Aerial photographic interpretation of forest stands on Lubrecht Experimental Forest, Montana

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AERIAL PHOTOGRAPHIC INTERPRETATION OF FOREST STANDS

ON LUBRECHT EXPERIMENTAL FOREST, MONTANA

by Kurt B. Teuber

B.S. Forestry, University of Montana, 1979

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Date
The purpose of this study was to develop and demonstrate a technique for mapping and evaluating forest stands from conventional aerial photography. Stands were stereoscopically delineated on 1:24000 scale panchromatic photography. The study area was a 14,000 acre (5665 ha) portion of Lubrecht Experimental Forest, considered typical of mid-elevation coniferous forests of west-central Montana. Stand delineation and description was based on a photointerpretation criteria recognizing 15 different overstory vegetation and topographic variables. Photointerpretation variables were used as independent variables in statistical analyses to estimate eight different stand attributes. Regression analysis was used to predict cubic and board foot volume per acre, cubic and board foot growth per acre, average site index, and average yield capability. Discriminant analysis was used to predict habitat and forest type.

Most of the photointerpretation variables were found to be significantly related to at least one stand attribute. Derived regression equations explained from a maximum of 89% of the variation in board foot volume per acre to a minimum of 53% of the variation in average yield capability. Habitat types were correctly classified 58% and forest types 66% of the time.

A total of 1260 stands were delineated with an average size of 11.6 acres (4.7 ha). A stand map of the study area was produced photogrammetrically. The basic photointerpretation technique is believed to be a useful means of expanding forest inventory data to unsampled stands.
Acknowledgments

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I am especially grateful to Professor Fred Gerlach, thesis committee chairman, for his advice, encouragement, and patience, and without whose support this project would not have been possible.

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CHAPTER I

INTRODUCTION

Intensive forest management planning depends on accurate, detailed, and timely information describing conditions on specific portions of the landscape. Forest inventory information provides the basis for most management decisions. However, to be useful in a local context, this information must be related to discrete, identifiable land units upon which local management applications are based. This is especially important where substantial spatial variation exists among forest resource values.

Numerous forest classification and mapping systems have been devised to facilitate coordinated forest resource planning. Most have been oriented towards single-factor resource evaluations. Individual resources, such as vegetation, soils, habitat types, etc., are often mapped separately and superimposed to derive interpretations for different areas. While this approach may be adequate for assessing resource characteristics at specific points across the landscape, such as on a grid system, it does not necessarily produce land units which are logical or
practical from a management standpoint. Also, single-factor resource surveys tend to overlook the fact that forest resource attributes do not occur independently but are actually interrelated components of a complex natural system.

An alternative approach, based on the concept of the interrelated nature of forest resources, assumes that similar natural areas, as defined by a set of indicators such as vegetation and geomorphic characteristics, are subject to similar natural processes and responses to management (Dyer 1975). Rowe (1971) suggests that "the one main purpose in inventorying the forest land resource is to provide a framework for integrated resource planning and the most informative classification will therefore be based on the total landscape rather than on any single component of it, whether vegetation, soil, geomorphology, or climate". Assuming correlations exist between the resource attributes of interest and the criteria used to differentiate areas, this approach has the potential of identifying discrete land units with multiple management-related resource characteristics. Also, a number of pertinent landscape indicators may be obtained directly from topographic maps, aerial photographs, and other remote sensing imagery.
Aerial photography is commonly used in mapping and evaluating forest stands. Though not as accurate or detailed as field inventory data, certain types of data useful in forest planning can be obtained over a large area rapidly through aerial photointerpretation. "The boundaries of forest types and other stand-condition classes can be delineated with greater ease and accuracy, within broad limits, from stereoscopic examination of aerial photographs than can be done on the ground" (Husch, Miller, and Beers 1972). Traditionally, stand mapping has been basically a single-factor operation, oriented primarily towards existing timber species or volumes.

A relatively new approach to stand mapping involves the use of statistical techniques to predict various stand attributes from photointerpreted landscape indicators. By recognizing both measurable forest overstory and topographic or physiographic variables in a photointerpretation scheme, it may be possible to estimate measures of stand volume, productivity, and composition using predictive statistical models, at an accuracy suitable for planning purposes. This technique has recently been demonstrated in Montana, with moderate success, using high-altitude photography (Martin and Gerlach 1981, USFS 1982).
The purpose of this study was to apply this stand mapping technique using conventional, medium-scale panchromatic aerial coverage of a portion of Lubrecht Experimental Forest, Montana. The specific objectives were:

1) To develop a photointerpretation scheme for delineating and describing forest stands in terms of directly observable vegetation and topographic characteristics,

