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Photo—Charles F. "Rick" Monroe

FOREST STAND MAPPING AND EVALUATION ON STATE AND PRIVATE LANDS IN MONTANA

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INTRODUCTION

State and private forest lands in Montana form a significant part of the State's total forest resource base. Current data show 6.2 million acres in State and private (S&P) ownership and 16.4 million acres of federal forest land (USDA-FS 1977). In the last decade, timber harvests from S&P lands increased from 409 million board feet (MBF) to 654 and now account for 56 percent of Montana's current timber production (Hearst 1979). The S&P forests also provide a significant land base for water, forage, wildlife, mineral production and recreational use.

The current Montana Forest Survey (MFS) will produce new information for the S&P lands. This Survey, designed as an extensive inventory of the forest resources, will provide new tabulations of forest characteristics for county and subcounty units. The MFS was initiated in 1975 with completion scheduled for 1982. The mapping of forest land classes was not included in the MFS due to funding limitations in 1975. The mapping of forest land characteristics has become necessary for the application of MFS data to increasingly intensive forest management needs. Therein lies the importance and purpose for this research and development work.

In 1977, the U.S. Geological Survey in cooperation with other federal and state agencies began acquiring high-altitude aerial photography. This aerial photography is called "quad-centered" because it is designed to cover the area within a 7-1/2 minute (1:24,000 series) quadrangle map in a single frame. Completed for Montana in 1979, this photography provides a cost-effective media for mapping S&P Forests.

RESEARCH AND DEVELOPMENT OBJECTIVES

The essential problems of this study involved using quad-centered photography for forest classification mapping and integrating MFS data within the classification system for the characterization of mapped units. This situation is opposite to the normal design of a resource mapping and inventory system. Therein, the desired information output defines the mapping requirements first and the design of photointerpretation criteria, photo sampling and ground sampling follow. A satisfactory design produces accurately mapped units adequately described by photointerpretation and ground truth data. This was the goal of this research, and led to the following objectives:

1. Develop photointerpretation criteria and procedures for forest land unit mapping using quad-centered aerial photography.

2. Test the association between the forest land unit delineation criteria and actual ground conditions.

3. Select and test methods for expanding ground truth data to the delineated forest land units.

4. Test the expansion of MFS field sample data to the delineated forest land units.

5. Prepare sample products illustrating the information output from quad-centered photography and extensive field samples.

SUPPORTING RESEARCH AND DEVELOPMENT

Examination of the quad-centered photography suggested that the use of a conventional forest type classification scheme would be difficult or impossible. Also, the expansion of an extensive field sample to conventional forest type delineations having low reliability would produce estimate errors too high for practical use. For these reasons, it seemed necessary to employ a new system for delineating forest land units. This required an investigation into the rational of techniques for delineating and classifying land and the photointerpretation criteria on which they are based.

The expansion of ground sample information to identifiable units of land ("inplace" information) requires the existence and identification of land tracts containing relatively homogeneous ecological conditions. Foresters have traditionally thought of such units as stands, defined as being groups of similar tree species of similar size and condition growing on similar sites. This study assumes that homogeneous land units can be delineated in the landscape and that forest resources within these delineated units can be treated as a homogeneous population.

Traditionally, extensive forest inventories have paid little attention to individual land tracts. The Montana Forest Survey (MFS), exemplifying the traditional approach, uses stratified random point sampling on a systematic grid design. No effort is made to delineate individual tracts or to generate information by specific land unit classes. Rather the inventory provides estimates of forest resources and conditions on an extensive basis.

In 1970 the Forest Service, Region 1, modified its inventory design to provide "inplace" information. In this design, land areas are delineated from aerial photos and field samples are taken within selected land units (Stage and Alley 1972). Ground attributes derived from field samples within individual land units are directly assigned to similar unsampled land unit types (strata) and expanded to extensive areas based upon the proportion of area occupied by a given strata (Brickell 1977). This method of attribute assignment and field sample expansion requires that the number of strata be kept small enough to permit an adequate field sampling of each stratification. The number of different types of land units delineated for any one National Forest in Region 1 has been less than 25.

An alternative to the above procedure is to derive relationships between the characteristics defining a land tract and the ground-determined attribute. Ground attributes are then estimated for unsampled land units using prediction equations (Lund 1978). A major consideration in such a design is that the characteristics defining a land tract be both empirically related to the ground attributes and also derivable from aerial photographs.

Traditional forest photointerpretation characteristics, such as crown canopy coverage, crown texture, stand height, disturbance, logging, etc., have been widely used for forest stratification and resource estimation. Region 1 uses such criteria in their land stratification, and several stand volume tables have been developed from such criteria (Stage and Alley 1972; Avery 1966; Moessner 1960). In addition, these criteria have been shown to be visible on high-altitude photography and to be usable for forest resource analysis (Hudson et al. 1976; Lauer and Benson 1973). The use of forest overstory characteristics for land tract delineations is, however, limited. Land units delineated solely from forest overstory characteristics have little permanence, because natural and cultural activities constantly alter the vegetation. Also, existing overstory conditions tell little about the future productivity or successional sequence of an individual tract.

The use of topographic characteristics, such as slope angle, aspect, slope position, elevation, etc., for land delineation provide a means for identifying more permanent units on the landscape. In addition, topographic features often show sharper boundaries than forest overstory characteristics. Their incorporation into a land unit classification scheme permits the delineation of more permanent and more recognizable land tracts on the air photos. The geometric and image quality of high-altitude photography has been shown to be suitable for capturing such topographic data at medium mapping scales (Gut and Hohle 1977).

Topographic features have also been shown to be related to ecological conditions, i.e., species distribution, habitat type, and productivity. A number of studies have found a close association between the presence of individual plant species (understory and overstory) and topographic characteristics (Mueggler 1965; Hack and Goodlett 1960). Martin (1979) classified land units by habitat type with moderate success using topographic variables measured from high resolution medium-scale aerial photography. Lee and Sypolt (1974) observed significantly different rates of tree growth between north and south aspects even under abundant soil-moisture conditions. Other studies have reported associations between site index and topographic variables, such as elevation, topographic position, aspect, and slope angle (Deitschman and Green 1965; Cox, et al. 1960; Myers and Van Deusen 1960; Moessner 1948).

The delineation and classification of homogeneous land units from aerial photography using a combination of both forest overstory and topographic characteristics could result in a large number of different strata. To assign attributes to unsampled land units directly from samples within a similar class would require prestratification of field plots and a large number of field samples. Derivation of inplace information over extensive areas should, therefore, be based upon identifiable relationships between photointerpreted characteristics and ground attributes. Multivariate statistical methods can then be used to determine the degree of correlation between variables and to develop prediction equations.

Multiple regression and discriminant analysis techniques have been used to predict "inplace" attributes for unsampled land units. Tremble and Weitzman (1956) used multiple regression to predict site index from slope angle, aspect, slope position, and soil depth. Productivity classes were predicted from elevation, slope angle, aspect, and LANDSAT data using discriminant analysis (Getter and Tom 1977). Martin (1979) applied discriminant analysis to predict forest habitat types from topographic characteristics. The use of these statistical techniques in extensive "inplace" inventories has not been widely reported.

RESEARCH METHODS AND ANALYTICAL PROCEDURES

This study used high altitude photography to delineate forest land units and to describe these units using both forest overstory and topographic variables. The statistical association between the photointerpretation variables and selected ground attributes was then examined, and the photointerpretation variables were formulated into equations for predicting ground attributes. Study tasks involved identifying study areas, selecting materials and instruments, developing photointerpretation criteria, mapping forest land units, collecting field data and identifying statistical relationships.

STUDY AREAS

Two locations were selected for study: a small area for testing photointerpretation criteria against an intensive ground sample, and a larger area where the more extensive Montana Forest Survey data could be used for ground truth.

The first study area, encompassing the Virginia Peak 7-1/2 minute quadrangle in the Crazy Mountains of central Montana, was selected because it was considered to be representative of a larger working circle of the MFS (Long 1978).

The second study area, in the Bridger and Gallatin Mountain ranges in south-central Montana, was selected because recently completed Montana Forest Survey summary field plot data were available.

Approximately half of the field plots taken for the MFS in the Gallatin, Meagher, and Park Counties working circle were located in this second study area.

