

FOREST AND RANGE INVENTORY AND MAPPING

by

Robert C. Aldrich

BIOGRAPHICAL SKETCH

Robert C. Aldrich is Principal Research Forester with the Remote Sensing Project in Berkeley. He received his B. S. and M. F. degrees from the New York State College of Forestry at Syracuse University in 1944 and 1948, respectively. Mr. Aldrich has been employed by the Forest Service for 23 years and has devoted his career to the applications of remote sensing to forest surveys. Between 1948 and 1954 he was assigned to the Forest Survey unit at the Southeastern Forest Experiment Station at Asheville, North Carolina. In 1954, he transferred to the Forest Insect Laboratory at the Agricultural Research Center in Beltsville, Maryland, where he conducted research in survey techniques for detecting and evaluating forest insect outbreaks. He has been in his present position since 1965. Mr. Aldrich has authored or coauthored over 25 publications on the subjects of photo interpretation, aerial survey techniques, and remote sensing in forestry. He is a member of the American Society of Photogrammetry and the Society of American Foresters.

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Robert C. Aldrich¹INTRODUCTION

Gathering information about earth's forest and range resources will be a challenge for space-age remote sensing in the years ahead. Environmental experts are already saying that earth's rapidly expanding population will soon demand more food, forest products, and unpolluted water than present resource management practices can provide. To improve the situation, resource managers will require more information at much shorter intervals than is economical at the present time. Increasing the use of remote sensing may reduce costs and make surveys at more frequent intervals possible.

In the United States, demands for more highways, electric power, and consumer products are already creating rapid changes in the forest environment. We have a steadily increasing problem with air pollution and its effect upon vegetation (1), a shifting forest acreage caused by land-use changes, and a forecast for decreasing net forest growth and volume (2). To combat these effects, we must improve land management practices and policies to better utilize range and forest land and keep idle lands productive.

Remote sensing, including conventional aerial photography, is a tool for gathering information about the forest and range resources. And now since man has solved some of the mysteries of space, we have a new dimension in remote sensing--pictures taken from platforms 160-480 km (100-300 miles) above the earth with photographic or electronic sensors. Although these synoptic pictures have a ground resolution of only 46-122 meters (150-400 feet), they should be useful for generalized regional forest and range appraisals. Furthermore, prospects are bright for repeated earth coverage at intervals as short as every 18 days by polar orbiting spacecraft (ERTS); as this system develops, forest and range information systems and maps may be updated to show the situation as often as needed. In time, we feel that technological improvements in camera optics, films, and electronic scanner outputs will increase ground resolution and the kinds and quality of information taken from space imagery.

Regardless of ground resolution, imagery taken from space will never eliminate the need for larger scale aerial photographs and ground measurements. Foresters and range conservationists will always be a vital part of the information-gathering system. If we combine a limited amount of ground measurements with other levels of information in multistage sampling designs, the efficiency of extensive forest and range appraisals should be improved.

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MULTISTAGE SAMPLING

The theory of sampling in more than one step is not new to forest or range inventories (3, 4, 5). Forest and range managers around the world have been using medium-scale aerial photographs, combined with ground data, for many years in two-step sample designs. Many of you are familiar with these. One classic example is the forest inventory using stratified sampling. First, the forest is stratified into relatively homogeneous vegetative types and volume classes on aerial photographs. This reduces variation between population units within classes. As a result, fewer ground plots are needed to attain the same sampling error that can be achieved by simple random sampling alone, and total survey costs are minimized. But multistage sampling, by including several stages, can make even greater improvements in efficiency. The gains are made because we use the additional information found at each stage to select the next stage. We can use existing medium-scale photographs, high-altitude small-scale photographs, space photographs, and even maps and combine them with large-scale photographs and ground samples in a survey design by using probability sampling theory (6). This theory is commonly referred to as p.p.s.--probability proportional to size.

PROBABILITY SAMPLING THEORY

Langley (7) extended the theory of probability sampling to multistage sampling designs in conjunction with timber mortality surveys and National Forest management plan inventories. This technique was first used successfully on a forest insect damage survey to estimate the volume of dead timber (8). Since then, it has been extended to general forest surveys that use more than one photographic scale. These are multistage sampling surveys with arbitrary probabilities of sample selection at each stage (photographic scale). In this technique, the sampling probabilities are derived by using the information made available through the use of increasingly finer ground resolution of remote sensors at each stage. At the last stage, detailed measurements are made for the survey parameters on the ground. These measurements are then projected back through the sampling formula to obtain estimates for the entire survey area.

Basically, probability sampling allows us to select the sample in each stage based upon some prior information. In a forest survey, the prior information is most likely to be a prediction of something related to volume--perhaps stand density, type, or area. The better the correlation between the prediction and the estimate at each stage, the lower the variance will be. However, if there is a negative correlation, the sampling variance will be higher than if we had used simple random sampling at that stage.

Probability sampling designs have several advantages over other sampling designs. One is that the number of costly ground samples required to obtain estimates of volume within acceptable limits of error can be reduced significantly. In addition to being efficient, the design provides unbiased estimates and statistically valid sampling errors at all stages. Furthermore, it improves operational efficiency by concentrating our effort in those areas of the greatest interest at each stage.

Let's look at an example of multistage sampling using photographs taken from space as the first level of information.

A MULTISTAGE FOREST INVENTORY

The vertical photographs of earth taken during NASA's Apollo 9 multiband photography experiment (SO-65) gave foresters their first good look at extensive forested areas from space. Of the four film and filter combinations tested in this experiment, infrared color film (Ektachrome Infrared, SO-180) with a Photar 15 filter (0.510 to 0.890 μm), showed the greatest promise for separating forest from nonforest areas. Extensive range lands also were photographed in this experiment, but we decided to test our sampling theories in two forested areas (9).² One of these is in the Mississippi River valley and includes about 2 million hectares (5 million acres). The other area covers about 1.9 million hectares (4.7 million acres) in the states of Georgia and Alabama southwest of Atlanta, Georgia (Fig. 1).

Please keep in mind that we were concerned only with determining the potential usefulness of space photographs in an operational survey environment. We wanted to answer two basic questions: (1) can information obtainable from space photographs make a contribution toward reducing the sampling error of a timber inventory, and (2) how can support aerial photography be used in controlling the variation within relatively large primary sampling units delineated on space photographs?

