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Space Photos for Land Use and Forestry

Interpreters can separate forest and nonforest land uses on Apollo 9 infrared-color photos and apply the data to inventory estimates.

INTRODUCTION

PHOTOGRAPHS TAKEN from space can provide valuable information about forest land. They show the distribution of forests and their relationship to other land use, including urban centers, and major transportation systems. In studies now under way they are providing information on the distribution of relative timber volumes useful for selecting first-stage samples in multistage forest inventory sampling designs.

In making a forest inventory we are primarily concerned with measuring volume and growth. This information is needed by local, state, and Federal land management agencies for policy making and management decisions. For instance, current timber volume and growth projected *X* number of years can show whether future volumes will meet increased population demands. If they will not, improved management practices are recommended that may include timber stand improvements, reforestation, and increased protection from fire, insects, and diseases.

ABSTRACT: *Infrared-color film taken as part of NASA's Apollo 9 multiband space photography experiment was the best of four film-filter combinations tested, to separate forests from other land uses. Interpretation of forest on infrared-color is based on color (hue, value, and chroma) and texture; the minimum ground resolution was found to be 300 feet. Automated interpretation of forest area may be feasible in the future because relative differences in film density appear to be related to land use. Results of a multistage forest inventory on two 5-million acre areas were conflicting. Information on the space photographs reduced the sampling error by 58 percent for an inventory in the Mississippi valley, but no such reduction was achieved in a similar inventory in Georgia.*

Generally speaking there are two types of forest inventories: the intensive kind usually made for high-value timber tracts under management, and the extensive kind. Extensive forest inventories, such as those conducted by the U. S. Forest Service's nationwide Forest Survey,* are made for all forest land regardless of value and whether or not it is managed. These surveys are made economical by the combined use of aerial photographs and statistical sampling designs that reduce costly ground work.

Remote sensors, including aerial photographs, are merely the tools for gathering data for the information needed. Space photography is remote sensing at long range, i.e., from a distant vantage point. If verticality of the imagery can be maintained, a 100-mile square, or larger area, can be covered on one photograph. From this distant vantage point, the observer can view all of the forest in a region. Although photo index sheets made from conventional photographs will give a similar view, they have many distortions, and many index sheets are required to cover the same ground area included on one space photograph.

By stratifying land use on space photo-

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* Forest Survey is a branch in the Division of Forest Economics and Marketing Research, Forest Service, U. S. Department of Agriculture, Washington, D. C. The Forest Survey was authorized by the McSweeney-McNary Forest Research Act of May 22, 1928.

graphs the number of conventional photographs required to make a forest inventory might be reduced. For instance, more than 3,500 photographs of a 1:20,000 scale would be required for stereoscopic coverage of a 100-mile square area. To cover the entire southern forest region of the United States—a gross area of 513 million acres—only 80 photographs from space would be required. Successful use of space photography will depend on how closely information from space is related to information on conventional photographs.

A number of investigators have studied the applications of remote sensing to earth resources surveys[2,3,11]. They are enthusiastic about the benefits of remote sensing for agriculture and forestry. But they all envision surveys using space imagery in combination with high-altitude and other conventional support photography. Katz,[4] on the other hand, believes that a fleet of high-altitude jet aircraft would have political benefits and provide more information at less cost than the satellite programs.

It is not the purpose of this paper to compare the relative benefits of space and conventional photography, nor to justify the cost of satellite photography for forest inventories. Instead, this paper considers the question: "Can forest be separated from other land uses, and how?" Both manual and automated interpretation were investigated. An example is given to demonstrate how space photography and conventional photography were combined with ground samples in a forest inventory for two 5-million acre areas in the Southern United States.

NASA SPACE PHOTOGRAPHY

Photography taken during NASA's Apollo 9 multiband photography experiment (SO-65) gave foresters their first good look at extensive forested areas from space. In the space experiment, four special Hasselblad** 70 mm. cameras equipped with 80-mm. focal-length lenses were mounted in the window of the spacecraft hatch. Several combinations of films-filters were used (Table 1).

Two sets of photographs were selected from the Apollo 9 test for the study reported in this paper. One set was taken over a portion of the Mississippi valley and includes sections of Arkansas, Louisiana, and Mississippi (Figure 1). The other set was taken over a portion of Alabama and Georgia. The scale of these photographs was checked and found to be 1:2,430,000. We will refer to these two areas hereafter as the Mississippi area and the Georgia area, respectively. The photographs were supplied by the Earth Resources Division of the Manned Spacecraft Center, Houston, Texas, for the purpose of examining the potential of space photography for earth resources inventories.

RECOGNITION OF FOREST LAND CLASSES

The Apollo 9 photographs are the best taken of forest areas since the beginning of the space program. They provided several advantages for forest land interpretation. First, the deciduous tree species (hardwoods) were without leaves. This omission resulted in a distinctive color characteristic that allowed the interpreter to evaluate where deciduous trees predominated. And it provided clues to the location of evergreen (pine) forests and where mixtures of both pines and hardwoods occurred. Another advantage was the absence of crops on the greater part of the agricultural land. Although fields had been plowed in preparation for planting, it was apparent that few crops other than overwintering cover types and pasture were present. This condition made it possible to separate easily the forest from nonforested areas. Finally, the timing of Apollo 9 made it possible to photograph the two areas during a season when the chances of success were as good or better than any other, i.e., a season with more days of clear weather than any other.

One disadvantage of space photographs at

TABLE 1. FILM FILTER DATA FOR THE NASA MULTIBAND PHOTOGRAPHY EXPERIMENT SO-65[1]

Camera	*Film*	*Filter*	*Film/Filter Transmittance Response*
A	SO-180 Ekta. Infrared	Photar 15	0.510–0.890 micrometers
B	3400 Panatomic-X	Photar 58B	0.470–0.610 micrometers
C	SO-246 B/W Infrared	Photar 89B	0.680–0.890 micrometers
D	3400 Panatomic-X	Photar 25A	0.590–0.715 micrometers

[1] Source: Apollo 9 Preliminary Plotting and Indexing Report, Mapping Sciences Laboratory, National Aeronautics and Space Administration, Manned Spacecraft Center, Houston, Texas, April 1, 1969.