2) To statistically estimate various attributes of individual stands based on their photointerpreted characteristics; specifically, to employ the following procedures:

a) prediction of timber volume and growth per acre, average site index, and average yield capability by multiple regression analysis,

b) prediction of habitat type and forest type by discriminant analysis,

c) verification of attribute predictions on selected stands, and

3) To photogrammetrically produce a forest stand map of the study area.
It was the intent of this study to develop and refine a new and innovative technique in forest inventory and mapping with practical local application. With the rapid growth of computer systems in resource management, it has become increasingly feasible for local forest managers to store and manipulate massive amounts of data and apply sophisticated mathematical techniques operationally. If reliable estimates of the desired stand attributes can be obtained through the procedures specified above, the role of aerial photointerpretation in forest inventory may be greatly enhanced.
The forest stand is defined as "an aggregation of trees or other growth occupying a specific area and sufficiently uniform in species composition, age arrangement, and condition as to be distinguishable from the forest or other growth on adjoining areas" (Davis 1966). In practice, the term is used rather loosely, and may have various meanings, depending on the level of consideration. For the purposes of this paper, it will be assumed that a stand represents a manageable land unit with relatively homogeneous overstory vegetation and site quality characteristics. Regardless of the terminology, the emphasis is on localized areas which are the basic land units of intensive forest management applications.

Stratification of the forest into relatively homogeneous stands or type-classes from aerial photography dates back to the late 1800's in its earliest applications (Spurr 1960). Not until the early 1950's, however, were photointerpretation and statistical techniques combined to provide more efficient forest inventory designs. The most
common application of aerial photointerpretation in forest inventory has been to identify distinct, homogeneous strata in a stratified sampling scheme, which are then subsampled on the ground for more detailed information (Husch, et al. 1972, Cunia 1978). Substantial gains in sampling efficiency (over simple random or systematic sampling) using photointerpreted strata have been demonstrated consistently (Bickford 1953, 1961, Kendall and Sayn-Wittgenstein 1961, Moessner 1963, MacLean 1972, 1981). Cunia (1978) states: "The procedure of prestratified sampling with proportional or optimum allocation, where the strata are delineated by aerial photointerpretation and where the sampling within strata are done systematically, is probably one of the most common inventory procedures in use today around the world".

The purpose of most stratified sampling schemes, however, is to provide estimates of means for the total population, rather than estimates for individual units. Several researchers have suggested extrapolating ground-sampled stratum means back through the delineated strata as the basis for providing mapped, "in-place" inventory data (Kendall and Sayn-Wittgenstein 1961, Stage and Alley 1972, Lund 1978). This technique may work as long as the criteria used in delineating strata are logically and consistently related to the parameter(s) of interest. Problems arise, however, when multiple objectives (such as
volume, growth, and site assessment) are specified in the inventory design (Frayer 1974). In multi-parameter stratified sampling schemes, inflated variances may result for some parameters if the several parameters of interest are not all positively and highly correlated with each other (Wensel 1974), and volume and growth may actually be negatively correlated in some cases. If additional criteria are specified for defining strata in relation to various parameters, the potential number of strata may quickly become unwieldy, and require an inefficient amount of field data collection.

An alternative method for characterizing delineated units (the approach taken in this study) involves developing correlations between the ground-sampled parameters of interest and corresponding photointerpretation variables (Lund 1978, Martin and Gerlach 1981). Multiple stand attributes (volume, growth, site index, etc.) might then be extrapolated to unsampled stands using statistical prediction techniques. By this method, a number of different landscape indicators, relating variously to different stand attributes, could be collected by photointerpretation, stored in a data base, and used as needed in separate equations.
Development of an efficient stand delineation scheme required consideration of basic stand dynamics and the ability to photographically detect differing stand conditions. The location of stand boundaries is dependent upon basically three factors: 1) past cultural or management practices, 2) natural disturbances, such as fire, or insect and disease outbreaks, and 3) the inherent biophysical capability of the land, which is in turn the result of a complex mixture of climate, soils and geology, and topography.

Thus, a multi-purpose stand mapping scheme ought to involve recognition of relatively temporal vegetational features, as well as more permanent physical characteristics of the landscape. Jaakkola and Draeger (1971) list several considerations which should be kept in mind when designing a stand delineation scheme:

- In delineation, one classifies material having diffuse boundaries between classes into discrete categories. This characteristic diffuse quality is a feature of nearly all natural populations, such as forests. Consequently, the delineation may be arbitrary, even though the criteria for delineation may be quite explicit. On the other hand, some stands, such as recently logged areas, possess sharp boundaries and are easily delineated. Thus the degree of difficulty for the delineation process varies considerably from one stand to another.
-The definitions of the classes to be delineated are not necessarily mutually exclusive.

-The nature of the classification is often multi-dimensional; i.e., there may be several nested classifications to be interpreted simultaneously ... although the final output is a single map. Thus, the stand boundaries compromise all of the characteristics involved.

