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ERTS DATA USER INVESTIGATION TO DEVELOP A MULTISTAGE FOREST SAMPLING INVENTORY SYSTEM

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16. Abstract

A unique digital timber volume estimation system was developed for use with the MSS CCT tapes. The system was tested on a 64-square-mile area in Northern California's Trinity Alps. The outcome of a systematic experiment, in which several possible combinations of bands 5 and 7 and a contrast measure were tried, showed that an estimated gain in precision of 50% can be obtained in a multistage sampling design. The difference between bands 5 and 7 proved to be of special importance for the estimation of biomass in the form of timber volume.

In addition, an interpretation model for highflight U2 photographs was developed. A maximum multiple correlation coefficient of 0.74 was obtained for the regression model, explaining 55% of the variation in timber volume as estimated from aerial photos and ground measurements. An interpretation model for MSS color composites is in the testing stage.

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PREFACE
(Significant Results)

During this reporting period we have developed a digital timber volume prediction system for use with the ERTS-1 MSS CCT tapes.

The system was tested on a 64-square-mile area in Northern California's Trinity Alps. A systematic experiment was conducted in which 16 possible combinations of bands 5 and 7, the difference between these bands, and a contrast measure extracted from them, were tried.

From the experimental outcome, it was estimated that a gain of 50% in sampling precision can be obtained in a multistage forest survey when using the digital volume estimation system. The difference between bands 5 and 7 proved to be of major importance for the estimation of biomass, when expressed in the form of timber volume, as 20% of the gain was contributed by this factor. Contrast contributed positively to the estimated gain, but its contribution was small, and probably not statistically significant.

In addition, an interpretation model for highflight U2 photographs was developed. A maximum multiple correlation coefficient of 0.74 was obtained from the regression model, explaining 55% of the variation in timber volume per square mile on the ground.

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1.0 INTRODUCTION

This report is the second half-yearly progress report describing the progress made in the ERTS-1 investigation concerning the development of a multistage forest inventory system. The background and objectives for such a system were described in our first half-yearly report. In this report we described the work performed under Task II of the present investigation. A precision annotation system was developed which was used to annotate sampling units on the ERTS imagery and the highflight U2 photographs.

In the present report we will describe work performed under Task III, concerning the digital and manual interpretation of the ERTS and U2 images.

The main body of this report is divided into three parts: (1) an outline of the developed digital interpretation system; (2) a discussion of the evaluation of this system; and (3) a report concerning manual interpretation techniques for ERTS images and U2 photographs.

The report is concluded with a description of the planned activities for the next reporting interval and a section with a summary and conclusions.

2.0 THE DIGITAL INTERPRETATION SYSTEM

The digital interpretation system was developed on the premise that a special system would be needed for the purpose of a multistage forest inventory. The special characteristics of the problem at hand requiring a special system are: (1) the presence of extremely rough and mountainous terrain; (2) a continuously varying timber species mix with varying crown cover; (3) the need to estimate biomass in the form of timber volume; and (4) the required capability to interpret relatively small and accurately located sampling units with irregular ownership boundaries. These requirements are much different from the agricultural conditions that govern the characteristics of other digital classification systems.

The system described in this report is made up of two main components: (1) an image handling system; and (2) a classification and volume estimation system. The image handling system was especially designed for use in multistage sampling. It has a flexible sub-setting capability, which together with the previously developed annotation system, allows one to precisely extract a sub-image covering a sample unit or a land parcel. The classification and volume estimation system consists of two sub-systems: (1) the training system; and (2) the timber volume estimation system. In the training system, an unsupervised clustering algorithm is used to interpret terrain classes from the digital data. These classes are linked to known timber volumes by means of a linear model. The training results are then applied in the volume prediction system, with which timber volumes for unknown areas are assigned.

We describe the principles and operating procedures for the two sub-systems in the following two sections.

2.1 The Image Handling System

The image handling system was designed to achieve the following objectives: (1) to be able to locate sample units in the digital data with sufficient accuracy; (2) to minimize tape handling and random access retrieval; and (3) to work with nxn matrices of pixels ("intels"), rather than on a pixel-by-pixel basis.

A flow diagram indicating the operational use of the system is shown in Figure 1.

The first step in using the system is to define with relatively low accuracy the overall area of interest. This is done by specifying the distances in the x and y directions in nautical miles (nm) of the upper left corner of the area from the upper left corner of the frame, as well as the dimensions of the area in nautical miles. These coordinates are then input to the first program which reads the MSS data tapes, joins the scan lines across 25 nm strips, and separates the video data by channel. The output tapes, one for each requested channel, contain only the video data for the area of interest. Unnecessary tape handling is avoided by only using those input tapes which contain video data for the area, and by restricting the number of output tapes to the number of requested channels.

In a multistage forest survey, the first program would be used to select the forested area on the ERTS frame on which the inventory is to be made.

The second step extracts the sample unit areas from the general area. Considerable accuracy is required for this purpose, and thus the input for the second program consists of accurately specified corner coordinates for the sub-image. These coordinates are transformed to pixel locations, using skew and rotation parameters determined from a least-squares adjustment of the MSS data. The input for the least-squares adjustment are image coordinates and pixel locations of a set of corresponding points. The resulting RMSE of this adjustment is

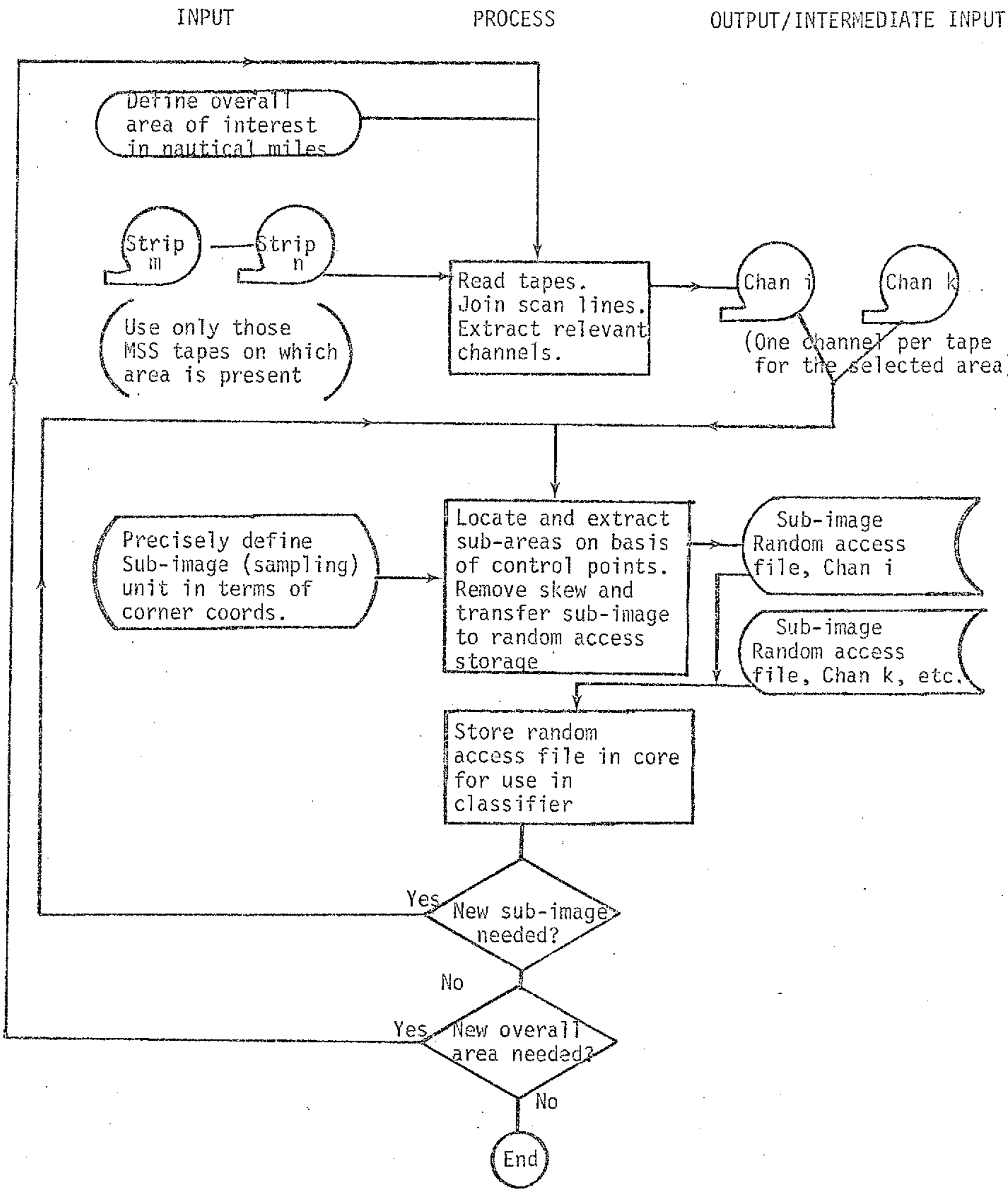


Figure 1. Flow Diagram for Image Handling System.