Our first task was to examine the infrared color transparencies and relate color and film densities to land classes on the ground. We also needed to decide what parameter on the photo could be related to forest volume. A variable-intensity light table and a Bausch and Lomb Zoom 70 Stereoscope³ were used for this examination (Fig. 2).

From this preliminary examination, we decided that the best relationship would be between forest area (proportion) and cubic-foot volume. As a population unit we selected a 6.4- x 6.4-kilometer (4- x 4-mile) block. Our reason for this was intuitive. We felt that units this large would (1) be readily identifiable from an aircraft for photographing at a larger scale, (2) be large enough that we could make a meaningful prediction of timber volume, and (3) be large enough that between-unit variation in timber volume per acre of forest land would be relatively low within identifiable strata.

² Range scientists at the Rocky Mountain Forest and Range Experiment Station, Forest Service, U. S. Department of Agriculture, Fort Collins, Colorado, are studying correlations between vegetation types and photographic images in preparation for multistage sampling surveys in Southwestern United States.

³ Trade names and commercial enterprises or products are mentioned solely for necessary information. No endorsement by the U. S. Department of Agriculture is implied.

We found there are two fairly homogeneous strata within the Mississippi area (10). One stratum is predominantly upland pine and hardwood and the other stratum is predominantly bottomland or upland hardwoods without any significant pine (Fig. 3). Since the Apollo 9 mission was flown in early March when the hardwood (deciduous) forests were defoliated, these forests were represented by a bluish green color on the infrared film. Hardwoods that occurred along streams and rivers (bottomland hardwoods) registered as a medium to dark blue. The darker blue occurred in many places in the Mississippi valley where streams and rivers had overflowed their banks. Pine forest, primarily loblolly pine (*Pinus taeda* L.), and shortleaf pine (*Pinus echinata* Mill.) in pure stands were highly infrared reflectant and had a dark purplish red color on infrared color transparencies. We also found that pine is darker than pure hardwoods. Thus, stands appear to have a mottled texture where small clumps of pine and hardwoods grow together.

In the Georgia-Alabama area, homogeneous strata were more difficult to define on the space photograph. Here the entire area is more or less homogeneous with blocks of pure pine, hardwood, and mixed stands broken by agricultural fields (Fig. 4). However, we finally decided on two strata--one that is predominantly agricultural and one that is predominantly forest. Our reason for this was intuitive. We felt that forest land in a predominantly agricultural area would reflect differences in site and should represent a different population strata. I will discuss the results of this a little later. For now, I would like to limit myself to the Mississippi valley portion of the forest inventory test.

The first level of information for the forest inventory was derived by subdividing the space photograph into blocks approximately 6.4- x 6.4-kilometers (4- x 4-miles) in size or 4,144 hectares (10,240 acres) (Fig. 5). There were 480 of these population units. After the primary sample units had been delineated, each block was examined with the aid of a 7X power stereoscope (Fig. 2). From this examination the interpreter estimated the proportion of forest land. This estimate was used as a prediction of the relative timber volume in the block. After all squares had been examined and predictions made, a sample of five blocks were drawn at random with probability proportional to the predicted volume. One of these blocks is shown enlarged about 16 times in Figure 6.

Between April 15 and April 24, 1969, the Forest Service remote sensing research aircraft⁴ and crew flew photographic missions in support of this inventory study. The five primary sample blocks selected were flown with a camera package that consisted of a Crown Graphic camera with a Polaroid back and two Maurer KB-8 70 mm. cameras mounted in a single frame (Fig. 7).

The first stage of the inventory was a 1:60,000 scale Polaroid mosaic for each primary sample block. We used Polaroid to obtain and rapidly interpret the imagery while still airborne. Why this was necessary will be explained later.

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The 1:60,000 scale was chosen so that the entire sample block would fit within a 101.6- x 127.0-mm. (4- x 5-inch) film format in one photographic pass. When the Polaroid mosaic had been constructed, a transparent overlay was used in the aircraft to divide the primary samples into 12 equal strips (Fig. 8). These strips represented a path approximately 536 meters (1,760 feet) wide on the ground. Here is where Polaroid photos were necessary. We could examine the strips quickly while still in the aircraft and predict the timber volume based upon the proportion of forest in each strip. The forest information on these photographs was sufficient for predicting timber volumes as a basis for selecting strips for the next stage. Using this second level of information, we selected two random strip samples in each block with probability proportional to the predicted volume in each strip. A hand-operated adding machine and a book of random numbers were all that were required to do this.

The selected strips were marked on the Polaroid mosaic and the mosaic handed to the aircraft pilot. Using the mosaic as a flight map, the pilot flew over the two strips with two 70 mm. cameras operating simultaneously. One camera with a 38 mm. (1-1/2 inch) lens photographed the strip at a 1:12,000 scale in negative color (Fig. 9). Meanwhile, the second camera with a 228-mm. (9-inch) lens was triggered in bursts of 3 exposures at 8- to 10-second intervals to produce three 1:2,000 scale color transparencies with 60 percent overlap (Fig. 10). The 1:12,000 photography covered the entire strip, whereas the 1:2,000 scale photo triplets consisted of a systematic sample with a random start taken down the center of the strip (Fig. 11).

We returned to our headquarters in Berkeley where the 1:12,000 scale photographs were printed and assembled into strip mosaics. The exact boundaries of the strips were delineated on the mosaics. Then, the photo coordinates of these boundaries were digitized at 0.254 mm. (0.01 inch) intervals using a Bendix Datagrid digitizer (Fig. 12). The area within each strip was computed from these data. The proportion of the strip covered by the 1:2,000 scale photos was computed from the number of 1:2,000 scale photographs obtained in a strip and the area of the strip. The inverse of this proportion was used to expand the timber volume estimates from the cluster to the strip level.

The 1:2,000 scale clusters of color transparencies made up stage three of the survey design. They were made up of three pictures with 60 percent overlap to provide stereoscopic coverage of the center frame. There were from 13 to 20 triplets per strip, depending on airspeed and altitude; the total for all triplets was 175.

The center photograph of each triplet was divided into 4 square plots equal to approximately 0.25 hectare (0.6 acre) each (Fig. 9). This size plot is convenient for locating and measuring on the ground.

Each large-scale photo plot was examined stereoscopically and stand height, crown closure, and crown diameter measured. Stand height was measured with a parallax wedge, crown diameter with a crown diameter wedge, and crown closure with a dot grid. With these three measurements, a composite cubic-foot volume table was entered and the volume read for each plot (11). Separate estimates were made for pine and for hardwood. From the total photo plots in each strip, one plot was selected for measurement on the ground. Again, the selection

probabilities were proportional to the predicted timber volume at this level.

