ROBERT C. ALDRICH
U S D A Forest Service
Berkeley, Calif. 94701

Detecting Disturbances in a Forest Environment

The high accuracies reported for high-altitude and space imagery should open up new avenues for improving nationwide forest inventories.

ABSTRACT: *The interchange between forest and nonforest land and most man-made and natural forest disturbances can be detected on 1:120,000-scale color-infrared film. Bulk multispectral scanner imagery from the Earth Resources Technology Satellite combined and enhanced at a scale of 1:1,000,000 shows major changes in forest and nonforest land-use categories, many timber harvested areas, and some natural disturbances. Late fall to late spring is the best period of the year for detecting forest disturbances. In a study in Georgia, 79 percent of the disturbances in one county were detected on an ERTS color composite for April 1973 with only 12 percent commission error.*

INTRODUCTION

ANNUAL or periodic surveys for detecting forest disturbances are becoming more feasible every year because of new remote-sensing technology. High-resolution cameras, films, and even multispectral scanners available today can produce extremely useful synoptic views of earth from high altitudes. For example, land-use changes, regardless of their size, can be detected on 1:120,000-scale Aerochrome Infrared (CIR) film.* Even low-resolution data from the Earth Resources Technology Satellite (ERTS) multispectral scanner (MSS) if combined and enhanced at a scale of 1:1,000,000 will disclose 80 to 90 percent of the exchanges of land use between forest and nonforest categories. In addition, such data will show 25 to 90 percent of the less distinct disturbances in the forest, depending on the category.

A test to determine the feasibility of monitoring forest disturbances on high-altitude photography and ERTS MSS imagery (Figure 1) is now underway in the southern piedmont subregion west of Atlanta, Georgia. In this study the permanent forest survey ground sample plots in several counties will be monitored periodically for disturbances during the lifetime of ERTS-1.

Why are these forest disturbances so important? Because they cause changes in the forest area base upon which forest inventories are built. These changes also affect the volume and growth of the timber resource. Because of these changes, national and state forest inventory information based on the reinventory of widely scattered permanent ground sample plots remeasured about every 10 years can become obsolete within a few years unless the data base is updated. To reinventory all the ground samples at shorter intervals—say, 5 years—would be far too expensive. However, by utilizing up-to-date remote-sensing techniques and a small ground sample the costs might be reasonable.

This paper reports a preliminary investiga-

* Trade names and commercial enterprises or products are mentioned solely for information. No endorsement by the U. S. Department of Agriculture is implied.