In this report, the first study area is referred to as the Virginia Peak study area; the latter is called the Bridger-Gallatin or MFS study area.

MATERIALS AND INSTRUMENTS

Specially prepared film diapositives of 1:76,000 scale quad-centered panchromatic photography were obtained for PI work. These diapositives were printed emulsion down so that delineations could be placed on the film base. The PI work was done using a Bausch and Lomb Zoom 95 stereoscope. In general, the actual PI delineations were made at 6 to 10 power magnifications (viewing scale approximately 1:10,000). A base map was prepared by determining the coordinates of terrain control points and plotting these points and the map border on a CALCOMP drum plotter. The base map was used to control the orientation of the annotated stereomodels in a Kelsh plotter. The delineated forest land units (FLUs) were mapped at a Kelsh model scale of 1:16,000. The compiled FLU map was later reduced to 1:24,000 and registered to the original quad map.

Ground measurements in the Virginia Peak area were made using a Brunton pocket transit, Relaskop, cloth tapes, steel diameter tapes, and increment borers. Ground measurements in the Bridger-Gallatin area followed Forest Survey procedures. The main difference between the two study areas was the collection of field data for analysis purposes in the Virginia Peak area, while MFS data was used to derive and assign ground attributes within the Bridger-Gallatin area.

PHOTOINTERPRETATION VARIABLES

Selection of PI criteria and variables emphasized image characteristics which were directly observable or measureable on the photographs, and deemphasized interpretation of ground conditions. For example, direct interpretations of forest stand conditions were rejected in favor of observations of image pattern, texture, crown size, etc. The PI variables used for Virginia Peak are listed in Table 1; the variables used in the Bridger-Gallatin area are listed in Table 2. The major differences between these two sets of PI variables is an increase from three to four categories for many variables and an increase in the number of categories for slope, aspect, and elevation. These changes were made to better represent the range of conditions that could be observed on the airphotos.

Most of the variables in Tables 1 and 2 could be determined directly from the airphoto. Pattern, texture, and height were estimated ocularly with reference to representative stands. Crown canopy

Table 1.—Photointerpretation Variables
for Virginia Peak Data

PATTERN (TREE DISTRIBUTION)
- Uniform
- Mottled
- Broken

OVERSTORY TEXTURE
- Coarse
- Medium
- Fine
- Two-Storied

CROWN CANOPY COVERAGE
- < 30%
- 30-50%
- 50-70%
- 70-80%
- > 80%

AVERAGE OVERSTORY HEIGHT
- < 40'
- 40-80'
- > 80'

AVERAGE OVERSTORY CROWN SIZE
- < 7'
- 7-14'
- > 14'

AVERAGE ELEVATION
- 2,000' classes

LAND & OVERSTORY MODIFIERS
- None
- Logged
- Fire
- Unknown Disturbance
- Rocky Surface
- Hardwoods (20-60%)
- Hardwoods (>60%)

ASPECT
- 315-45° (North)
- 45-135° (East)
- 135-225° (South)
- 225-315° (West)
- Flat (<5° Slope Angle)

SLOPE ANGLE
- <5° (<9%)
- 5-18° (9-32%)
- 18-30° (32-58%)
- >30° (58%)

SLOPE POSITION
- Ridge
- Midslope
- Valley Bottom

CONTOUR CURVATURE (FORM)
- Concave
- Straight
- Convex
- Undulating

Table 2.—Photointerpretation Variables
for Montana Forest Survey Data

PATTERN (TREE DISTRIBUTION)
- Uniform
- Mottled
- Partially Broken
- Broken

OVERSTORY TEXTURE
- Coarse
- Medium Coarse
- Medium Fine
- Fine
- Two-storied

CROWN CANOPY COVERAGE
- < 30%
- 30-50%
- 50-70%
- 70-80%
- > 80%

AVERAGE OVERSTORY HEIGHT
- < 30'
- 30-60'
- 60-90'
- > 90'

AVERAGE OVERSTORY CROWN SIZE
- < 7'
- 7-12'
- 12-16'
- > 16'

AVERAGE ELEVATION
- 500' classes

CONTOUR CURVATURE (FORM)
- Concave
- Straight
- Convex
- Undulating

LAND & OVERSTORY MODIFIERS
- None
- Logged
- Fire
- Unknown Disturbance
- Rocky Surface
- Mass Failure Surface
- Breaklands
- Hardwoods (20-60%)
- Hardwoods (>60%)

ASPECT
- 0-45°
- 45-90°
- 90-135°
- 135-180°
- 180-225°
- 225-270°
- 270-315°
- 315-360°
- Flat (<5% Slope Angle)

SLOPE ANGLE
- 1-5%
- 5-15%
- 15-25%
- 25-35%
- 35-45%
- 45-55%
- 55-65%
- 65-75%
- 75-85%
- > 85%

SLOPE POSITION
- Ridge
- Midslope
- Midslope Drain
- Valley Bottom

coverage and crown size were measured with reference templets. Slope angles were determined by reference to representative slope lengths with angle measures obtained from topographic maps. Aspect and slope position were estimated directly from the airphoto, and circle templets were used for contour curvature determinations. Elevations for delineated units were taken from topographic maps. The variable "modifier" indicated the amount of vegetation or surface disturbance, or observable variation from a "normal" undisturbed stand.

FOREST LAND UNIT DELINEATION AND MAPPING

Actual photointerpretation (PI) consisted of two steps: (1) delineation of forest land units (FLUs), and (2) classification of the delineated FLU. In placing boundary lines, the interpreter did not initially attempt to identify specific categories of PI variables, but rather sought to delineate observable tracts, homogeneous in terms of forest cover and topography. After an area had been delineated, the interpreter recorded the specific categories for each PI variable within each delineated tract on a separate coding form. A unique sequential number identified each delineated FLU on both the photo and coding sheet. The coded PI characteristics were key-punched and entered into a computer file. A sample printout of the PI variables coded for each FLU is shown in the Appendix.

Minimum mapping unit size was determined on a sliding scale. Areas of forest versus nonforest were mapped to as small a unit as 10 acres. Adjacent forested land units were delineated down to 20-acre tracts if they differed on at least two PI variables, and were delineated to as small as 40 acres when they differed on only one characteristic. An example of a delineated diapositive is shown in Figure 1.

The next procedure was to map the delineated forest land units for the Virginia Peak quadrangle and three quadrangles in the Bridger-Gallatin area (Sedan NW, NE, & SE). The purpose for mapping was threefold: (1) to demonstrate methods for photogrammetrically transferring the photo delineated land units to a base map, (2) to provide illustrative maps of the forest land units, and (3) to provide a ready means for locating the Virginia Peak field sample plots within their respective land units.

One method of photogrammetrically mapping the delineated land units used a Kelsh stereoscopic plotter. The most critical aspect of this process was the identification of properly located image points on the aerial photos for which ground coordinates could be obtained. These image points are the control points used in orienting the aerial photographs in the Kelsh plotter to obtain a correct photo-to-map transfer. Ground coordinates for the control points were obtained by scaling their ground positions from 7-1/2 minute

Figure 1.--Delineated aerial photo for Sedan SE

quadrangle topographic maps using an electronic digitizer. Having identified control points and plotted their ground positions on a compilation base, the delineated diapositive and its stereomate were placed in the Kelsh plotter and oriented to the mapped control. The delineated FLUs were drawn on the compilation base along with their sequential identification number. Features such as roads and major streams were also plotted from the airphotos. The completed compilation sheet was redrafted, photographically reduced to 1:24,000 scale (2.64 inches per mile), and photocomposited as an overlay to a 7-1/2 minute base map quadrangle. Comparison of the plotted roads and streams with the 7-1/2 minute base map provided a check on the accuracy of the photo-to-map transfer. A typical forest land unit overlay superimposed onto the Sedan SE 7-1/2 minute quadrangle is shown in the Appendix.