Each selected plot was located on a 23- x 23-cm. (9- x 9-inch) enlargement of the 1:12,000 scale and 1:2,000 scale photographs. A packet of these photos was given to a field crew to aid in locating the plots on the ground.

Each plot was precisely located on the ground and the perimeter marked with a string line. Each tree's diameter was measured and recorded by species. A separate tally was kept for hardwoods and softwoods. The tree diameters were used to predict each tree's volume from a volume table. The timber cruiser adjusted each tree volume for defects and deformities in the tree. Then using these predictions, four to six trees were selected (a minimum of two in hardwoods and two in softwoods) on which precise measurements were made of bole characteristics using an optical dendrometer (Fig. 13). The solid wood volumes of these sample trees were calculated by computer from the dendrometer measurements.

After the tree volumes were obtained at the last stage, they were expanded back through the sampling formula to obtain an estimate of the total volume of timber present in the survey area, i.e., the area covered by the Apollo 9 photography.

The estimated timber volume in each stratum is computed from this equation:

$$v = \frac{1}{m} \sum^m \frac{1}{p_i n_i} \sum^{n_i} \frac{1}{p_j} \frac{A_j}{a_c} \frac{1}{p_p t_p} \sum^{t_p} \frac{v_k}{p_k}$$

in which

v_k is the measured volume of the k^{th} sample tree on a selected ground plot,

p_k is the probability of selecting the k^{th} sample tree,

p_p is the probability of selecting the p^{th} plot from the cluster of plots delineated on the 1:2,000 scale 70 mm. photos in a strip

p_j is the probability of selecting the j^{th} sample strip in a sample 4- by 4-mile square area,

p_i is the probability of selecting the i^{th} sample square

a_c is the area covered by the cluster of 1:2,000 scale 70 mm. photographs within a strip,

A_j is the total area of the j^{th} sample strip,

t_p is the number of sample trees measured on the p^{th} plot,

n_i is the number of sample strips in the i^{th} 4- by 4-mile square,
 m is the number of 4- by 4-mile squares included in the primary sample.

Judging our results in relation to the original objectives, we would have to say that we met both success and setbacks. In the Mississippi area, we estimated the gross total volume at 63 million cubic meters (2.225 billion cubic feet) of timber with a sampling error of 13 percent using only 10 ground plots. This constitutes a sampling intensity of one to one million in terms of area. Half the error was attributed to the tree volume tables used on the ground to relate to dendrometer measurements. If we had used the 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 combining the benefits from stratifying on the space photographs with the benefits of variable probability, we reduced the error to 13 percent. This is a 58 percent reduction in sampling error (from 30.7 percent to 13 percent) directly attributable to information interpreted on the Apollo 9 photographs.

There is no standard sampling design for all forest inventories. This was exemplified in the Georgia area inventory where we were not very successful; in fact, the results were disappointing. Using exactly the same sampling plan as in Mississippi, we estimated a gross total volume of 75.6 million cubic meters (2.670 billion cubic feet) of timber. The sampling error was a high 30 percent. More 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.

We are continuing to study the Georgia area to isolate the sources of variation at each stage in the sample. By this means we hope to be able to learn ways of reducing the sampling error and improve the multistage sampling design to suit this area.

DISCUSSION

I have devoted most of my lecture to one forest inventory application of remote sensing. This was necessary because of time limitations. However, it would be unfair not to mention a few other challenging applications of remote sensing that are related to surveys of our forest and range resources. One of these--remote sensing to detect stress symptoms in forest and range vegetation--is being discussed at another session. Another potential application of remote sensing that is being studied is the relationship between vegetation, soil, and water. Here, hydrologists hope to find relationships that will be useful in managing surface and subsurface water supplies (12).

One of our Forest Service range research projects at Fort Collins, Colorado, is studying remote sensing in connection with rangeland inventories (13). They have found that infrared color photographs taken from space provide a synoptic base for classifying and prestratifying groups of associated plant communities. These photographs provide information on the location and areal extent of

generalized vegetation types and are useful for broad land-use planning and management decisions. However, for quantitative information about the plant communities in these generalized strata, multiscaled sample photography is necessary. For instance, range scientists have found 1:80,000 color and infra-red color films good for mapping ecosystem boundaries. But, 1:20,000 scales are required to map units where only subtle image differences exist between units. To measure range plant density and dispersion by species, range scientists have found that scales larger than 1:2,400 are most helpful.

I hope that I have, in this very short period, brought to you a reasonable picture of the state of the art in remote sensing for forest and range inventories and mapping. We still have a long way to go before some of these techniques can be used on an operational basis. However, by the time the Earth Resources Technology Satellites (ERTS) and Skylab space missions are flown in 1972, we should be able to tell what kind and what quality of information can be extracted from remote sensors and how it can be used for surveys of forest and range resources.

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GLOSSARY OF TERMS

Cluster: All photo triplets within a sample strip.

Crown closure: Proportion of total ground covered when tree crowns are projected vertically to the ground (measured with a dot grid template).

Crown diameter wedge: A simple device printed on transparent film to measure tree crowns in units of 0.0254 mm. (0.001 inch) between two diverging calibrated lines.

DBH (d.b.h.): Diameter at breast height.

Dendrometer (optical): An optical device somewhat similar to a range finder used to measure precise tree bole diameters and vertical heights.

Dot grid: A systematic pattern of dots printed on transparent film. The number of dots per unit of area is varied depending on the intensity of sampling required.

Hardwoods: Angiosperms. Usually deciduous but sometimes persistent leaves.

Hardwoods, upland: Occurring on upland, dry or well-drained sites.

Hardwoods, bottomland: Occurring on low, wet, poorly drained sites.

Large-scale: Aerial photographs with a representative fraction of 1:500 to 1:10,000.

Medium-scale: Aerial photographs with a representative fraction of 1:12,000 to 1:30,000.

Multistage: More than two sampling levels in the sampling design.

Multiscaled: More than one aerial photographic scale used in the sampling design.

Parallax wedge: A simple device printed on transparent film used to measure parallax difference between the bottom and tops of trees on overlapping photographs. Differences in parallax are usually measured in units of 0.001 mm. and converted to tree height using conversion tables.

Photo coordinates: The x and y position of data points referenced to a common origin.