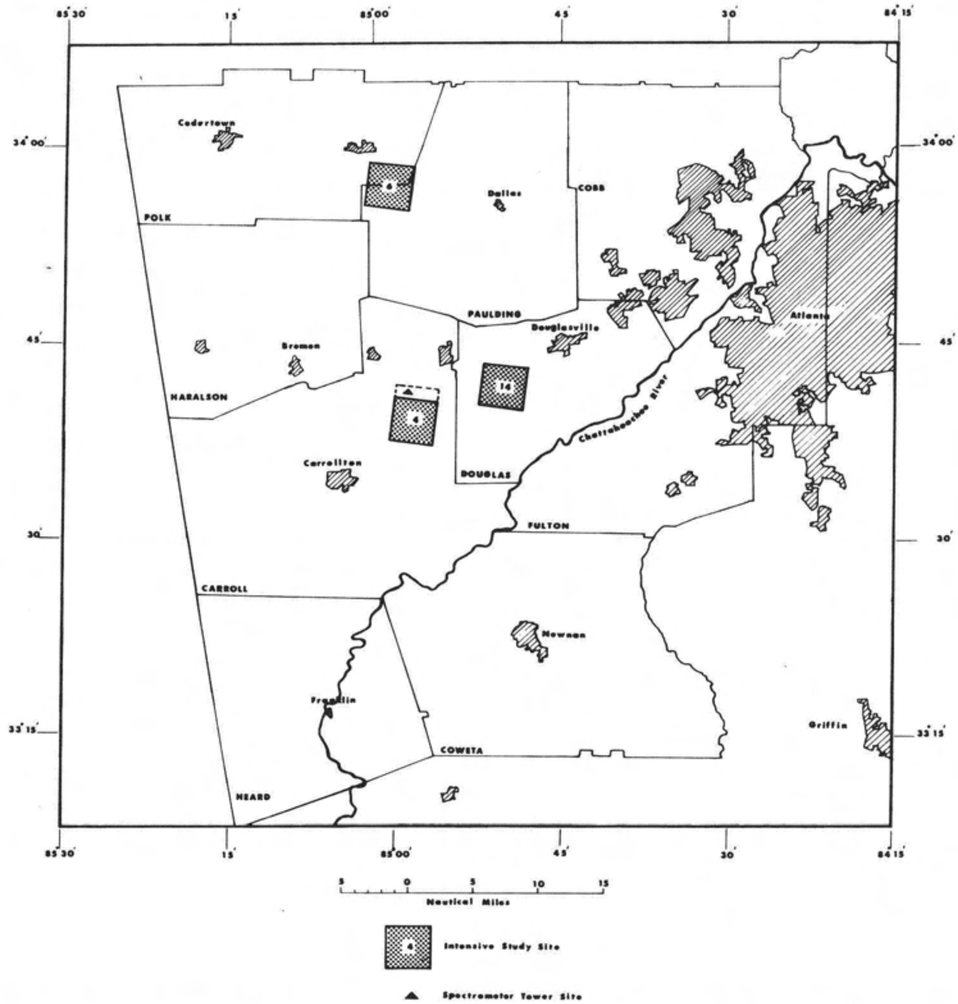

FIG. 1. The study area includes nine counties in the southern piedmont land resources subregion west of Atlanta, Georiga.

tion made in Carroll County, Georgia, that (1) identifies the conditions required to detect forest disturbances, (2) categorizes disturbances that can be detected by remote-sensing techniques at different altitudes, and (3) estimates the probabilities of success in detection from different remote platforms.

THE PROBLEM

The study is in one of the richest timber-growing regions of the United States. The region has many diversified forest types and many different growing conditions. If coupled with the expanding industrial economy of this area, it is a challenge to quantify accurately the changes taking place. For instance, the increasing industrialization and growing human population create land-use changes, almost overnight. Forest land is cleared for home and industrial developments, for transportation and public utility lines, and in some instances, even for agriculture. Conversely, many people are migrating from the farm to the city, abandoning farm land that reverts back to forest—either slowly by natural regeneration or rapidly by machine planting.

Beyond these more obvious disturbances, timber harvest and improved forest management practices are changing the forest—both in appearance and in volume and growth. Vast areas of private and government-owned lands are harvested or treated silviculturally to improve the cover type and the growth and quality of the timber. These changes as well as those created by natural catastrophes, such as fire, insect infestations, disease, and floods must be measured periodically to keep the forest inventory information base current and useable for decision-making.

The possibilities of using remote sensing to solve this problem is of great concern to the nationwide Forest Survey conducted by the Forest Service of the United States Department of Agriculture. For instance, could synoptic views of one or more counties be used to check permanent ground plots one or more times between reinventories that are now 10 to 12 years apart? If a disturbance is detected either on or near a plot, this plot could be visited on the ground and retallied. On the other hand, plots where no disturbing influences are detected would either be ignored or sampled at a very low intensity. Growth, volume, and natural mortality for plots not reinventoried could be adjusted by projection techniques. However, this is not a simple problem because a disturbance can be a single tree, lost through mortality or cutting, or it can be the complete removal of all trees and conversion of the land to some nonforest use. Obviously the single tree loss will be most difficult to detect regardless of the remote-sensing technique used. However, these losses can be measured on the ground sample and are fairly constant over time. So single-tree losses are not important in the context of this study. Instead we are more concerned with major disturbances. We have placed them into 22 categories (Table 1) which are combined into nine classes most likely to be recognized by remote-sensing techniques. The basis for these combinations is a similarity in visible characteristics on the imagery. The nine classes are defined in Table 2.

TABLE 1. CLASSIFICATION OF FOREST DISTURBANCES, ACCORDING TO FOREST SURVEY GROUND INVENTORY, HIGH-ALTITUDE PHOTOGRAPHS, AND EARTH RESOURCES TECHNOLOGY SATELLITE IMAGERY

FOREST SURVEY (ground)	CODE	HIGH ALTITUDE (photo)	CODE	ERTS (satellite)	CODE
No disturbance	00	No disturbance	000	No disturbance	000
Harvesting/artificial regeneration	01				
Harvesting/natural regeneration	02	Harvesting and Silvicultural Cuttings	020	Harvesting and Silvicultural Treatments	020
Harvesting-no regeneration	03				
Commercial thinning	04				
Precommercial thinning	05				
Cleaning, release, intermediate, cutting	06				
Hardwood control (poisoning	08				
High grading	11				
Clearing and site preparation	07	Land Clearing	070	Land Clearing	070
Damage by insects, disease, wildfire, weather	12	Insects, Disease, Damage	121		
Man-caused flooding	13	Wildfire Damage	122	Damage from Natural Causes	120
Prescribed burning	09	Flooding	123		
Natural regeneration	19				
Artificial regeneration	20				
Artificial regeneration after site preparation	16	Natural regeneration	191	Regeneration	
Artificial regeneration without site preparation	17	Artificial regeneration	201		
Major drainage effect	10		10		
Grazing	14				
Turpentining	15	Other	990	Other	990
Fencing, firebreaks, trash pits, etc.	18				
Other	99				

