# SPACE SCIENCES LABORATORY

76-10434
NASA CR-
144487



# SKYLAB DATA AS AN AID TO RESOURCE MANAGEMENT IN NORTHERN CALIFORNIA

(E76-10434) SKYLAB DATA AS AN AID TO RESOURCE MANAGEMENT IN NORTHERN CALIFORNIA Final Report, 1 Oct. 1974 - 15 Oct. 1975 (California Univ.) 44 p HC $4.00 CSCL 08F
N76-28610
Unclas
G3/43 00434

A report of work done by scientists at the University of California, Berkeley, under NASA Contract No. NAS 9-14420

Final Report
15 October 1975

UNIVERSITY OF CALIFORNIA, BERKELEY

# SKYLAB DATA AS AN AID TO RESOURCE MANAGEMENT IN NORTHERN CALIFORNIA

Principal Investigator: Dr. R. N. Colwell

Contributors: A.S. Benson, Wm. C. Draeger, M.J. Gialdini
S.J. Titus, R.W. Thomas, and S.L. Wall



Prepared for:

Johnson Spacecraft Center
Houston, Texas

Remote Sensing Research Program
Space Sciences Laboratory
University of California
Berkeley, California 94720

a

TECHNICAL REPORT STANDARD TITLE PAGE

| 1. Report No. | 2. Government Accession No. | 3. Recipient's Catalog No. |
|---|---|---|
| 4. Title and Subtitle<br>Skylab Data as an Aid to Resource Management in Northern California | | 5. Report Date<br>October 15, 1975 |
| | | 6. Performing Organization Code |
| 7. Author(s)<br>Dr. R. N. Colwell et al | | 8. Performing Organization Report No. |
| 9. Performing Organization Name and Address<br>Remote Sensing Research Program<br>Space Sciences Laboratory<br>University of California, Berkeley Ca. 94720 | | 10. Work Unit No. |
| | | 11. Contract or Grant No.<br>NAS 9-14420 |
| 12. Sponsoring Agency Name and Address<br>National Aeronautics and Space Administration<br>Lyndon B. Johnson Space Center<br>Houston, Texas 77058 | | 13. Type of Report and Period Covered<br>Final Report<br>October 1, 1974 - October 15, 1975 |
| | | 14. Sponsoring Agency Code |
| 15. Supplementary Notes | | |

16. Abstract

A study to determine the information content of Skylab S190 infrared ektachrome (CIR) imagery for wildland resource inventories, a timber inventory based entirely on manual photo interpretation techniques was performed. In this study the S190A imagery was utilized as the first stage in a multistage sampling design. The objectives included: 1) determining the abilities of human photo interpreters to distinguish timber volume classes on S190 data: 2) determining the efficiency of simple random sampling applied to a multistage sampling design and 3) demonstrating a method of obtaining timber volume information of a reasonably large area (192 square miles located within the Plumas National Forest) that is timely, cost-effective and does not require the use of a computer.

| 17. Key Words (Selected by Author(s)) | 18. Distribution Statement |
|---|---|
| Forestry, Interpretation Techniques<br>Photo Interpretation, Remote Sensing, Multistage sampling | |

| 19. Security Classif. (of this report) | 20. Security Classif. (of this page) | 21. No. of Pages | 22. Price* |
|---|---|---|---|
| Unclassified | Unclassified | | |

Table of Contents


| | Page No. |
|---|---|
| 1.0 INTRODUCTION | 1 |
| 2.0 PROCEDURE | 3 |
| 2.1 Selection of a Study Area | 3 |
| 2.2 Volume Estimates by Human P.I's on Primary Sample Units (PSU's) | 3 |
| 2.3 Selection of Primary Sample Units (PSU's) for Secondary Sample Unit (SSU) Volume Estimation | 6 |
| 2.4 Large-Scale High Resolution Aerial Photography Acquisition and Interpretation | 9 |
| 2.5 Ground Work | 11 |
| 3.0 RESULTS | 13 |
| APPENDIX I. Estimation Procedure | 16 |
| APPENDIX II Analysis of the Information Content of Skylab S190A Data | 18 |

## Table of Figures


| | | Page No. |
|---|---|---|
| Figure 1 | Diagram of Sampling Design | 4 |
| Figure 2 | Study Area Shown on S190A Enlargement | 5 |
| Figure 3a | PSU Delineation on 1:60,000 High Altitude Color Infrared Photography | 7 |
| Figure 3b | PSU and SSU Delineations on 1:60,000 High Altitude Color Infrared Photography | 8 |
| Figure 4 | Large-Scale Aerial Photography Example | 10 |
| Figure 5 | Photo of Ground Crew | 12 |


## Table of Tables


| | | |
|---|---|---|
| Table I | Summary of Estimates by Three Estimators | 14 |


APPENDIX II


| | | |
|---|---|---|
| Table 1 | Correlations between Photo-Interpreter on a Skylab S190A Imagery and Photo-Interpreter D on Zeiss 1:60,000 High-Flight Photography by Timber Stratum | 14 |
| Table 2 | Correlations between Photo-Interpreter B on Skylab S190 Imagery and Photo-Interpreter D on Zeiss 1:60,000 High-Flight Photography, by Timber Stratum | 20 |
| Table 3 | Correlations between Photo-Interpreters on Skylab S190A Imagery and Photo-Interpreter D on Zeiss 1:60,000 High-Flight Photography Considering only Timber Versus Non-Timber Interpretation | 20 |
| Table 4 | Correlations between Photo-Interpreters on Skylab S190A Imagery and Photo-Interpreter D on Zeiss 1:60,000 High-Flight Photography Considering only Timber Versus Non-Timber Interpretation | 21 |
| Table 5 | Correlations between Photo-Interpreters on Skylab S190A Imagery Considering only Timber Versus Non-Timber Interpretation | 22 |

| | | Page No. |
|---|---|---|
| Table 6 | Estimated Effects (Errors) for Factors and Interactions in the Two-Way Analysis of Variance for Skylab Photo-Interpretation Results | 23 |
| Table 7. | F-Tests Based on Two-Way Analysis of Variance | 24 |
| Table 8 | Tukey Multiple-Comparison Test (Assuming Effect Independence) for Significance of P.I. Effect (Errors) Estimated for the Two-Way Analysis of Variance | 26 |
| Table 9 | Tukey Multiple-Comparison Test (Not Assuming Effect Independence) for Significance of P.I. Effect (Errors) Estimated for the Two-Way Analysis of Variance | 27 |
| Table 10 | Scheffe Multiple-Comparison Test for Significance of P.I. Effect (Errors) Estimated for the Two-Way Analysis of Variance | 28 |
| Table 11 | Scheffe Multiple-Comparison Test for Significance of Interactions Effect (Errors) Estimated for the Two-Way Analysis of Variance | 30 |
| Table 12 | Estimated P.I. effects (Errors) by Timber Stratum for the One-Way Analysis of Variance for Skylab Photo-Interpretation Results | 32 |
| Table 13 | Tukey Multiple-Comparison Test (Assuming Effect Independence) for Significance of P.I. Effect (Errors) by Timber Stratum Estimated for the One-Way Analysis of Variance | 33 |
| Table 14 | Estimated P.I. Effects (Errors) by Timber Stratum for the One-Way Analysis of Variance for both Skylab Photo Interpretation and High-Flight Photo Interpretation Results | 36 |
| Table 15 | Tukey Multiple-Comparison Test (Assuming Effect Independence) for Significance of P.I. Effect (Errors) by Timber Stratum, Estimated for the One-Way Analysis of Variance | 37 |

# SKYLAB DATA AS AN AID TO RESOURCE MANAGEMENT IN NORTHERN CALIFORNIA (EPN NO. 454, TASK 4.3)

## .0 INTRODUCTION

In order to determine the information content of Skylab S190 infrared ektachrome (CIR) imagery for wildland resource inventories, a timber inventory based entirely on manual photo interpretation techniques was performed. In this study the S190A imagery was utilized as the first stage in a multistage sampling design. The objectives included: 1) determining the abilities of human photo interpreters to distinguish timber volume classes on S190 data: 2) determining the efficiency of simple random sampling applied to a multi-stage sampling design and 3) demonstrating a method of obtaining timber volume information of a reasonably large area (192 square miles located within the Plumas National Forest) that is timely, cost-effective and does not require the use of a computer.

The need for timber volume surveys is based on the premise that sound forest management practices are dependent upon the availability of accurate, timely, and economical forest inventory data, which includes timber volume information. Forest inventory requirements in the intensively managed temperate regions of the world include data not only on timber volume but also on timber stand condition, growth rate, ownership, soils, bedrock geology, surface geology, mineral extraction, subsurface water, surface water, vegetation, wildlife, land use, land productivity, climate, historical and cultural patterns, population market values, and transportation. However, 28% of the world's land area is covered by forest, containing some 12½ trillion cubic feet of timber, and only a small portion of this vast area is intensively managed. Within the non-intensively managed or unmanaged forests, low-cost "volume only" surveys are needed, as man for the first time finds it possible to place these forests under management. This project will demonstrate a procedure for providing low-cost timely "volume only" information without requiring any sophisticated computer terminals. The procedures for selecting sampling sites and estimating timber volumes from the Skylab S190A imagery and aircraft imagery at each stage of the sampling scheme will be discussed in following sections and will indicate the roles played by the S190A imagery, supporting high-flight imagery, and large-scale aerial photography in performing this "volume only" survey.