-The dynamics of stand boundaries must be considered when one is determining the photo requirements for forest stand delineations. If stand boundaries are of a permanent character, then existing photography may be adequate. However, if the stand boundaries are of a dynamic nature, then periodic updating using recently acquired photography may be necessary.

-So called "ground truth" pertaining to stand delineations is difficult to collect.

This study was concerned with statistically deriving estimates of stand volume, productivity, and composition based on a single delineation system. Although techniques for photogrammetric estimation of stand attributes have been developed, rarely have multiple attributes been estimated from a given set of photointerpretation criteria. Pertinent theoretical considerations and investigated techniques for each of these components are reviewed here.
TIMBER VOLUME ASSESSMENT

Of the various forest photointerpretation concepts applied in this study, aerial volume estimation is perhaps the most straightforward, well documented, and successful. Numerous methods have been devised, ranging from subjective estimation of broad volume classes, to intensive, highly precise tree measurements on large-scale imagery; from simple sampling designs using crude measurement devices, to sophisticated multi-stage designs involving the use of space imagery and automated image analysis. These various techniques are well covered in the standard texts dealing with this subject (American Society of Photogrammetry (ASP) 1960, Spurr 1960, Loetsch and Haller 1964, Avery 1966, Husch, et.al. 1972, ASP 1975, Paine 1981). The focus of attention here, however, will be on measurements obtainable by conventional, manual photointerpretation techniques, which are useful in timber volume estimation as independent variables in multiple regression analysis.

The most useful ground-based tree measurements for estimating tree volumes are, respectively, stem diameter (usually as dbh, diameter breast height) and total tree height. On aerial photography, height can be measured directly on stereoscopic coverage by differential parallax, while dbh can be approximated by photo measurement of crown
diameter. In a manner analogous to ground-based methods, these photo variables may be used as independent variables in regression equations for predicting tree volumes. Predicted volumes may then be generated and used in the construction of aerial tree volume tables, which are entered with photo-measured height, crown diameter, or, usually, both.

Aerial tree volume estimates can never be as accurate as ground-based estimates for several reasons, measurement error being the most obvious. Highly precise photogrammetric measurements of tree height and crown diameter are possible on large-scale photography in fairly open timber. However, this becomes increasingly difficult on smaller scales of photography and in dense timber, especially when crowns begin to blend together and individual trees become less distinct.

Another, more subtle source of error arises from the fact that crown diameter is not always a reliable indicator of dbh. Since, by basic geometric principles, volume varies with the square of diameter, error in volume estimation due to a lack of correlation between crown diameter and dbh is likely to be magnified. Although crown diameter has been shown to be correlated with dbh (the curve describing the relationship is slightly S-shaped), the effects of stand
density, site quality, and age confound the relationship, and estimates of dbh based solely on crown diameter are generally associated with a large amount of error (Spurr 1960, Paine 1981). Smith (1965), using carefully measured felled-tree data, found that 92-97% of the variation in volume for three western conifer species (Douglas-fir, western hemlock, and western red cedar) could be explained with dbh and height, while 69-79% could be accounted for using crown diameter and height. Hence, tree volume is more closely correlated with dbh than crown diameter, and in terms of photointerpretation variables, height is a relatively more important factor in tree volume estimation.

A further requirement in tree volume estimation is that the imagery be of sufficient resolution to allow accurate tree counts, so that tree volumes can be expanded to an area basis. Nevertheless, if high-quality, large-scale photography is available, aerial tree-volume tables or equations may be very useful in areas of high-value timber and/or relative inaccessibility. In particular, the increasing refinement in recent years in the use of large-scale 70-mm photography has opened up new opportunities in intensive forest inventory (Aldred and Lowe 1978).
Because of the special requirements in the use of single-tree aerial volume tables and equations, and the difficulty of measuring and counting individual trees, the stand volume approach, wherein per acre volume is estimated from photo variables describing homogeneous stand conditions, is more commonly applied. The primary independent variables in aerial stand volume tables and equations are average stand height, crown closure or canopy coverage, and, to a lesser extent, average crown diameter. Various combinations and transformations of these basic variables are present in almost all aerial stand volume equations, the form of the equations depending on species, locality, photographic scale, etc. Average stand height — usually the average of several dominant or codominant trees in a fixed-area plot or delineated stand — is consistently highly correlated with volume. Crown closure, defined as the percentage of an area covered by tree crowns projected vertically to the ground, is also usually well correlated with volume. As a replacement for individual crown counts, percentage crown coverage can be easily measured by the use of a transparent reference template, and the use of this variable partly accounts for the greater practicality and desirability of the aerial stand volume approach. Average crown diameter is usually not well correlated with stand volume and is often not included in stand volume
regressions. However, many photointerpreters find that it does contribute enough to be included; if not by itself, as part of an interaction term. The combination of canopy coverage and crown diameter may be useful, since canopy coverage by itself provides little indication of stand density without some measure of the average crown size (Smith 1965).