TABLE 2. DEFINITION OF NINE DISTURBANCE CLASSES THAT CAN BE RECOGNIZED BY REMOTE SENSING

1. *No disturbance:* Areas where there are no detectable changes in the forest cover.
2. *Harvesting:* Forest areas which have been subject to a timber removal operation. This operation usually results in a rather severely disturbed area with numerous interlacing woods roads, skidways, and either complete or almost complete removable of the merchantable trees.
3. *Silvicultural treatments:* Forest areas, such as pine plantations or natural hardwood stands, given a cultural treatment to improve their vigor or growth. Although high-grading is a poor practice and not considered a silvicultural treatment in the normal sense, it would appear the same as partial removal or intermediate selective type cutting.
4. *Land clearing:* Usually preceded by timber removal or harvesting; then the site is prepared by slash and stump removal, and may eventually be replanted with tree seedlings. However, this category can also include tree removal, site preparation, and conversion to nonforest land uses. Land that has been cleared but not converted usually shows windrows of slash and tree trunks—this land is usually still considered commercial forest.
5. *Insects and disease:* Under endemic conditions, attacks by insects and disease may mean the mortality of a single tree. Under epidemic conditions it may mean mortality of hundreds of trees in a single spot. Faded tree crowns or openings in the stands are indicative of tree mortality.
6. *Wildfire:* May include crown fires as well as ground fires. Prescribed burns are restricted to the ground and may appear exactly like wildfires. The actual "going" fires may be detected, but it is usually the noninfrared-reflective burned vegetation and humus material that show as blackened areas on remote-sensing imagery.
7. *Flooding:* Whether man-made or natural can inundate forest land and cause tree damage or death. Permanently flooded areas must be removed from the forest area base. The extent of these areas is obvious on infrared imagery. Intermittently flooded forest may be permanently damaged or survive once the water has receded.
8. *Regeneration* whether natural or artificial means an increase in the forest area base where nonforest land is converted to forest land. Areas of regeneration may be apparent in early years by evidences of fire trails built by the landowner to protect his investment from wild fire. Indications of tree growth will appear in 3 to 5 years after planting.
9. *Other:* Land suspected of being disturbed but yet it does not fit any of the above categories. For example, this includes land being worked for turpentine. On remotely sensed imagery such land would appear similar to silviculture cuttings but with little or no removal and slight disturbance of the ground cover.

PROCEDURES

One problem in interpretation and analysis based on the use of unconventional types of remote-sensing imagery is how to handle the data; this certainly was true in this study. Four types of imagery representing four different scales were involved. They ranged in scale from 1:20,000 to 1:1,000,000. The four data types were: (1) 1:20,000 panchromatic U. S. Agricultural Stabilization and Conservation Service (ASCS) photography; (2) 1:120,000 Aerochrome Infrared (CIR) taken by the U. S. National Aeronautics and Space Administration,* (3) 1:1,000,000 simulated CIR composites of ERTS (bands 4, 5 and 7); and (4) 1:63,360 scale ASCS black-and-white photo index sheets. These data were used both individually and collectively to study and define the remote-sensing considerations relative to detecting forest disturbances and to test the accuracy of detection.

PHOTO INTERPRETATION CONSIDERATIONS

Starting with the lowest resolution imagery (the ERTS CIR simulated color composite for scene 1264-15445), we began what we hoped would be an unbiased approach to detect disturbances. To confine our attention to Carroll County, we used a 1:1,000,000-scale transparent film overlay made from the original 1:250,000-scale base map for Atlanta (Figure 2). Next, the ERTS scene and overlay were mounted for viewing on the photo illuminator of a Bausch and Lomb Zoom Transfer Scope (ZTS).

To detect a disturbance, it is first necessary to have a photograph or other type of imagery taken some time earlier than the ERTS image. For this we chose a photo index sheet for photography, taken in February 1966, produced at a scale of 1:63,360. We did this because the ZTS could not accommodate the 50×-scale change needed to compare 1:20,000-scale photographs with ERTS images at 1:1,000,000 scale. We also found that the ZTS could not accommodate the 16×-scale change from the ERTS image to the index sheets. However, this scale change was easily taken care of by adding a 0.5× lens to the 1× map objective. This addition permitted the index sheet scale to be reduced to about 1:125,000 scale. A foot switch was added to the ZTS to blink either the photo illuminator or the map illuminators. The *blinker* improved the registration of the two images and also helped to isolate forest disturbances.