Gross timber volume was the variable estimated in the sampling design based on random sampling at each of three stages. Sampling units were selected at each stage at random because it was not known how well human interpreters could differentiate between timber and non-timber classes on S190A imagery in the first stage, and by utilizing random sampling techniques, the ability to separate these classes could be established quantitatively. In the first stage timber volume was estimated from the percentage of area occupied by each of 4 timber volume classes within 2 mi. x 2 mi. squares delineated on the S190A imagery. For the second stage, randomly selected squares from the first stage were transferred by visual inspection on to 1:60,000 and 1:120,000 infrared ektachrome photography and then divided into five rectangular flight lines. Photo interpreter delineations c the timber volume classes were measured within each square and areal percentages of the volume classes were calculated. A number of these rectangular blocks were selected at random for the acquisition of large-scale high-resolution aerial photography coverage. Measurements of percentage crown closure and average stand heights were made on .4 acre plots located on the large-scale photography to arrive at the third stage photo volume estimate using Chapman's photo stand volume equations. Individual photo plot volumes were calculated

---

*Chapman, Roger C. 1965. Preliminary Aerial Photo Stand Volume Tables for Some California Timber Types. USDA-FS, Pacific Southwest Forest and Range Experiment Station, Research Note 93.

from regression estimators derived from precise measurements of volume made on randomly selected trees with a Barr & Stroud dendrometer during the ground phase of the study. The ground volume measurements were then expanded through the various stages of the sample design to estimate the total timber volume located on the 192 square mile study area (see Fig. 1 for a diagram of the sampling design).

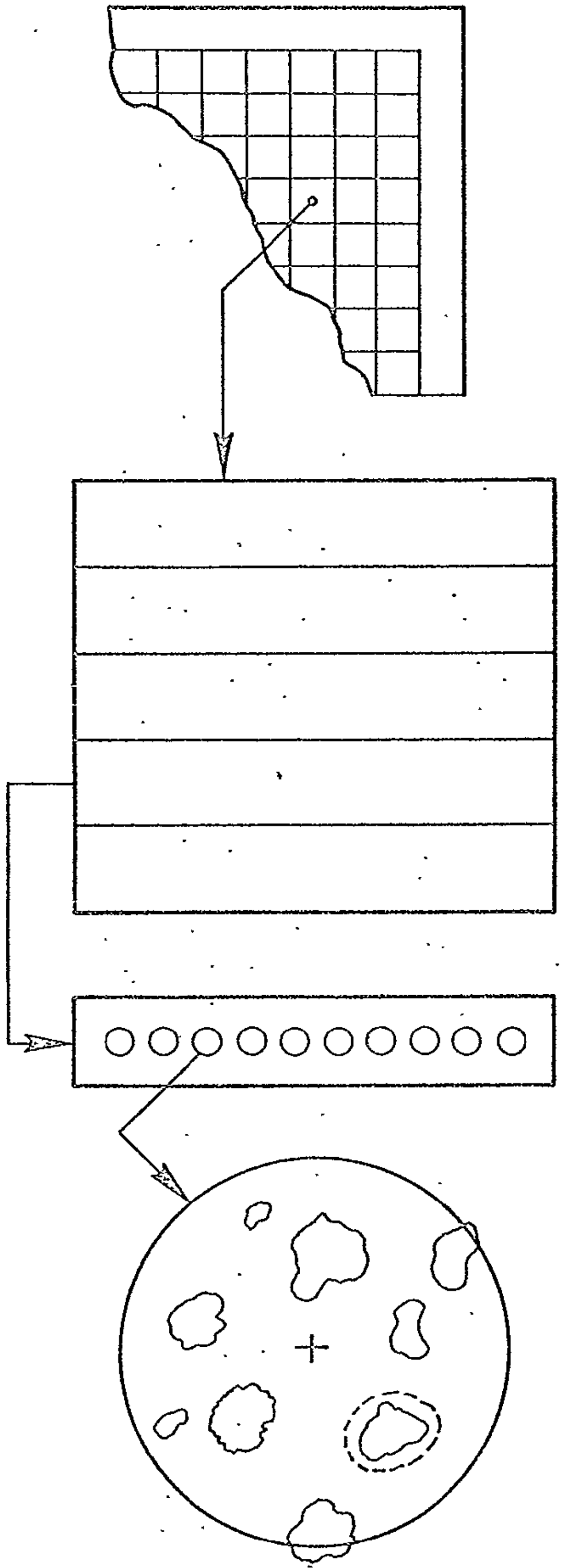
## 2.0 PROCEDURE

### 2.1 Selection of a Study Area

An area, closely approximating that found on the USGS Bucks Lake 15 minute quadrangle, was located on a Skylab 3 S190A infrared ektachrome transparency and enlarged to a scale of 1:170,000 on an 8 x 10 inch print (Fig. 2). The area, 12 miles by 16 miles on the ground, was chosen because of historical and current information pertaining to it that the Remote Sensing Research Program currently has on file. Also, complete coverage of the area with recent 1:60,000 and 1:120,000 resource photography was available. The S190A infrared ektachrome imagery was chosen for interpretation because the contrast between timber and non-timber areas is more readily apparent especially hardwoods and brush versus conifers.

### 2.2 Volume Estimates by Human P.I.'s on Primary Sample Units (PSU's)

The 12 mile x 16 mile study area was divided into 48 squares (primary sample units: PSU's), each 2 miles on a side. The size of the PSU's was based on (1) a practical area that can be interpreted on S190A imagery enlarged to a scale of 1:170,000, (2) an area easily divided into flight lines which can be photographed by a light aircraft using a 35mm camera system and (3) the ability of the ground crew to complete the ground work for a flight line in one day. Within each square, interpreters estimated the percentages of the area occupied by, 1) a timber density of less than 10,000 bd.ft./ac = T1, 2) a timber density of 10,000 - 20,000 bd.ft./ac = T2, 3) a timber density greater than 20,000 bd.ft./



A. A portion of the enlarged Skylab 3 S190A Infrared Ektachrome image showing the PSU grid for volume estimates for Stage I.

B. A selected PSU transferred to a 1:60,000 resource photograph and divided into 5 rectangular flight lines for the volume estimates for Stage II to be made on each flight line.

C. Ten .4 acre circular photo plots located on a selected flight line for the Stage III volume estimate.

D. Selected photo plot to be visited on the ground for precise tree volume measurements. Encircled tree is one of four selected to be measured for volume data input to the regression estimator formula that will estimate individual tree volumes on all photo plots.

FIG. 1 DIAGRAM OF THE SAMPLING DESIGN

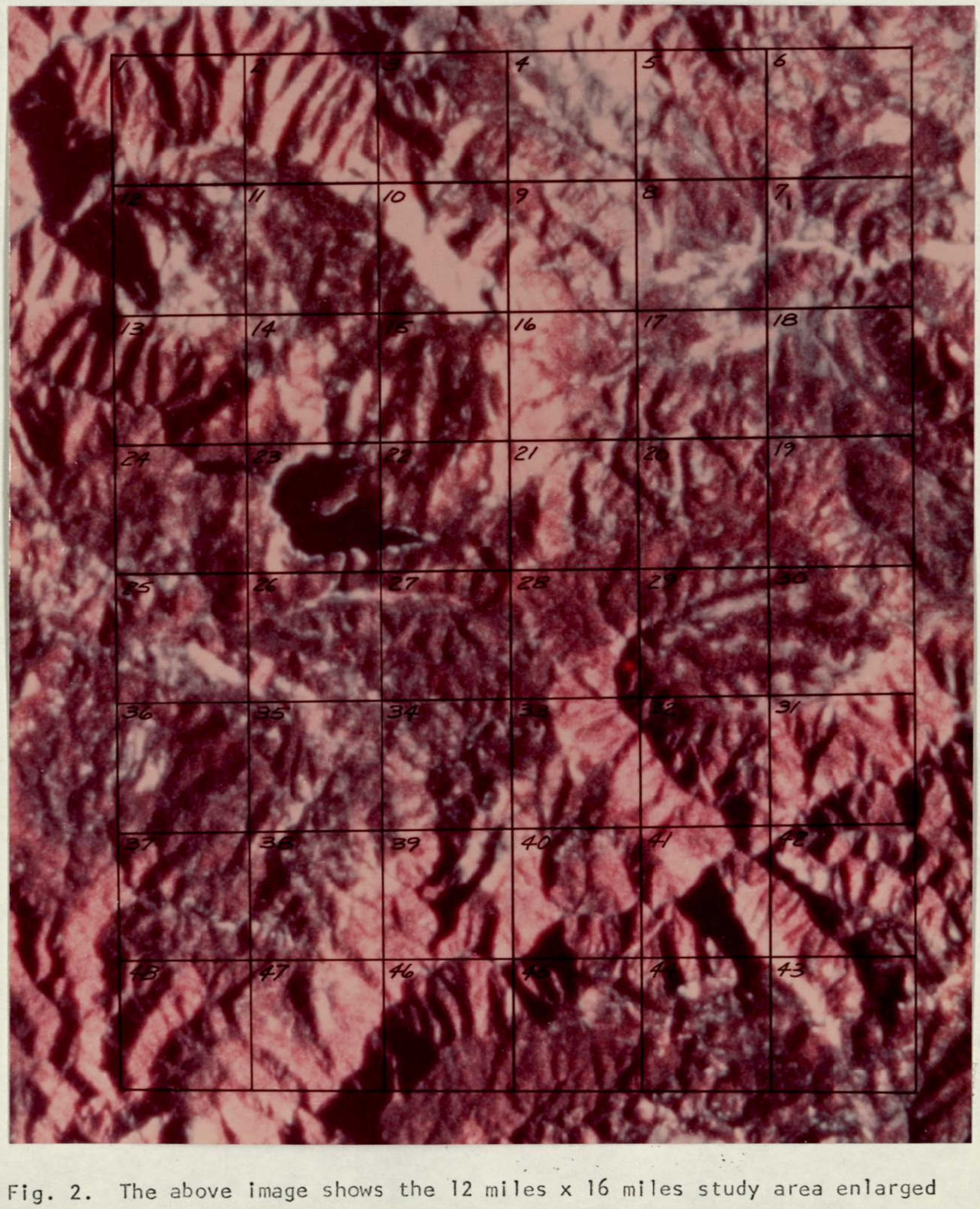



Fig. 2. The above image shows the 12 miles x 16 miles study area enlarged to a scale of 1:170,000 from a Skylab S190A infrared ektachrome photograph. The grid represents the 2 miles x 2 miles Primary Sampling Units.

ac, = T3, and 4) non-timber = NT (brush, hardwoods, bare soil, rock, grass, etc.). The interpreters based their estimates on comparisons with training areas chosen from 1:120,000 scale color infrared photography acquired by the RB 57 aircraft.