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

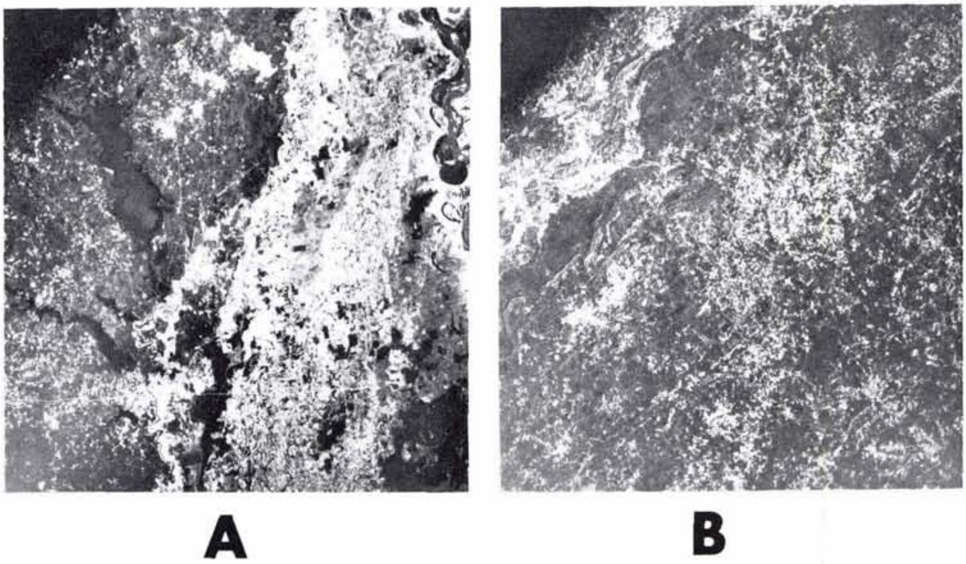

FIG. 1. Apollo 9 photographs of the Mississippi area *A* and the Georgia area *B*. The illustrations were made from the infrared color transparency.

this time of year is the frequent high-water levels resulting from snow-melt in the northern latitudes—particularly in the Mississippi valley. In this experiment, high water had flooded many of the bottomland hardwood sites and made them appear very much like water. Also, soil moisture was extremely high in croplands close to the bottoms. This moisture and extremely high humus content gave soils a dark appearance very similar to that of forest.

IDENTIFICATION OF BEST PHOTOGRAPHY

The Apollo 9 films were examined by placing them on a Richards variable-intensity light table and using a Bausch and Lomb Zoom 70 stereoscope to evaluate the four multiband images (Figure 2). We were able to rate the four films by their value for forest interpretation.

Infrared-color (SO-180) with a Photar 15 filter was by far the best imagery (Figure 1). The Mississippi area coverage is a classical example of proper exposure, whereas the Georgia area coverage was too dark. This indicates that under the conditions in Georgia, the exposure could have been improved by allowing more light to reach the film. Despite this exposure problem, the interfaces between forest and nonforest were not too difficult to define. Only where soil moisture was excessive and soil humus content high were nonforested areas misinterpreted as forest.

For forest interpretation, Panatomic-X (3400) film with a Photar 25A (red) filter was the second best of the four films (Figure 3A). Resolution was better than the infrared-color (SO-180). Although the rendition density scale is inferior to the infrared-color, it was superior to all the other films in the test. If used in combination with the infrared-color, this film could be helpful in separating forest from nonforest. In addition, road networks were better resolved on this film so that it is useful for identifying specific sites.

The infrared aerographic (SO-246) with a

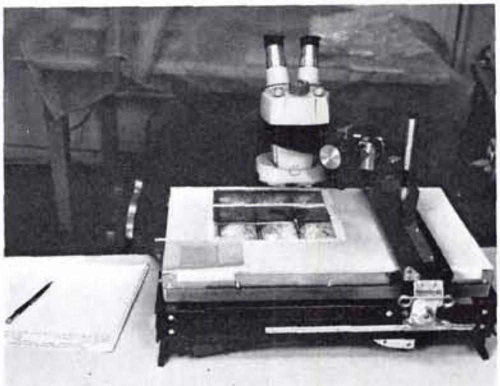

FIG. 2. A Bausch and Lomb 70-mm. Zoom Stereoscope on a Richards variable light table was used to interpret the small-scale imagery.