In addition to the Kelsh plotter, an analytical photogrammetric mapping method was used for photo-to-map transfer on the Virginia Peak and Sedan SE quadrangles. This analytical approach was conducted by the USDA-Forest Service, Geometronics Development Group (WO), using duplicates of the delineated diapositives and control points. The principal element in the analytical process is a digital terrain model, a grid of x, y, and z (elevation) coordinates, forming a mathematical representation of the land surface. The terrain model used was developed by the Defense Mapping Agency from 1:250,000 scale topographic maps. The first step in the analytical photo-to-map transfer was to digitize the delineated forest land units for input to a computer file. The control points were then used to develop a set of transformation constants which, when combined with data from the digital terrain model, mathematically adjusted the photo coordinates of the digitized FLUs to corrected map coordinates. Output from this procedure was a computer drawn map overlay of the forest land units, including their appropriate identification numbers, scaled to a 7-1/2 minute quadrangle, and an acreage listing of each mapped unit. The forest land unit overlay for the Sedan SE quadrangle superimposed on a topographic map base is shown in the appendix.

FIELD SAMPLING AND GROUND ATTRIBUTE COLLECTION

An intensive field sample was conducted for the Virginia Peak area to test the suitability of the delineated forest land units for predicting ground attributes. The sample design consisted of a number of transects, each having five variable (basal area factor) plots located 100 meters apart. No effort was made to prestratify plot selection or to locate plots within specific land units. The beginning plot was randomly selected on a 100 meter grid intersection of the Universal Transverse Mercator (UTM) coordinate system, and the traverse direction was randomly selected from one of the four grid quadrants, north, south, east, or west. Forty-two transects were run, with forest data collected on 161 plots (some sample points occurred in nonforest types). The field data collection form used at each sampling point is shown in the Appendix.

The collected data were key-punched and computer-processed to calculate average-per-acre values and other desired measures of ground attributes for each plot. The processing routines used algorithms similar to the Montana Forest Survey (MFS). The ground attributes determined for each plot for Virginia Peak and those obtained from the MFS are listed in Table 3.

The Virginia Peak field plots were readily located to their respective forest land unit by overlaying a plot of the grid intersections on the land unit map overlay. The photointerpreted characteristics associated with each plot were combined with the calculated ground attributes in a computer file for later statistical processing.

Field sampling was conducted in two phases. Results from the first phase were used to estimate the number of field plots needed to reach a target five percent standard error for the Virginia Peak study area. Table 4 shows the final variance, standard error of the mean, and five percent confidence interval for the mean for each ground attribute.

Ground attributes from the Montana Forest Survey were obtained from location summaries provided by the Montana Division of Forestry. Each MFS field location was plotted on the aerial photographs and the landscape around each location delineated and classified. The PI characteristics and MFS attributes were combined in a computer file for later processing. Ground attributes and PI characteristics were collected for 78 forested MFS locations. The ground attributes obtained for each MFS location are listed in Table 3.

STATISTICAL PROCEDURES

Statistical analyses were performed to determine the degree of association between the PI variables and ground attributes and to predict the ground attributes (dependent variables) from the PI characteristics (independent variables). For each study area, a computer file was created containing the PI variables and ground attribute values associated with each field sample plot or MFS field location.

The dependent ground variables were measured on two different scales. Volume, growth, site index, yield, and stocking were considered to be interval (continuous) scale variables, and habitat type and forest type were considered nominal (categorical) scale variables. The scale of the dependent variables determined the statistical procedure used. Depending on the statistical procedure,

Table 3.—Ground Attributes

VIRGINIA PEAK	MONTANA FOREST SURVEY
Total Cubic Foot Volume (Ft^3/Ac)	Total Cubic Foot Volume (Ft^3/Ac)
Total Board Foot Volume (BFS/Ac)	Total Board Foot Volume (BFS/Ac)
Average Site Index (50 Yr)	Average Site Index (50 Yr)
Average Unadjusted Yield (Ft^3/Ac/Yr)	Weighted Unadjusted Yield (Ft^3/Ac/Yr)
Growing Stock Annual Cubic Foot Growth (Ft^3/Ac/Yr)	Growing Stock Annual Cubic Foot Growth (Ft^3/Ac/Yr)
Growing Stock Annual Board Foot Growth (BFS/Ac/Yr)	Growing Stock Annual Board Foot Growth (BFS/Ac/Yr)
Habitat Type	Growing Stock Per Acre Stocking (%)
	Forest Type
	Habitat Type

Table 4.—Evaluation of Virginia Peak Field Sample Accuracy

GROUND ATTRIBUTES	VARIANCE	STANDARD ERROR OF THE MEAN	CONFIDENCE INTERVAL AT 0.05 p
Total Cubic Foot Volume	5,025,508	5.7%	11.2%
Total Board Foot Volume	88,592,144	6.1%	12.0%
Average Site Index	64	1.9%	3.5%
Average Unadjusted Yield	246	3.2%	6.4%
Growing Stock Annual Cubic Foot Growth	384	6.8%	13.7%
Growing Stock Annual Board Foot Growth	11,367	7.1%	13.9%

the independent PI variables were treated as either nominal or ordinal scale variables. The data were analyzed using computer routines from SPSS (Statistical Package for the Social Sciences, Nie et al. 1975).

Analysis of Ground and PI Variables

Table 5 shows the mean, standard error of the mean, standard deviation, and range of each continuous scale dependent variable in the Virginia Peak (VP) and Bridger-Gallatin (MFS) data sets.

Although the range and standard deviation for most variables is greater for the Virginia Peak data then the MFS data, the larger Virginia Peak sample size generally produced lower standard error percentages. Both data sets indicate comparable and acceptable sampling errors. The figures in Table 5 suggest that two different populations were sampled.

A preliminary analysis of variance indicated that two Virginia Peak variables, cubic foot and board foot volume, could each be stratified into two groups, based on the PI variable "land and overstory modifier." The modified group data represented forest land units which had been recently disturbed or which contained high percentages of hardwoods in the overstory. The nonmodified group were essentially mature, undisturbed coniferous forest stands. This stratification permitted examination of the independent PI variables and the dependent ground variables separately for the two groupings. The MFS data set was not stratified because the sample size was too small to permit reliable groupings.

A statistical measure of significance and degree of association was computed between each PI and ground variable. For continuous scale, dependent variables, e.g., volume, site index, etc., significant differences between category means were detected using one-way analysis of variance (Fisher's F test); statistical association was computed using eta squared. Eta squared, or the correlation ratio, is a measure of the proportion of variance in a dependent variable accounted for by an independent variable. It is an index of the degree to which values of a dependent variable can be predicted from the classes of an independent variable.

For dependent ground variables measured on a nominal scale (habitat and forest type), statistical significance was measured by a Chi-square test and the degree of association by lambda (Guttman's coefficient). Lambda measures the percentage improvement in predicting categories of a dependent variable when categories of an independent variable are known. Lambda, like eta, ranges in value from zero to one.

Table 5.--Statistical Characteristics of Continuous Dependent Variables

	Number of Samples (N)		Mean ($\bar{y}$)		Standard Error of the mean ($s\bar{y}$)		Percent Standard Error of the mean (% $s\bar{y}$)		Standard Deviation (s)		Range (Rg)	
ATTRIBUTE	VP	MFS	VP	MFS	VP	MFS	VP	MFS	VP	MFS	VP	MFS
Total Cubic Foot Volume	161	76	3,093.7	1,589.1	177.1	128.7	5.7%	8.1%	2,247.8	1,122.3	8,340.0	5,308.0
Nonmodified Cubic Foot Volume	112	--	4,041.4	--	174.0	--	4.3%	--	1,841.0	--	7,955.0	--
Modified Cubic Foot Volume	46	--	988.1	--	218.6	--	22.1%	--	1,482.7	--	6,892.0	--
Total Board Foot Volume	161	76	12,120.5	4,679.3	741.8	444.6	6.1%	9.5%	9,412.3	3,876.0	39,864.0	16,011.0
Nonmodified Board Foot Volume	112	--	15,879.6	--	777.0	--	4.9%	--	8,233.1	--	38,768.0	--
Modified Board Foot Volume	46	--	3,758.1	--	830.8	--	22.1%	--	5,635.0	--	26,293.0	--
Cubic Foot Growth	161	75	22.1	26.1	1.5	2.3	6.8%	8.8%	19.6	20.1	124.0	97.0
Board Foot Growth	161	76	118.4	98.5	8.4	9.9	7.1%	10.1%	106.7	86.1	694.0	344.0
Average Site Index	141	73	37.7	38.1	0.7	1.0	1.9%	2.6%	8.0	8.5	40.0	41.0
Average Annual Yield	140	73	40.5	41.8	1.3	1.6	3.2%	2.6%	15.7	13.3	79.0	91.0
Average Stocking	--	76	--	75.8	--	4.1	--	5.4%	--	35.1	--	149.0

These univariate statistics of significance and association provided measures for the importance of the relationship between individual independent PI variables and each dependent ground variable. Additional multivariate analyses were performed to evaluate the combined effects of the independent PI variables for predicting ground attribute variables.