To arrive at a volume estimate within each PSU, the percentage area of each volume class was multiplied by a specified weighting factor. For a volume of less than 10,000 bd.ft. per acre, the weight was 1. The factor for 10,000-20,000 bd.ft. per acre was 2 and for greater than 20,000 bd.ft. per acre the weight was 3. Non-timber classes were multiplied by 0. The timber-class weighting factors were chosen as representative of the relative magnitude of volume present i.e. multiplying the area of a PSU in T1 by 1 gives a relative volume figure for the area in class T1.

## 2.3 Selection of Primary Sample Units (PSU's) for Secondary Sample Unit (SSU) Volume Estimation

The next step was the selection of a number of the PSU's for partial coverage with large-scale high resolution aerial photography and the delineation of second stage volume estimates. Six squares were chosen at random from the population of 48 PSU's and delineated on high altitude 1:60,000 photography (Fig. 3a). The sample size was based on the variability of the area and upon the uncertainty as to how well volume classes can be interpreted on Skylab S190A infrared ektachrome imagery.

Each of the six squares was divided into five flight lines. Each flight line was a rectangular area 2 miles long and approximately 2,100 feet wide, oriented in an east-west direction (Fig. 3b). One flight line was selected at random from the five possible in each square. The volume estimate for this flight line was made in a fashion similar to the volume

Fig. 3a. The image above illustrates one of the PSU's (PSU No. 3) delineated on a portion of a 1:60,000 high altitude color infrared photography. The boundaries of the PSU have been carefully transferred from the S190A enlargement and, due to relief displacement, no longer appear square.

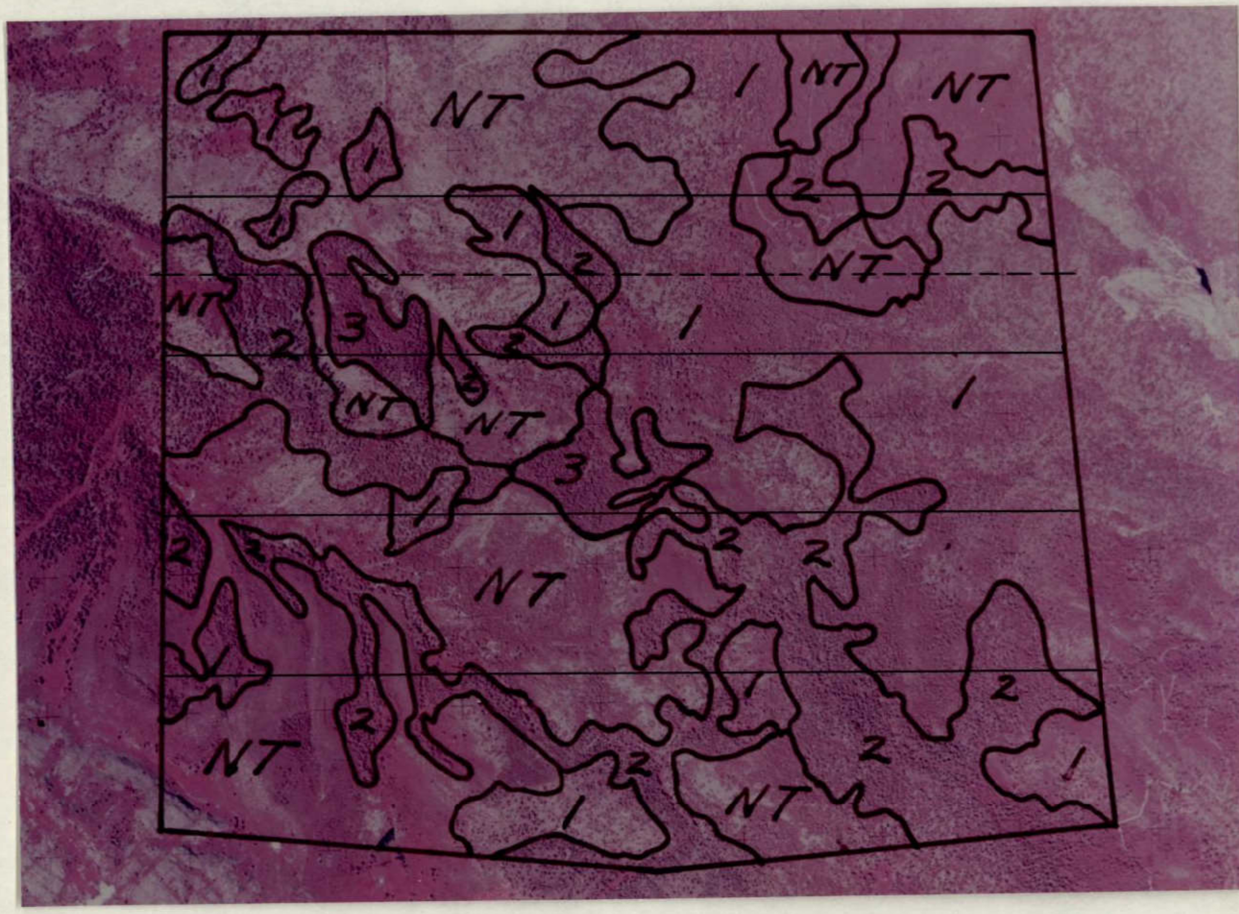


Fig. 3b. This image shows the same PSU with the four timber volume class delineations present as well as the divisions for the secondary sampling units. The dotted line in the center of one of the SSU's indicates a randomly selected flight line for acquisition of low-altitude high resolution photography for tertiary sample unit volume estimation.

estimate for the PSU's on the S190 imagery. The only change, however, that the volume classes were delineated within each block and a coordinate digitizing device connected to a mini-computer was used to calculate the area of each class present. From these area calculations, percentages of total area occupied by each volume class within each chosen flight line could be determined and the appropriate weights applied for calculating a total volume estimate for each selected flight line (SSU).

Each selected flight line was also located on a topographic map sheet to determine its average elevation above sea level. This information along with the flight line delineation on a high altitude 1:60,000 photograph was used as navigational aids in acquiring the large-scale high-resolution aerial photography used to make the third stage volume estimations.

## 2.4 Large-Scale High Resolution Aerial Photography Acquisition and Interpretation

Two 35 mm cameras were used to obtain low altitude photography of the selected secondary sampling units simultaneously at two different scales (Fig. 4). A 24 mm focal length, wide-angle lens was used to acquire complete coverage of each sampling unit at an approximate scale of 1:7,500, and a 200 mm focal length was used to obtain large scale stereo triplets, scale approximately 1:1,000, from which to make precise photo estimates of timber volume. The camera with the telephoto lens was equipped with a motorized film drive which enabled each stero triplet to be taken within one second at five second intervals while the camera with the wide-lens was operated manually to obtain single frames at five second intervals. The photo coverage for each SSU consisted of ten stereo triplets and ten wide angle photographs.