in the neighborhood of 2.0 pixels. The sub-image indicated by the transformed corner coordinates is extracted from the relevant channel tapes, corrected for skew, and then transferred to a random access storage device. This procedure is repeated for each channel.

The third step brings the image for the desired channel into core ready for use. An identification block is carried along with the image which specifies the position of its pixels in relation to those of its parent image as well as the channel number and other pertinent information.

Any image can be displayed on the line printer using a set of sixteen characters. Each one is uniquely related to a part of the spectral response range. Part of a printout of a band 7 of frame E 1094-18224 in shown in Figure 2.

2.2 The Classification System

The classification system developed for this study is different from most other systems in that the final product does not consist of a discrete set of classes. Instead, the results consist of point estimates of a continuous variable; namely, biomass in the form of timber volume. In this report the term classification system may be misleading. However, at an intermediate stage the image is divided into discrete classes.

Although the system makes use of an unsupervised data clustering routine, it cannot be termed an unsupervised classification system. The terrain classes are converted to percentages of areas occupied by the class in a given parcel. These area percentages are then regressed

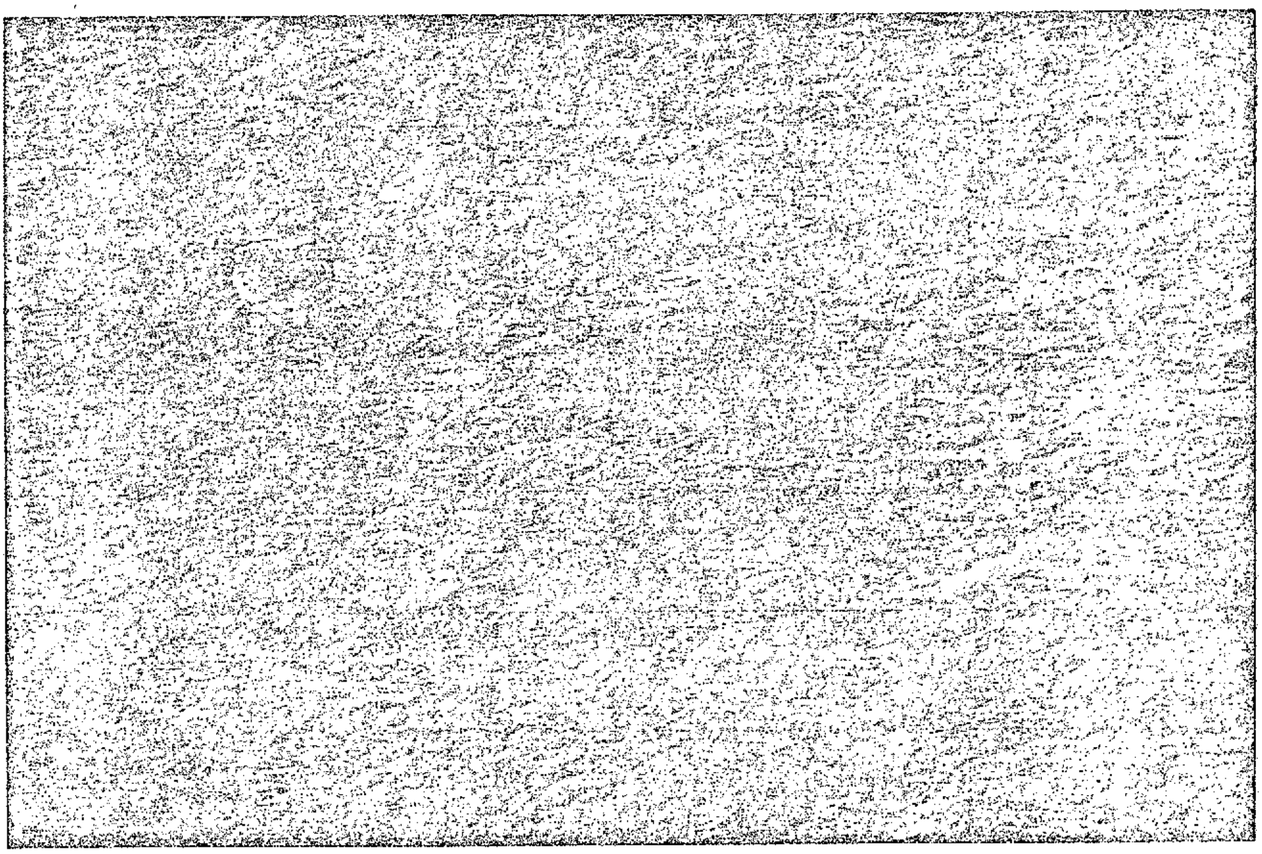


Figure 2. Computer Printout Display of MSS Band 7, Frame E 1094-18224.

on a set of known timber volume estimates for a certain training area. The results are applied to estimate timber volumes in other areas.

As shown in Figure 3, the system consists of two parts: (1) the training system; and (2) the timber volume estimation system. In the following sections we discuss these two components and the programs used for each.

2.2.1 <u>The Training System</u>

This part of the system is used on a designated training area for which timber volume estimates are available. The training area should be representative of the rest of the terrain. The output of the system is a basic set of parameters needed for the timber volume estimation. As can be seen in the first part of Figure 3, the training system consists of six programs, some of which are also employed in the timber volume estimation process. We will briefly discuss each of the programs and related techniques.

(a) <u>The Feature Extraction Program</u>. The image of the training area is blocked up in elements termed "intels." The system is particularly suited for work with 4x4 and 8x8 pixel intels. For each intel the feature extraction program extracts one tone and one contrast measure for each spectral band.

To compute these measures, we are using the fast Walsh (Hadamard) transform algorithm in a computational form described by van Roessel (1972). The computation level used so far is the first level. That is, when using an 8x8 intel size we are working with the 4x4 grey value sub-totals to compute the overall total as well as three contrasts.