Plot: A unit of area selected for measurement of forest variables; type, volume, site, growth, etc.

Population unit: A single member of a defined population.

Primary sample: Population units selected for the first stage in multistage sampling surveys.

Probability: The mathematical basis for prediction. For an exhaustive set of outcomes, probability is the ratio of the outcomes that would produce a given event to the total number of possible outcomes.

Probability, arbitrary: Samples selected at random without judgment.

Probability, variable: Samples selected at random from a variable set of values. The probability of selecting any member of the set is dependent on its value; size, area, volume, diameter, height or others.

Probability proportional to size: The probability of a sample being selected is dependent on the size of the units to be sampled; area, volume, diameter, height, or others.

Sampling error: The standard error of the estimate. A measure of the variation that might be expected between sample estimates if repeated estimates were made. Variation depends on the sampling method, the sample size, and the variability among the individual units in the population sampled.

Small-scale: Aerial photographs with a representative fraction smaller than 1:40,000.

Strata: Areas of the same or similar forest type, volume, site, or other interpretable quality.

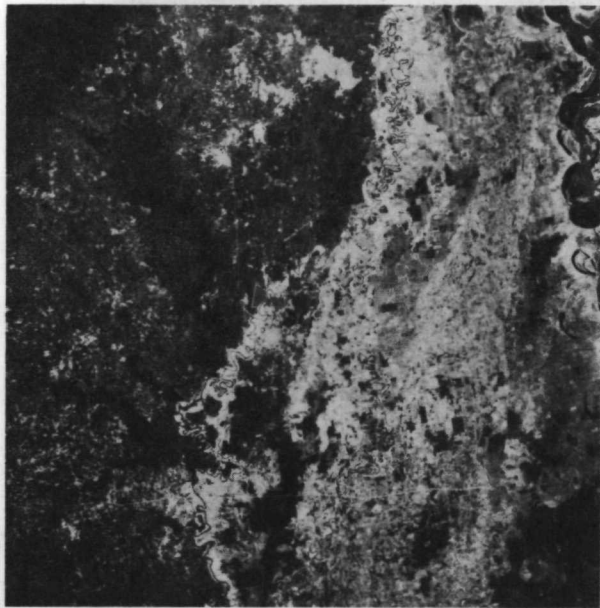
Stratification: Dividing an area into strata.

Timber cruiser: Term used to describe a forester or forestry technician who estimates, measures, marks, and records a tally of forest trees according to some prescribed sampling design.

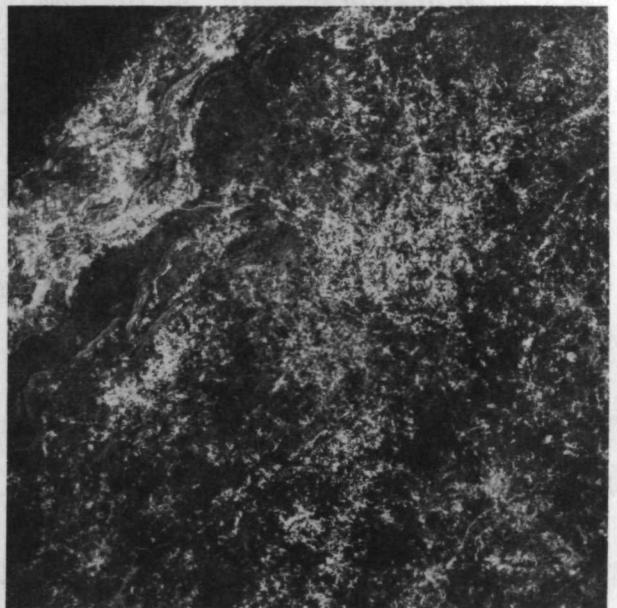
Triplet: Three overlapping (60 percent) aerial photographs used as a photo sample.

Volume table: Tree volumes by d.b.h. and merchantable height by tree species.

Volume table, composite: A volume table for both softwoods and hardwoods.



A



B

Figure 1. Apollo 9 photographs of the Mississippi area (A) and the Georgia-Alabama area (B). These illustrations were made from infrared color transparencies.