With the ERTS color composite in place on the illuminator and the photo index sheet

* Photography by RB-57 Aircraft Support Mission 205, June 1, 1972.

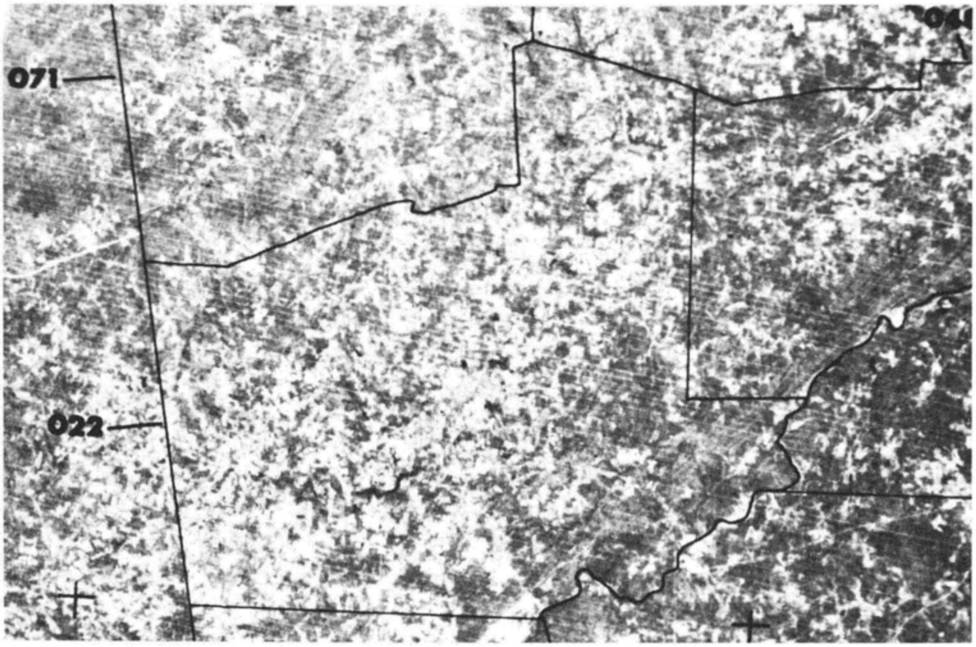

FIG. 2. A 1:1,000,000-scale transparent overlay was used to outline Carroll County, Georgia, on Earth Resources Technology Satellite bulk color composites; this portion of ERTS scene 1264-15445 is enlarged to a 1:500,000 scale.

under the map objective, we then systematically scanned the ERTS scene by referring to a transparent overlay with regularly spaced grid lines. As the position of the field of view on the ERTS scene was changed, the photo index sheet was moved. In this way it was possible and simple to traverse the county without losing one's position on the ERTS scene. As the scene was scanned, each suspected disturbance in the forest was circled directly on the index sheet.

Once the entire county had been covered, the ERTS scene was removed from the photo illuminator and replaced by a 1:120,000-scale CIR photographic transparency. County lines were drawn on protective acetate photo covers to help locate areas for interpretation. Each area circled on the photo index sheet was then *cross-examined* on the 1:120,000-scale photo. In addition, all other disturbances not detected in the first look at ERTS imagery were also noted. Information recorded at this time was in three categories: (1) disturbances correctly identified; (2) disturbances incorrectly identified (commission errors); and (3) disturbances not identified (omission errors). All disturbances not identified during the first look at ERTS imagery were reexamined as before and those that could be positively identified were recorded.

Finally, we were in a position to describe and illustrate the nine categories (Table 1). The illustrations were 35-mm copies of representative areas on the ERTS scene, on the 1:120,000-scale CIR photographs, and the 1:20,000-scale panchromatic photographs taken in both January 1960 and February 1966.

PHOTO INTERPRETATION TEST

An experienced photo interpreter was asked to examine 245 locations circled on the February 1966 photo-index sheets for Carroll County, simultaneously with an April 13, 1973, ERTS color composite (scene 1264-15445). Before starting, the interpreter was given a short orientation in the identification of disturbances and an opportunity to practice using the ZTS. He was instructed to be as objective as possible and was told that not all of the 245 points were real disturbances (only 209 were verified disturbances). He was to record the following information for each area:

Type of disturbance: (a) no disturbance, (b) harvesting (tree removal), (c) land clearing, (d) natural regeneration, (e) artificial regeneration, or (f) other (undecided).