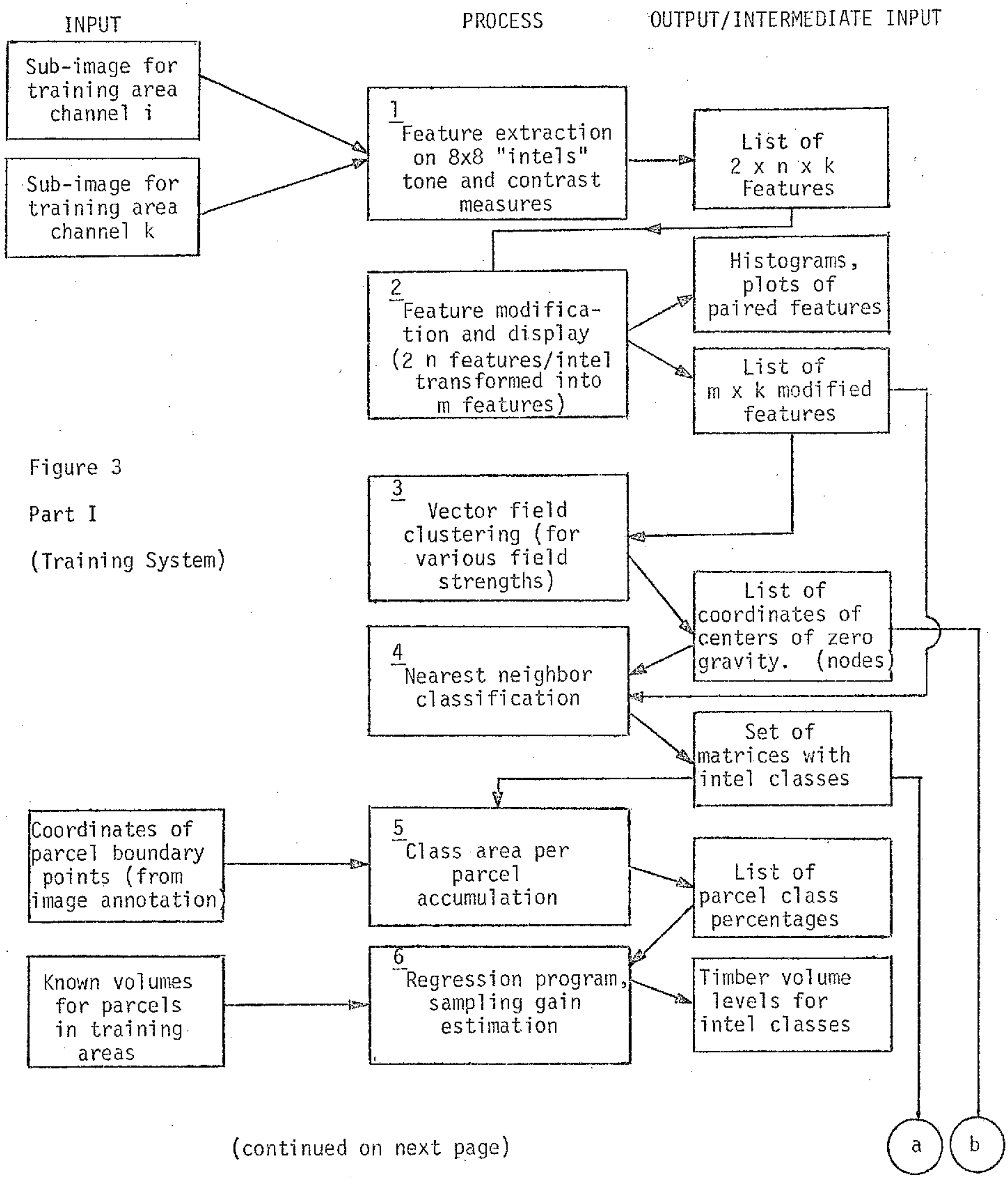


Figure 3

Part I

(Training System)

(continued on next page)

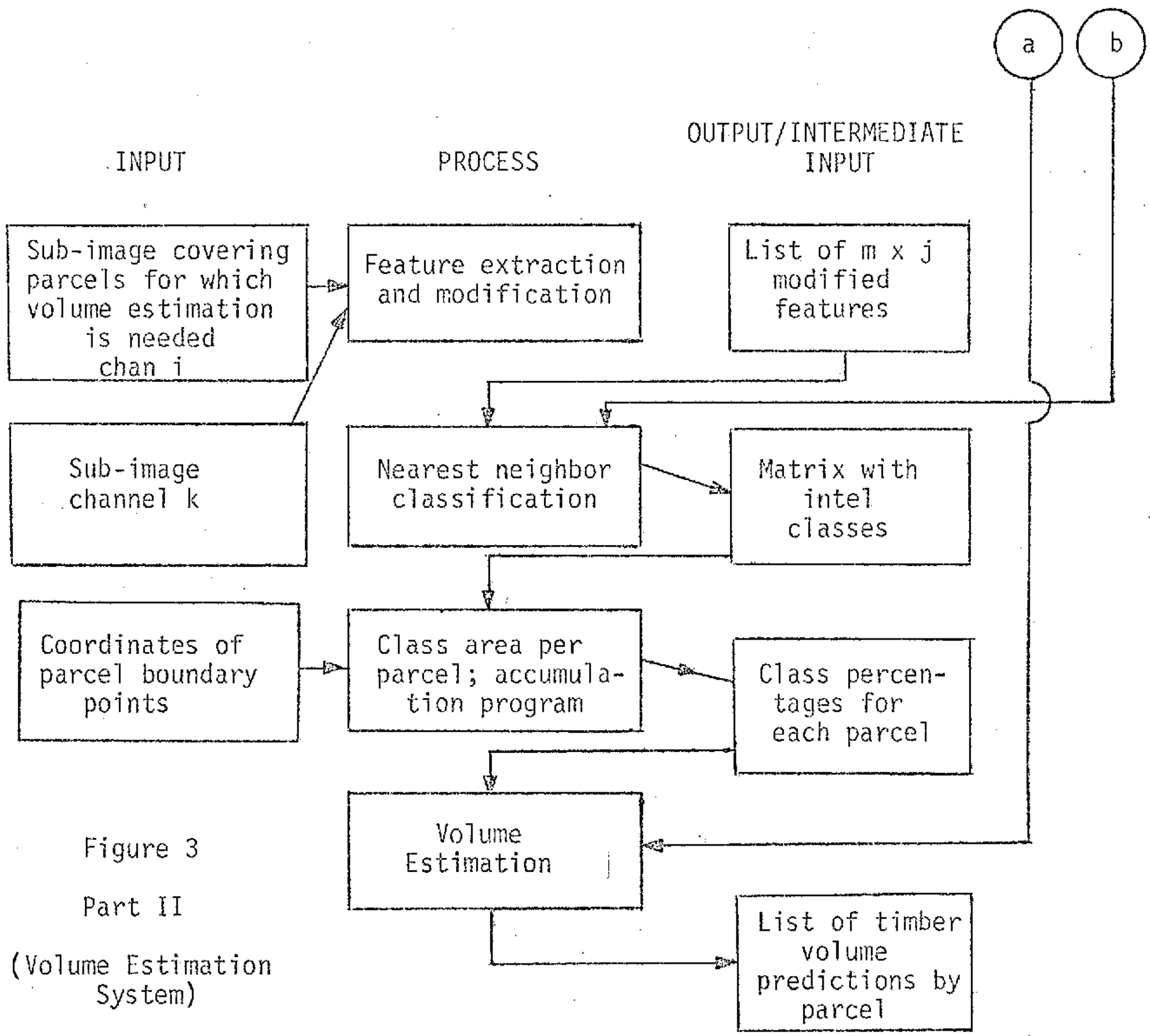


Figure 3. Flow Diagram of Digital Interpretation System

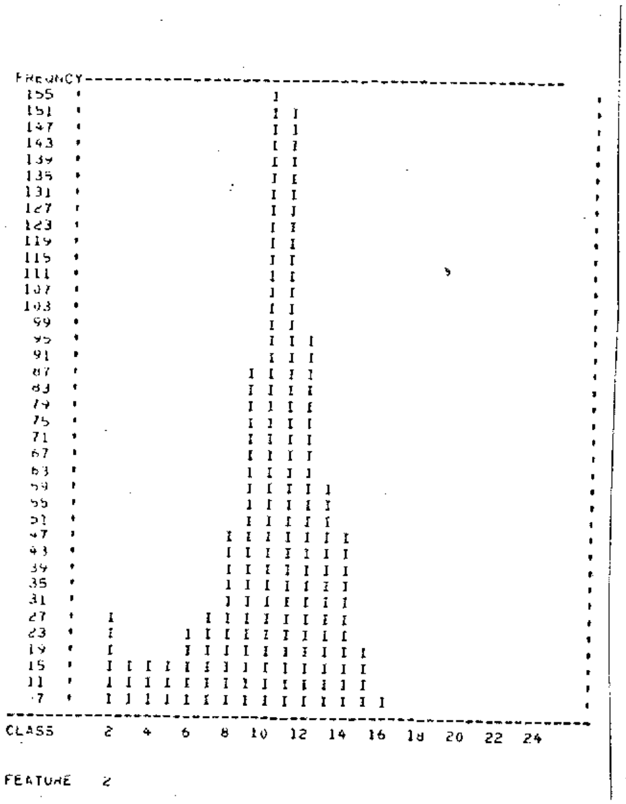
The overall total for the 8x8 intel is the tone value used. The square root of the sum of the three contrasts squared provides us with a rotation-independent contrast measure. To make this measure partially translation independent, the transform frame is moved around in a sub-image consisting of the intel plus a margin of one fourth of the intel size. The maximum contrast for all possible positions of the transform frame is the contrast used.