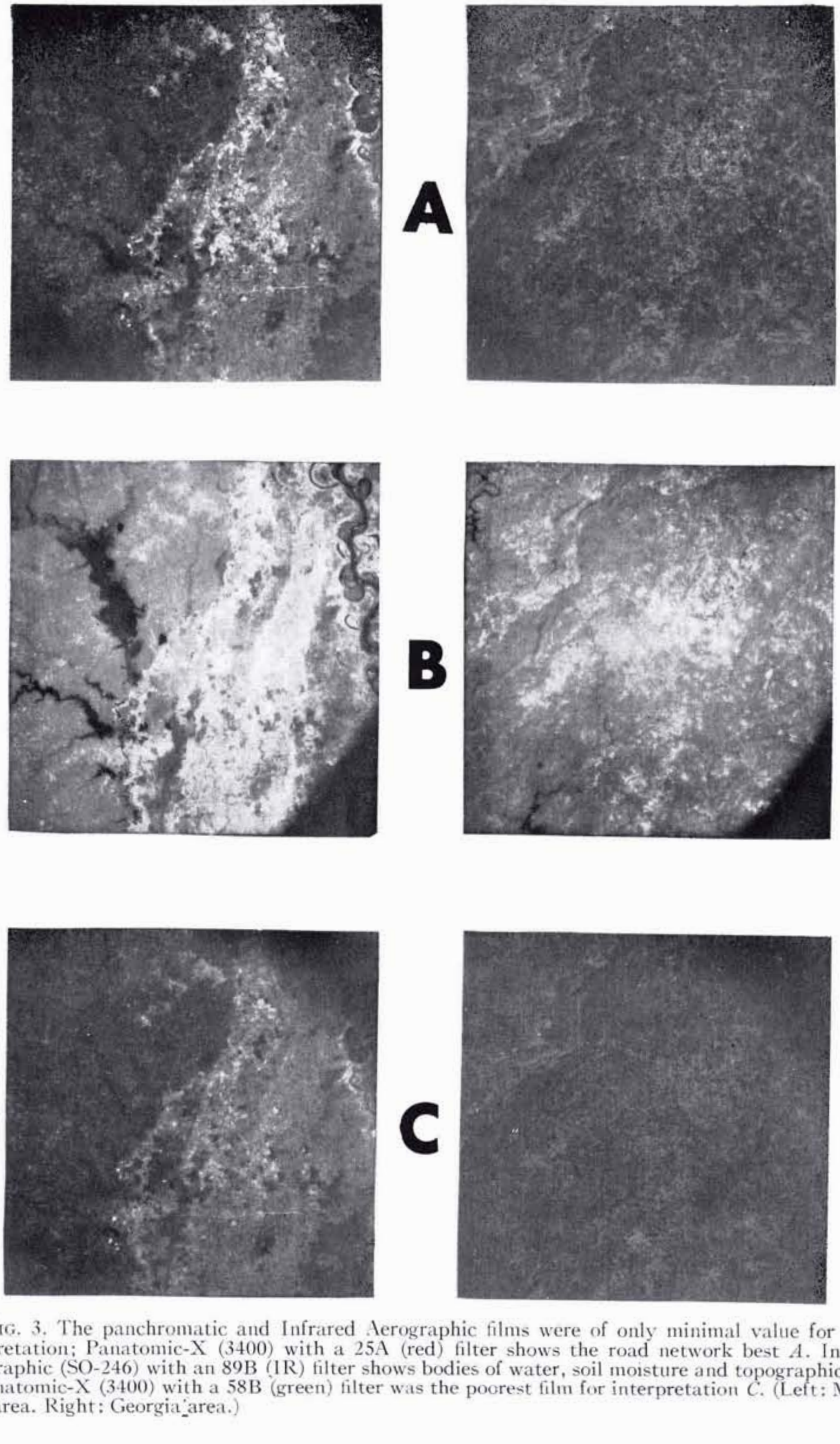

FIG. 3. The panchromatic and Infrared Aerographic films were of only minimal value for forest interpretation; Panatomic-X (3400) with a 25A (red) filter shows the road network best *A*. Infrared Aerographic (SO-246) with an 89B (IR) filter shows bodies of water, soil moisture and topographic relief *B*. Panatomic-X (3400) with a 58B (green) filter was the poorest film for interpretation *C*. (Left: Mississippi area. Right: Georgia area.)

Photar 89B (IR) filter had an extremely short gray density scale (Figure 3B). We found it difficult to identify a forest from other uses that photographed in the same dark tone. If used alone, this film has little value for forest identification but can be useful for identifying bodies of water, soil moisture conditions and topographic relief.

The fourth film, Panatomic-X (3400) with a Photar 58B (green) filter proved to be the poorest of the four films (Figure 3C). Both resolution and contrast were inferior and, because of poor contrast density, this film was extremely flat in appearance.

On the basis of these preliminary findings, we decided to use the infrared-color film. The Panatomic-X with 25A filter and the infrared aerographic with 89B filter were used only sparingly to help make some of the more difficult interpretations.

INTERPRETABLE FOREST INFORMATION

The minimum forest area that can be detected on Apollo 9 imagery is 300 feet in the shortest dimensions. This limitation was determined by many measurements using medium-scale support photography as a control. This means, to be detectable, a 300-foot-wide woodlot would have to be 0.0015 inch on the space photograph (scale: 1:2,430,000)—a measureable image using a stereomicroscope under 7.5× magnification. Woodlots of this size are easily recognized against lighter backgrounds such as plowed fields (Figure 4A). Although the likelihood of recognizing the same woodlot against darker backgrounds such as pasture, wet fields, and old abandoned fields is less, the chances for detection are still good (Figure 4B). Woodlots smaller than 300 feet can often be detected if their presence is already known. However, they usually appear as a dark smudge on lighter-toned surrounding areas (Figure 4C).

The multiband photography mission was flown in early March when the hardwood (deciduous) forests were not foliated. At this time of year hardwoods appear a bluish green color on the infrared-color transparencies (Figure 5A). Hardwoods found along streams and rivers (bottomland hardwoods) register a medium to dark blue on the space photograph (Figure 5B). The darker blue occurred in