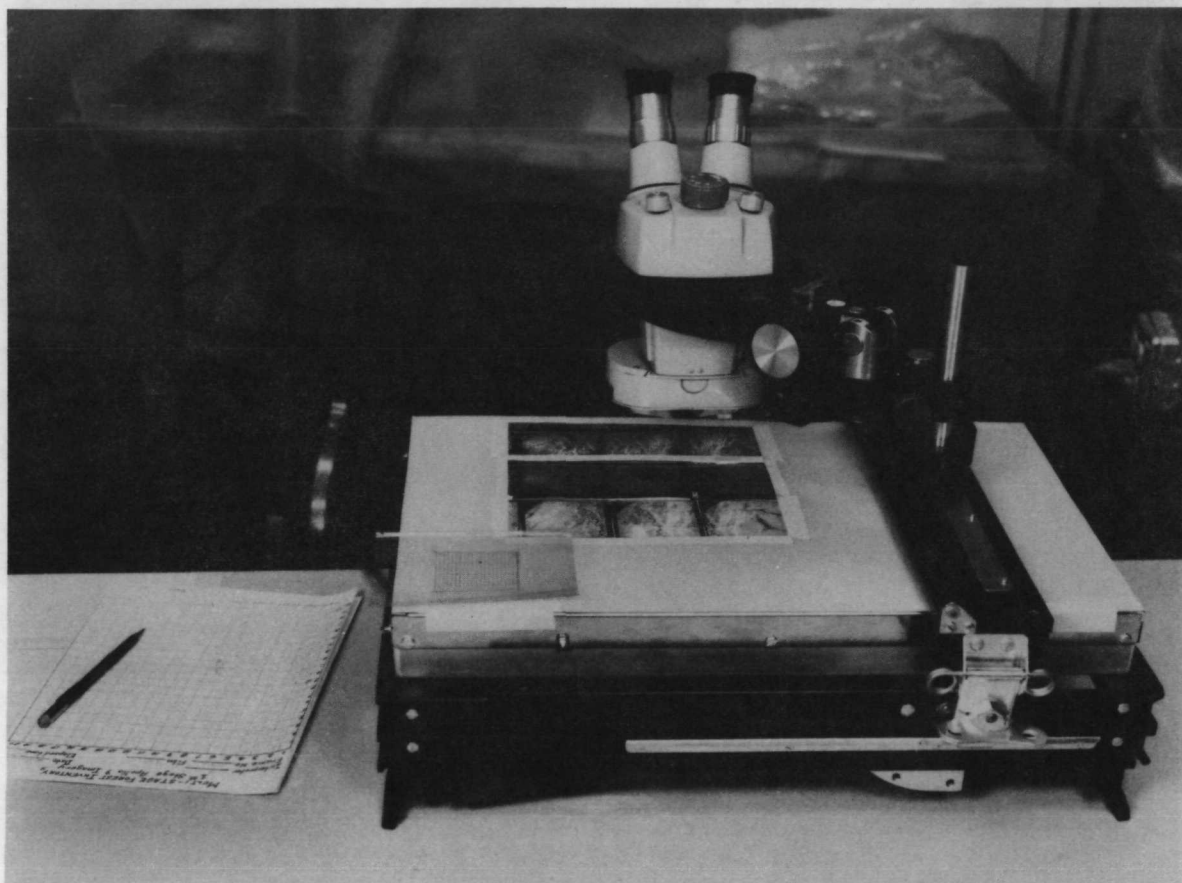


Figure 2. A Bausch and Lomb Zoom 70 Stereoscope on a Richards variable-intensity light table was used to interpret the small-scale imagery.

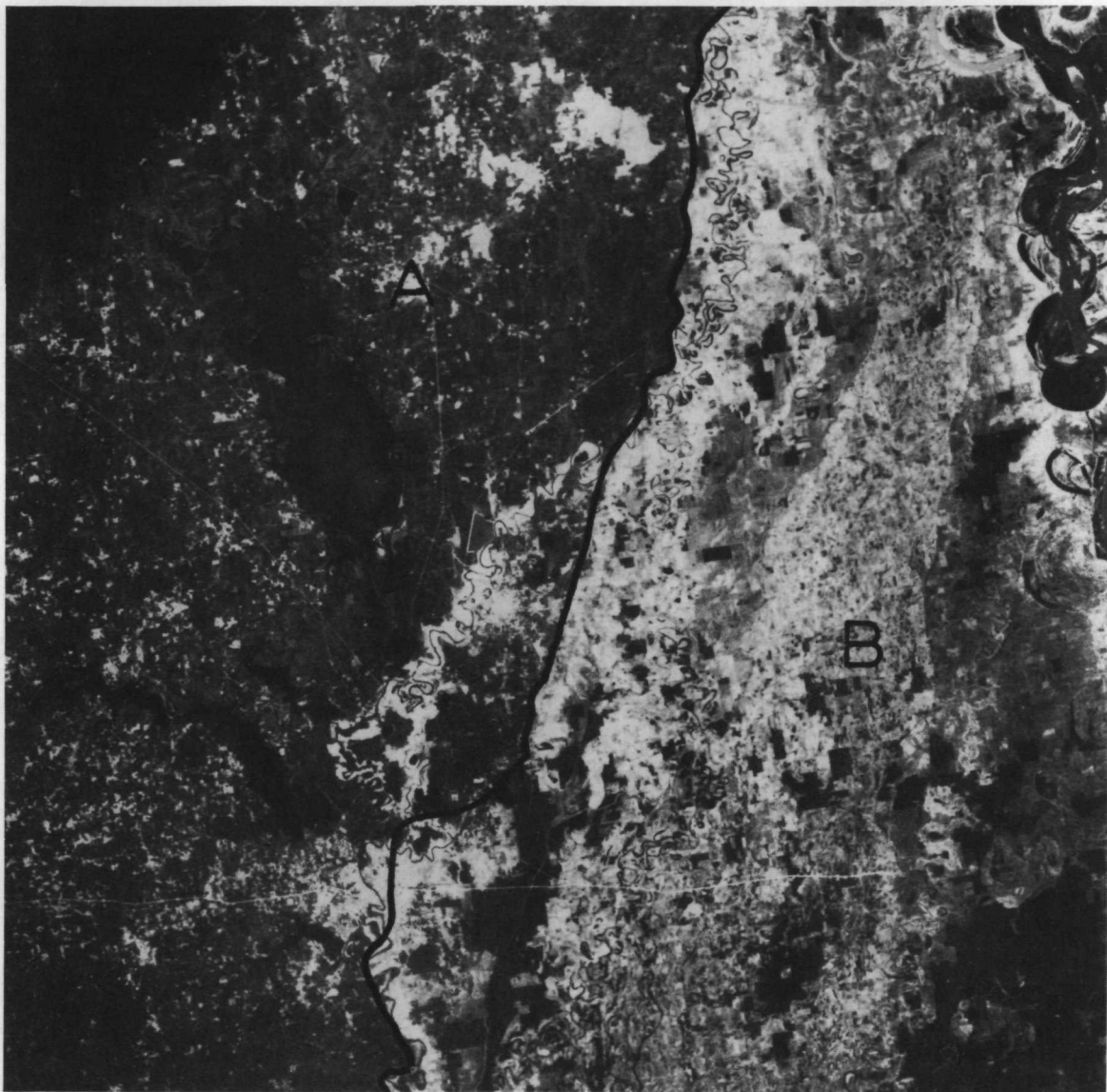


Figure 3. Apollo 9 frame 3740 enlarged 2.5X to illustrate two strata; predominantly pine with upland and bottomland hardwoods (A), and predominantly upland and bottomland hardwoods with little or no pine and associated with cultivated fields (B).



Figure 4. Apollo 9 frame 3792 enlarged 2.5X to illustrate two strata; predominantly agricultural (A) and predominantly mixed pine and hardwoods (B).