The final output of the program is a list of 2 x n x k features, where n is the number of channels used, and k is the number of intels in the area to be classified.

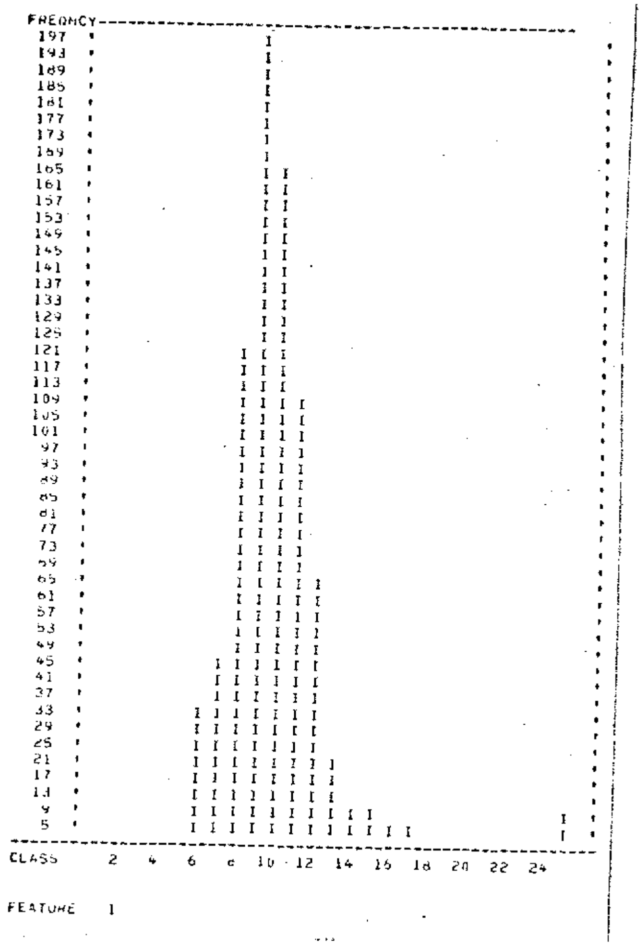
(b) The Feature Modification and Display Program. Feature extraction is followed by feature modification and display. Modifications may consist of taking combinations of tone values for various bands, such as the difference or the ratio. For this purpose one may write a short modification routine. Consequently, no restrictions are placed on the type or number of possible modifications.

For each type of modified feature the program displays a histogram. Histogram examples for features compiled from the tone values of 816 8x8 intels for the sub-image covering our first test area (3.1) are shown in Figure 4. The first two histograms are for bands 5 and 7 respectively; the third histogram shows the frequencies for the differences of the tone values of these bands. All tone values were standardized and transformed to a 0-30 range.

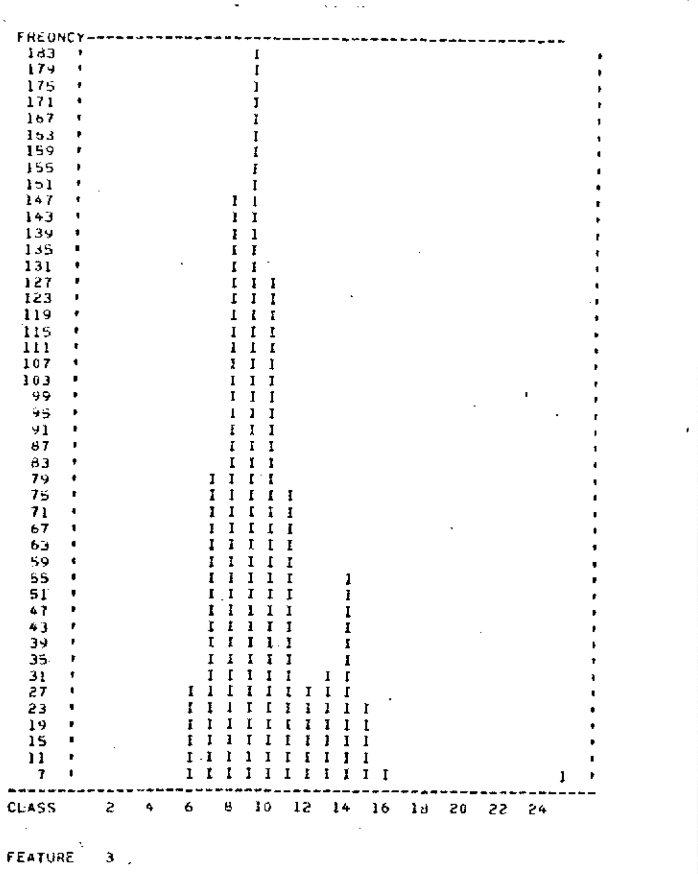
In addition to the histograms, two-dimensional plots are displayed for all combinations of modified features. An example of a plot of the tone values of band 5 (x-axis) versus the tone values of



Band 7



Band 5



Band 5 - Band 7

Figure 4. Histograms for Standardized (0-30) Tone Values from 816 8x8 intels.

band 7 (y-axis) for the same 816 intels is shown in Figure 5.

The output consists of a list of modified features of dimension m x k, where m is the number of modified features per intel.

(c) The Clustering Program. The basic component of the unsupervised classification program is the data clustering routine.

Normally clustering routines are based on the assumption that the data will fall into clusters which are representative of multivariate normal distributions, with adequate separation zones between clusters. We anticipated that the difficult mountainous terrain with which we were working would yield data that would not adhere to these clustering conditions.

With this in mind, we selected G. A. Butler's (1968) vector field approach for the clustering algorithm. This method permits one's perspective of the data to range from locally sensitive (where each data point is a cluster) to the globally sensitive (where the entire sample set is a cluster), by manipulating a single parameter, which we have named the field strength.

Basically, a gravitational field is generated in the n-dimensional sample space by using the simple Newtonian formula for an attractive force between two bodies, in which the squared distance has been replaced with a general power of the distance ($F = m_1 m_2 S^{-r}$, where S is the distance between two points with masses m_1 and m_2 and -r is the field strength). A gradient searching technique is then used to look for nodes or centers of zero gravity in the vector field. These nodes are representative of the cluster centers.