Land-use trend : (a) no change, (b) forest to agriculture, (c) forest to urban, (d) forest to water, or (e) agriculture to forest.

The results of this interpretation were

summarized by disturbance class, land-use trend, and size class. Size class was determined from 1:120,000-scale photographs on which the disturbances had been positively identified. The classes were: (a) 1-5 acres (0.4-2.0 hectares), (b) 6-25 acres (2.4-10.1 hectares), (c) 26-50 acres (10.5-20.2 hectares), (d) 51-100 acres (20.6-40.5 hectares), (e) 101-500 acres (40.9-202.3 hectares), or (f) over 500 acres (over 202.7 hectares).

GROUND TRUTH

From January 2 to 12, 1974, we visited on the ground 40 disturbed locations in Carroll County. Eighteen of these locations were Forest Survey plots on which some type of disturbance was recorded either during the reinventory of 1972 or by interpretation of current photography in 1973. Twenty-two additional locations were selected from a listing of 64 *off plot* disturbances that represented harvesting and silvicultural treatments, natural regeneration, artificial regeneration, and the *other* category. We did not sample the *cleared* category because we concluded that the photo verification would be correct in every instance.

On each ground plot, the type of disturbance was observed and recorded. Also recorded were the condition of the forest cover and ground cover, years since disturbance, and other information pertinent to interpretation by remote sensing. A photograph was taken to record these ground conditions at the time of year the plot was visited.

RESULTS AND DISCUSSION

The results of any remote-sensing test depend heavily on the quality of the products used. This relationship is most evident if photographic color reproductions are interpreted by conventional photo interpretation techniques. With color we must rely on the darkroom technician to produce images as they appear naturally and then, in turn, reproduce these images consistently from one batch to the next. Color standards are even more important if interpreting low-resolution imagery, such as color composites made from ERTS MSS data. This is because there is little else to interpret except the components of color (hue, chroma, and value) and some gross spatial data. The results reported here depend no less on color reproduction than in any other test.

REMOTE SENSING CONSIDERATIONS

Three important conditions must be met before recognition of disturbances in a forest environment is possible. First and foremost, it is necessary to have a base photograph taken at some earlier date so as to be able to measure changes (Figure 3). For the Forest Survey, this date might be three to five years prior to the inventory, depending on the circumstances.

Second, it is necessary to have a picture of the same scene made by a remote sensor as close to *real time* as possible. This need is particularly acute in areas where changes are occurring most frequently. Third, it is necessary to have compatibility in photographic scale for both the base photograph and the current photograph. If the scales vary widely, specialized equipment such as the ZTS will be needed to view the imagery. On the other hand, images of equal or near-equal scale can be interpreted on conventional photo interpretation equipment; for example, an Old Delft Scanning Stereoscope might be used. This makes repeated 1:120,000-scale CIR photography very attractive because the scale is large enough to plot precise sample locations, yet it covers an extensive area (225 square miles or 503 square kilometers) and would include many plots on a single setup (30 to 50).

The best scale for detecting disturbances is that which results in the greatest accuracy at the lowest cost. The smallest practical scale for aircraft photography now is 1:120,000. This same scale if acquired from space platforms would be equally good for our purpose, but it would depend on the use of higher-resolution cameras and films that are not now available for civilian use. Skylab has demonstrated that hard-film returned from space at scales as small as 1:2,500,000 could be very useful for detecting disturbances upon an enlargement of 10 to 15 times. Unfortunately, because of a series of misfortunes with weather and equipment, we were unable to acquire Skylab data for this study site. However, regardless of which system we talk about, the practicality of any system for low-cost forest inventories will depend to a great extent on whether acquisition costs are underwritten by other agencies, such as NASA or the Department of Defense. Because of budget limitations, the Forest Survey could not afford to pay for satellite data acquisition.