Prediction Equations

Prediction equations were formulated using multiple linear regression techniques for the continuous scale dependent variables (volume, growth, etc.), and using discriminant analysis for the nominal scale dependent variables (habitat type and forest type).

The first step in the multiple regression procedure was to create a "dummy" variable for each category of each independent PI variable. A dummy variable was formed by coding each category of each independent variable as a separate variable and assigning a score (one or zero) for all cases depending upon their presence or absence in each of the categories. The dummy variables were entered into the multiple linear regression procedure in a step-wise manner, based upon the respective contribution of each dummy variable toward the reduction in the residual sums of squares.

The regression equations developed for each of the continuous scale dependent variables have the linear form:

$$Y = a + b_1D_1 + b_2D_2 \ldots. + b_nD_n$$

The constant "a" and the coefficients, b_1, b_2, etc., are computed through a recursive least squares procedure. The "Ds," or dummy variables, assume the value zero or one. For each dependent variable, the predicted value, Y', is calculated using only one term for each PI variable. For example, using only the pattern and texture variables, the prediction equation appears first as:

$$Y = a + b_1DP_1 \text{ (uniform) } b_2DP_2 \text{ (mottled) } + b_3DT_1 \text{ (coarse) } + b_4DT_2 \text{ (medium) } + b_5DT_3 \text{ (fine)}$$

and reduces to:

$$Y' = a + b_1DP_1 + b_5DT_3$$

for an FLU having uniform pattern and fine texture.

All of the independent PI variables were converted to dummy variables, although some of them consisted of ordinal or interval scale classes. These class values were not used because of uncertainty of linear relations between the independent PI and dependent variables. Also, the class values were considered to be too broad to adequately represent continuous values. No interaction dummy variables were created because an N-way analysis of variance indicated no significant interaction effects.

The regression procedure provided a number of statistics for evaluating the reliability and significance of the prediction equations. The R^2 statistic measures the proportion of variation in a dependent variable accounted for by the independent variables. The standard error of the estimate is a measure of the dispersion of the actual values from the predicted values. The F-ratio is a measure of the overall goodness of fit of the regression equation to the actual data, or the significance of the equation. These statistics provided a means for evaluating the predictive power of the independent PI variables and for comparing the Virginia Peak data with the Bridger-Gallatin data.

Prediction equations for the nominal scale dependent variables (habitat type and forest type) were formulated using discriminant analysis. This technique produces a separate prediction equation (similar in form to a regression equation) for each category of the dependent variable. By solving each of the equations for each case, a set of discriminative scores were generated. These scores were then converted into probabilities for predicting the dependent variable category for each case. Comparison of the predicted category frequency with the actual frequency gives the percentage of correctly classified categories for each dependent variable.

Theoretically, the independent variables used in discriminant analysis should be interval scale measures. However, ordinal values, low to high rankings, can be used in place of continuous values to derive the prediction equations. This substitution results in some loss in the efficiency of the model.

RESEARCH RESULTS

EMPIRICAL INDICATORS

The procedures developed for forest land unit delineation and classification are considered to be operationally workable. Using zoom stereoscopes with film transparencies, forest overstory, and topographic characteristics can be readily detected, measured, interpreted, and delineated on the quad-centered aerial photography. By sequentially numbering each delineated FLU and coding its characteristics on a separate coding sheet, a large amount of data can be captured without resorting to lengthy and complex map legends. Experience suggests that, after a training period of 1 month or less, an interpreter can delineate and classify about 20 FLUs per hour on a sustained basis.

The experience gained in using the photointerpretation classification criteria on four different quadrangles resulted in revisions to the classification system (Tables 1 and 2). Particularly noteworthy is the change from three to four categories for many variables. It was found that with three categories, most units were classified as the middle category, with the other categories reserved for extreme conditions. A fourth class was added in order to properly depict differences among average conditions. When the revised PI criteria were used to classify Montana Forest Survey field plots, it was found that the variations observable on the airphotos were better described by the new criteria than by the original Virginia Peak criteria.

Additional revisions to the classification variables may be desirable. Inclusion of other landscape descriptors, such as the watershed order, geomorphic genesis or soil type of a delineated unit, may contribute to the improvement of prediction equations. Expanding the number of PI variables may, however, affect the reliability of the prediction equations. If the field sample is too small, the additive effects among the different possible combinations of PI variables may not be adequately represented in the prediction equations.

Using the original Virginia Peak PI classification variables, over 600 land units were delineated on an average 7-1/2 minute quadrangle. The average stand size was about 50 acres on the two quads for which land unit acreages were determined. The number of unique forest unit types (units that differed on at least one PI variable) averaged over 450 per quad. It appears that the PI land unit classification system did, indeed, capture the diversity of the forested landscape.

ANALYTICAL INDICATORS

The analytical or statistical results are presented in the form of univariate tests and multivariate tests. The univariate tests indicate the significance and degree of association between each PI variable and each ground variable. The multivariate tests show the statistical significance between a single dependent ground variable and combinations of the independent PI variables. They also indicate the reliability with which ground variables can be predicted from combinations of the PI variables. The specific univariate or multivariate procedure employed was determined by the scale-of-measure for the dependent ground variable, i.e., nominal (categorical) or interval (continuous).

Significance of Forest Land Unit Classification

Tables 6A and 6B present the result of the univariate tests of significance between the PI variables and the interval scale ground variables for the Virginia Peak and MFS data, respectively. In

Table 6A, two ground determined independent variables (aspect and elevation) were added to the list of PI variables. The ground aspect variable represents nine classes of aspect (eight 45° intervals and flat) as compared to five classes for the PI aspect variable. Ground elevations were grouped by 500-foot intervals as compared to 2,000 foot intervals for the PI elevation variable. These ground-determined variables were added to provide comparability with the MFS data.

Overall, the forest overstory PI variables (pattern, texture, canopy cover, height, and crown size) had a greater degree of association with the ground variables than the topographic PI variables (slope, aspect, etc.). All of the PI variables, except form, were significantly associated with at least one dependent ground variable in at least one of the study areas. The forest overstory PI variables were more closely associated with current vegetation conditions, such as volume, while the topographic variables were largely associated with site potential, such as site index and yield. Annual growth was associated with both the overstory and topographic PI variables.

Major differences exist between the two tables. In the MFS study area (Table 6B), none of the topographic variables, except elevation, were significant. A probable explanation for this is the lack of topographic variability in the Bridger-Gallatin mountains. This area is characterized by steep, rectilinear mountain slopes with intervening narrow stream bottoms.

In contrast, the Virginia Peak area contains both steep slopes along with more gently sloping forested benches and wider stream valleys. Another factor may have been the larger number of PI slope and aspect classes used for classifying the MFS data. The number of slope and aspect classes used in the Virginia Peak area was about half the number used in the MFS area. When a larger number of aspect classes were tested against the Virginia Peak data (ground aspect, Table 6A), the statistical significance of the association was substantially less than when only five classes were tested. Had the slope and aspect classes used in the MFS area been combined into fewer classes, their statistical significance may have been greater.

The absence of statistical significance between form and any dependent variable is largely due to the lack of an adequate sample in any of the form categories other than "straight." In the MFS area all but two of the 76 sample points were classed as "straight." In both the Virginia Peak and MFS study areas, the topography is quite sharp with few rounded convex or concave slopes. In areas expressing more "mature" topography where streams and other erosional processes have created more rounded slopes, contour curvature (form) may be a more important PI variable.