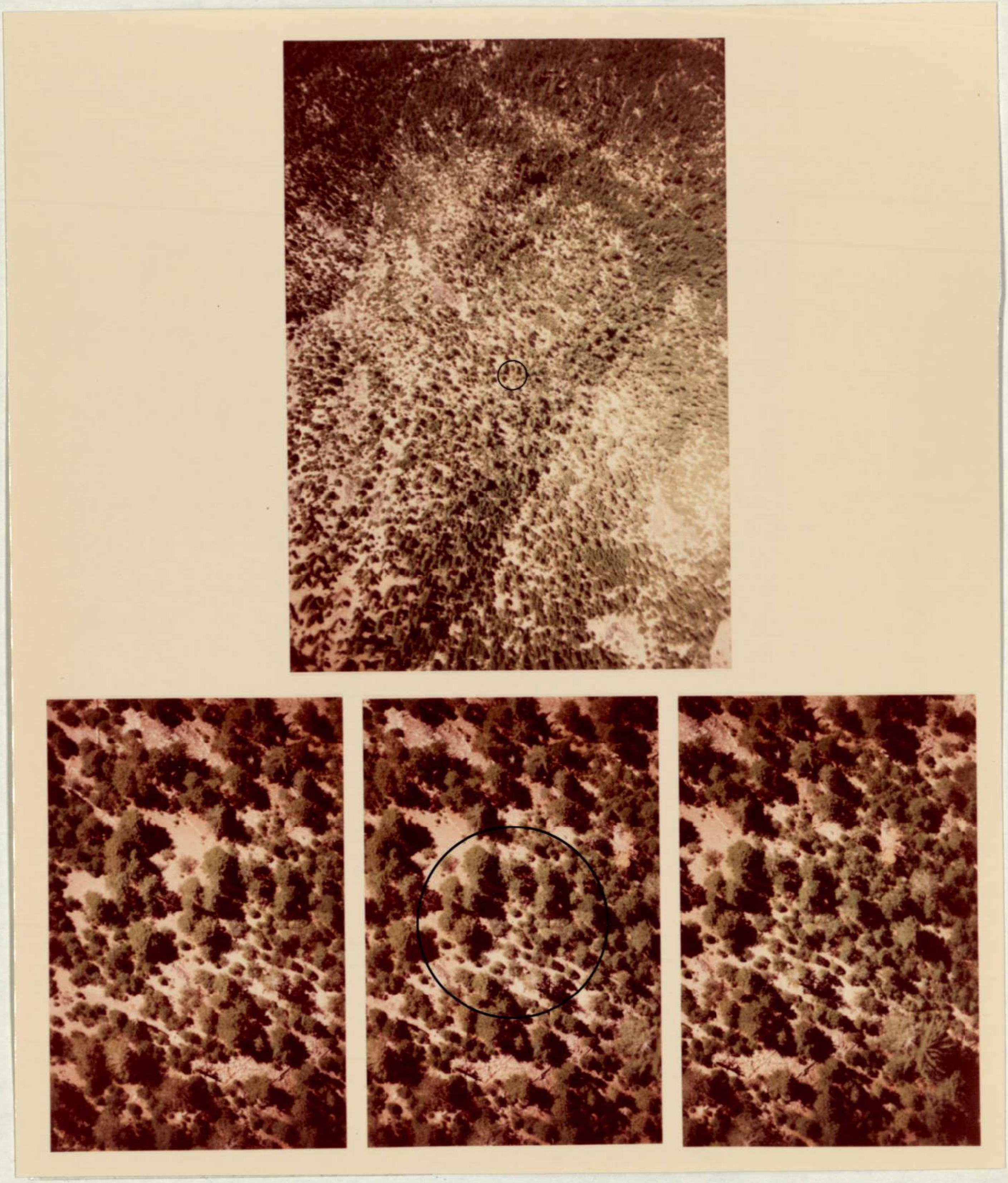


Fig. 4. The top photo was taken with a 24 mm lens and the bottom photos illustrate the stereo triplet obtained by the telephoto lens at the same time. The inked circle on the bottom center photo delineates the scale-adjusted 0.4 acre ground plot.

The wide-angle photos of each secondary sampling unit were mosaicked together to show its full area. The center of the middle photo for each stereo triplet was used as the plot center, and these were located and marked on the mosaic. The plot centers were also located on a topographic map and the elevation of each was determined.

The scale of each photo plot was determined, and a 0.4-acre circular plot was drawn about the photo plot center. For all photo plots, average stand height and percentage crown closure were estimated in order to make individual photo plot volume estimates (calculated by Chapman's stand photo volume equations) that serve as the tertiary sample unit (TSU) estimate. Two plots were drawn at random from each SSU to be visited on the ground for precise plot volume measurements, including four trees selected at random from each plot for measurement with an optical dendrometer.

## 2.5 Ground Work

Each tree selected above was measured precisely on the ground with a Barr & Stroud optical dendrometer to calculate the individual volumes (Fig. 5).* The large scale photographs were used to locate the photo plot centers as well as the trees within the plots to be measured. All trees within the plot were identified as to species and measured for DBH. The plot radius as located on the ground was measured for its true distance and this was used to more accurately estimate both the photo scale and the plot area. The dendrometer measurements were brought back from the field and entered into a computer program that calculated merchantable stem volumes by species for the individual trees. These volumes were

*The measurements taken with this device consisted of diameters outside bank, at specified points along the stem of the tree, in order to determine tree volume.

Fig. 5. The photo on the left shows the Barr and Stroud optical dendrometer in use. The photo on the right shows the tree diameter being measured with a diameter-tape.

then regressed with photo volume estimates to derive the prediction equations for stand volume given a photo volume estimate. The volume estimates derived at each stage were expanded through the sample design (multi-stage random sampling) to estimate the total volume for the study area.

## 3.0 RESULTS

Since selection of sample units was with equal probabilities, it was possible to make estimates using two different estimators and also using two

2 different auxiliary variables. Using a ratio estimator allowed combining

Explain the information available from the S190A imagery with direct measurements, and for comparative purposes a simple random sampling estimator was also used. The auxiliary data consisted of a weighted volume estimate, described earlier and also the number of acres in timber, obtained from the basic data described earlier. Results of these estimates are portrayed in Table 1. While the estimates obtained by each of these methods are roughly comparable in magnitude, the most important observation is that simple random sampling was actually more precise, with an RSE of 0.1315. This result may at first seem strange since this technique does not take advantage of the auxiliary S190A data; however as is pointed out by Cochran* auxiliary variables do not necessarily lead to increased precision. Gains in precision depend on the correlation between the auxiliary variable, x, and the variable of interest, y. Cochran gives a formula for a minimum correlation, $e_o$, which must be met in order for gains in precision to occur. By comparing the correlations obtained in this application with $e_o$ in Table 1 it is easily confirmed that no gain in precision is likely to occur with this particular auxiliary data. Therefore, for this particular population and S190A imagery, it can be concluded that simple random is the most precise among these three estimation alternatives. Details of the estimation procedure are given in Appendix 1. No! It is not given!

*Cochran, W.O. 1963, Sampling Techniques, pg. 165.

Table I Summary of Estimates by THREE Estimators

| Estimator / Estimates | Ratio X = Wtd. Vol. Est. | Ratio X = Area of Timber | Simple Random |
|---|---|---|---|
| $\hat{Y}$ | 528,663,956 | 517,386,458 | 547,838,296 |
| $SE(\hat{Y})$ | 83,108,888 | 81,256,237 | 72,054,597 |
| RSE | 0.1572 | 0.1571 | 0.1315 |
| $\hat{R}$ | 2891.9 | 5802.6 | - |
| $p_{xy}$ | -0.1766 | 0.0395 | - |
| $p_o = \dfrac{\hat{R}\,\hat{S}_x}{2\,\hat{S}_y}$ | 0.2124 | 0.2811 | - |

DEFINITIONS:

$\hat{Y}$ = Estimated total volume of timber in cubic feet trees 5" + DBH

$SE(\hat{Y})$ = Standard error of Y

RSE = RELATIVE STANDARD ERROR, $SE(\hat{Y})/\hat{Y}$ $SE(\hat{Y})/\hat{Y}$

$\hat{R}$ = $\sum y/\sum x$

$p_{xy}$ = Correlation between x and y

$\hat{S}_x$ and $\hat{S}_y$ = Standard deviation of x and y, respectively.

From this study it appears that the Skylab S190A imagery is not of sufficiently high resolution to provide timber volume information for inventory purposes. Skylab S190B imagery was not available for this study area so it was not possible to make any direct comparisons between the S190A and S190B products. Inspection of the higher resolution S190B imagery covering an analogous area, however, indicates potential gains in inventory precision if it is used in place of the S190A imagery in the weighted estimate multistage design.

APPENDIX 1

Estimation Procedure

As described earlier, the sampling system is comprised of three stages with random sampling, without replacement, at each stage. Since the population is finite and relatively small, the finite population correction is appropriate. Following the notation of Cochran 1963, Sampling Techniques (pg. 285) the values for y, the estimated population mean volume per acre, and its estimated variance v(y) are obtained as follows.

Let

$y_{ijk}$ = volume/acre as "measured" at the ijk$^{th}$ .4 acre circular plot

$y_{ijk}$ = f (Chapman volume estimate) = Vol. for the i$^{th}$ PSU, j$^{th}$ SSU, k$^{th}$ TSU obtained by regressing sample data from both photo and ground data.

Then,

$$\bar{\bar{y}} = \sum_i^n \sum_j^m \sum_k^k y_{ijk} / nmk ,$$

6 = n first stage samples

1 = m second stage samples

10 = k third stage samples

And

$$v(\bar{\bar{y}}) = \frac{1 - f_1}{n} s_1^2 + \frac{f_1(1 - f_2)}{nm} s_2^2 * + \frac{f_1 f_2 (1 - f_3)}{nmk} s_3^2$$

where,

$$f_1 = \frac{n}{N} = \frac{6}{48} = .125 , \quad f_2 = \frac{m}{M} = \frac{1}{5} = .2 , \quad f_3 = \frac{k}{K} = .0015625$$

(Sampling fractions)

$$s_1^2 = \frac{\sum_i^n (\bar{y}_i - \bar{\bar{y}})^2}{n - 1} = \frac{\sum_i^n \bar{\bar{y}}_i^2 - n\bar{\bar{y}}^2}{n - 1}$$

If variance $v(\bar{\bar{y}})$ is calculated using just first stage terms $\left(\frac{1-f_1}{n} s_1^2\right)$, then d.f. for confidence statements will be $n-1$, i.e. 5 in this case.

$$* \; s_2^2 = \frac{\sum_i^n \sum_j^m (\bar{y}_{ij} - \bar{\bar{y}}_i)^2}{n(m-1)} = \frac{\sum_i^n (\sum_j^m \bar{y}_{ij}^2 - m\bar{\bar{y}}_i^2)}{n(m-1)} \quad , \quad \bar{\bar{y}}_i = \frac{\sum_j^m \sum_l^k y_{ijl}}{mk}$$

$$s_3^2 = \frac{\sum_i^n \sum_j^m \sum_l^k (y_{ijl} - \bar{y}_{ij})^2}{nm(k-1)} = \frac{\sum_i^n \sum_j^m (\sum_l^k y_{ijl}^2 - k\bar{y}_{ij}^2)}{nm(k-1)} \quad , \quad \bar{y}_{ij} = \frac{\sum_l^k y_{ijl}}{k}$$

* Not available since m = 1. Hence estimated variance is lower than true variance. Justification can be given for using the approximation without second term since $f_1$ = .125 and in other applications $f_1$ might be even smaller. Thus the first term asymptotically represents the primary contribution to the sampling variance, and the effects of later stages of sampling are reflected in the value of the estimate rather than its form (Kendall & Stuart, The Advanced Theory of Statistics, Vol. 3, p. 200).