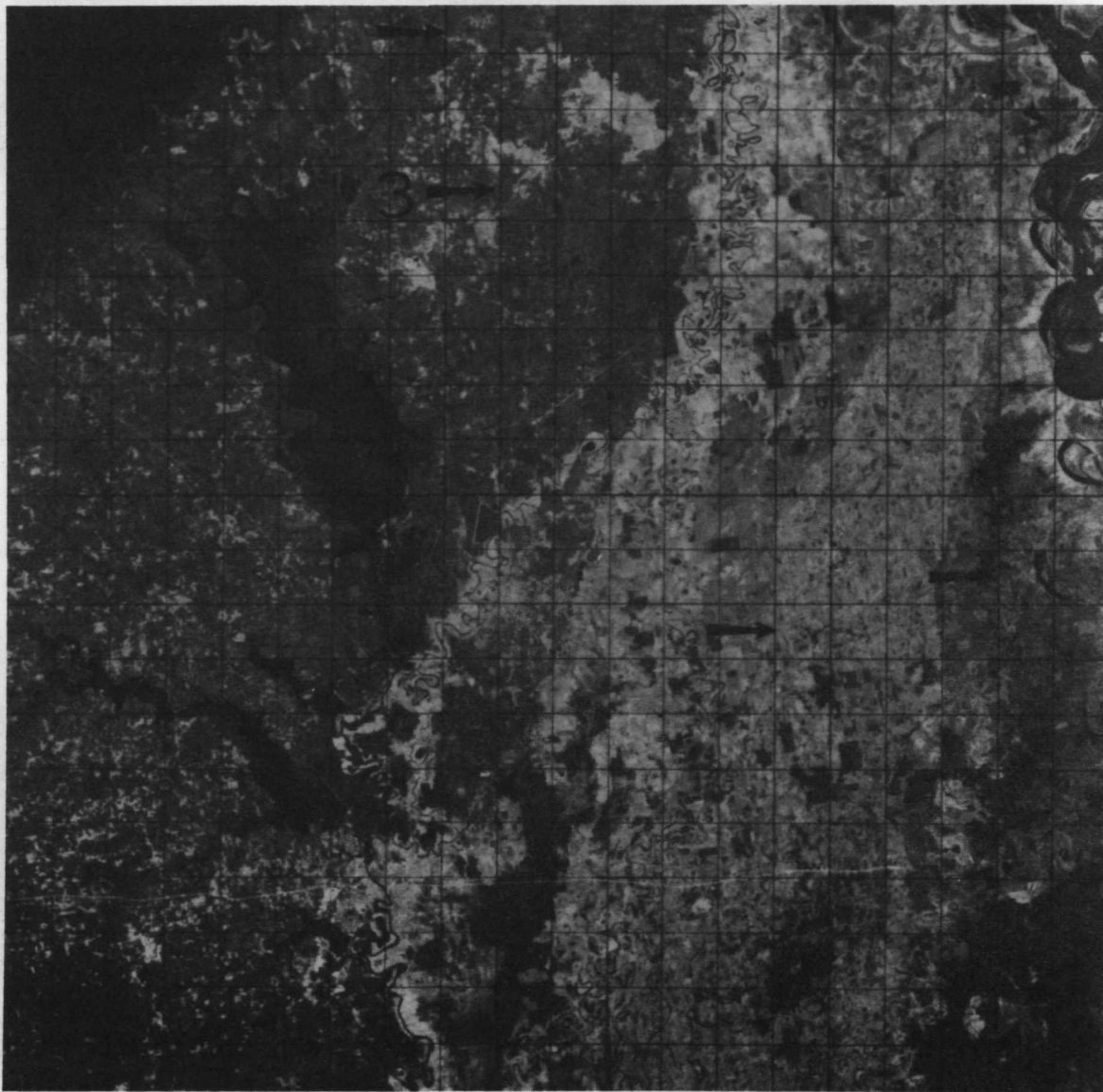


Figure 5. The interpreted portion of Apollo 9 infrared color frame 3740 for the Mississippi area shown with 6.4- x 6.4-km. (4- x 4-mile) grid template attached. Black arrows point to first-stage sample blocks--the sample block at (3) in the upper left-hand corner appears in Figure 6.