Table 6A.—Univariate Significance and Degree of Association between Each PI Variable and Each Interval Scale Ground Variable (Virginia Peak)

	Nonmodified Cubic Foot Volume		Modified Cubic Foot Volume		Nonmodified Board Foot Volume		Modified Board Foot Volume		Cubic Foot Growth		Board Foot Growth		Average Site Index		Average Annual Yield	
PI Variables	F	eta ^{2}	F	eta ^{2}	F	eta ^{2}	F	eta ^{2}	F	eta ^{2}	F	eta ^{2}	F	eta ^{2}	F	eta ^{2}
Pattern	2.58*	.05	2.09*	.12	1.35	.02	2.87*	.12	.11	.00	.03	.00	.26	.00	4.06**	.06
Texture	3.08**	.08	11.51**	.21	6.78**	.16	10.68***	.20	11.45***	.20	13.52***	.23	17.76***	.28	27.38***	.38
Canopy Cover	1.91	.05	4.62***	.31	.73	.02	4.01***	.28	2.60**	.07	3.11**	.08	4.47***	.12	5.89***	.15
Height	.08	.00	13.36***	.23	.36	.01	12.42***	.22	9.26***	.12	11.26***	.14	14.62***	.17	15.00***	.18
Crown Size	3.17**	.05	10.17	.19	5.64***	.09	9.59***	.18	11.19***	.14	12.32***	.14	11.09***	.14	16.31***	.19
Modifier	—	—	7.33***	.25	—	—	12.81***	.37	1.72	.04	2.37*	.05	2.46*	.05	2.46*	.05
PI Aspect	3.74***	.12	8.64***	.38	2.23*	.07	11.78***	.46	2.18*	.06	2.54**	.07	2.75**	.07	9.42***	.22
Ground Aspect 1/	1.86*	.13	3.24	.36	1.89*	.13	6.28***	.52	.69	.04	.78	.04	.74	.04	3.97***	.19
Slope	1.76	.05	.29	.01	.82	.02	.12	.01	3.96***	.08	4.33***	.09	7.05***	.13	23.23***	.34
Position	.29	.01	.90	.02	1.08	.02	.35	.01	7.04***	.09	7.42***	.10	3.91**	.04	15.20***	.18
Form	1.15	.03	.31	.01	.86	.02	.58	.03	.09	.00	.20	.00	.09	.00	.71	.02
PI Elevation	1.03	.02	.08	.00	.22	.00	.02	.00	4.73**	.06	4.79***	.06	5.19***	.07	14.52***	.17
Ground Elevation 2/	1.19	.04	1.19	.08	1.30	.05	2.97*	.17	3.54***	.09	3.68***	.10	6.49***	.16	14.00***	.29

1/ Aspect categorized into nine groups based on ground measurements.

2/ Elevation categorized into 500 foot classes based on map estimates.

* Significant at $p > 0.1$ level ** Significant at $p > 0.05$ level *** Significant at $p > 0.01$ level

Table 6B.—Significance and Degree of Association between Each PI Variable and Each Interval Scale Ground Variable (MFS Data)

Variables	Cubic Foot Volume		Board Foot Volume		Cubic Foot Growth		Board Foot Growth		Average Site Index		Average Annual Yield		Average Stocking	
	F	eta ^{2}	F	eta ^{2}	F	eta ^{2}	F	eta ^{2}	F	eta ^{2}	F	eta ^{2}	F	eta ^{2}
Pattern	12.55***	.34	5.10***	.18	2.30*	.07	4.54***	.16	1.51	.06	1.53	.06	14.70***	.40
Texture	1.41**	.06	4.07***	.15	.67	.03	2.99**	.11	2.71*	.11	2.01	.08	.46	.02
Canopy Cover	8.70***	.33	4.22***	.19	2.86**	.14	3.47**	.16	1.40	.08	1.44	.08	12.74***	.42
Height	9.90***	.22	17.10***	.32	1.14	.03	3.71**	.09	.63	.02	3.80**	.10	3.17*	.08
Crown Size	6.51***	.15	7.87***	.18	1.63	.04	2.30	.06	.77	.02	.80	.02	2.14	.06
Modifier	3.87***	.22	2.39**	.15	.61	.04	1.94*	.12	1.26	.07	1.64	.09	8.11***	.37
Aspect	.50	.06	.50	.05	.83	.09	.90	.10	1.40	.13	1.31	.12	1.12	.12
Slope	.86	.07	.60	.05	.54	.05	1.79	.13	1.51	.10	.52	.04	1.12	.09
Position	.49	.02	.41	.02	.22	.01	.34	.01	.99	.04	.23	.01	1.29	.05
Form	.27	.01	.45	.01	.11	.00	.94	.03	1.76	.05	.58	.02	.40	.01
Elevation	2.08**	.22	2.57**	.26	.35	.05	.42	.05	1.33	.16	.67	.09	.93	.11

Another major difference between the two tables is the relative importance of the PI variables "pattern" and "texture." In the MFS area, pattern appeared to be a much more important variable than texture. Texture, largely influenced by the irregularity of the overstory surface, indicates age and size variability within a stand. In the Virginia Peak area many stands are older, composed of larger and more variable size trees, and often uneven aged; in the MFS area, most stands are more homogeneous in terms of tree size and age. The different texture classes thus represented greater stand differences in the Virginia Peak than in the MFS area. Also, in the Virginia Peak area most stands are relatively dense and unbroken, while in the MFS data area many stands have scattered openings and a more broken pattern of tree distribution. Pattern therefore became the more important variable in describing stands in the MFS study area.

Differences also exist between similar dependent ground variables, such as between board foot and cubic foot volume. For example, texture and crown size are more closely associated with board foot volume than to cubic foot volume, while pattern and canopy cover are related more to cubic foot than to board foot volume. These differences are expectable because texture and crown size like board foot volume are more reflective of tree size, while pattern and canopy cover, like cubic foot volume, are more reflective of total stand density.

Table 7 shows the significance and degree of association between each nominal scale dependent ground variable and each independent PI variable. Like the interval scale ground variables, the results for the Virginia Peak data are substantially different from the MFS data. All of the independent variables in the Virginia Peak area were significantly associated with the habitat type phases. However, the values for lambda show this association to be weak, that is, knowledge of any single PI variable increases our ability to predict habitat type phase by no more than 8 percent.

For the MFS study area, only the PI variable "elevation" was significantly associated with habitat type phase. The strength of this association was relatively high (lambda was 0.21). A number of PI variables were significantly associated with the MFS forest type, but only elevation was strongly related to forest type. The weak association between MFS habitat type phases and the independent variables may be due to the large number of habitat type phases. The test results might been more positive had these phases been combined into fewer groups. All the statistics in Tables 6 and 7 underestimate the significance and association between each PI and each ground variable. This underestimation arises by treating all the PI variables as nominal scale variables, when in fact most of these variables could be considered as ordinal measures.

Table 7.—Significance and Degree of Association between Each Pi Variable and Each Nominal Scale Ground Variable

PI Variable	VP HABITAT TYPE PHASE 1/		MFS HABITAT TYPE PHASE 2/		MFS FOREST TYPE 3/	
	CHI-SQUARE (X^2)	LAMBDA (λ)	CHI-SQUARE (X^2)	LAMBDA (λ)	CHI-SQUARE (X^2)	LAMBDA (λ)
Pattern	47.34*	0.00	70.20	.08	35.01*	0.00
Texture	133.20***	.05	55.77	.06	18.55	0.00
Canopy Cover	128.21***	.08	94.87	.10	52.22**	0.00
Height	104.22***	.07	41.25	.06	28.44**	0.00
Crown Size	97.50***	.04	40.90	.05	9.70	0.00
Modifier	193.35***	.04	109.66	.05	52.29**	0.00
PI Aspect	175.40***	.07	149.72	.10	52.87	0.00
Ground Aspect	200.12***	.03	N/A	N/A	N/A	N/A
Slope	130.24***	.06	91.99	.08	39.21	.03
Position	68.99***	.05	40.17	.05	17.43	.03
Form	75.08**	.03	47.30	.03	6.09	.03
PI Elevation	87.55***	.02	268.03***	.21	139.67***	.27
Ground Elevation	207.32***	.06	N/A	N/A	N/A	N/A

1/ Based on 18 categories
2/ Based on 28 categories
3/ Based on 9 categories

Photointerpretation Prediction Results

Table 8 summarizes the results of the multiple linear regression analysis performed on the interval scale dependent variables (volume, growth, site index, yield, and stocking). The R^2 values range from a low of .50 to a high of .82. The MFS data had slightly higher R^2 values than the Virginia Peak data. The average residual shown in Table 8 is the average absolute difference between the actual dependent variable values and the predicted value. These values are generally lower for the MFS data than for the Virginia Peak data. As indicated by the F-ratios, all but one of the derived prediction equations were significant at the .001 probability level.