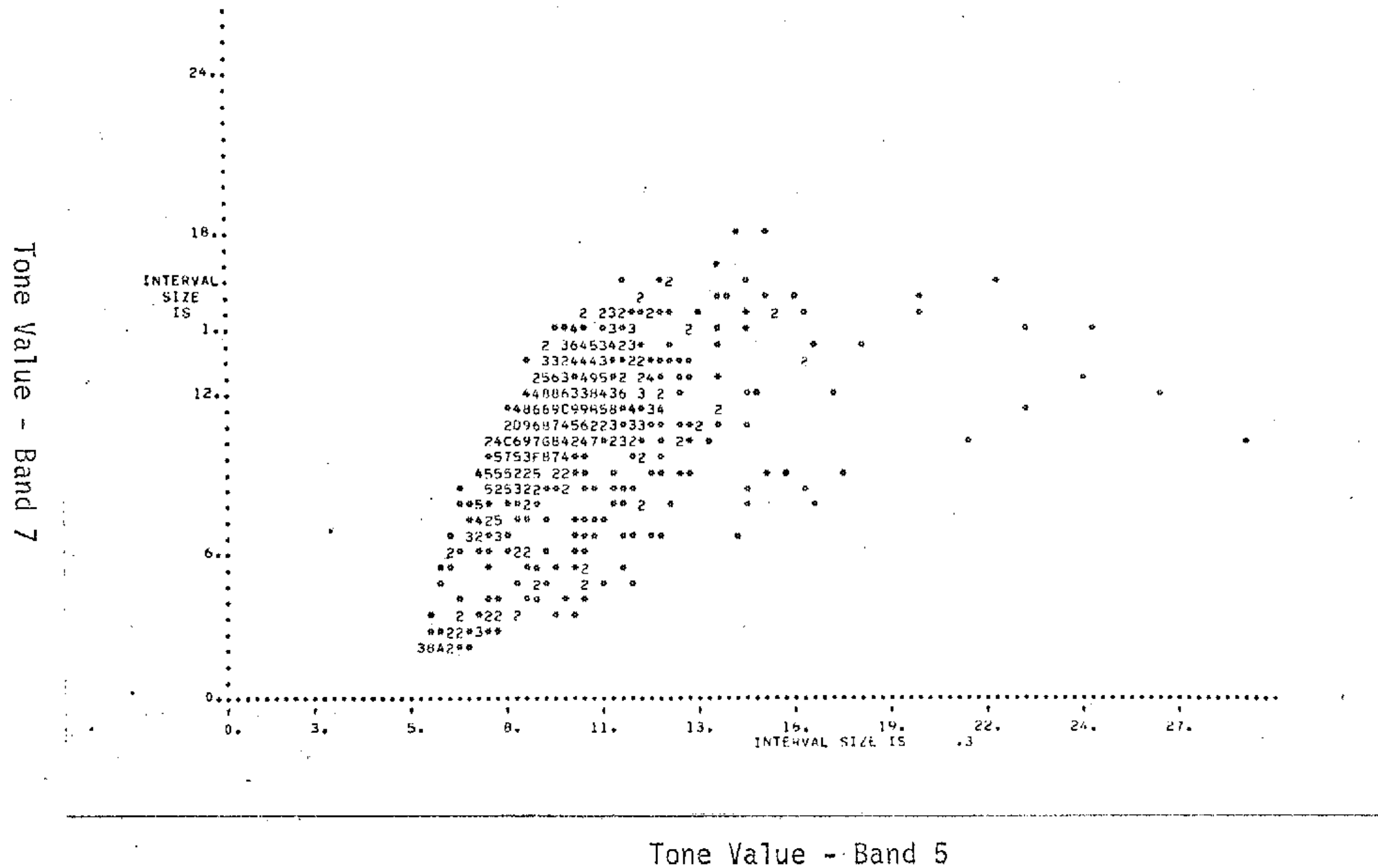


Figure 5. Plot of Tone Values (Standardized) of Band 5 versus Band 7 for 818 8x8 intels.

Several modifications to Butler's original technique were made. The major disadvantage was the large number of computations to be carried out. For each step in the sample space, the distance and the force components from all other sample points must be computed. We partly eliminated this disadvantage by thinning the sample space with another clustering algorithm, the "chain" algorithm (Andrews, 1972). Rather than using a unit mass for all the sample points, we work with a reduced set of points with non-unit mass. The same chain algorithm is also used to define a small set of starting points, from which the gradient search for the zero gravity centers is started.

It was also desirable to include some kind of clustering stability evaluation as any desired degree of clustering can be obtained by varying the field strength. We arrived at a procedure whereby the field strength is reduced stepwise over a certain range, and the new starting points for each iteration are the nodes from the previous iteration. The degree to which the old nodes resist being combined, while reducing the field strength is a measure of the clustering stability. Typically, the field strength is varied from -3. to -2. with increments of 0.1.

(d) <u>The Nearest Neighbor Classification Program</u>. After the cluster centers have been found, the intels can be classified according to the cluster with which they are associated. Roese (1969) has used a maximum likelihood procedure, on the assumption that his clusters resembled multi-variate normal distributions. However, we are using simple non-parametric nearest neighbor classification, on the assumption that the data with which we are working are by no means normally distributed. The classification is based on the Euclidean distance between the point to be classified and the cluster centers. The point is assigned the class of the center to which it is closest. The n-dimensional space used is standardized by subtracting from each type of feature the overall mean and by dividing by the standard deviation for each axis.

The output of the program consists of a set of matrices (one for each field strength) indicating the class number for each intel.

(e) The Class Area Per Parcel Accumulation Program. The next program uses the interpretation matrices to determine the area percentage of the total parcel area that is occupied by a given class.

From the interpretation matrices a classification image is generated by expanding the matrix in the form of 8x8 blocks of class numbers for each class number in the original matrices.

Land parcels, or aggregates of land parcels, are specified as input to the program. The pixel coordinates of the parcel corners are retrieved from a previously prepared list. The parcel boundary is then superimposed on the classification image, and the pixels of any given class that are within the boundary are tallied and divided by the total number of pixels in the parcel.

To count the class pixels within the parcel an "in or out" algorithm developed by T. Smith is used. This algorithm handles any kind of boundary, including boundaries within boundaries.

The final output of the program is a list by parcel of the area percentages of each class.

(f) Regression and Sampling Gain Estimation Program. The final program in the training system combines the area percentages of of the classes by parcel with the known timber volumes for the parcels. A regression is performed in which the dependent variable is the known timber volume, the independent variables are the class percentages. This regression is based on the following model:

$$V_j - \overline{V} = \beta_1 P_{1j} + \beta_2 P_{2j} + \beta_3 P_{3j} + \ldots + \beta_i P_{ij} + \varepsilon_j \qquad (1)$$

where V is the timber volume per square mile for parcel j; $\overline{V}$ is the average timber volume per square mile computed over all j parcels; P_{ij} is the class proportion of class i in parcel j; β_i represents the differential volume level for class i (in other words, if the parcel is all in this class we add β_i to $\overline{V}$); and ε_j is an error term.

Note that we subtract the average volume per square mile from the dependent variable, rather than estimate a constant term in the regression equation. The reason is that the proportions add up to 1, so that the X matrix would not be of full rank if we also carried a unit column.

To evaluate the results we examine the following regression statistics: (1) the multiple correlation coefficient; (2) an F statistic for testing the hypothesis: $\beta_1 = \beta_2 = \beta_i = 0$, in other words, the interpretation system provides statistically significant results; (3) t values for the individual betas, to test the significance of their difference from zero.

In addition, predicted volumes $\hat{V}_j$ are computed. These predicted volumes and the known volumes are then used to estimate the gain in efficiency that would result from the use of the predicted volumes in a variable probability sampling scheme. If we denote the variance for simple random sampling by V_{srs} and the variance for variable probability sampling by V_{vps} then the increase in precision is computed as follows:

$$G\% = \frac{V_{srs} - V_{vps}}{V_{srs}} \times 100\% \qquad (2)$$

It can be shown that G% does not depend on the sample size.

2.2.2 The Timber Volume Prediction System

The major outputs of the training part of the digital interpretation system are the zero gravity center or node coordinates and the timber volume levels for the classes corresponding to the nodes. These outputs are the controlling parameters for the volume estimation system.

As is shown in the second part of Figure 3, the sub-image for which volume estimation is needed is the input to the feature extraction and modification program. The list of features is then entered into the nearest neighbor classifier where the intels are classified according to distances of the point to the centers of zero gravity. The resulting matrix with intel classes is then run through the class area per parcel accumulation program in which the class percentages in the relevant sampling units are accumulated. These percentages are then entered into the volume estimation routine along with the volume levels from the training system. The result is a set of volume predictions for all the parcels that were contained in the sub-image from which the features were extracted.

The process is repeated for all relevant sub-images. The final list of volume predictions is used in the multistage inventory to determine the probability with which each unit will be selected for inclusion in the inventory sample.

3.0 EVALUATION OF THE DIGITAL INTERPRETATION SYSTEM

The interpretation system is being evaluated for two test areas within the overall area of our test site. To date, the experiments for one test area are complete and we are about to start the evaluation of the system performance for the other test area. We described the test areas, the experimental design used and the experimental outcome in the following sections.