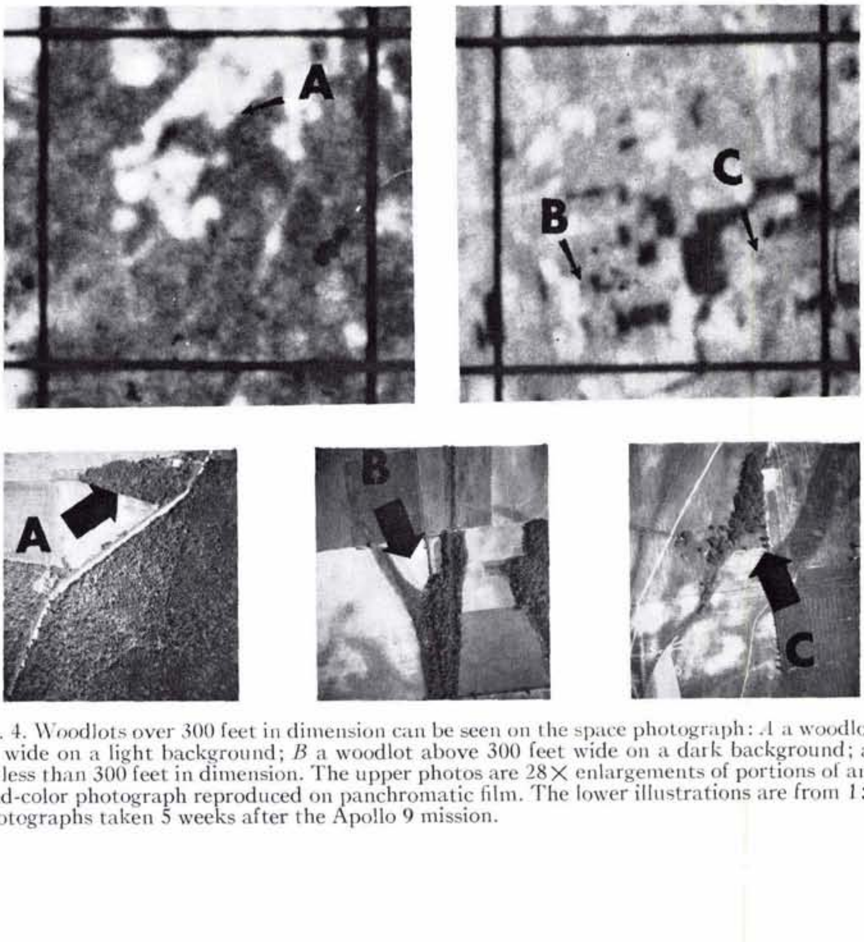

FIG. 4. Woodlots over 300 feet in dimension can be seen on the space photograph: *A* a woodlot above 300 feet wide on a light background; *B* a woodlot above 300 feet wide on a dark background; and *C* a woodlot less than 300 feet in dimension. The upper photos are 28× enlargements of portions of an Apollo 9 infrared-color photograph reproduced on panchromatic film. The lower illustrations are from 1:12,000-scale photographs taken 5 weeks after the Apollo 9 mission.

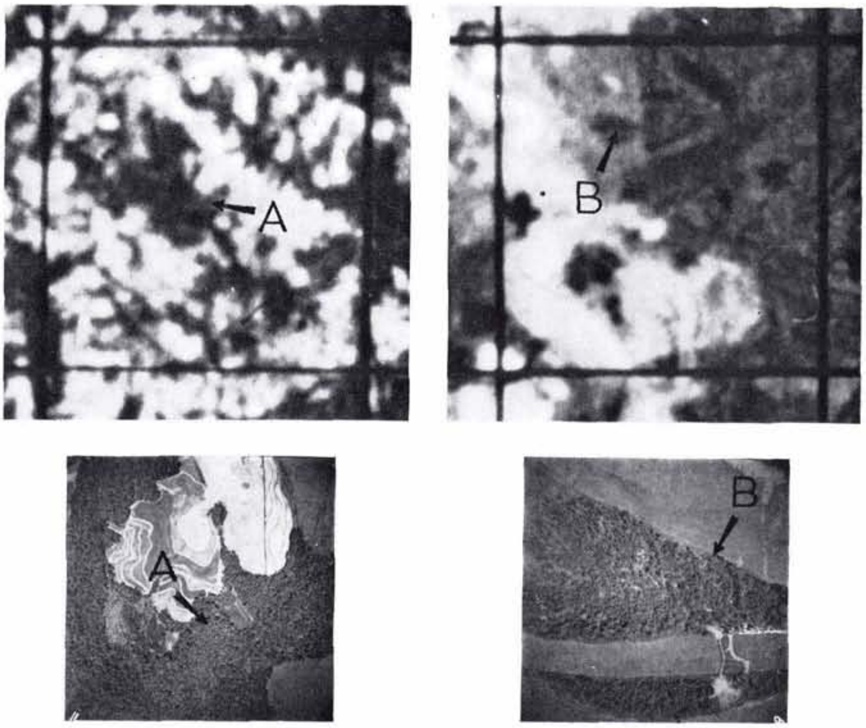

FIG. 5. On infrared-color photographs taken in March, the hardwood (deciduous) forests appear a bluish green color. These register in a medium gray tone on the panchromatic copy at *A*. Bottomland hardwoods register a medium to dark blue on the space photograph. The darker tones at *B* are caused by high water under the bottomland forest stands. The same timber stands are shown at *A* and *B* on 1:12,000-scale photographs taken shortly after the Apollo 9 mission.

many places in the Mississippi valley where streams and rivers had overflowed their banks.

Pine forests (primarily loblolly pine [*Pinus taeda* L.] and shortleaf pine [*Pinus echinata* Mill.]) in pure stands have a dark purplish red color on infrared-color transparencies (Figure 6). In film density, the pine forest is darker in value than pure hardwoods. Although there is some variation in value, or density, within the photographs because of optical fallout, density should be a valuable criterion for interpretation.

Where pine and hardwood species are found mixed, forest land classification should be based on texture as well as hue, value and chroma. Mixed stands appear to have a mottled texture where clumps of pine and hardwood (smaller than 300 feet) grow together. Color descriptions and standard Munsell Color Notations for forest and nonforest classes are found in Table 2.