The regression statistics for the two study areas are similar. Although the Virginia Peak cubic foot and board foot volume dependent variables were stratified into modified and nonmodified groups, it appears the overall results are comparable with the MFS data. The MFS data had a higher R^2 value for cubic foot volume than Virginia Peak, but a lower R^2 for board foot volume. Comparison of the R^2 for site index and average yield between the two areas shows a similar trend, higher site index R^2 for MFS data, but lower R^2 for average yield. The R^2 for both cubic foot and board foot growth is higher for MFS data than Virginia Peak data, but the SEE and average residual are nearly identical for the two areas.

The similarity of the regression analysis results for the different ground variables was surprising. Because attributes such as volume and stocking are directly observable, and site index and yield are influenced by permanent physical characteristics of the land, these variables should lend themselves to prediction using remotely sensed data. Growth, conversely, is highly variable over time and subject to temporal nonpermanent physical conditions such as weather, insect infestations, etc. The degree of success achieved in predicting growth was unexpected.

Because a number of individual sample points often occurred within the same Forest Land Unit (FLU) having identical PI characteristics, the Virginia Peak data were grouped by FLU and reanalyzed. This required calculating the average value of each interval scale ground variable from all samples occurring within the same FLU. These average values were combined with the PI variables interpreted for each FLU creating a new aggregated data set for the 79 sampled FLUs in the Virginia Peak study area.

Table 9 presents the regression results for the aggregated Virginia Peak data. Aggregating the Virginia Peak sample data increased the R^2 and decreased the SEE and average residual for every dependent variable. This improvement in the regression statistics using average FLU ground values suggests that the PI variables were quite descriptive of the natural variability within forest stands.

Table 8.—Summary Regression Results

	R^2	F	STANDARD ERROR OF THE ESTIMATE (SEE)	AVERAGE RESIDUAL $\frac{\lvert(Y-Y')\rvert}{N}$
Cubic Foot Volume				
MFS	.65	4.76***	783.4	518.1
Virginia Peak Nonmodified	.53	3.71***	1,408.0	959.0
Virginia Peak Modified	.75	8.01***	872.9	497.7
Board Foot Volume				
MFS	.60	3.41***	2,939.5	1,930.0
Virginia Peak Nonmodified	.59	4.42***	5,862.5	3,935.9
Virginia Peak Modified	.82	10.72***	2,310.7	1,356.4
Cubic Foot Growth				
MFS	.64	3.14***	15.1	9.7
Virginia Peak	.50	3.90***	12.7	9.0
Board Foot Growth				
MFS	.58	2.35***	70.1	43.0
Virginia Peak	.52	4.42***	67.0	48.5
Average Site Index				
MFS	.65	2.62***	6.6	3.7
Virginia Peak	.55	6.06***	5.8	4.3
Average Yield				
MFS	.55	2.03**	9.5	5.2
Virginia Peak	.68	9.57***	9.8	6.9
Average Stocking				
MFS	.74	5.13***	22.3	13.6
Virginia Peak	N/A	N/A	N/A	N/A

Table 9.—Regression Results for Virginia Peak Data
Averaged by Forest Land Units

	R^2	F	STANDARD ERROR OF THE ESTIMATE (SEE)	AVERAGE RESIDUAL $\frac{\lvert Y-Y' \rvert}{N}$
Total Cubic Foot Volume				
All FLUs 1/	.83	7.07***	1,075.2	641.6
Nonmodified FLUs 2/	.73	3.06***	1,088.4	593.6
Modified FLUs 2/	.99	80.45***	162.1	54.7
Total Board Foot Volume				
All FLUs	.84	7.62***	4,238.6	2,582.7
Nonmodified FLUs	.80	5.07***	3,990.7	2,368.2
Modified FLUs	.99	69.41***	652.7	246.2
Total Cubic Foot Growth	.66	2.89***	12.1	7.0
Total Board Foot Growth	.68	4.04***	60.5	38.0
Average Site Index	.72	3.80***	4.6	2.8
Average Yield	.86	8.33***	6.2	3.7

1/ A total of 79 FLUs were sampled.

2/ A total of 58 FLUs were nonmodified and 19 FLU's were modified.

Results of the discriminant analysis classification procedure were less than desired, but still considered acceptable. Table 10 shows the classification results. The phases, types, groups, and series shown in Table 10 represent different levels in the habitat type classification heirarchy, with phase being the most detailed level and series the least. The series level describes the potential climax tree species for an area, while the phase level describes both the potential climax overstory and the understory community composition.

Overall, 39 percent of the habitat type classes were correctly predicted for Virginia Peak and 25 percent for the MFS study area, while forest types were correctly classified in 63 percent of the samples. At the series level, habitat type classification results increased to 73 percent and 71 percent for the Virginia Peak and MFS data, respectively. Table 10 also shows the classification results when either the first or second most probable class was accepted as the correct class. In other words, Table 10 shows that habitat series in the MFS area could be correctly classified into one of two probable series 85 percent of the time.

Table 11, the classification matrix for MFS forest types produced by discriminant analysis, shows the different classes predicted for the actual cases. Douglas-fir was the most common type encountered. It was misclassified 16.7 percent of the time as lodgepole pine, and 9.5 percent as being noncommercial. In the MFS area, however, almost all of the noncommercial stands were composed predominantly of Douglas-fir. The lodgepole pine type was the most misclassified type. This result is expected because of the wide variety of sites which support lodgepole in the Bridger and Gallatin mountains, and because of its intermixture with most of the other forest types.

The poor discriminant analysis classification results can be attributed in part to the use of ordinal scale, instead of interval scale, independent PI variables. The discriminant prediction equations might be improved by further reordering or transformation of the independent variables, in order to provide a more linear relation between the PI variables and habitat or forest types.

The intent of the prediction procedures is not to describe specific attribute values for individual sites, but to give information about probable average conditions existing at a particular time for different types of land units. It is anticipated that in an operational program, the predicted attribute values or classes would be generalized into broader categories or value ranges. These ranges would then be used to describe delineated land units. Overall, the results of the prediction procedures are comparable to those for extensive inventories, and the results of the volume estimation for the aggregated forest land units show relatively high R^2s.

Table 10.—Discriminant Analysis Classification Results

	Percent Correctly Classified	
	MOST PROBABLE GROUP	FIRST AND SECOND MOST PROBABLE GROUP
Virginia Peak Habitat Type		
Phase (18 Phases)	37.3	58.4
Type (15 Types)	39.1	60.3
Groups (12 Groups)	41.6	60.3
Series (3 Series)	73.3	80.8
MFS Habitat Types		
Phase 28 Phases)	23.3	42.5
Type (25 Types)	24.7	48.0
Groups (13 Groups)	53.4	65.8
Series (7 Series)	71.2	84.9
MFS Forest Types (9 Types)	62.7	81.3

Table 11.—MFS Data Forest Type Classification Matrix 1/

	PREDICTED								
ACTUAL	Douglas-fir	Engelmann spruce	Engelmann spruce Subalpine fir	Lodgepole pine	Aspen	Cottonwood	Noncommercial	Pinyon-Juniper	Whitebark - Limber pine
Douglas-fir	27 64.3%	——	——	7 16.7%	1 2.4%	2 4.8%	4 9.5%	1 2.4%	——
Engelmann Spruce	——	3 100.0%	——	——	——	——	——	——	——
Engelmann spruce Subalpine fir	1 11.1%	——	7 77.8%	1 11.1%	——	——	——	——	——
Lodgepole pine	1 8.3%	1 8.3%	3 25.0%	4 33.3%	——	——	2 16.7%	——	1 8.3%
Aspen	——	——	——	——	1 100.0%	——	——	——	——
Cottonwood	——	——	——	——	——	1 100.0%	——	——	——
Noncommercial	——	——	——	——	——	——	1 100.0%	——	——
Pinyon-Juniper	——	——	——	——	——	——	——	2 100.0%	——
Whitebark-Limber pine	——	——	——	——	——	——	——	——	1 100.0%

1/ Upper number is actual number of samples, lower number is percent of actual type.