3.1 The Test Areas

Our first test area is a 64-square-mile portion of ERTS frame E 1094-18224 covering the northern part of California's San Joaquin Valley and the Trinity Alps. The test area is situated in the vicinity of Trinity Dam, and covers a part of Clair Engle Lake, associated with this dam. The terrain is mountainous with elevations ranging from 2000-8000 ft.

The second test area is also a 64-square-mile test area, imaged on frame E 1094-18222. The area is further north, in the vicinity of the junction of Coffee Creek with the Trinity River. Elevations here range from 5000-7000 ft.

Both test areas are contained in the Trinity National Forest, and are covered with timber stands consisting of a mixture of red and white fir, ponderosa pine and douglas fir.

The ownership pattern in both test areas is of the checker-board type. The individual land parcels are all approximately one square mile, alternately owned by the Southern Pacific Land Company and the Federal Government. Our ground truth in the test areas consists of volume data for some of the S. P. land parcels.

One of the main reasons for selecting the two test areas was that the first area contains a water body, whereas the second test area is all land.

The portion of ERTS frame E 1040-18222 covering the first test area is shown in Figure 6. Band 5 is represented in Figure 6a, and band 7 is shown in Figure 6b. Note the accentuation of the underlying terrain form and water in the band 7 image, and the more detailed information (partly due to vegetation) in the band 5 image. This difference proved to play an important role in the digital interpretation, as discussed in section 3.3.

3.2 The Experimental Design

We described in the previous section how "known" timber volumes are regressed on the class area proportions for a set of parcels. This ground truth in the form of known volumes is essential for the training of the interpretation system. In the present case, however, not all land parcels had ground volume timber estimates. We therefore had to resort to photo interpretation for the interpolation of volumes between adjacent parcels with known volumes. This photo interpretation was performed on RC-10 U2 photographs by a highly trained photo-interpreter with extensive ground experience in the areas. Ground volumes are known only for one fourth of all parcels in the first test area. Half of the parcels of the second area have known timber volumes. We designated the mixture of known and interpreted volumes as "ground truth," keeping in mind how the volume figures were obtained.

At the same time, we developed a more objective interpretation system for the U2 photographs with other photo-interpreters. They

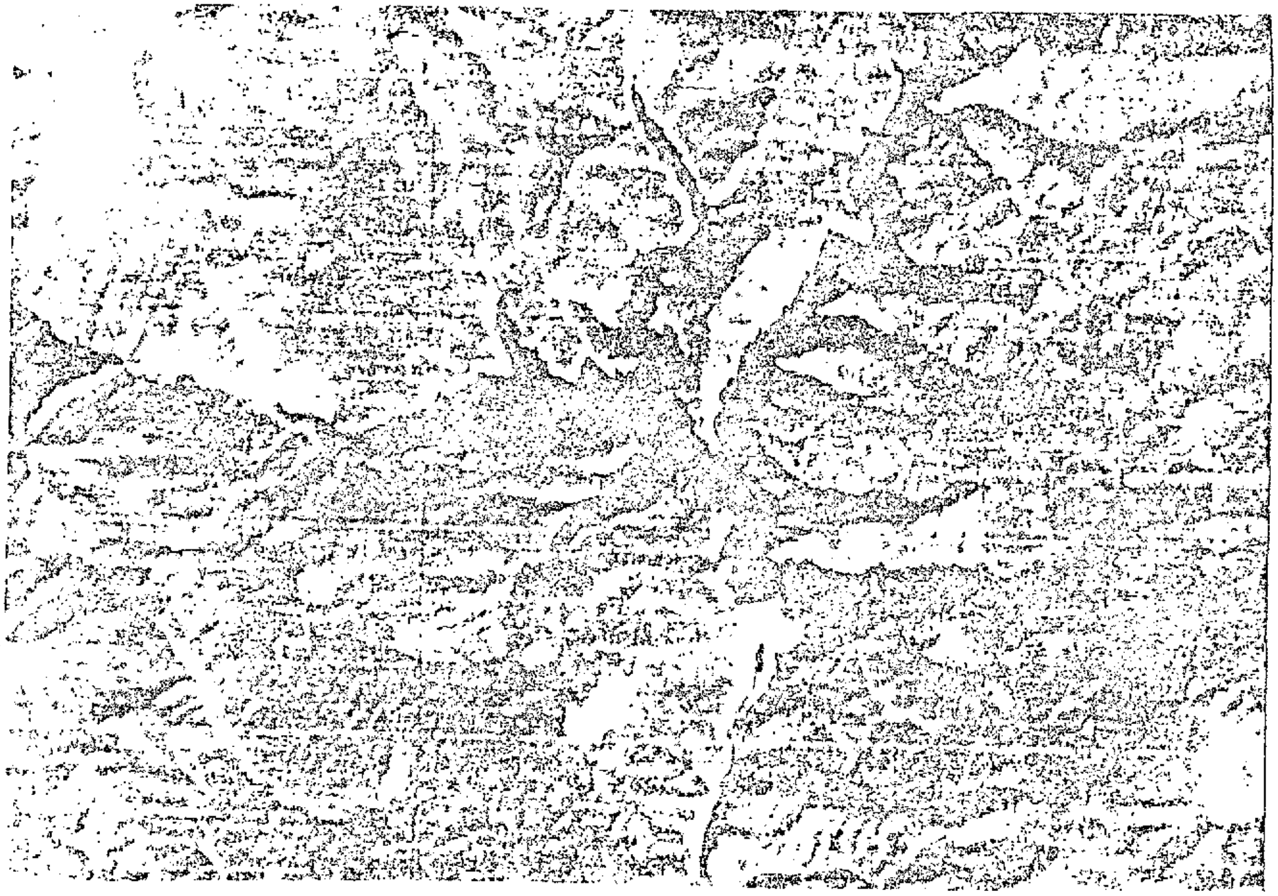


Figure 6a. First Test Area, 64-square-mile Portion of ERTS Frame E 1040-18222, Band 5.