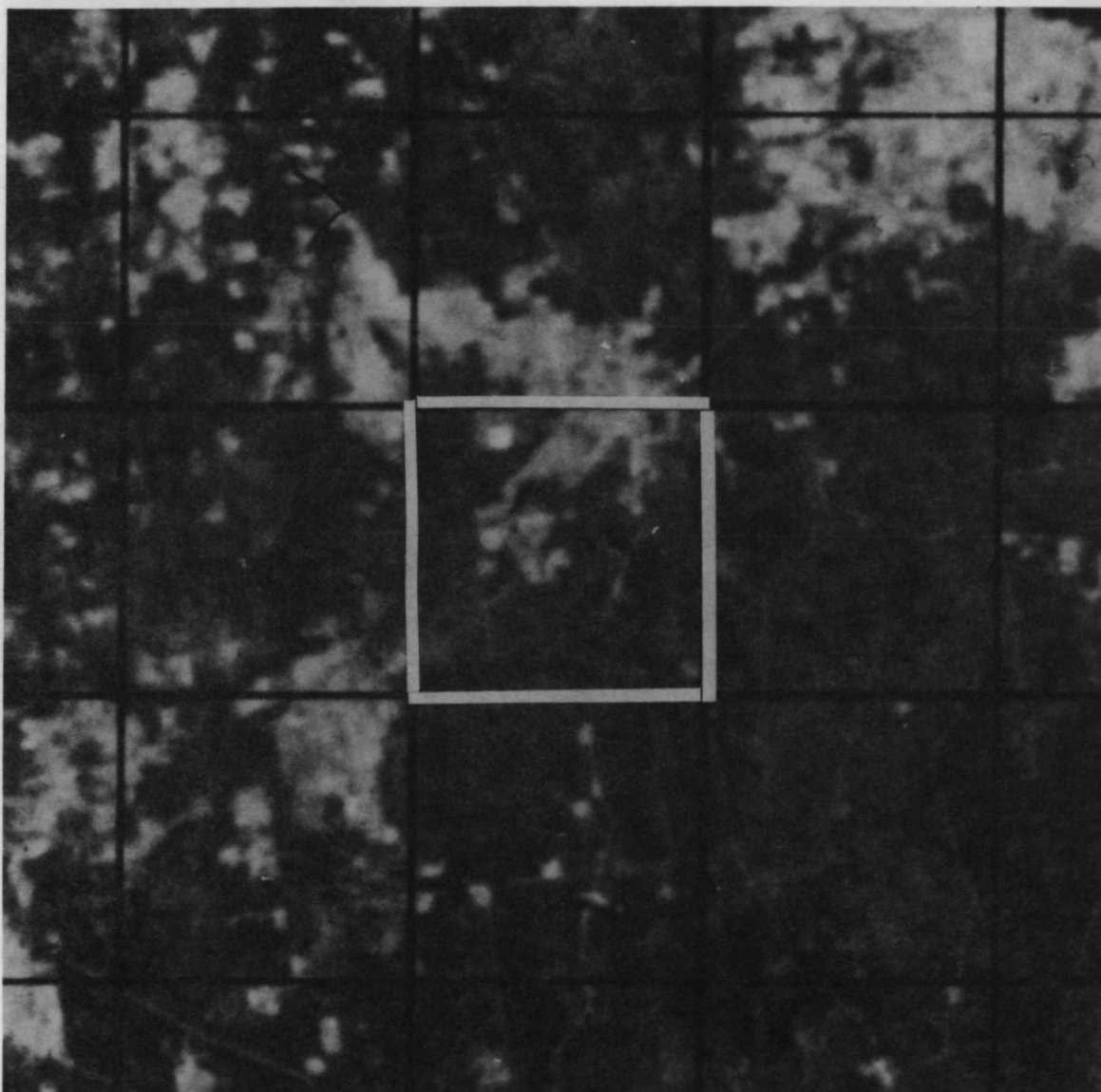


Figure 6. This 16X enlargement of a portion of the space photo shows one of the first-stage samples in the Mississippi area. The block outlined in white appears at (3) in Figure 5 and is also shown in Figure 8.

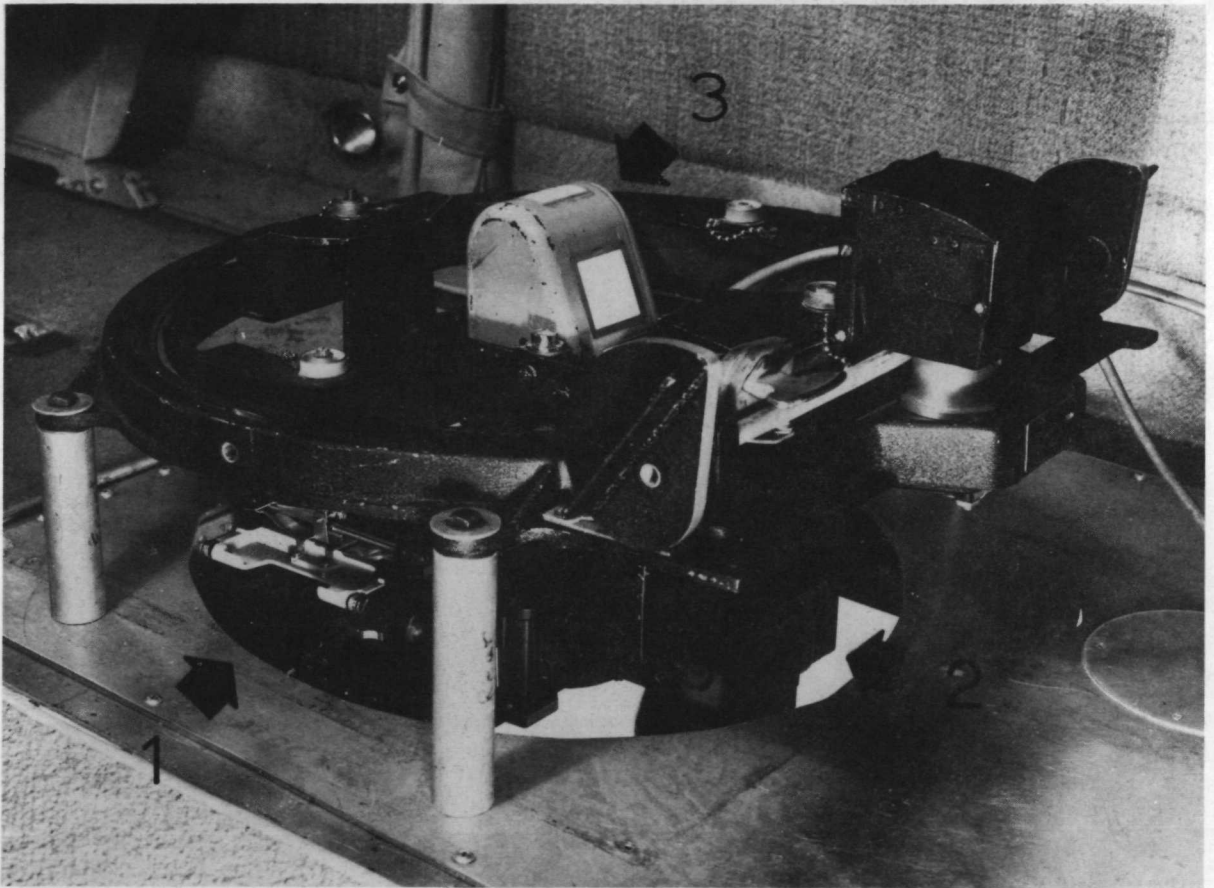


Figure 7. This aerial camera setup was used to obtain support photography for primary sampling units selected from the space photographs: (1) Crown Graphic with Polaroid back and 75 mm. lens; (2) J. A. Maurer KB-8 70 mm. camera with 38 mm. lens; and (3) J. A. Maurer KB-8 with a 228 mm. lens.



Figure 8. 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) is shown with a grid overlay used to select two strips for the next sampling stage. This block appears at (3) in Figure 5 and also in Figure 6. The area outlined in white corresponds to the 1:12,000 photo coverage in Figure 9.



Figure 9. This 1:12,000 scale photograph covers the area outlined in white in Figure 8. The area outlined in black corresponds to the coverage of the 1:2,000 scale photograph shown in Figure 10. Each sample strip was completely covered by 1:12,000 scale photography. The photo shown is a 2.2X enlargement made from negative color film.



Figure 10. This 1:2,000 scale photograph corresponds to the area outlined in black on the 1:12,000 scale photograph in Figure 9. The grid divides the center photograph (shown) of each sample triplet into four plots approximately 0.25 hectares (0.6 acres) in size. Photo is a 2.2X enlargement made from the original 70 mm. color transparency.