SAMPLE PRODUCTS

The Kelsh plotted and computer plotted forest land unit overlays for the Sedan SE quadrangle are shown in the Appendix. The Kelsh overlay has been redrafted and photographically superimposed on a topographic base. Comparison between the two differently constructed overlays showed a very close match of land unit boundaries. Direct comparison of the Kelsh and computer produced overlays for the Virginia Peak quad, however, showed numerous positional shifts between boundary lines. One possible explanation for these shifts is that different control points were used to produce the Virginia Peak overlays. Greater care was taken in choosing control points for the Sedan SE quad, and identical control was used in both mapping methods.

The importance of good photogrammetric control in the mapping process cannot be overemphasized, as evidenced by the Virginia Peak map overlays. Control in forested areas can be especially difficult because of the lack of well-defined features in areas of continuous forest cover. In addition, because most forested areas are quite rural, these areas receive low priority for map revision or new mapping. These conditions can lead to a real deficiency in the availability of control.

A computer printout of the PI characteristics describing each delineated forest land unit is shown in the Appendix. The sequential numbers on the listings correspond with the numbers on the forest land unit overlays. By passing the PI characteristics through the appropriate regression or discriminant analysis equations, ground attributes for each forest land unit can be estimated and assigned to the land unit. A computer file of inplace inventory data is thus created. This data base can, in turn, be searched to identify areas of high volume, overstocking, or high yield, or it can be used to describe the forest conditions within a selected area.

Another data base was created for the two quadrangle overlays produced by computer mapping. For these quads, the boundaries, acreage, and forest land unit number of each land unit polygon were stored in a computer file.

CONCLUSIONS

This study has shown a successful application of quad-centered aerial photography for mapping forest lands. The results suggest a practical means for mapping forest land units which are descriptive of the existing variation in land form and vegetation. The photointerpretation variables, criteria, and classification scheme are unique to forest mapping methods.

The regression and discriminant analysis results indicate a reliable procedure for expanding a limited ground sample to produce inplace information. This means that a mapped inplace forest land unit can be described by its PI variables which, in turn, can be used to predict the volume, site index, habitat type, etc., for that land unit. Note that these equations have not been tested. The correlations exist between the PI variables and the ground variables in the two data sets. However, the equations were not used to predict the ground attributes for unsampled forest land units for a subsequent comparison to ground determined values.

This forest mapping system can be integrated into the MFS under the direction of the Montana Division of Forestry. The use of MFS data for the development of prediction equations is as reliable as those produced from the field data collected for this study. Two ways to improve the reliability of these equations are to increase the number of samples within a given area, or to broaden the sample area to include more ground plots. Care must be taken in expanding the sample area so as not to include dissimilar ecological regions. It is important to note that the variation accounted for by any PI variable is different for each ecological region, as well as for each ground attribute.

The objectives of the McIntire-Stennis research and the operational development work in cooperation with the USDA-Forest Service have been successfully concluded.

SUMMARY

This study produced methods for integrating a forest land unit mapping system into the MFS. These methods included the development of unique delineation and classification criteria based on the combination of land form and vegetation components. Prediction equations were developed through the relationship of these components with ground determined attributes. These equations provide for characterization by volume, growth, site index, yield, habitat type, and forest type of forest land units from the PI variables determined for the units during delineation. The predictions or characterizations should be reliable enough for many operational inplace information needs.

A staged implementation procedure is recommended. The first stage should be a pilot project for a county area providing for further development of the operational methods and further testing of the predictive power of the PI variable equations. This stage would provide for improvements in methodology and prediction reliabilities for inplace units before the general application of the system in subsequent stages.

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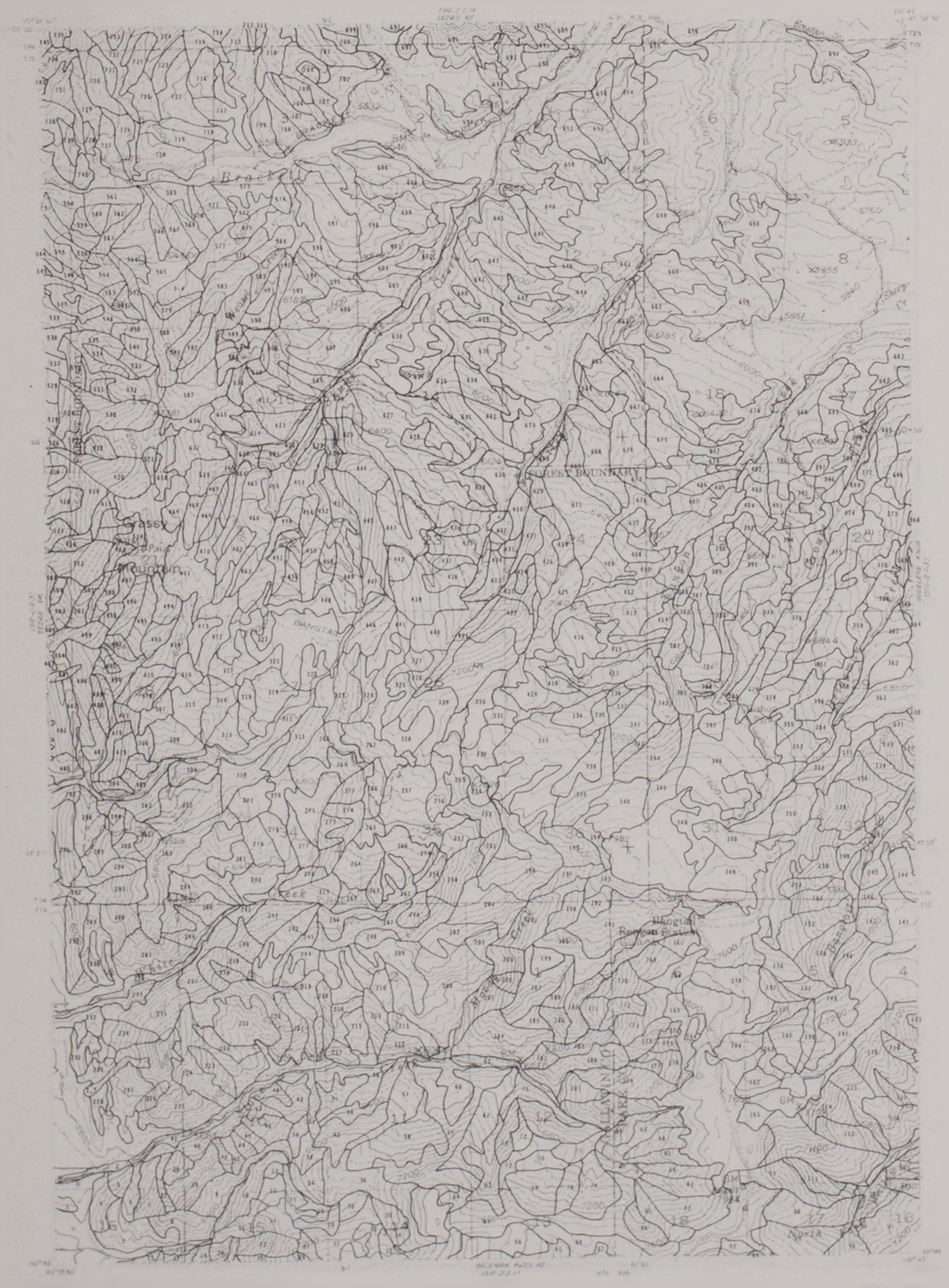
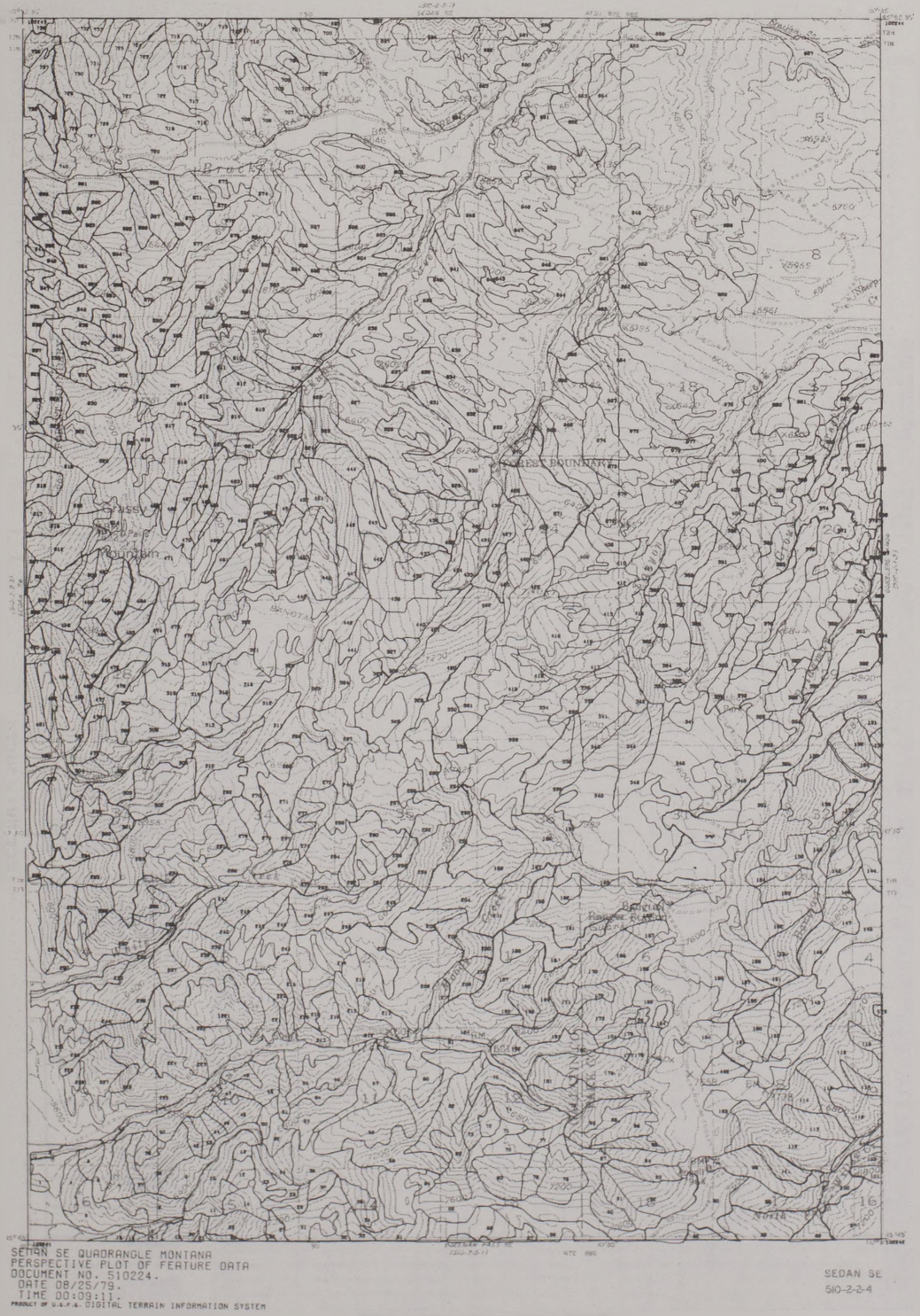
APPENDIX