The season of the year can be a critical factor for viewing low-resolution (50-100 meters) imagery, such as ERTS (Figure 4). If high-altitude photographs are used, seasonal differences do not seem to be quite as important because of the better resolution. A gen-

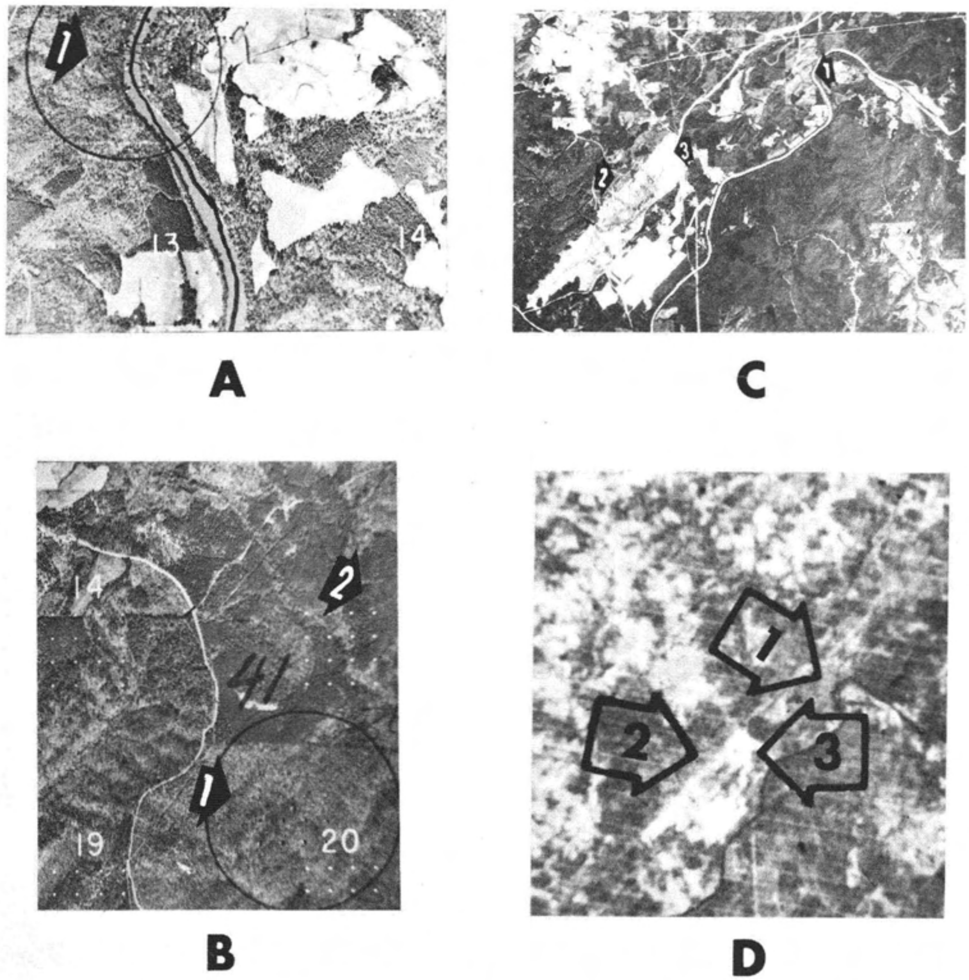

FIG. 3. Forest disturbances are detected by comparing a current image with an image taken at some earlier date. For instance, the land shown at *A1* on a February 1966 (1:20,000-scale panchromatic) photograph appears disturbed at *C1* on a 1:120,000-scale CIR photograph taken in June 1972, and at *D1* on ERTS color composite for scene 1264-15445, April 13, 1973. A pulpwood cutting area is shown at *B1*, *C2*, and *D2*, respectively. Land cleared for a power station is shown at *B2*, *C3*, and *D3*, respectively. The ERTS image has been enlarged to 1:265,000.

eral rule for ERTS is to choose imagery during the period from early spring to late spring as a first choice, and from the period late fall to late winter as a second choice. The reason for this difference is that during these periods the deciduous hardwoods are either leafless or newly leafed out in IR-reflectant foliage, and the discrimination between deciduous hardwoods and coniferous trees is at its best. On the other hand, summer and early fall ERTS images are oversaturated with IR reflectance and cutover and uncut hardwoods show little difference. Furthermore, site disturbances and the effects of woods roads and log skidways are completely obscured in summer and can be of no help in interpretation.

PHOTO INTERPRETATION TEST

We detected and verified 209 forest disturbances on 1:120,000-scale CIR photography in Carroll County, Georgia (Table 3).

One photo interpreter working independently detected and correctly classified 165, or 79 percent, of the disturbances on an ERTS color composite for April 13, 1973 (Table 4). Another 23 disturbances, or 11 percent, were misclassified. However, if detection is more important than the influence, then 90 percent of all disturbed areas were detected.