Since $\bar{\bar{y}}$ estimates the average volume per acre, the total volume on the area ($\hat{T}y$) may be estimated as

$\hat{T}y = X\bar{\bar{y}}$ , where X = acreage of population

$v(\hat{T}y) = X^2 v(\bar{\bar{y}})$ , assuming that the acreage is known without error.

Confidence intervals are calculated in the usual way,

$$P(\hat{\theta} - t_{m-1,\, \alpha/2} \sqrt{v(\hat{\theta})} < \theta < \hat{\theta} + t_{m-1,\, \alpha/2} \sqrt{v(\hat{\theta})}) = 1 - \alpha$$

or

$$\hat{\theta} \pm t_{m-1,\, \alpha/2} \sqrt{v(\hat{\theta})} \quad \text{with probability level } 1 - \alpha$$

where

$\theta$ = the population parameter of interest

$\hat{\theta}$ = the estimate of interest (either $\bar{\bar{y}}$ or $\hat{T}y$)

$v(\hat{\theta})$ = estimated variance of $\hat{\theta}$

## APPENDIX II ANALYSIS OF THE INFORMATION CONTENT OF SKYLAB S190A DATA

### Correlation Analysis as Applied to Photo-Interpretation Results

The first stage in this multi-stage inventory design was for a human interpreter to separate three timber volume classes from non-timber on enlarged S190A imagery. In order to determine how accurately this could be done, 18 of the 48 total PSU's were delineated and interpreted for volume classes on Zeiss scale 1:60,000 infrared Ektachrome high altitude imagery. The 18 selected were the only ones for which stereo coverage was already on hand. A skilled interpreter delineated the 3 timber volume classes and the non-timber class on the high altitude imagery and precisely determined the percentage of the total area covered by each class with an area calculation device. These results, assumed to be an accurate account of ground conditions, were correlated with the interpretation results of each of three interpreters on the enlarged portion of the S190A imagery. The initial analysis (Tables 1, 2, & 3) showed poor correlation (generally less than .50) between interpreters and high flight imagery over all volume classes, including the non-timber class, suggesting it is not possible to differentiate volume classes on the S190 imagery. The volume classes of 10,000-20,000 board feet/acre and greater than 20,000 board feet/acre were combined in an attempt to improve the correlation but the results showed improvement only in the non-timber class for all interpreters (.62-.67 correlation) while the timber volume classes ranged from .44 to -.07. This only strengthened the conclusion of the inability to differentiate timber volume classes. However, when all volume classes were combined to see the correlation between timber and non-timber as interpreted on S190A and as delineated on 1:60,000 photography (Table 4) the coefficients ranged from .62 to .67 for non-timber and from .61 to .66 for timber. The correlations between interpreters on S190 imagery alone (Table 5) were .81 to .91 which leads to the conclusion that it is possible to consistently differentiate between timber and non-timber on enlarged S190A imagery, but it is not possible to consistently differentiate any volume classes within the timber areas.

## Analysis of Variance and Multiple Comparison Tests To Judge Significance of Photo-Interpretation Results

In order to quantify and determine the significance of error for individual photo-interpreter (P.I.) results among timber strata, a two-way analysis of variance (Scheffe, 1959) was performed. The three Skylab photo-interpreters (P.I.'s) were considered levels of factor two. Data for each P.I.-timber stratum combination consisted of the difference between the appropriate Skylab and high-flight percent timber area estimates on each of the aforementioned 18 PSU's. It was assumed that these differences for individual PSU's were independent within and between photo-interpreters and that the overall distribution of the differences approached a normal distribution.

The analysis of variance then gave least-square estimates for the expected error (relative to the high-flight data) due to using (1) a given photo-interpreter over all timber strata, (2) a given timber stratum over all P.I.'s, and (3) a given P.I.-timber stratum combination. These error estimates are given in Table 6. F-statistics were then formulated (see Table 7) from the variance of these expected errors to test the null hypotheses that

(of area)

TABLE 1. CORRELATIONS BETWEEN PHOTO-INTERPRETER A ON SKYLAB S190A IMAGERY AND PHOTO-INTERPRETER D ON ZEISS 1:60,000 HIGH-FLIGHT PHOTOGRAPHY BY TIMBER STRATUM

| | | Photo-Interpreter A | | | | |
|---|---|---|---|---|---|---|
| | | T1 | T2 | T3 | T4 | |
| Photo-Interpreter D | T1 | .01 | .69 | -.30 | -.46 | T1 = Timber Stratum 1 |
| | T2 | .25 | .08 | -.05 | -.23 | T2 = Timber Stratum 2 |
| | T3 | .01 | -.26 | .24 | .07 | T3 = Timber Stratum 3 |
| | NT | -.21 | -.67 | .27 | .62 | NT = Non-Timber Strat |

TABLE 2. CORRELATIONS BETWEEN PHOTO-INTERPRETER B ON SKYLAB S190 IMAGERY AND PHOTO-INTERPRETER D ON ZEISS 1:60,000 HIGH-FLIGHT PHOTOGRAPHY, BY TIMBER STRATUM

| | | Photo-Interpreter B | | | | |
|---|---|---|---|---|---|---|
| | | T1 | T2 | T3 | T4 | |
| Photo-Interpreter D | T1 | .33 | .39 | -.14 | -.64 | T1 = Timber Stratum 1 |
| | T2 | .16 | -.12 | -.24 | .06 | T2 = Timber Stratum 2 |
| | T3 | -.35 | .09 | .12 | .15 | T3 = Timber Stratum 3 |
| | NT | -.26 | -.35 | .35 | .49 | NT = Non-Timber Strat |

TABLE 3. CORRELATIONS BETWEEN PHOTO-INTERPRETER C ON SKYLAB S190 IMAGERY AND PHOTO-INTERPRETER D ON ZEISS 1:60,000 HIGH-FLIGHT PHOTOGRAPHY, BY TIMBER STRATUM

| | | Photo-Interpreter C | | | | |
|---|---|---|---|---|---|---|
| | | T1 | T2 | T3 | T4 | |
| Photo-Interpreter D | T1 | .49 | .54 | -.20 | .66 | T1 = Timber Stratum 1 |
| | T2 | .03 | -.05 | -.10 | .19 | T2 = Timber Stratum 2 |
| | T3 | -.22 | .31 | -.28 | .02 | T3 = Timber Stratum 3 |
| | NT | -.41 | -.75 | .54 | .47 | NT = Non-Timber Strat |

TABLE 4. CORRELATIONS BETWEEN PHOTO-INTERPRETERS ON SKYLAB S190A IMAGERY AND PHOTO-INTERPRETER D ON ZEISS 1:60,000 HIGH-FLIGHT PHOTOGRAPHY CONSIDERING ONLY TIMBER VERSUS NON-TIMBER INTERPRETATION

| | | Photo-Interpreter A | |
|---|---|---|---|
| | | Timber | Non-Timber |
| Photo-Interpreter D | Timber | .66 | -.67 |
| | Non-Timber | -.66 | .67 |

| | | Photo-Interpreter B | |
|---|---|---|---|
| | | Timber | Non-Timber |
| Photo-Interpreter D | Timber | .61 | -.62 |
| | Non-Timber | -.61 | .62 |

| | | Photo-Interpreter C | |
|---|---|---|---|
| | | Timber | Non-Timber |
| Photo-Interpreter D | Timber | .63 | -.64 |
| | Non-Timber | -.63 | .64 |

TABLE 5. CORRELATIONS BETWEEN PHOTO-INTERPRETERS ON SKYLAB S190A IMAGERY CONSIDERING ONLY TIMBER VERSUS NON-TIMBER INTERPRETATION

| | | Photo-Interpreter B | |
|---|---|---|---|
| | | Timber | Non-Timber |
| Photo-Interpreter A | Timber | .81 | -.81 |
| | Non-Timber | -.81 | .81 |

| | | Photo-Interpreter C | |
|---|---|---|---|
| | | Timber | Non-Timber |
| Photo-Interpreter A | Timber | .84 | -.84 |
| | Non-Timber | -.84 | .84 |

| | | Photo-Interpreter C | |
|---|---|---|---|
| | | Timber | Non-Timber |
| Photo-interpreter B | Timber | .91 | -.91 |
| | Non-Timber | -.91 | .91 |

TABLE 6. ESTIMATED EFFECTS (ERRORS) FOR FACTORS AND INTERACTIONS IN THE TWO-WAY ANALYSIS OF VARIANCE FOR SKYLAB PHOTO-INTERPRETATION RESULTS.