FOREST STAND PHOTO DELINEATION CHARACTERISTICS FOR MONTANA QUADRANGLE: SEDAN SE 7 1/2′, MT

STAND NUMBER	PATTERN	TEXTURE	CANOPY COVER	STAND HEIGHT	CROWN SIZE	STAND MODIFIER	EXPOSURE	SLOPE ANGLE	SLOPE POSITION	SLOPE FORM	ELEVATION
1	UNIFORM	MEDIUM	70-80%	40-80′	7-14′	HDWDS <60%	NORTH	30-60%	MIDSLOPE	STRAIGHT	4000-6000′
2	MOTTLED	COARSE	70-80%	40-80′	>14′	HDWDS >60%	FLAT	<10%	VALLEY	CONCAVE	4000-6000′
3	UNIFORM	MEDIUM	70-80%	40-80′	7-14′		NORTH	30-60%	MIDSLOPE	STRAIGHT	4000-6000′
4	MOTTLED	MEDIUM	70-80%	40-80′	7-14′		WEST	30-60%	MIDSLOPE	UNDULATING	4000-6000′
5	BROKEN	COARSE	50-70%	40-80′	7-14′		SOUTH	30-60%	MIDSLOPE	UNDULATING	4000-6000′
6	BROKEN	MEDIUM	50-70%	40-80′	7-14′	? DISTURB	EAST	30-60%	MIDSLOPE	CONCAVE	4000-6000′
7	MOTTLED	MEDIUM	70-80%	40-80′	7-14′		WEST	30-60%	MIDSLOPE	UNDULATING	4000-6000′
8	MOTTLED	FINE	50-70%	<40′	<7′		SOUTH	30-60%	MIDSLOPE	STRAIGHT	4000-6000′
9	BROKEN	MEDIUM	30-50%	40-80′	7-14′		SOUTH	30-60%	MIDSLOPE	STRAIGHT	4000-6000′
10	UNIFORM	FINE	70-80%	40-80′	7-14′		WEST	30-60%	MIDSLOPE	STRAIGHT	6000-8000′
11	MOTTLED	FINE	30-50%	<40′	<7′		SOUTH	30-60%	MIDSLOPE	STRAIGHT	6000-8000′
12	MOTTLED	MEDIUM	70-80%	40-80′	>14′		NORTH	10-30%	MIDSLOPE	STRAIGHT	6000-8000′
13	UNIFORM	FINE	<30%	<40′	<7′	LOGGED	NORTH	10-30%	MIDSLOPE	STRAIGHT	6000-8000′
14	UNIFORM	FINE	<30%	<40′	<7′	LOGGED	WEST	30-60%	MIDSLOPE	STRAIGHT	6000-8000′
15	UNIFORM	FINE	>80%	40-80′	7-14′		NORTH	30-60%	MIDSLOPE	STRAIGHT	4000-6000′
16	MOTTLED	MEDIUM	70-80%	40-80′	7-14′		EAST	30-60%	MIDSLOPE	STRAIGHT	6000-8000′
17	UNIFORM	FINE	>80%	40-80′	7-14′		EAST	30-60%	MIDSLOPE	STRAIGHT	6000-8000′



Manually Drawn Forest Land Unit Map



Computer Drawn Forest Land Unit Map

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TREE DATA SHEET

LOCATION NUMBER	POINT NUMBER	BAF	TREE NUMBER	TREE HISTORY	SPECIES	DBH (TO 0.1 INCH)	10 YEAR RADIAL GROWTH	TREE AGE	TREE HEIGHT (TO ONE FOOT)	CROWN RATIO	CROWN CLASS	RELATIVE CROWN CANOPY POSITION	SURFACE DEFECT	INTERNAL DEFECT	TOTAL VOL. LOSS	DAMAGE/ CAUSE OF DEATH	TREE/ COVER CLASS	DEAD CONDITION	SITE TREE CODE	HABITAT TYPE	TOPO. POSITION	HORIZ. CONFIG.	STAND ORIGIN	ASPECT/SLOPE/ PHYSIO. CLASS	STAND CLASS	SEED SOURCE	FOREST TYPE	STAND SIZE CLASS	ELEVATION (TO TEN FEET)	DATE (DAY, MONTH, YEAR)	REMARKS
1 2 3	4 5	6 7	8 9	10 11	12 13 14	15 16 17	18 19	20 21 22	23 24 25	26	27	28 29	30 31	32	33	34 35	36 37	38 39	40 41	42 43 44	45	46	47	48 49 50	51	52	53 54	55	56 57 58 59	60 61 62 63 64 65	
1 2 3	4 5	6 7	8 9	10 11	12 13 14	15 16 17	18 19	20 21 22	23 24 25	26	27	28 29	30 31	32	33	34 35	36 37	38 39	40 41	42 43 44	45	46	47	48 49 50	51	52	53 54	55	56 57 58 59	60 61 62 63 64 65	