AUTOMATED FOREST CLASSIFICATION

The possibilities of automating the interpretation of space imagery was investigated. A General Aniline and Film Corporation (GAF) Model 650 Automatic Recording Microdensitometer was used to scan 20 sample strips on the Apollo 9 infrared color photographs for the Mississippi and Georgia areas. An analog chart recording was made for each strip using a red (Wratten 92), green (Wratten 93), blue (Wratten 94), and a visual filter (Wratten 106) that approximates the spectral response of the human eye. The sample strips were located on 1:20,000 panchromatic U. S. Department of Agriculture photographs.

Recorder chart distances were proportioned to the same strip on the panchromatic prints. Using the specially taken photographs as *truth*, prints were classified into 11 land-use classes. From these classes the mean densities were computed for each land-use class (Table 3). Although the number of samples is insufficient for statistical analysis, the data indicate possibilities for future work in this area.

A MULTISTAGE FOREST INVENTORY

The multistage forest inventory reported here was made for two areas: the Mississippi area including 7,680 square miles and the

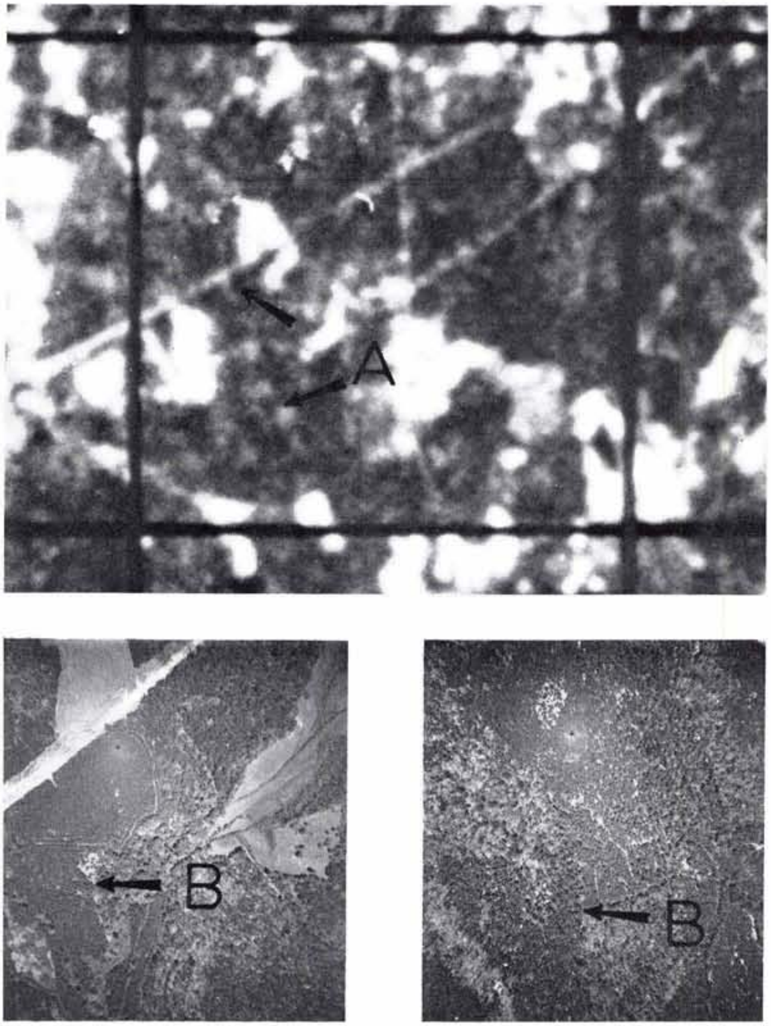

FIG. 6. Pine forests are characterized by a dark purplish red color: *A* on the 28× panchromatic enlargement of the infrared color photograph, the pine appears a medium to dark gray tone (see arrow); *B* the same pine timber is shown on a 1:12,000-scale photograph taken shortly after the Apollo 9 mission.

Georgia area including 7,360 square miles. This inventory sought to demonstrate how space photography could be used in a resource survey and to calculate the gain from using low-resolution data as a first level of resource information.

The theory of sampling in more than one phase is not new to forest inventories. For many years foresters have been stratifying forests into homogeneous classes on aerial photographs to reduce volume variation and consequently the number of costly ground samples. These two-phase, and sometimes three-phase, sample designs are usually more efficient for extensive forest inventories than using ground plots alone. Multistage sampling in its present context, however, can include several stages and can make even greater gains. Information from existing medium-scale photographs, high-altitude small-scale photographs, or even maps can be combined in a sampling design with large-scale photographs and ground samples. The stages in the design can be combined using new probability sampling theory [5,10,6].

Basically, probability sampling allows us to select the sample in each stage based upon some *a priori* information. In the space-oriented forest inventory reported here, the first level of information is derived by subdividing the space photo into equal-size blocks and predicting the relative volume of timber in each block. For this interpretation we felt that the proportion of forest would be related to timber volume. Thus, we predicted the proportion of forest for each block.

TABLE 2. FOREST AND NONFOREST CLASSIFICATIONS DESCRIBED BY MUNSELL COLOR NOTATIONS ON APOLLO 9 INFRARED COLOR FILM

Land Classification	*Color*[1] *Description*	*Standard Munsell Notations* *hue*	*value*	*chroma*
Pine	moderate to dark purplish red	10RP 10RP	4 3	8 6
Hardwood	moderate to dark bluish green	2.5BG 2.5BG	5 3	6 4
Mixed	mottled combinations above created by patches, less than 300′ diameter	10RP 2.5BG	— —	— —
Plowed Fields	pinkish gray to light purplish gray	7.5RP 10RP	8 8	0 1
Pasture	moderate pink, strong pink to deep pink	10RP 10RP 10RP	8 7 6	6 8 10
Muddy Water	moderate blue	5B	5	6
Clear Water	dark blue	5B	3	6
Cut-over Forest	light bluish green	2.5BG	7	4

[1] Source: Kelly, Kenneth L., and Deane B. Judd. The ISCC-NBS Method of Designating Colors and a Dictionary of Color Names. NBS Circ. 553. U. S. Dep. Commerce. 1955.