Early attempts at volume table construction using these variables were done by alignment chart and manual curve-fitting methods (Moessner 1957, Spurr 1960). Gradually, multiple regression analysis became a more common method of relating photo-measured variables to stand volume, especially with the advent of high-speed electronic computers. In one of the first definitive studies in aerial stand volume table construction by regression analysis, Gingrich and Meyer (1955), working in oak stands in Pennsylvania with 1:12000 scale photography, developed regression equations predicting cubic foot volume per fifth acre plot in trees five inches dbh and larger, and seven inches dbh and larger. Using average height and crown closure as independent variables, they found that 72% of the variation in volume for trees five inches dbh and larger could be accounted for with a standard error of 25% of average plot volume, and 76% of the variation in volume for trees seven inches dbh and larger could be accounted for
with a standard error of 29% of mean plot volume. A total of 93 plots were sampled. Crown diameter was found to be significantly correlated with volume, but the partial correlation of crown diameter was non-significant when the effects of height and crown closure were removed. Hence, variables containing crown diameter in these regressions showed up as non-significant.

In mature conifer stands of interior British Columbia, Allison and Breadon (1961), using 1:15840 scale photography, developed a regression equation using average height and canopy coverage which could account for 67% of the variation in cubic foot volume per acre, with a standard error of 268 cubic feet per acre (±8% of mean volume). However, their regression was done primarily to adjust regional volume table estimates to local conditions, and was based on only 33 sample plots. Also, their minimum diameter limit was 11.1 inches dbh - fairly high by most standards today.

Pope (1962) provides a very thorough discussion on the use of multiple regression in aerial stand volume table construction for Douglas-fir in the Pacific Northwest. Using 1:12000 scale photography, 282 fifth-acre plots were established both on the photos and in the field. Because analysis of the basic data indicated curvilinearity in the relationship between height and volume, the square of height
was used and found to be a particularly important independent variable. The best single variable studied was height squared times crown closure, accounting for about 80% of the variation in both cubic and board foot volume per acre. His final equations, using various combinations of height, crown closure, and their squares and products, provided an R-squared value of .82 (accounting for 82% of the variation) for cubic foot volume per acre, with a standard error of 29% of mean plot volume, and an R-squared value of .84 for board foot volume per acre with a standard error of 35% of mean plot volume. Once again, crown diameter was found to be not significantly correlated with stand volume. However, in 1974, Paine and Rogers (Paine 1981), using the same data, found that crown diameter was significant when used in a triple interaction term with height and crown closure, though the theoretical basis for such a term is rather obscure.

In the Rocky Mountain states, several aerial stand volume tables have been developed by Moessner (1957, 1963). Composite aerial volume tables for mixed conifer stands were constructed from regression equations based on data from 460 fifth-acre plots throughout the region (1963). Again, height and crown coverage were found to be the most useful independent variables and crown diameter was only of minor importance and not included in the final equations. The
equation for cubic foot volume per acre accounted for 74% of the variation, with a standard error of 50% of the mean plot volume (1370 cu. ft. per acre). The board foot volume equation also accounted for 74% of the variation, with a standard error of 61% of the mean plot volume (7747 bd. ft. per acre).

The intended use of most aerial stand volume tables is to provide rough volume estimates for a large number of systematically distributed photo plots, which are then adjusted to local conditions based on a subsample of ground plots. Rogers (1959) describes an inventory technique in which photo plot data is related directly to ground plot data by regression, in essence creating a local aerial volume equation and eliminating the need for a stand volume table before photointerpretation. At the time that paper was written, performing regression analysis with a large set of data could be a formidable task, and the availability of a preconstructed aerial volume table was an important consideration. However, as the increasing availability of computers has brought the ability to perform complex and tedious mathematical operations within reach of almost all forestry personnel, it would seem that the need for preconstructed aerial volume tables would become less crucial in future inventories.
This enhanced capability may also allow the derivation of more sophisticated prediction equations, incorporating a larger array of independent variables. For instance, in almost all of the stand volume studies cited above, site quality is mentioned as a likely influence on volume per acre but is not controlled for. If variables correlated with site quality could be incorporated into these equations (the "other things being equal" interpretation) it may be possible to achieve greater precision in aerial volume estimates. While it is usually desirable, even with machine processing, to keep equations as simple as possible, this must be balanced against possible gains from larger equations and the precision requirements of the volume inventory.

SITE QUALITY ASSESSMENT

Assessment of forest site quality, or potential productivity, is one of the most perplexing, and important, problems in forest inventory. Site quality is the reflection of a complex of interrelated biotic, edaphic, topographic, and climatic factors, and is generally estimated indirectly by various simplified indicators. "Estimates of productivity are essential for the practical evaluation of forest areas, and opinions on this subject differ mainly as to the relative merits of growth-rate
indices and the means of deriving them" (Rowe 1962). The
current study attempted to statistically predict two
commonly used measures of forest productivity, site index
and habitat type, from photointerpreted variables.
Theoretical concepts and techniques relating to
photogrammetric assessment of these attributes are reviewed
here.