| FACTOR OR INTERACTION | LEVEL | LEAST-SQUARE ESTIMATE OF FACTOR OR INTERACTION EFFECT |
|---|---|---|
| Photo-Interpreters | P.I. A | $\hat{\alpha}_1 = -12.95$ |
| | P.I. B | $\hat{\alpha}_2 = 15.88$ |
| | P.I. C | $\hat{\alpha}_3 = -2.93$ |
| Timber Stratum | 1 | $\hat{\beta}_1 = -1.34$ |
| | 2 | $\hat{\beta}_2 = .012$ |
| | 3 | $\hat{\beta}_3 = 1.328$ |
| Photo-Interpreter x Timber Stratum | A x 1 | $\hat{\gamma}_1 = -3.07$ |
| | A x 2 | $\hat{\gamma}_2 = 10.86$ |
| | A x 3 | $\hat{\gamma}_3 = -7.79$ |
| | B x 1 | $\hat{\gamma}_1 = -3.51$ |
| | B x 2 | $\hat{\gamma}_2 = -9.48$ |
| | B x 3 | $\hat{\gamma}_3 = 12.99$ |
| | C x 1 | $\hat{\gamma}_1 = 6.58$ |
| | C x 2 | $\hat{\gamma}_2 = 1.38$ |
| | C x 3 | $\hat{\gamma}_3 = -5.20$ |

Model for 2-way ANOVA.

$$y_{ij} = \mu + P_i + T_j + (PT)_{ij} + \epsilon_{ij}$$

effect

TABLE 7. F-TESTS BASED ON TWO-WAY ANALYSIS OF VARIANCE

1. For P.I. effect (error) over all timber strata

$$F = \frac{\text{sum of squares}_{-\hat{\alpha}} - \text{sum of squares}_{\text{Total}}}{\text{Sum of Squares}_{\text{Total}}} \cdot \frac{\nu}{q} \quad \text{where } q = 2,\ \nu = 153$$

$$F = \frac{83893 - 60750}{60750} \cdot \frac{153}{2}$$

$F = 29.14 \quad p<.01$ $\qquad F_{153,2,.001} = 99.501$

2. For timber stratum effect (error) over all P.I.'s

$$F = \frac{\text{sum of squares}_{-\hat{\beta}} - \text{sum of squares}_{\text{total}}}{\text{Sum of squares}_{\text{Total}}} \cdot \frac{\nu}{q} \quad \text{where } q = 2,\ \nu = 153$$

$$F = \frac{60942 - 60750}{60750} \cdot \frac{153}{2}$$

$F = .24 \quad p>.10$

3. For interactions effects (errors) over all P.I.'s and all timber strata

$$F = \frac{\text{sum of squares}_{-\hat{\gamma}} - \text{sum of squares}_{\text{Total}}}{\text{Sum of squares}_{\text{Total}}} \cdot \frac{\nu}{q} \quad \text{where } q = 4,\ \nu = 153$$

$$F = \frac{70300 - 60750}{60750} \cdot \frac{153}{4}$$

$F = 6.02 \quad p<.01$ $\qquad 13.63$

the P.I. errors, timber strata errors, and P.I.-timber strata interaction errors were not statistically significant. The P.I. and interaction hypotheses were rejected at the one-half percent level indicating that some P.I. and interaction errors were significantly different from zero. The timber strata hypothesis was accepted at the 10 percent level and it was therefore concluded that photo-interpretation errors attributable to differences in timber strata were not significant.

To determine which P.I. errors were significant three types of multiple comparison tests (Scheffé, 1959) were applied to the results of the analysis of variance. These were (1) the Tukey test assuming independence of P.I. errors, (2) the Tukey test not assuming independence of P.I. errors, and (3) the Scheffé multiple comparison method. Since the analysis of variance requires the sum of the level effects for a given factor (i.e., the sum of the P.I. expected errors) to add to zero in order to obtain unique least-square estimates for those errors, the second Tukey test was included to check the first for any changes resulting from the violation of error independence.

Parameters to be tested consisted of the difference between each calculated P.I. expected error value and its ideal value of zero. In addition, differences were formed pairwise between interpreter errors to determine which P.I. results significantly differed. All three multiple comparison tests allow a statement of statistical significance for a given error difference to hold true for all such differences of the same magnitude for any chosen level of significance.

The results of these three tests are summarized in Tables 8 through 10. Note that all three multiple comparison tests give the same results

TABLE 8. TUKEY MULTIPLE-COMPARISON TEST (ASSUMING EFFECT INDEPENDENCE) FOR SIGNIFICANCE OF P.I. EFFECT (ERRORS) ESTIMATED FOR THE TWO-WAY ANALYSIS OF VARIANCE

| Contrast (i.e. Difference) | Test Statistic[1] | Computed Level of Significance[2] (Reject Null Hypothesis of No Significant Difference if p<.10) | |
|---|---|---|---|
| $\hat{\Psi}_1 = \hat{\alpha}_1 - \hat{\alpha}_2$ | $q = -10.37$ | $p<.01$ | where: $q_{3,153_{.10}} = 2.93$ |
| $\hat{\Psi}_2 = \hat{\alpha}_1 - \hat{\alpha}_3$ | $q = -3.59$ | $.01\ p<.05$ | $q_{3,153_{.05}} = 3.36$ |
| $\hat{\Psi}_3 = \hat{\alpha}_2 - \hat{\alpha}_3$ | $q = 6.74$ | $p<.01$ | $q_{3,153_{.01}} = 4.20$ |
| $\hat{\Psi}_4 = \hat{\alpha}_1 - o$ | $q = -4.64$ | $p<.01$ | |
| $\hat{\Psi}_5 = \hat{\alpha}_2 - o$ | $q = 5.69$ | $p<.01$ | |
| $\hat{\Psi}_6 = \hat{\alpha}_3 - o$ | $q = -1.05$ | $p>.10$ | |

(1) Tukey Test Statistic Assuming Independence $= q_{p;k,\nu} = \dfrac{\hat{\Psi}}{as}$

where $\Psi$ = estimated contrast

$a^2$ = inverse of the no. of observations made by a given P.I. in the experimental layout for the given analysis of variance procedure

$s$ = square root of the mean square for residual error in the analysis of variance

$p$ = significance level

$k$ = no. of P.I. error estimates

$\nu$ = degrees of freedom for the residual error in the analysis of variance

(2) Level of significance = p= probability that the null hypothesis of no significant difference is true given the computed contrast.

TABLE 9. TUKEY MULTIPLE-COMPARISON TEST (NOT ASSUMING EFFECT INDEPENDENCE) FOR SIGNIFICANCE OF P.I. EFFECT (ERRORS) ESTIMATED FOR THE TWO-WAY ANALYSIS OF VARIANCE

| Contrast (i.e. Difference) | Test Statistic[1] | Computed Level of Significance[2] (Reject Null Hypothesis of No Significant Difference if p<.10) |
|---|---|---|
| $\hat{\Psi}_1 = \hat{\alpha}_1 - \hat{\alpha}_2$ | q = 13.04 | p<.01 |
| $\hat{\Psi}_2 = \hat{\alpha}_1 - \hat{\alpha}_3$ | q = 4.53 | p<.01 |
| $\hat{\Psi}_3 = \hat{\alpha}_2 - \hat{\alpha}_3$ | q = 8.51 | p<.01 |
| $\hat{\Psi}_4 = \hat{\alpha}_1 - 0$ | q = - 5.85 | p<.01 |
| $\hat{\Psi}_5 = \hat{\alpha}_2 - 0$ | q = 7.19 | p<.01 |
| $\hat{\Psi}_6 = \hat{\alpha}_3 - 0$ | q = - 1.33 | p>.10 |

where: $q_{3,153_{.10}} = 2.93$

$q_{3,153_{.05}} = 3.36$

$q_{3,153_{.01}} = 4.20$

(1) Tukey Test Statistic = $q_{p;k,\nu} = \dfrac{\hat{\Psi}}{\sqrt{a^2-b}\; s}$

where $\Psi$, a, s, p, k, $\nu$ are as defined in Table 8, and

$$b = \frac{\text{cov}\ (\hat{\alpha}_i, \hat{\alpha}_j)}{s^2}$$

for the i and j of the contrast of interest, $i \neq j$

(2) Defined in Table 8

TABLE 10. SCHEFFE MULTIPLE-COMPARISON TEST FOR SIGNIFICANCE OF P.I. EFFECT (ERRORS) ESTIMATED FOR THE TWO-WAY ANALYSIS OF VARIANCE.

| Contrast (i.e. Difference) | Test Statistic[1] | Computed Level of Significance[2] (Reject Null Hypothesis of No Significant Difference if p<.10) |
|---|---|---|
| $\hat{\Psi}_1 = \hat{\alpha}_1 - \hat{\alpha}_2$ | F = 18.79 | p<.01 |
| $\hat{\Psi}_2 = \hat{\alpha}_1 - \hat{\alpha}_3$ | F = 3.41 | .01 p<.05 |
| $\hat{\Psi}_3 = \hat{\alpha}_2 - \hat{\alpha}_3$ | F = 12.03 | p<.01 |
| $\hat{\Psi}_4 = \hat{\alpha}_1 - o$ | F = 11.41 | p<.01 |
| $\hat{\Psi}_5 = \hat{\alpha}_2 - o$ | F = 17.15 | p<.01 |
| $\hat{\Psi}_6 = \hat{\alpha}_3 - o$ | F = .58 | p>.10 |

where: $F_{2,153\ .10} = 2.35$

$F_{2,153\ .05} = 3.07$

$F_{2,153\ .01} = 4.79$

(1) Scheffé Test Statistic = $F_{p;q,\nu} = \dfrac{\hat{\Psi}}{q\hat{\sigma}^2_{\hat{\Psi}}}$

where. $\hat{\Psi}$ = estimated contrast

$\hat{\sigma}^2_{\hat{\Psi}}$ = estimate of the variance for the estimated contrast

$= s^2 \sum_1 \frac{c_1}{J_1}$

where $s^2$ = mean square of residual error in the analysis of variance

1 = index for the estimated P.I. effects

$J_1$ = no. of observations made by a given P.I. in the experimental layout for the given analysis of variance

$c_1$ = a contrast defined by the contrast of interest viz: $\hat{\Psi} = \sum_1 c_1 \hat{\alpha}_1$

9 = degrees of freedom for P.I. effects

q = no. of P.I. effects minus one

$\nu$ = degrees of freedom for the residual error in the analysis of variance

p = level of significance

(2) Defined in Table 8.

except for the difference between the P.I. A and C errors in the second Tukey method. In this case, the difference is just slightly more statistically different from zero than indicated by the other two methods.