TABLE 3. MEAN FILM DENSITY FOR FOREST AND NONFOREST LAND CLASSIFICATIONS USING A GAF MICRODENSITOMETER[1] ON APOLLO 9 IR COLOR FILM—APOLLO FRAMES 3790, 3791

Land Classification	*Number of Observations*	*Mean Film Density with Red Optical Filter*
Pine Forest	31	3.87
Hardwood Forest	12	3.55
Mixed Forest	15	3.50
Plowed Fields	10	2.44
Improved Pasture	16	2.62
Abandoned Cropland	6	3.04
Roads	12	3.31
Forest and Pasture	8	3.31
Forest and Abandoned Cropland	2	3.28
Orchard	1	2.62
Orchard and Pasture	1	2.60

[1] GAF Automatic Recording Microdensitometer, Model 650, set with lamp voltage at 15 volts. Optics set at 75 magnifications with 1.15 mm diameter aperture and a red filter (0.750μ).

The first stage of the sampling design consists of five blocks drawn at random with probability of selection proportional to the predicted volumes. The larger the volume, the greater the chance of selection. In this way samples are taken where they are most likely to do the greatest good.

SUPPORT PHOTOGRAPHY

Between April 15 and April 24, 1969, the Pacific Southwest Station's remote sensing research aircraft and crew flew photographic missions in support of this inventory study. The missions were flown for selected sample blocks in the Mississippi and the Georgia areas. Two Maurer KB-8 70-mm cameras, and a Crown Graphic camera with a Polaroid back, were mounted together in a single mount (Figure 7). The two 70-mm cameras were operated by separate intervalometers for 60-percent overlap in line of flight. The Crown Graphic was triggered by hand at one-minute intervals by using a long cable release. Cameras, films, and photographic mission descriptions are given in Table 4.

PHOTO INTERPRETATION

Three stages in the multistage sampling design involved photo interpretation. The first interpretation job was to stratify forest and nonforest land on the Apollo 9 photographs as a basis for selecting first-stage samples. Portions of three frames were required to interpret each area. The infrared-color (SO-180) was used as the primary source of information. A transparent grid template

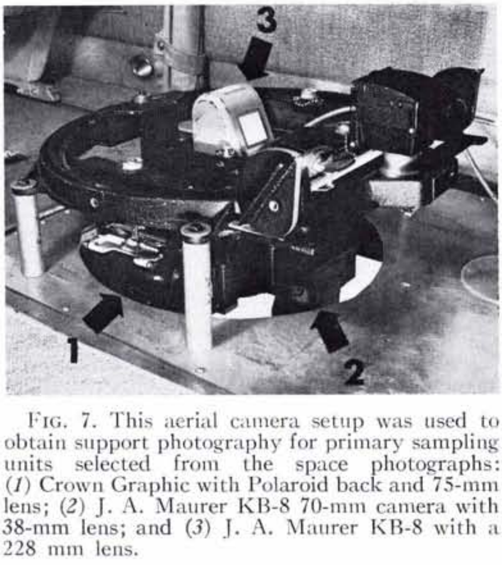

FIG. 7. This aerial camera setup was used to obtain support photography for primary sampling units selected from the space photographs: (*1*) Crown Graphic with Polaroid back and 75-mm lens; (*2*) J. A. Maurer KB-8 70-mm camera with 38-mm lens; and (*3*) J. A. Maurer KB-8 with a 228 mm lens.

TABLE 4. CAMERA AND PHOTOGRAPHIC MISSION DESCRIPTIONS FOR THE APOLLO 9 FOREST INVENTORY STUDY

Camera	*Focal length (mm)*	*Filter*	*Film*	*Altitude (feet)*	*Scale*	*Number frames*
Crown Graphic	75	Yellow	Polaroid 400	15,000	1:60,000	40
Maurer KB-8	38	HF-3	Aero-neg	15,000	1:120,000	40
Maurer KB-8	228	Wratten 15	IR color	15,000	1:20,000	400
Maurer KB-8	38	HF-3	Aero-neg	1,500	1:12,000	550
Maurer KB-8	228	1A	Ansco D/200	1,500	1:2,000	1,011

divided the areas into equal four-mile squares—Mississippi had 480 squares, and Georgia 460 squares (Figure 8). A Bausch and Lomb Zoom 70 stereoscope mounted on a variable-intensity light table was used to interpret the films (Figure 1). The proportion of forest area in each square sample block was predicted and recorded.

Five random sample blocks were selected in each area with probability of selection proportional to the predicted volume. The remote sensing aircraft then flew support photography for each of the 10 primary sample blocks.

The first stage of the inventory was a 1:60,000-scale Polaroid mosaic for each primary sample block. A transparent overlay was used in the aircraft to divide the primary samples into 12 strips (Figure 9). The strips were quickly interpreted in the aircraft to predict timber volume based on the proportion of forest. This second level of information was the basis for selecting two random strip samples with probability proportional to the volume in each strip.

After the two sample strips had been selected for the second stage, the Polaroid (1:60,000) mosaic was passed to the pilot. Using the mosaic as a flight map, the pilot flew over the two strips with two 70-mm cameras operating simultaneously. One camera photographed the strip at 1:12,000 scale in negative color. The second camera exposed 1:2,000 scale color transparencies in series of three at specified 8- to 10-second intervals.