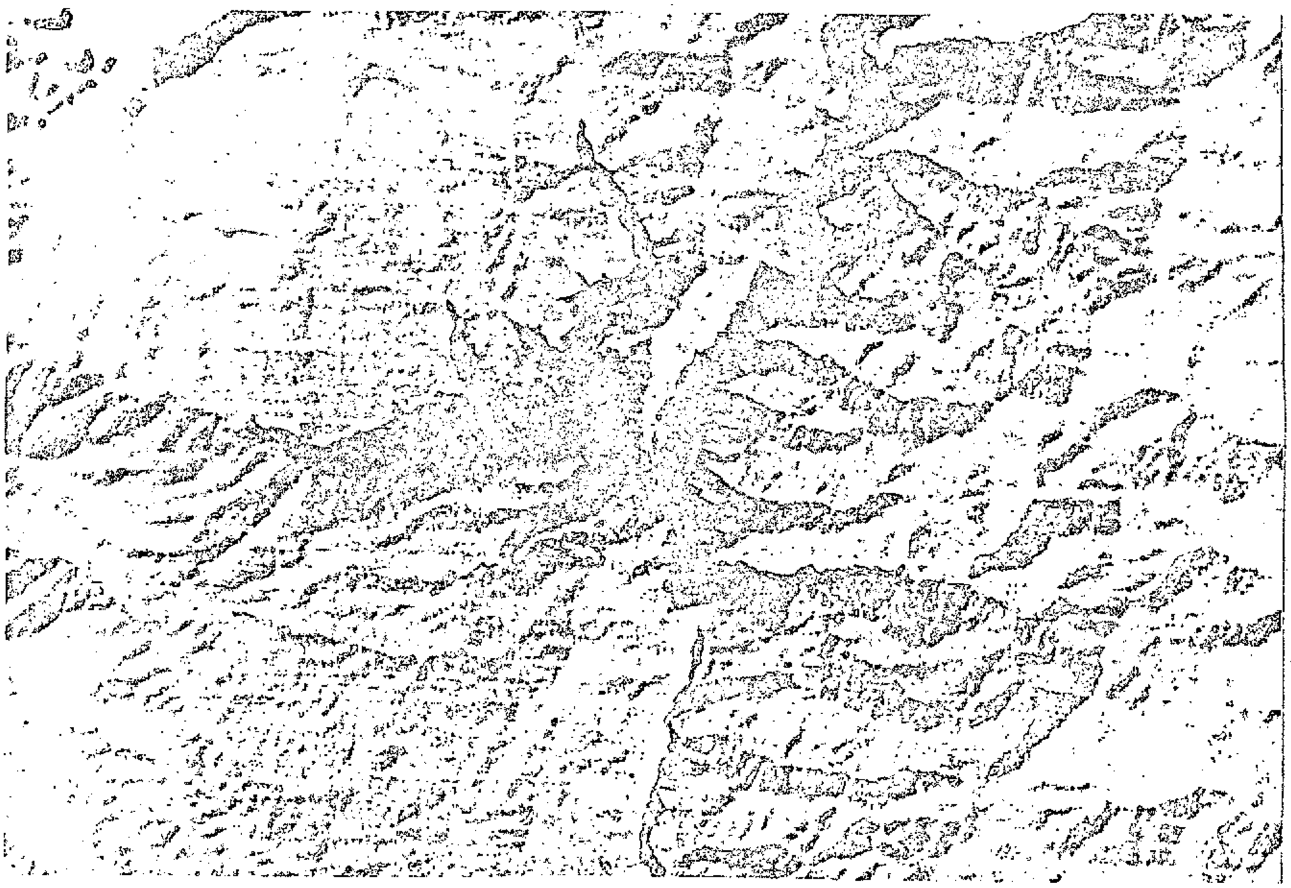


Figure 6b. First Test Area, 64-square-mile Portion of ERTS Frame E 1040-18222, Band 7.

estimated a set of independent variables on the photographs, rather than making a subjective volume estimate directly. This interpretation system is described in section 4.1. Volume estimates obtained from these independent variables, as combined in a regression equation were obtained for both test areas. We will subsequently refer to them as the U2 estimates.

The "ground truth" volumes and the U2 estimates were both used as the dependent variable in the regressions with the class area proportions for the 64 parcels. The purpose of using both types of estimates is that in a multistage inventory, one would either have the option to directly correlate between the ERTS estimates and ground estimates (a two stage survey) or to include another intermediate stage of aerial photography such as the U2 estimates (a three stage survey). The hypothesis being tested is that a higher correlation is possible between ERTS and U2 estimates, than between ERTS and ground estimates, because of the closer resemblance of the resource on two types of imagery than on imagery and the ground.

For both types of regression, either with "ground truth" or with U2 estimates, we obtained several indicators for the statistical significance of the results and the increase in efficiency obtainable with them (section 2.2.1 [6]).

The objective of the experiment was to test different combinations of spectral bands and different types of features extracted from the images. Specifically, we were interested in the following two hypotheses: (1) inclusion of a contrast feature increases the precision gain; and (2) the inclusion of the difference between bands 5 and 7 increases the precision gain. The latter hypothesis was of interest as various authors have recommended the ratio or the difference of these bands as being useful for biomass estimation (Vincent, 1973; Turner, 1973). To examine these ideas we designed a comprehensive experiment of the factorial type in which we tested 16 different combination of bands and features. Specifically, we experimented with the following factors: (1) factor a: band 5 present or absent; (2) factor b: band 7 present or absent; (3) factor c: the difference between bands 5 and 7 present or absent; (4) factor d: contrast measure for all bands or differences between bands used. Combinations of these factors resulted in the following "run" combinations listed in Table I.

3.3 Evaluation of Experimental Outcome

For each of the run combinations listed in Table I digital interpretations were made. The results are presented in Table II, where for each run combination are listed: (1) the multiple correlation coefficient (R); (2) the F statistic for the significance of the differential volume levels (F); (3) the 95% point of the appropriate F distribution (P); (4) the estimated gain obtainable when the predictions are applied in a variable probability sampling scheme (G%): and (5) the number of volume levels estimated (NV). Results are listed both for the regressions with the "ground truth" and the U2 timber volume estimates.

Several interesting conclusions can be drawn from Table II. Most important, we can conclude that an estimated gain in precision of over 50% is possible when using ERTS MSS data to define sampling probabilities at the first stage of a forest inventory sampling design. G% values of 50.8% and 57.9% were obtained for run abc. The corresponding F statistics (9.96 and 14.35) are highly significant at all probability levels

TABLE I

"RUN" DESCRIPTIONS FOR FACTORIAL EXPERIMENT

Run Combination		Run Description
1.	(1)	Information for the best run combination applied at random in the regression program. Thus, results entirely due to chance
2.	a	Band 5 alone
3.	b	Band 7 alone
4.	ab	Bands 5 and 7
5.	c	The difference between bands 5 and 7
6.	ac	Band 5 and the difference between bands 5 and 7
7.	bc	Band 7 and the difference between bands 5 and 7
8.	abc	Bands 5 and 7 and the difference between bands 5 and 7
9.	d	Contrast measures for bands 5 and 7 alone
10.	ad	Band 5 and its contrast
11.	bd	Band 7 and its contrast
12.	abd	Bands 5 and 7 and their contrasts
13.	cd	The difference between bands 5 and 7 and the difference between contrasts for bands 5 and 7
14.	acd	Band 5, the difference between bands 5 and 7, and the difference between the contrasts for bands 5 and 7
15.	bcd	Band 7, the difference between bands 5 and 7, and the difference between contrasts for bands 5 and 7
16.	abcd	Bands 5 and 7, the difference between bands 5 and 7, and the difference between the contrasts for bands 5 and 7

(compare with 2.04). Thus the hypothesis that the digital interpretation of the ERTS MSS tapes can be used to increase the precision of sampling for timber volume is strongly confirmed.

TABLE II

RESULTS OF ERTS MSS DIGITAL INTERPRETATION RUNS

Run	"Ground truth"					U2 estimates				
Comb.	R	F	P	G%	NV	R	F	P	G%	NV
(1)	.32	1.49	2.04	8.5	10	.26	1.08	2.08	5.8	9
a	.32	2.33	2.17	9.5	7	.29	1.91	2.17	10.3	7
b	.40	11.74	2.76	15.4	3	.55	26.94	2.76	31.3	3
ab	.54	16.45	2.53	34.7	4	.67	14.30	2.14	49.3	8
c	.56	10.84	2.25	40.9	6	.67	19.78	2.25	52.5	6
ac	.62	9.02	2.08	44.9	9	.70	13.90	2.08	54.6	9
bc	.67	10.40	2.04	53.7	10	.68	17.48	2.17	53.7	7
abc	.66	9.96	2.04	50.8	10	.73	14.35	2.04	57.9	10
d	.56	8.01	2.14	32.5	8	.63	7.74	2.04	42.3	11
ad	.57	5.70	2.04	33.8	11	.62	7.30	2.04	41.8	11
bd	.46	4.72	2.14	19.9	8	.54	7.04	2.14	31.0	8
abd	.50	10.52	2.37	28.2	5	.55	13.13	2.37	32.8	5
cd	.57	5.13	1.96	41.3	12	.71	8.68	1.88	56.9	14
acd	.55	10.61	2.25	36.0	6	.62	15.21	2.25	42.9	6
bcd	.53	16.01	2.53	36.9	4	.68	35.44	2.53	52.9	4
abcd	.60	17.05	2.37	45.9	5	.70	29.34	2.37	55.1	5

However, one can wonder whether the significant results are not entirely due to the fact that the test area contains a water body. Water can be detected quite easily on MSS band 7, and naturally a zero timber volume is associated with a water class. To examine this notion we present in Table III the 10 differential volume levels for the 10 classes of run abc and their corresponding t statistics at the 5% level of significance (two tailed test).