Examination of Tables 8 through 10 shows that both P.I. A and P.I. B had errors significantly different from zero over all timber strata. That is, their results significantly differed from those obtained by interpretation of high-flight imagery. Only P.I. C had no significant difference from zero (at the 10 percent level) indicating that the expected Skylab interpretation error, relative to the high-flight base, attributable to that P.I. was not statistically significant. Note also that results of all photo-interpreters over all timber strata significantly differed from each other. The strongest differences occurred between P.I.'s A and B, and B and C.

Differences involving expected errors due to P.I.-timber stratum interactions were formulated in a way similar to that for P.I.'s alone. These differences were then tested for statistical significance by the Scheffé method. Results are given in Table 11. Examination of the table indicates that no interaction errors by themselves, when compared to zero error, are statistically significant. However, three differences between interaction errors are significant. Two of these involve photo-interpreters A and B, one in the context of timber stratum 2 and the other in timber stratum 3. The physical significance to be attached to this result may be obtained by examining the magnitude of interactions. Then from Table 6 it is seen that P.I. A tended to call more of timber stratum 3 as timber stratum 2 while P.I. B did the opposite.

ORIGINAL PAGE IS
OF POOR QUALITY

TABLE 11. SCHEFFE MULTIPLE-COMPARISON TEST FOR SIGNIFICANCE OF INTERACTIONS EFFECT (ERRORS) ESTIMATED FOR THE TWO-WAY ANALYSIS OF VARIANCE.

| Contrast | Test Statistic[1] | Computed Level of Significance[2] (Reject Null Hypothesis of No Significant Difference if p<.10) |
|---|---|---|
| $\hat{\Psi}_1 = \hat{\gamma}_{1,1} - 0$ | F = .11 | p>.10 |
| $\hat{\Psi}_2 = \hat{\gamma}_{1,2} - 0$ | F = .14 | p>.10 |
| $\hat{\Psi}_3 = \hat{\gamma}_{1,3} - 0$ | F = .49 | p>.10 |
| $\hat{\Psi}_4 = \hat{\gamma}_{2,1} - 0$ | F = 1.34 | p>.10 |
| $\hat{\Psi}_5 = \hat{\gamma}_{2,2} - 0$ | F = 1.02 | p>.10 |
| $\hat{\Psi}_6 = \hat{\gamma}_{2,3} - 0$ | F = .02 | p>.10 |
| $\hat{\Psi}_7 = \hat{\gamma}_{3,1} - 0$ | F = .69 | p>.10 |
| $\hat{\Psi}_8 = \hat{\gamma}_{3,2} - 0$ | F = 1.91 | p>.10 |
| $\hat{\Psi}_9 = \hat{\gamma}_{3,3} - 0$ | F = .31 | p>.10 |
| $\hat{\Psi}_{10} = \hat{\gamma}_{2,1} - \hat{\gamma}_{2,2}$ | F = 2.34 | .05<p<.10 |
| $\hat{\Psi}_{11} = \hat{\gamma} - \hat{\gamma}$ | F = 2.45 | .05<p<.10 |
| $\hat{\Psi}_{12} = \hat{\gamma} - \hat{\gamma}$ | F = 2.86 | .05<p<.10 |

where: $F_{4,154_{.10}} = 1.99$
$F_{4,154_{.05}} = 2.45$
$F_{4,154_{.01}} = 3.48$

(1) Scheffé Test Statistic = $F_{p;q,\nu} = \dfrac{\hat{\Psi}}{q\hat{\sigma}_{\hat{\Psi}}}$

where = $\hat{\Psi}, \hat{\sigma}_{\hat{\Psi}}, p, \hat{\nu}$ are as defined as in Table 10, and

$q$ = degrees of freedom for interactions
= no. of interactions minus one

$l$ = index for the estimated interaction effects

$J_l$ = no. of observations in the experimental layout for the given analysis of variance relating to the calculation of the estimated interaction of interest.

$c_l$ = a constant defined by the contrast of interest, viz: $\hat{\Psi} = \sum_l c_l \hat{\gamma}_l$.

(2) Defined on Table 8

In order to gain a better perspective on the effect of error associated with each photo-interpreter within each timber volume stratum, two types of one-way analysis of variance were carried out. The first consisted of determining the size of expected errors for P.I.'s within each timber stratum and also the non-timber stratum (see Table 12). Data for this case consisted of the difference between Skylab and high-flight timber stratum area estimates for each P.I. in each of the 18 PSU's which had high-flight timber estimates. F-tests formulated from sums-of-squares associated with P.I. effects, the remaining sums-of-squares not accounted for by P.I. effects, and the associated degrees of freedom were used to test the null hypothesis that P.I. errors were not significant.

Rejection of this hypothesis occurred only in timber volume strata 1 and 2. A Tukey multiple comparison test assuming independence of P.I. errors was then utilized in these two strata. The assumption of P.I. effect (error) independence was utilized here since results from the Tukey multiple comparison tests based on the two-way analysis of variance results were very similar. Results are given in Table 13. In both timber strata 1 and 2, P.I. B and C effects were statistically significantly different, while A and C were as well, in timber volume stratum 1. Importantly, note that the F-tests for timber stratum 3 and non-timber and the Tukey test for 1 and 2 indicate that no P.I. errors differed significantly from zero.

These last results differ with those of the second type of one-way analysis performed. Data for this second approach consisted of the actual photo-interpreter percent area estimates by PSU for each timber stratum. In this case, estimates for the high-flight were considered in the analysis

TABLE 12. ESTIMATED P.I. EFFECTS (ERRORS) BY TIMBER STRATUM FOR THE ONE-WAY ANALYSIS OF VARIANCE FOR SKYLAB PHOTO-INTERPRETATION RESULTS

| | LEVEL | LEAST SQUARE ESTIMATE OF FACTOR EFFECT |
|---|---|---|
| Timber Stratum 1 | P.I. A | $\hat{\alpha}_1 = 4.4$ |
| | P.I. B | $\hat{\alpha}_2 = 11.6$ |
| | P.I. C | $\hat{\alpha}_3 = 7.2$ |
| Timber Stratum 2 | P.I. A | $\hat{\alpha}_1 = 6.09$ |
| | P.I. B | $\hat{\alpha}_2 = 8.29$ |
| | P.I. C | $\hat{\alpha}_3 = 14.38$ |
| Timber Stratum 3 | P.I. A | $\hat{\alpha}_1 = 7.33$ |
| | P.I. B | $\hat{\alpha}_2 = 4.60$ |
| | P.I. C | $\hat{\alpha}_3 = 2.67$ |
| Timber Stratum 4 | P.I. A | $\hat{\alpha}_1 = -.60$ |
| | P.I. B | $\hat{\alpha}_2 = 1.73$ |
| | P.I. C | $\hat{\alpha}_3 = 1.13$ |

TABLE 13. TUKEY MULTIPLE-COMPARISON TEST (ASSUMING EFFECT INDEPENDENCE) FOR SIGNIFICANCE OF P.I. EFFECT (ERRORS) BY TIMBER STRATUM ESTIMATED FOR THE ONE-WAY ANALYSIS OF VARIANCE.