**Site Index**

Site index is defined as the height attained on a given
site by free-growing dominant and codominant trees of a
given species at a given base age, such as 50 or 100 years.
This is based on the fact that height is the best single
tree measurement related to site potential and is less
influenced by stand density than other tree dimensions.

Site index curves describing the course of height
growth on different sites have been derived for most
commercially important tree species. Though not without its
inadequacies, site index is a simple, easily understood
concept, and is the most widely used measure of timber
productivity.

Since tree age cannot be determined accurately on
aerial photos, there are only limited possibilities for
estimating site index from photogrammetric tree
measurements. Colwell (1967) suggested that height measurements of the oldest, largest trees in a stand (which can be assumed to have reached their maximum heights) could be used in estimating site index. Since site index curves tend to flatten out and become asymptotic as trees become overmature, one might deduce site index by relating these height figures to the upper end of the appropriate curves. This approach might provide good results in mature, even-aged stands and when species can be accurately detected from the imagery. However, a critical assumption in the use of site index is that the sample trees have been dominant throughout their lives and have not been strongly affected by stand history, such as partial cutting operations. Many stands are composed of a complex mix of age classes, and often the oldest, largest trees are actually former understory trees which were previously suppressed. The described technique seems highly subject to error, and it is not known if it has ever been scientifically tested.

Another method for estimating site index from photo tree measurements involves the use of a height/crown diameter ratio. A tree of a given height on a poor site will be older than a tree of the same height on a better site. The older tree will tend to have a larger, spreading crown and will therefore have a lower height/crown diameter ratio. Using data for Scotch pine in Germany, Spurr (1960)
found that "the variation in the ratio between site classes is apparently great enough to permit its use in the determination of site quality from aerial photographs". However, the effectiveness of this variable may vary with species and stand density. In fact, Smith (1965) suggested that this ratio is probably a better measure of stand density than site index. He found that this variable accounted for 1.7% of the variation in site index with 167 western hemlock sample trees, 5% of the variation with 184 Douglas-fir trees, and 12% of the variation with 77 western red cedar sample trees. Paine (1981) produced a regression equation using the height/crown diameter ratio and percent crown canopy coverage as independent variables. This equation accounted for 79% of the variation in site index with a standard error of 10 feet (at the 100-year base age). However, he warned that not enough sample data was used in his analysis to make valid inferences.

Since many sites lack suitable sample trees for determining site index, either because of unsuitable stand conditions or deforestation, much research has been directed towards prediction of site index by relating it to limiting factors of the physical environment; i.e.: climate, soils, and topography. This is known as the factorial approach, and the usual technique follows these basic steps (Jones 1969):
1) Selection of environmental factors which might limit or otherwise be related to site index.

2) Selection from among these factors ones deemed practical to work with.

3) Definition of a study universe which will restrict as many of the other factors as feasible to a reasonable degree of uniformity.

4) Location of plots in stands suitable for site index determination.

5) Collection of site index and environmental data.

6) Prediction of site index using environmental factors as independent variables in stepwise regression analysis.

Numerous studies have been conducted relating measured soil and topographic parameters to site index. From the standpoint of aerial photointerpretation, however, topography is the only environmental factor which can really be observed and measured. Certain gross features of the soil can be observed (i.e., the presence of numerous rock outcrops would indicate relatively shallow, undeveloped soils (Choate 1961)), but most soil parameters can only be indirectly inferred on aerial photography, especially when most of the ground surface is covered by forest canopy.

Nevertheless, topographic and soil parameters are often highly correlated, and much of the effect of topography on site index may be expressed indirectly through its effect on soil parameters. Significant correlations have been found between topographic parameters (i.e., slope gradient,
configuration, and length, aspect, and elevation) with soil depth and organic matter content (Aandahl 1948), soil drainage (Troeh 1964), and stage of weathering (Young 1972). The influence of topography on soil and site was described by Kuchler (1967): "The importance of topography is revealed especially in the relation that exists between the vegetation on the one hand, and the water economy of the soil and the features of the microclimate on the other. Convex surfaces differ markedly from concave ones even though the contrast is ever so slight ... even the slightest rise will occasion an increased runoff and erosion of the finest soil particles ... In depressions, on the other hand, no matter how shallow, soil and water accumulate, promoting growth, but snow and cold air accumulate as well, retarding growth".