TABLE III

DIFFERENTIAL VOLUME LEVELS AND t STATISTICS FOR RUN abc

(U2 Estimates)

Class #	Differential Volume level (1000 bdft/ square mile)	t statistic (118 df)	Values of t (.05 significance level)
1	-2188	-2.83	-1.65
2	-2219	- .84	-1.65
3	- 702	- .82	-1.65
4	274	.21	1.65
5	- 203	- .08	-1.65
6	1662	2.03	1.65
7	3798	4.68	1.65
8	1439	1.22	1.65
9	381	.47	1.65
10	-3423	-7.09	-1.65

The most significant volume level is that of class ten. Inspection of the intel class matrix reveals that this class corresponds to the water body. Thus, wherever water occurs the model would subtract 3,423,000 bd.ft. from the average timber volume level of 5,291,300 bd.ft. The difference is close to the standard error of estimate for the model. However, other classes, namely 1, 6 and 7 also are statistically significant, judging from their t values. For classes 6 and 7 the model would add 1,662,000 and 3,798,000 bd. ft., respectively. These differential levels are certainly not due to water. Thus, we may reject the notion that all the explained variation would be due to the presence of the water body. We hope to confirm the value of the system with the second test area as it contains no water.

Some other important conclusions can be drawn from the experimental results in Table II. To support these conclusions we can analyze the experiment in terms of the effects of the various factors and their interactions, making use of the 2^4 factorial design of the experiment. For the response variable we selected G%. The computed effects are presented in Table IV.

TABLE IV
EFFECTS FOR DIGITAL INTERPRETATION EXPERIMENT
(Response variable G%)

Effect	"Ground Truth"	U2 estimates
Mean	33.3	41.9
A	4.3	2.3
B	4.8	7.1
AB	4.0	4.3
C	21.0	22.7
AC	-3.1	-3.7
BC	1.3	-3.9
ABC	-2.2	-3.2
D	2.0	5.0
AD	-1.0	-4.9
BD	-7.9	-10.1
ABD	1.2	0.4
CD	-9.6	-7.8
ACD	1.7	0.4
BCD	4.6	11.1
ABCD	4.0	-0.3

The mean for the regressions with the U2 estimates is about 9% larger than the mean for the regression with the "ground truth" volumes. This difference tends to confirm the hypothesis that the ERTS digital interpretation results correlate better with other imagery interpretation data than with direct ground truth. However, we had ground volume estimates for only one-fourth of all parcels. The other parcels had interpolated volumes only. Thus another possibility would be that the interpolation technique was not as good as the multivariate interpretation model that was used to obtain the U2 estimated ground volumes.

The second conclusion that can be drawn from the effects of Table IV is that the difference between bands 5 and 7 (C effect) dramatically influences the gain in precision with an additive effect of approximately 22%. This confirms the hypothesis that the difference between bands 5 and 7 is extremely useful for the purpose of biomass estimation.

The third conclusion that can be made is that the effect of the inclusion of contrast is positive, but otherwise small. It is therefore probable that the use of a contrast measure would not pay in an operational mode under similar terrain and environmental conditions evaluated at the same time of year.

A part of the experiment will be repeated for the second test area, and we hope to confirm the results that we have obtained with the first area.

4.0 MANUAL INTERPRETATION TECHNIQUES

In parallel with the development of digital interpretation techniques, we are working on the development of "manual" interpretation techniques. We are developing models for both ERTS MSS images and U2 RC-10 photographs.

4.1 U2 RC-10 Photographic Interpretation Model

Our aim was to develop a regression type interpretation model, for which the independent variables could be interpreted from the U2 photographs. This type of model would be more consistent, and less subjective than a direct ocular estimation method. The dependent variable used was timber volume per square mile.

We started out with the interpretation of eight variables, namely, (1) percentage of parcel on southern exposure; (2) percentage of southern exposure covered with conifer forest; (3) density of the conifer covered portion; (4) percentage of large trees on this portion; and the variables 5-8 being a repeat of the first four variables for the northern exposure.

We soon discovered, however, that slope (exposure) did not seem to contribute much in the regressions, so that we added the variables for each exposure to obtain a four variable model.

The basis of the development for the model was 40 land parcels with known volumes. Interpretations were made of B&W and false color photographs by two interpreters, who repeated their interpretations twice. Final results in the form of multiple correlation coefficients are presented in Table V:

TABLE V
MULTIPLE CORRELATION COEFFICIENTS BETWEEN
U2 PHOTO INTERPRETATIONS AND "GROUND TRUTH"

	B&W	Color
Interpreter 1	-	0.65
Interpreter 2	0.72	0.74

We also evaluated the gain in efficiency that is possible with the U2 interpretation model. The percentages obtained were 40.3% and 49.9%, respectively.

The final model in use at the moment is as follows:

$$V = C\ (D + D^2 + L + L^2) \qquad (3)$$

where V is the predicted volume, C is the percentage covered by conifers, D is the overall vegetation density (crown cover) and L is the percentage of large trees. This last variable is mostly guessed at by the interpreters, but nevertheless seems to contribute significantly to the model.

4.2 ERTS MSS Color Composite Manual Interpretation Model

At the moment we are also developing a regression type interpretation model for manual interpretation. For this purpose, an overlay has been prepared for an ERTS color composite image of our test area, showing the exact location of the 64-square-mile parcels of the first test area that were also used in the digital interpretation experiment.

For each of these parcels we will estimate the value or intensity of the red color of the color composite, as well as the area of the parcel that is in red. These interpreted values will then be used as independent variables in a regression model using variable "ground truth" timber volumes. A direct comparison between the manual and digital interpretation techniques will be made.

5.0 WORK PROJECTED FOR NEXT REPORTING INTERVAL

In the next reporting interval we plan to finish the manual interpretation work of the ERTS MSS color composite images. When this work is complete we will have all the necessary models for the last step in our investigation.

This last phase will consist of a trial forest inventory in which we apply the techniques developed under this contract in a situation that is as realistic as possible. A multistage inventory will be simulated consisting of an ERTS stage, a U2 stage, a 1:40,000 photographic stage, a 70mm stage, and a ground inventory stage. The last three stages have been evaluated in a forest inventory conducted by EarthSat for the Southern Pacific Land Co. We will therefore examine the increase in efficiency that could be obtained in a similar inventory by adding an ERTS stage and a U2 stage.

For the simulated inventory we have selected a set of 4x2 primary sampling units (PSU's), which have had no change in timber volume since the previous inventory. On the ERTS stage we will interpret all possible PSU's with our digital interpretation system. At the U2 level we will apply our regression interpretation model. The results will then be incorporated in the multistage estimators to obtain estimates of the sampling variance. These estimates can be compared directly with previously obtained values, so that the increase in efficiency, if any, due to ERTS images and U2 photographs can be evaluated.

6.0 SUMMARY AND CONCLUSIONS

In our previous Type II report for the period September 1972--February 1973, we described the image annotation system that we developed to annotate land parcels and sample units of ERTS images and U2 high-flight photography. Development of this system was called for under Task II of our contract proposal.

In the present report for the period February 1973--September 1973, we have reported the work performed for Task III of our contract proposal, namely the development of digital and manual interpretation methods for the prediction of timber volumes on ERTS images and U2 photography.

Our special digital interpretation system consists of two major components: (1) the image handling system and (2) the classification system. The system is unique in that it estimates a continuous variable, namely biomass in the form of timber volume.

An interpretation experiment was performed with the system, in which combinations of bands 5 and 7 and their difference as well as a contrast measure were systematically combined. A further conclusion drawn from the experiment is that an estimated maximum increase in sampling precision of 50% is due to the digital interpretation of MSS data. The major factor in raising this precision is the difference between bands 5 and 7 (an increase of about 20%). The inclusion of contrast made a positive but very small contribution.

A manual interpretation model for U2 photography was also developed. Here, the maximum multiple correlation coefficient obtained was 0.74 for interpretations on color infrared photography. A manual interpretation model for ERTS MSS color composites is still in the testing stage.

In the next reporting period we intend to apply the digital interpretation system and the U2 interpretation models in a simulated multistage forest survey to evaluate their usefulness under realistic operational conditions.

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