| Stratum | Contrast (i.e. Difference) | Test Statistic[1] | Computed Level of Significance[2] (Reject Null Hypothesis of No Significant Difference if p<.10) |
|---|---|---|---|
| Timber 1 | $\hat{\Psi}_1 = \hat{\alpha}_1 - \hat{\alpha}_2$ | q = -2.99 | $.05<p<.10$ |
| | $\hat{\Psi}_2 = \hat{\alpha}_1 - \hat{\alpha}_3$ | q = .52 | $p>.10$ |
| | $\hat{\Psi}_3 = \hat{\alpha}_2 - \hat{\alpha}_3$ | q = 3.51 | $.01<p<.05$ |
| | $\hat{\Psi}_4 = \hat{\alpha}_1 - o$ | q = - .82 | $p>.10$ |
| | $\hat{\Psi}_5 = \hat{\alpha}_2 - o$ | q = 2.17 | $p>.10$ |
| | $\hat{\Psi}_6 = \hat{\alpha}_3 - o$ | q = -1.35 | $p>.10$ |
| Timber 2 | $\hat{\Psi}_1 = \hat{\alpha}_1 - \hat{\alpha}_2$ | q = .36 | $p>.10$ |
| | $\hat{\Psi}_2 = \hat{\alpha}_1 - \hat{\alpha}_3$ | q = -3.49 | $.01<p<.05$ |
| | $\hat{\Psi}_3 = \hat{\alpha}_2 - \hat{\alpha}_3$ | q = -3.69 | $.01<p<.05$ |
| | $\hat{\Psi}_4 = \hat{\alpha}_1 - o$ | q = .99 | $p>.10$ |
| | $\hat{\Psi}_5 = \hat{\alpha}_2 - o$ | q = 1.35 | $p>.10$ |
| | $\hat{\Psi}_6 = \hat{\alpha}_3 - o$ | q = 2.34 | $p>.10$ |
| Timber 3 | $\hat{\Psi}_1 = \hat{\alpha}_1 - \hat{\alpha}_2$ | q = 2.56 | $p>.10$ |
| | $\hat{\Psi}_2 = \hat{\alpha}_1 - \hat{\alpha}_3$ | q = 2.14 | $p>.10$ |
| | $\hat{\Psi}_3 = \hat{\alpha}_2 - \hat{\alpha}_3$ | q = - .41 | $p>.10$ |
| | $\hat{\Psi}_4 = \hat{\alpha}_1 - o$ | q = 1.57 | $p>.10$ |
| | $\hat{\Psi}_5 = \hat{\alpha}_2 - o$ | q = .99 | $p>.10$ |
| | $\hat{\Psi} = \hat{\alpha} - o$ | q = .57 | $p>.10$ |

where: $q_{3,42_{.10}} = 2.987$
$q_{3,42_{.05}} = 3.436$
$q_{3,42_{.01}} = 4.271$

| | | | |
|---|---|---|---|
| Timber 4 | $\hat{\Psi}_1 = \hat{\alpha}_1 - \hat{\alpha}_2$ | q = - .62 | p>.10 |
| | $\hat{\Psi}_2 = \hat{\alpha}_1 - \hat{\alpha}_3$ | q = .14 | p>.10 |
| | $\hat{\Psi}_3 = \hat{\alpha}_2 - \hat{\alpha}_3$ | q = .76 | p>.10 |
| | $\hat{\Psi}_4 = \hat{\alpha}_1 - o$ | q = .16 | p>.10 |
| | $\hat{\Psi}_5 = \hat{\alpha}_2 - o$ | q = .46 | p>.10 |
| | $\hat{\Psi}_6 = \hat{\alpha}_3 - o$ | q = .30 | p>.10 |

(1) Test statistic defined in Table 8

(2) Defined in Table 8

as a fourth level of the photo-interpreter factor. Effects were calculated (see Table 14) and F-tests then rejected the null hypothesis of non-significance of P.I. effects in each timber volume stratum. The Tukey test assuming independence was then applied to the calculated P.I. effects.

Examination of Table 15 indicates that significant differences between the Skylab photo-interpreters generally follow the results of the first one-way analysis of variance. However, significant differences now exist between P.I.'s A, B, and C versus D (high-flight) P.I. effects. This last result is in contrast to the lack of significant differences relative to high-flight results found from the first type of analysis of variance discussed above. From this last comparison it can be concluded that the P.I. effect based on PSU by PSU error (first one-way analysis of variance procedure) and the expected P.I. effect based on over-all error (second one-way procedure) tend to give different results.

A comparison of photo-interpreter correlation results (Tables 1, 2, and 3) and photo-interpreter error (effect) sizes (especially from the one-way analysis of variance) as depicted in Tables 6, 12, and 14 allows the following observation: two interpreters' results can vary up or down together resulting in high positive correlations, but their respective average timber class estimates can be significantly different. This result suggests <u>two desirable objectives</u> for photo-interpretation performance within a given timber stratum from the standpoint of cost-effective sampling for timber volume estimation.

First there should be high correlation between Skylab and high-flight estimates. This situation would allow meaningful stratification between

TABLE 14 ESTIMATED P.I. EFFECTS (ERRORS) BY TIMBER STRATUM FOR THE ONE WAY ANALYSIS OF VARIANCE FOR BOTH SKYLAB PHOTO INTERPRETATION AND HIGH-FLIGHT PHOTO INTERPRETATION RESULTS

| | LEVEL | LEAST SQUARE ESTIMATE OF FACTOR EFFECT |
|---|---|---|
| Timber Stratum 1 | P.I. A | $\hat{\alpha}_1 = 6.08$ |
| | P.I. B | $\hat{\alpha}_2 = 9.92$ |
| | P.I. C | $\hat{\alpha}_3 = 12.75$ |
| | P.I. D | $\hat{\alpha}_4 = 8.91$ |
| Timber Stratum 2 | P.I. A | $\hat{\alpha}_1 = 1.95$ |
| | P.I. B | $\hat{\alpha}_2 = 4.95$ |
| | P.I. C | $\hat{\alpha}_3 = 18.52$ |
| | P.I. D | $\hat{\alpha}_4 = 11.62$ |
| Timber Stratum 3 | P.I. A | $\hat{\alpha}_1 = 8.82$ |
| | P.I. B | $\hat{\alpha}_2 = 6.52$ |
| | P.I. C | $\hat{\alpha}_3 = 4.45$ |
| | P.I. D | $\hat{\alpha}_4 = 2.15$ |
| Non-Timber Stratum | P.I. A | $\hat{\alpha}_1 = -.75$ |
| | P.I. B | $\hat{\alpha}_2 = 1.58$ |
| | P.I. C | $\hat{\alpha}_3$ 1.35 |
| | P.I. D | $\hat{\alpha}_4 = .52$ |

TABLE 15. TUKEY MULTIPLE-COMPARISON TEST (ASSUMING EFFECT INDEPENDENCE) FOR SIGNIFICANCE OF P.I. EFFECT (ERRORS) BY TIMBER STRATUM, ESTIMATED FOR THE ONE-WAY ANALYSIS OF VARIANCE.

| Stratum | Contrast (i.e. Difference) | Test Statistic[1] | Computed Level of Significance[2] (Reject Null Hypothesis of No Significant Difference if p<.10) |
|---|---|---|---|
| Timber 1 | $\hat{\Psi}_1 = \hat{\alpha}_1 - \hat{\alpha}_2$ | q = -4.40 | $.01<p<.05$ |
| | $\hat{\Psi}_2 = \hat{\alpha}_1 - \hat{\alpha}_3$ | q = 1.83 | $p>.10$ |
| | $\hat{\Psi}_3 = \hat{\alpha}_1 - \hat{\alpha}_4$ | q = 4.11 | $.01<p<.05$ |
| | $\hat{\Psi}_4 = \hat{\alpha}_2 - \hat{\alpha}_3$ | q = 6.23 | $p<.01$ |
| | $\hat{\Psi}_5 = \hat{\alpha}_2 - \hat{\alpha}_4$ | q = 1.28 | $p>.10$ |
| | $\hat{\Psi}_6 = \hat{\alpha}_3 - \hat{\alpha}_4$ | q = 5.95 | $p<.01$ |
| Timber 2 | $\hat{\Psi}_1 = \hat{\alpha}_1 - \hat{\alpha}_2$ | q = .64 | $p>.10$ |
| | $\hat{\Psi}_2 = \hat{\alpha}_1 - \hat{\alpha}_3$ | q = -4.38 | $.01<p<.05$ |
| | $\hat{\Psi}_3 = \hat{\alpha}_1 - \hat{\alpha}_4$ | q = 2.07 | $p>.10$ |
| | $\hat{\Psi}_4 = \hat{\alpha}_2 - \hat{\alpha}_3$ | q = -5.03 | $p<.01$ |
| | $\hat{\Psi}_5 = \hat{\alpha}_2 - \hat{\alpha}_4$ | q = -3.55 | $.05<p<.10$ |
| | $\hat{\Psi}_6 = \hat{\alpha}_3 - \hat{\alpha}_4$ | q = 6.45 | $p<.01$ |
| Timber 3 | $\hat{\Psi}_1 = \hat{\alpha}_1 - \hat{\alpha}_2$ | q = 4.49 | $.01<p<.05$ |
| | $\hat{\Psi}_2 = \hat{\alpha}_1 - \hat{\alpha}_3$ | q = 3.88 | $.01<p<.05$ |
| | $\hat{\Psi}_3 = \hat{\alpha}_1 - \hat{\alpha}_4$ | q = 1.95 | $p>.10$ |
| | $\hat{\Psi}_4 = \hat{\alpha}_2 - \hat{\alpha}_3$ | q = - .61 | $p>.10$ |
| | $\hat{\Psi}_5 = \hat{\alpha}_2 - \hat{\alpha}_4$ | q = -2.54 | $p>.10$ |
| | $\hat{\Psi}_6 = \hat{\alpha}_3 - \hat{\alpha}_4$ | q = -1.93 | $p>.10$ |

where: $q_{4,56_{.10}} = 3.35$

$q_{4,56_{.05}} = 3.79$

$q_{4,56_{.01}} = 4.70$

(1) Defined in Table 8

(2) Defined in Table 8

~~Why? (Random sampling is used!)~~

timber volume classes and would thus reduce the variance between PSU's and SSU's within a stratum. The result would be that <u>fewer</u> PSU's and SSU's would need to be subsampled to obtain timber volume estimates within specified allowable error and confidence level constraints. Therefore, costs of inventory would be minimized.

The second objective for photo-interpreter performance is low average expected errors for given timber strata. In this case, the probability that sample allocation will be to PSU's and SSU's that actually fall in their appropriate strata will be maximized. The efficiency of the sample design in producing sample means for timber strata as close as possible to their true population means will then be maximized.