A number of pertinent studies can be found describing significant differences in site index due to topographic factors. In western Washington, Tarrant (1950) found no significant difference in site index for Douglas-fir between two soil types, but did find a difference significant below the 5% level between mean site index values of convex and concave topography - both when each soil was considered separately and when the data for both soils were combined. Mogren (1959) defined three ponderosa pine "site area classes" in the Black Hills primarily on the basis of slope
and aspect, and found statistically significant differences between the mean site index values of the three classes. Myers and Van Deusen (1960) later refined this approach by deriving separate regression equations (for two types of bedrock) for the prediction of ponderosa pine site index in the Black Hills. Significant independent variables included slope gradient, slope position (expressed as distance upslope as a percentage of total slope length), aspect, and soil depth. On crystalline bedrock, 83% of the variation in site index could be explained, and 78% of the variation could be accounted for on limestone bedrock. Clary, et.al. (1966) found that the standard error of site index could be reduced by 30% when two soil types in northern Arizona were stratified by topography (swale vs. upland). Ferguson (1981) developed a method of overlay choropleth mapping for predicting red oak site index using slope gradient, slope position, slope orientation (aspect), and soil depth (two classes) as independent variables. His selection of independent variables was based on a previous soil-site study (Trimble and Weitzman 1956) which produced a regression equation accounting for 75% of the variation in site index.
In the northern Rockies, moisture is the environmental factor most often limiting to tree growth, and most soil-site studies in the region have identified topographic and soil parameters relating to this factor as being significant. However, there is also evidence that topography may influence tree growth more directly in its effect on photosynthetic rates and water deficits. A study in West Virginia (Lee and Sypolt 1974), under conditions of ample moisture and uniform soils, found significant differences in basal area growth rates between north- and south-facing adjacent slopes. According to Lee and Sypolt, the different growth rates "probably cannot be attributed solely to differences in physical or chemical properties of soils or to soil moisture regimes ... Characteristic growth differences that occur with aspect appear to be attributable to characteristic radiation and thermal regimes that directly affect the physiological processes of trees".

Only a few studies have attempted to statistically predict site index from photointerpretation or remotely sensed data, with mixed results. Smith and Bajzak (1961) used photointerpreted aspect, local slope position, general slope position, percent of slope, shape in profile, shape in contour, elevation, soil depth, and moisture regime as independent variables in multiple regression for prediction of site index at the University of British Columbia Forest.
Using all nine independent variables, 32% of the variation in site index could be accounted for, with a standard error of 23.7 feet, or 19.5% of the mean. Using only three variables, however, (elevation, moisture regime, and local slope position), a standard error of 23.8 feet was obtained. They concluded that site index classes could be better interpreted and mapped from the photos (1:15000 scale) subjectively. Details of their analysis are somewhat sketchy, but it is likely that better results could have been obtained with more refined independent variables. For instance, values for moisture regime were apparently obtained by arbitrarily ordering photointerpreted moisture regime classes against site index.

Choate (1961) had similar results in estimating Douglas-fir site index over a large area of Oregon and Washington. Using elevation, latitude, aspect, slope percent, shape in profile, shape in contour, and apparent soil depth (based on the presence of rock outcrops), a maximum of 28% of the site index variation could be accounted for. Elevation and latitude proved to be the most useful variables in this study, while aspect and slope, though significant, contributed relatively little to site index prediction. Possible reasons for the poor showing of slope and aspect, in both of these studies, could be due to the fact that these variables are not strongly correlated
with site index in that region, and to the somewhat arbitrary ratings assigned to these variables, especially aspect. Choate concludes that his results "are probably more important as indicators of the direction of future research. Such research might investigate new criteria as well as improve the evaluation schemes for some of those used in this study".

In a more recent study (Getter and Tom 1977, Tom and Miller 1980), researchers in Colorado used Landsat multispectral data, topographic and solar insolation data obtained from a digital terrain model, and photointerpreted vegetation cover type to classify 2.5-acre pixels into nine site index classes by discriminant analysis. Thirty-seven site index ground control plots were correctly classified 97% of the time using eleven independent variables.

**Habitat Types**

Classification of land units by site index or yield capability implies a single-factor interpretation, i.e., the production of timber. While site index is a convenient means of summarizing ecological characteristics in a practical form, other interpretations, such as successional trends or regeneration potential, cannot be inferred by this information alone. An alternative method of site classification involves the use of indicator vegetation as a
reflection of the environmental factors influencing site quality.

Much of the earliest site classification work in North America using ground vegetation as an indicator of site quality took place in Canada, in the form of forest site-types (Losee 1942, Rowe 1962, 1971, Jones 1969). Coincidentally, much of the pioneering work in aerial photointerpretation in forestry took place in Canada, due mainly to the vast amount of undeveloped forest area. As early as 1942, Losee (1942) developed a photointerpretation key using overstory species composition, canopy coverage, and topographic location to deduce forest site-types (defined by characteristic understory vegetation) of the Petawawa Experimental Forest in Ontario.