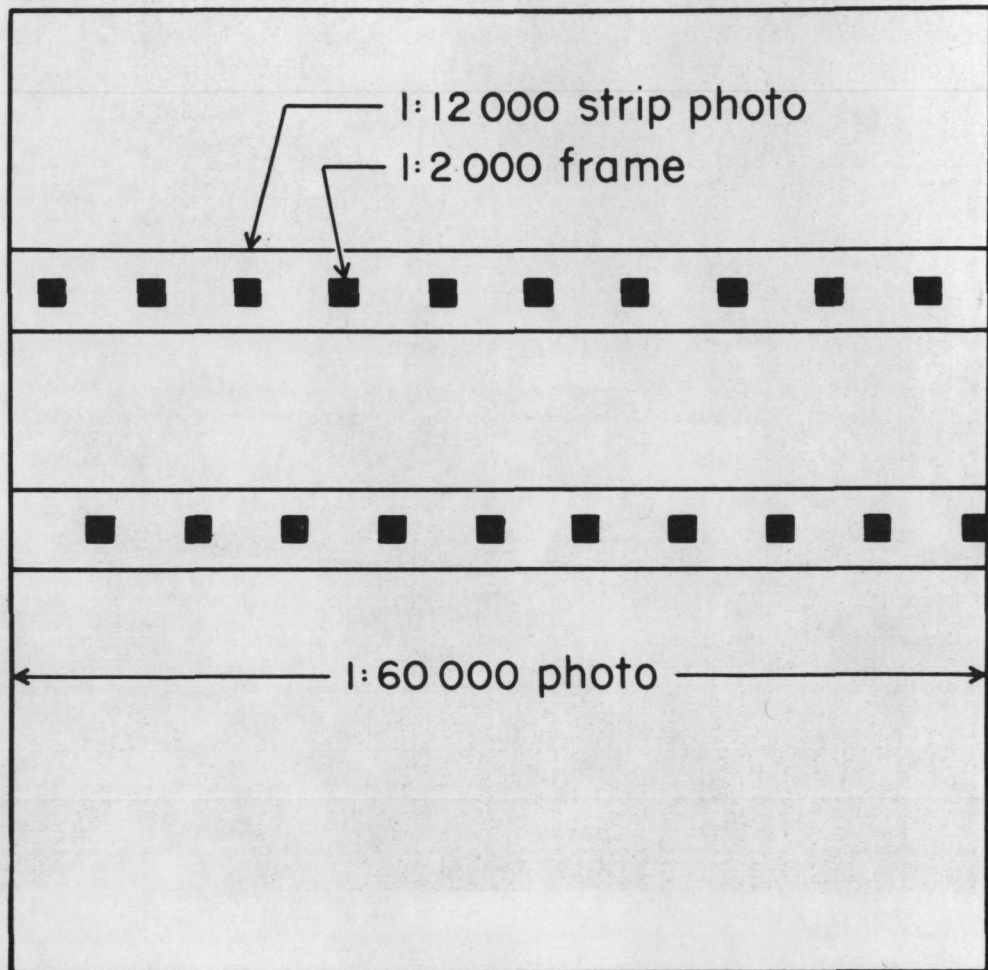


Figure 11. The scaled diagram shows how the two 1:12,000 scale 70 mm. photo sample strips and 1:2,000 scale 70 mm. color samples are related to each other and to the 1:60,000 scale Polaroid photograph.



Figure 12. Photo coordinates of sample strip boundaries outlined on 1:12,000 scale photo mosaics were digitized at 0.254 mm. (0.01 inch) intervals by using this Bendix Datagrid digitizer.

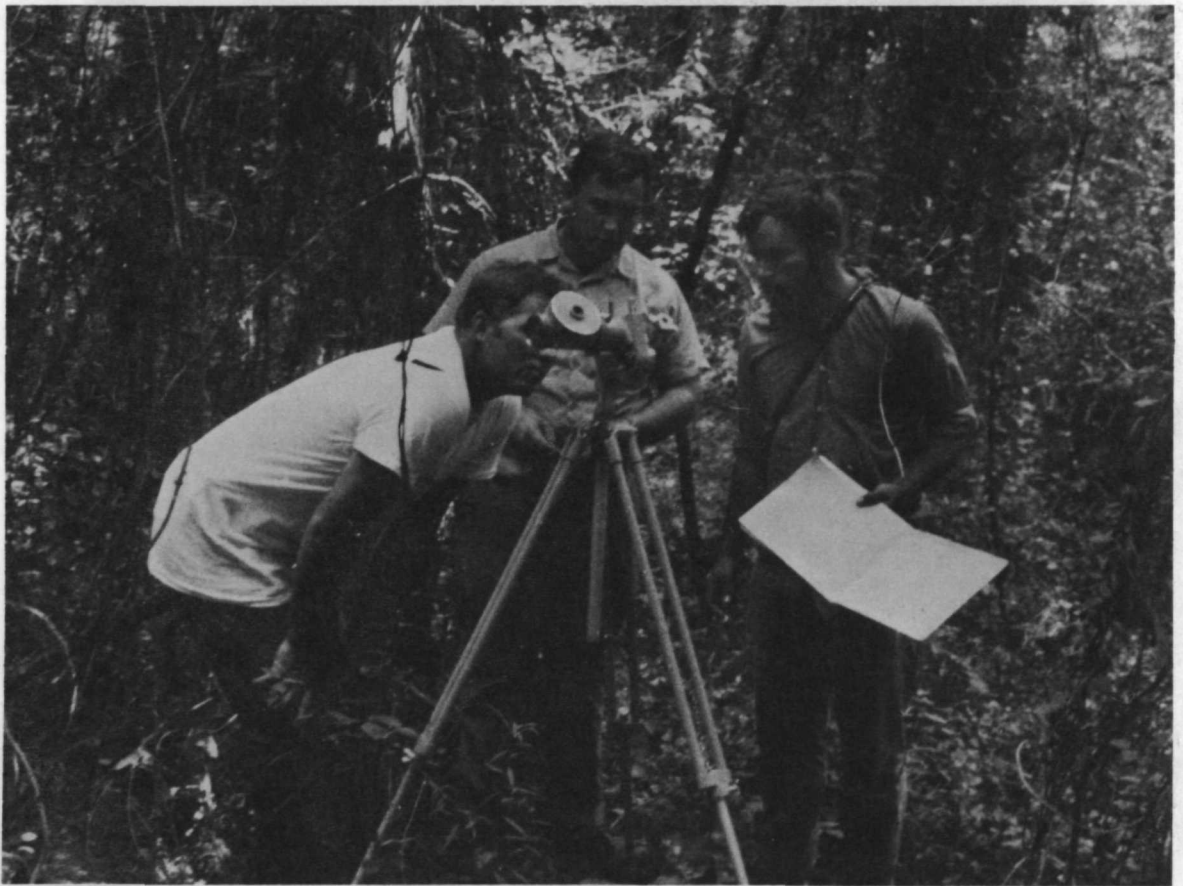


Figure 13. Ground crews used Barr and Stroud optical dendrometers to measure the boles on 4 to 6 trees on each ground plot.