Omissions and commissions would be the most serious types of error in a monitoring system. In this study, 21 verified disturb-

TABLE 3. NUMBER OF FOREST DISTURBANCES DETECTED ON COLOR-INFRARED PHOTOGRAPHS IN CARROLL COUNTY, GEORGIA, BY EARTH RESOURCES TECHNOLOGY SATELLITE CATEGORY AND SIZE CLASS

Size Class (acres)	Harvesting (020)	Land Clearing (070)	Regeneration (190)	Natural Causes (120)	Other (990)	TOTAL
1-5	4	70	1	0	1	76
6-25	9	53	5	0	10	77
26-50	8	9	0	0	1	18
51-100	4	7	1	0	0	12
101-500	9	3	0	0	3	15
500 +	7	3	1	0	0	11
TOTAL	41	145	8	0	15	209

TABLE 4. NUMBER OF FOREST DISTURBANCES DETECTED BY ONE PHOTO INTERPRETER ON EARTH RESOURCES TECHNOLOGY SATELLITE COLOR IMAGERY, BY SIZE CLASS.

Disturbance	Size Class (Acres) <5	5-25	26-50	51-100	101-500	500 +	Total	Percent Correct
Harvested forest land	2	6	5	4	5	7	29	71
Land Clearing								
No Change	0	2	0	0	1	1	4	100
Forest to Agriculture	40	30	4	5	1	0	80	80
Forest to Urban	6	11	3	0	0	1	21	91
Forest to Water	9	5	1	0	0	0	15	83
Natural Cause	0	0	0	0	0	0	0	—
Regeneration to Forest	1	1	0	0	0	0	2	25
Other	0	10	1	0	3	0	14	93
Total	58	65	14	9	10	9	165	—
	PCT	PCT	PCT	PCT	PCT	PCT	PCT	PCT
Correct	76	84	77	75	66	81	—	79

TABLE 5. NUMBER OF FOREST DISTURBANCES NOT DETECTED (OMISSION ERRORS) BY A PHOTO INTERPRETER ON EARTH RESOURCES TECHNOLOGY SATELLITE COLOR IMAGERY, BY CATEGORY AND SIZE CLASS.

Disturbance Category	Size Class (Acres) <5	5-25	26-50	51-100	100-500	500 +	Total
Harvesting	2	1	1	0	3	0	7
Land Clearing	6	2	0	1	1	1	11
Natural Cause	0	0	0	0	0	0	0
Regeneration	0	2	0	0	0	0	2
Other	1	0	0	0	0	0	1
Total	9	5	1	1	4	1	21

ances were omitted, i.e., not detected on ERTS, making for about a 10 percent error. Two-thirds of the omissions were less than 25 acres (10.1 hectares) and more than half of these were less than 5 acres (2.0 hectares) (Table 5). Although our data are limited, it seems that most omissions fall in small land clearings and cutover forest areas. Commission errors are caused by calling something disturbed which is not disturbed. These errors are important because in application to a survey program it would mean for each interpretation error there would be one unnecessary field visit. At the approximate cost of $100 per visit, such errors could be expensive unless the field crew could inventory the plot for other information on this occasion. There were 25 commission errors or in terms of the total number of disturbances, a 12 percent error. Both types of errors, omission and

