mapping. USDA Forest Service, Forest Insect and Disease Survey Methods Manual 1.1.1, 15 pp.

Liston, R.L. 1982. Photogrammetric methods for mapping resource data from high altitude panoramic photography. Photogrammetric Engineering and Remote Sensing 48:725-732.

USDA 1982. Gypsy moth defoliation in the Northeast - 1981. Forest Service, Northeastern Area, Broomall, PA, 13 pp.

Wert, S.L. and B. Roettgering. 1968. Douglas-fir beetle survey with color photos. Photogrammetric Engineering 34:1243-1248.

White, W.B., H.B. Hubbard, Jr., N.F. Schneeberger, and B.J. Raimo. 1978. Technological improvements in aerial spraying. USDA Combined Forest Pest Research and Development Program. Agr. Handbook 535, 15 pp.