The third level of information was provided by the 1:12,000-scale photographs printed on variable-contrast paper (Figure 10). These individual contact prints were assembled in the office to form an uncon-

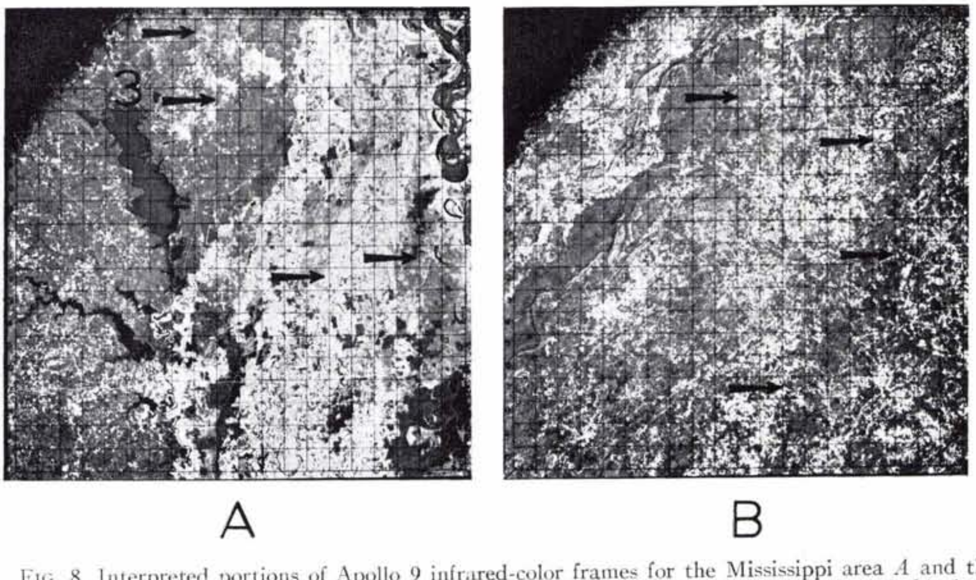

FIG. 8. Interpreted portions of Apollo 9 infrared-color frames for the Mississippi area *A* and the Georgia area *B* shown with grid templates attached. Black arrows point to first-stage sample blocks—the sample block at *3* in the left-hand photograph is shown in Figure 9.

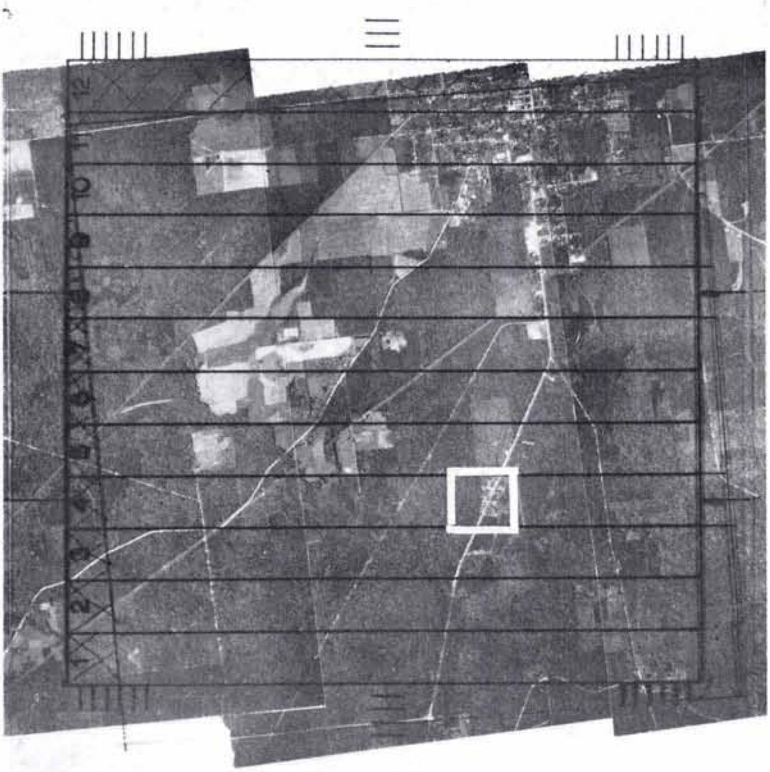

FIG. 9. The first stage of the forest inventory is a 1:60,000 scale Polaroid photo mosaic for each sample block selected from the Apollo frames. Block *3* of the Mississippi area is shown with a grid overlay used to select two strips for the next sampling stage. This block appears at *3* in Figure 8A.

trolled mosaic of each line. The strip coverage was transferred from the Polaroid print to the mosaic and marked in India ink. This procedure was followed to obtain greater precision in area estimates for the strips. We measured the relative area in each sample strip by using a Bendix Data Grid with analog to digital recorder. The *cursor* was moved to points at short intervals around the boundary of the strip and x and y coordinates for each point recorded on tape. These coordinates were converted to area in square inches using an ADP program routine. Relative strip areas were used to expand the volume predictions made for the large-scale color triplets to the strip.

Along each sample strip, 1:2,000-scale, color-photo triplets had been systematically exposed at 7- to 10-second intervals. The first triplet was taken by using a random start to satisfy the requirements for an unbiased random sample. Depending on the aircraft ground speed and altitude, 15 to 27 photo triplets were taken along each strip. The center photograph of each triplet was divided into four equal squares, each representing 0.625 acre if the scale was precisely 1:2,000 (Figure 11). Predictions of gross cubic-foot volume for each of these photo plots represents the fourth level of information for the inventory design.

Total cubic-foot volume was predicted for 1,348 photo plots in the two inventory areas. The average stand height, crown diameter and crown closure were estimated on each plot. Stand height was measured with a parallax[9]. Crown diameter was measured with distance-measuring wedges to the nearest 0.001 inch and converted to feet using a conversion table. A grid of 144 dots per square inch was used to measure crown closure[8]. With these three measurements, a composite cubic-foot volume table* was entered and volume read for each plot.

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* A composite stand volume table[1] was modified to include crown closure by 5 percent increments and crown diameters up to 40 feet.