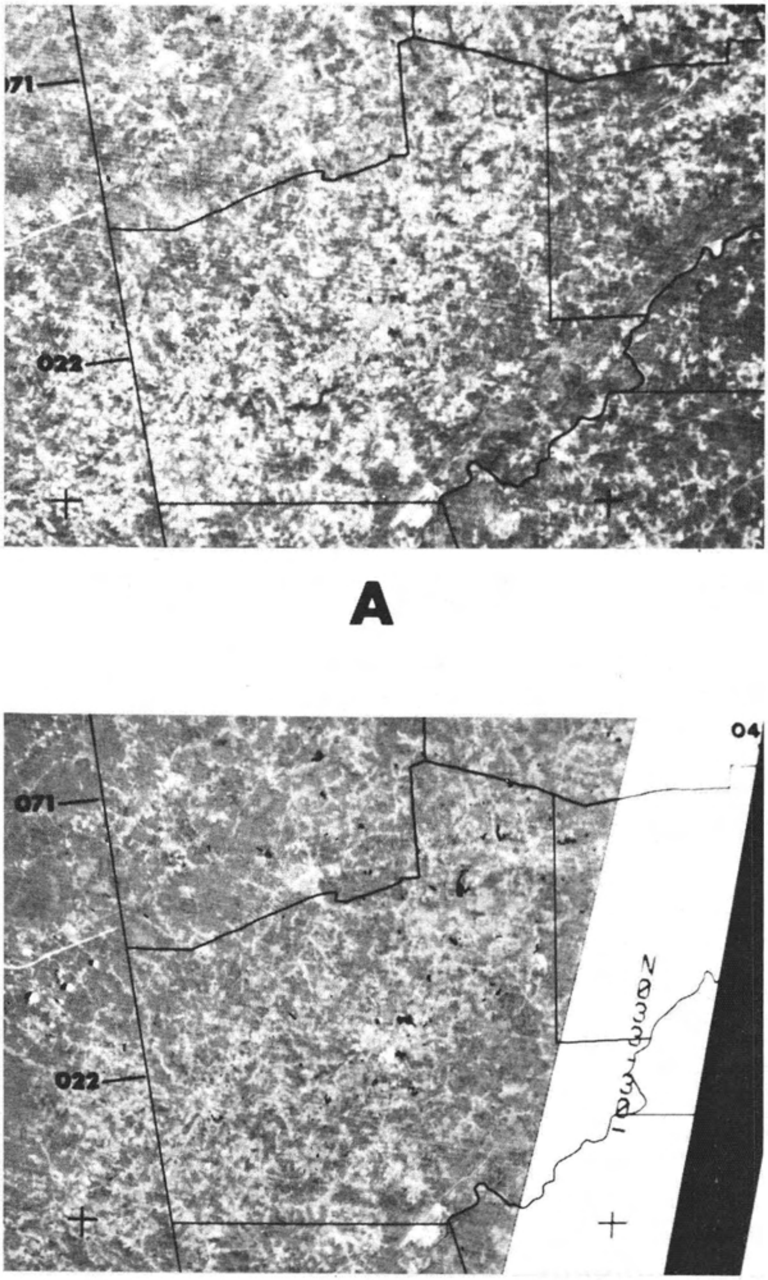

FIG. 4. Disturbances in the forest can be detected best during the period between late fall and late spring; (A) April 13, 1973. Infrared reflectant hardwood leaves and other vegetation oversaturate the images at other times of year as shown in *(B)* June 25, 1973. Images were copied from ERTS color composites at a scale of 1:1,200,000.

commission, can be reduced by improving the quality of color reproductions, and by additional experience and improved training in the use of low-resolution imagery.

Ground examination of 40 areas called disturbed since 1960 revealed that 33 could be detected and correctly classified on high-altitude photographs. These same areas could be detected but not classified on ERTS imagery. The seven misinterpretations were cause by (1) calling dark-toned (wet) fields artificial regeneration, (2) the inability to detect ground-fire damage after one year, (3) the inability to detect single-tree mortality, and (4) the inability to detect selective logging or stand improvement cuttings after two years.

From the ground check we have learned that the evidence of clearcutting and seed tree cutting can be detected up to eight years after the harvesting operation. We also learned that there is no time limit to detecting land cleared for nonforest use. Only the size of the clearing is a limitation—less than 1 acre on high-altitude photographs and 2 or 3 acres on ERTS imagery. However, nonforest land regenerated to forest land by natural or artificial methods cannot be detected until 3 years after planting. Association with other factors such as fire trails and site preparations can help interpret high-altitude photographs, but not low-resolution ERTS imagery.

CONCLUSIONS

The high accuracies in detecting forest disturbances on high-altitude and space imagery reported here should open up new avenues for improving nationwide forest inventories. One way might be to monitor permanent ground sample plots between present state reinventories. By cutting this period in half, the forest resource information base could be updated for more timely resource and land-management decisions. Ground sample locations would be revisited only where an activity of some kind was detected on the imagery. This could mean sampling only one of every four samples in a permanent sample design. As the greatest cost is the ground sample, the price of the intermediate inventory would be approximately one-fourth that of a complete reinventory.

Monitoring forest inventory plots by remote sensing implies the need for current imagery. The older the remote-sensing data, the less effective the monitoring system will be. But to fly high-altitude photographs or launch special forest resource satellites would be prohibitively expensive. Thus, to be feasible, the inventory system must rely on acquring remote-sensing coverage at nominal costs from outside sources. Although these sources are not yet available, the most probable sources in the future will include Agricultural Stabilization and Conservation Service, National Aeronautics and Space Administration, and the Department of Defense.

ACKNOWLEDGMENTS

Black-and-white reproductions of all ERTS images reproduced in this paper were made from 1:1,000,000-scale color composites produced from MSS bands 4, 5, and 7 by the NASA Goddard Space Flight Center, Greenbelt, Maryland. The ERTS data were furnished by NASA under the terms of Contract No. S-70251-AG with the U. S. Forest Service to conduct investigations with data received from the Earth Resources Technology Satellite.