The forest habitat type system is an ecological land classification system based on potential climax vegetation. Habitat types have been found to have a number of important interpretations in forest management and are currently used extensively for forest site classification in the northern Rockies (Daubenmire 1973, 1976, Deitschman 1973, Stage and Alley 1973, Pfister, et.al. 1977, Pfister and Arno 1980). "Responses to vegetation management can be expected to be generally similar on units of land with the same habitat type if the current vegetative community and other variables
are also considered" (Pfister and Arno 1980). However, timber productivity cannot necessarily be inferred based on a habitat type classification (Daubenmire 1976), and tests to ascertain ranges of yield capability by habitat type have revealed a large amount of variation in some cases (Pfister, et.al. 1977).

Actual habitat type classification of a specific area requires an examination of minor understory and overstory indicator species (details of the classification scheme can be found in Pfister, et.al. 1977). Hence, direct photointerpretation of habitat types is limited to identification of overstory tree species, which cannot usually be reliably identified on medium-scale panchromatic photography, and may not be the climax overstory component of the habitat type, anyway. It is generally acknowledged, however, that in a limited geographic area, holding the broad effects of climate constant, the pattern of habitat types across the landscape is closely associated with soils and topography. While topographic or landform characteristics interpreted from maps and aerial photos have been used extensively in habitat type mapping studies, the associations have been based primarily on subjective interpretations, augmented with a large amount of ground checking (Daubenmire 1973, Deitschman 1973).
Two recent studies (Martin 1979, Martin and Gerlach 1981) attempted to classify mapped land units by habitat type, using photointerpreted topography and overstory vegetation/1 as independent variables in discriminant analysis. Martin found that habitat type could be correctly classified to the phase level 43% of the time using land form (topography), 16% using existing overstory vegetation, and 48% using all variables, and to the type level 53% using land form, 26% using overstory vegetation, and 57% using all variables. Martin and Gerlach correctly classified habitat types 37% at the phase level, and 39% at the type level, using a combined set of overstory vegetation and topographic variables.

RELATED STUDIES

Most of the earlier studies mentioned above were concerned mainly with assessing a single stand attribute on a plot-wise basis—appropriate for extensive regional inventories, but not providing mapped, in-place stand information. In recent years, research in this area has

/1 While existing overstory vegetation may bear no resemblance to the potential vegetation indicated by the habitat type name, the rationale for using existing vegetation variables was that certain diagnostic characteristics of the existing vegetation may represent differences in site conditions.
emphasized the ability to accurately detect and map various stand condition classes and the use of more refined independent variables and prediction techniques. Much of the work in mapping has involved direct interpretation of stand conditions through the use of newer, specialized types of imagery. However, enhanced computer capabilities for data storage, manipulation, and analysis have also opened new opportunities for indirectly estimating stand attributes using conventionally photointerpreted variables.

In a comprehensive timber inventory of the Plumas National Forest in California (Titus, et.al. 1975), a multistage sampling scheme, involving Landsat imagery, large-scale aerial photography, and ground sampling, was used to provide per hectare estimates of six parameters: number of trees, square meter basal area, square meter basal area growth (5-year), cubic meter volume, board foot volume, and square meter surface area. Four broad vegetation strata were delineated on the Landsat imagery and then subsampled on large-scale aerial photo plots. Photointerpretation data were then linked to a subsample of ground plots by regression analysis. All parameters except one (number of trees per hectare) were estimated with a standard error of less than 10% of the mean. An automated image interpretation program was apparently used to provide graphic output for in-place mapping of vegetation and stand
condition classes.

The site index mapping study in Colorado (Getter and Tom 1977, Tom and Miller 1980) was innovative in that variables obtained from a variety of sources (Landsat multispectral data, digital terrain data, and photointerpreted vegetation) were used to predict and map site index classes.

Martin (1979) used 12 land form and existing vegetation variables, obtained by grid sampling on separately compiled maps (from different types of photography), to examine associations between these variables and habitat type distributions and to predict habitat type by discriminant analysis. While significant relationships were observed, neither mapped land form nor existing overstory vegetation unit boundaries coincided consistently with field checked habitat type boundaries. He concluded that land unit delineation in terms of quantifiable land form characteristics could provide a more sensitive classification of the environment than habitat typing, and that "the attainment of an acceptable percentage of correctly classified habitat types from land form characteristics suggests that close relationships may also be definable between land form and other resource attributes, such as site productivity, soil depth, soil
moisture, etc."

In a recent study in south-central Montana (Martin and Gerlach 1981), multiple stand attributes were statistically estimated from a set of stand delineation criteria used on high-altitude photography. The delineation criteria included overstory vegetation variables (photographic pattern and texture, canopy coverage, average stand height, and average crown diameter) and topographic variables (aspect, slope angle, slope position, contour curvature, and elevation). These variables were selectively chosen as independent variables to be used in the prediction of various attributes of the delineated stands. Regression analysis was used to predict cubic and board foot volume per acre, cubic and board foot growth per acre, average site index, and average yield capability. All regressions were significant at the .001 level of significance with calculated R-squared values as follows /2: cubic foot volume per acre (.73), board foot volume per acre (.80), cubic foot growth per acre (.66), board foot growth per acre (.68), average site index (.72), and average yield (.86).