One photo plot was selected as a ground sample from each strip in the two survey areas—10 in each area or a total of 20 samples. These samples were selected with probability proportional to volume and are called the fifth level of information in the inventory design.

Enlargements, each 9 by 9 inches, were made for each of the 1:12,000-scale 70-mm frames that included a large-scale photo plot selected for ground checking. These photographs printed on a low-shrink polyester panchromatic print material were useful for locating the ground sample plots for the fifth level of information.

GROUND SAMPLING

The photo plots selected were accurately located and cruised on the ground.† All trees within the 0.625-acre ground plot were tallied by species and *d.b.h.** and assigned a cubic foot volume from local volume tables. Adjustments were made for rough and rotten cull. Softwoods (pine and cypress) and hardwoods (deciduous) were listed separately.

Using the separate listings, we accumulated volumes and recorded them for each tree. A minimum of two, but preferably three, random numbers were selected for both hardwoods and softwoods between one and the total accumulated volume in each class on the plot. Sample trees for the last stage in the inventory were selected at the point in the accumulated volume listings where the random numbers fell—a selection with probability proportional to volume.

Each tree in the sample was measured with a Barr and Stroud dendrometer (Figure 12). Precise dendrometer measurements of the

FIG. 11. This 1:2,000-scale photograph corresponds to the area outlined in black on the 1:12,000-scale photograph in Figure 10. The grid divides the center photograph (shown) of each sample triplet into four plots approximately 0.625 acre in size. Photo is a 2.2× enlargement made from the original 70-mm color transparency.

FIG. 10. This 1:12,000-scale photograph covers the area outlined in white in Figure 9. The area outlined in black corresponds to the coverage of the 1:2,000 scale photography shown in Figure 11. Each sample strip was completely covered by 1:12,000 photographs. The photo shown is a 2.2× enlargement made from negative color film.

FIG. 12.—Ground crew used a Barr and Stroud optical dendrometer to measure the boles of 4 to 6 trees on each selected ground plot.

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† Inventory field work was done by Forest Service personnel from the Southeastern and Southern Forest Experiment Stations in Asheville, N. C., and New Orleans, La., respectively.

* Diameter-breast-high.

bole characteristics enabled a computation of gross cubic foot volume for each tree.

After the tree volumes were obtained in this final stage, they were expanded to the total area using the sampling formula. The formula and procedure for this expansion have been described by Langley (1969).

RESULTS

Judging our results in relation to the original objective, we would have to say that we met both success and setbacks. We achieved our greatest success in the Mississippi area, where we estimated the gross total volume at 2.225 billion cubic feet of timber with a sampling error of 13 percent, with only 10 ground plots. Half of the error was attributable to the tree volume tables used on the ground to relate to the dendrometer measurements. If we had used the same sampling plan, but used random sampling with equal probabilities at the first stage and without stratification, the sampling error would have been 30.7 percent. By adding the benefits from stratifying on the space photographs with variable probability, we reduced the error to 13 percent. This is a 58 percent reduction in sampling error directly attributable to information interpreted on the Apollo 9 photographs.

The inventory for the Georgia area was not so successful; in fact, the results were disappointing. Using exactly the same sampling plan, we estimated a total gross volume of 2.670 billion cubic feet of timber. The sampling error was a high 30 percent. Most important to our test, we were unable to show a gain in sampling efficiency as a result of using information on the space photographs. This failure was a result of poor correlation between our predicted volumes on the primary sample units (made on the space photographs) and estimated volumes on the corresponding sample blocks found by subsampling on the ground.

Why was the result in Georgia so different from that in Mississippi? One only has to look at the photographs in Figure 8 to see that the Mississippi area has three natural strata that can be easily identified. On the other hand, the Georgia area seems more uniform in appearance, making accurate stratification more difficult. The result was a greater reduction in volume variation through stratification in the Mississippi area.

The uniformity of the forests within each of the three strata in the Mississippi area probably contributed to further reductions in volume variation. In other words, the few ground samples were fairly representative of the volume to be found in each block in each stratum. In Georgia, however, land use is broken up into a *checkerboard* pattern, resulting in smaller forest ownerships and possibly greater variation in volume. Here, 10 ground samples were probably inadequate to measure the variation in volume.

Obviously we have made only a small dent in the research needed to quantify space photography for forest inventory sampling designs. We are continuing to work in this problem area to improve our volume predictions at all levels in the forest inventory sampling design.

CONCLUSIONS AND DISCUSSION

It has been demonstrated that interpreters can separate forest and nonforest land uses on infrared-color photographs from space. The characteristics of forest can be recognized by combinations of texture and color hue, chroma (strength), and value (density). The minimum ground resolution for forest on the Apollo 9 infrared-color photographs was approximately 300 feet. Multiband photographs taken on panchromatic and Infrared Aerographic films with Photar bandpass filters were of little value individually in forest interpretation.

Automated methods of stratifying forest and nonforest on space photography may be possible in the future. Preliminary tests with a GAF Model 650 automatic recording microdensitometer show very clearly the separations between forest and agriculture by film density. This discrimination by automated methods may make it possible to perform the first stage in forest inventories and monitor the forest resource on sequential photographic coverage for changes within some standard grid system. Where changes occur, the grid squares involved might be photographed beginning at a high altitude and multistage sampling used as suggested in this paper. The better ground resolution would enable us to measure more precisely the effect of change on volume and the resulting impact on growth.

The results of a multistage forest inventory between the two study areas were in sharp contrast. We did demonstrate that *a priori* information in space photographs can promote survey efficiency. For such data to be most useful the predicted variable on the space photograph must be closely related to the estimate made in the final ground stage. In the Mississippi area was such a relationship, and it resulted in a 58-percent reduction in the inventory sampling error. But in

Georgia, such a relationship was missing, whence the use of information in space photographs yielded no gain. Further research is needed to isolate the sources of error in all sampling stages.

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