As mentioned earlier, discriminant analysis was used to

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/2 Actually, two study areas were examined, with slightly different methods and results. Only the results most directly applicable to the current study are reported here.
classify stands by habitat type with a correct classification of 37% at the phase level and 39% at the type level. In addition, stand maps were compiled, by manual and computerized methods, to cover standard USGS 7.5-minute quadrangle sheets.

This study was essentially the precursor of the current study, and most of the basic concepts presented in the earlier paper were built upon and refined here. The current study differs mainly in the scale of photography used, the definition or resolution of the independent photointerpretation variables, and the geographic area of consideration, and was seen as a developmental test of the basic technique under different conditions. An effort was made here to use methods and materials (and to present results) suited to practicing foresters on a local, or district level.

In 1982, the Northern Region of the U. S. Forest Service implemented this technique semi-operationally for mapping and evaluating stands throughout Missoula and Mineral counties in Montana (USFS 1982). Again, stand delineation and photointerpretation was performed manually on high-altitude photography. However, the mapping phase of this project was almost fully automated, through the use of the Digital Terrain Information System (USFS 1981), a
state-of-the-art computer package for natural resource mapping and data manipulation. Stand attribute prediction results thus far have been mixed; however, due to the flexibility of this system for handling data input, improvements are anticipated with further research in this area.
CHAPTER III

STUDY AREA

Lubrecht Experimental Forest, a 23,000 acre (9300 ha) research facility of the University of Montana School of Forestry, is located approximately 30 miles (48 km) east of Missoula, Montana. The area is generally mountainous and is considered to be typical of mid-elevation coniferous forests of west-central Montana. Situated about 50 miles (80 km) west of the Continental Divide, the area is climatically mid-range between the more moist maritime climate to the north and west, and the drier, continental climate to the south and east.

For the period 1957-1979, the average annual monthly temperature recorded at Greenough (elevation approximately 4100 feet (1250 m) m.s.l.) was 39.2 F, with average monthly temperatures ranging from 16.9 F in January to 62.4 F in July. Average annual precipitation was 17.6 inches (447.0 mm), ranging from 12.2 inches (309.9 mm) in 1960 to 29.5 inches (749.3 mm) in 1975 (Steele 1980). Average precipitation is higher and temperature variations are less at higher elevations in the Forest.
The actual study area covered about 14,000 acres (5665 ha) of the Forest in a rectangular strip running east-west (see figure 1). The area includes Sections 7 through 24, T.13 N., R.14 W., and Sections 10 through 15, and 22 through 24, T.13 N., R.15 W., Principal Meridian Montana. Elevations range from just below 4,000 feet (1219 m) at the western edge of the study area and at the confluence of Cap Wallace Creek and Elk Creek, to just over 5,600 feet (1700 m), along the eastern edge of the study area, in the upper reaches of Cap Wallace Creek and North Fork Elk Creek.

The study area is located on the northerly slope of the Garnet Range. Geologically, the area is underlain primarily by Precambrian Belt rocks, Tertiary basin deposits, and igneous quartz monzonite (granite), with minor occurrences of Quaternary alluvial deposits, limestone, and other igneous intrusions (Brenner 1964). Gravelly and sandy loam soils (Inceptisols and Entisols) have developed on the Precambrian and igneous substrates, while soils on the Tertiary basin deposits are mainly silt loams and clays (Alfisols and Mollisols) (Brenner 1964, USDA Soil Conservation Service 1972).
The type of bedrock appears to be related to the landforms which have evolved in the study area. A casual inspection of topographic maps or stereoscopic aerial photo coverage reveals distinct topographic differences between east and west portions of the study area. From approximately Stinkwater Creek eastward, the landscape is characterized by generally accentuated relief, with many deeply cut canyons and tributary gullies, corresponding steep slopes, and relatively sharp ridgelines. This landform is best expressed in the southeastern quarter of the study area, which is entirely over granitic bedrock. Coarse, shallow soils and rock outcrops are common in this area. The western half of the study area is characterized by relatively subdued relief, with broad slopes and ridges, and a lack of well-defined stream channels. The Tertiary basin deposits are restricted mostly to the low-lying areas and depressions in the northwestern quarter of the study area. The associated topography is mildly undulating, almost flat, with many closed, undrained depressions. Roadcuts through this material near Lubrecht Camp reveal a reddish, puffed-up, clayey soil, indicative of bentonitic or montmorillonitic clays. Small stream channels draining upland areas near Coyote Park (in Precambrian Belt rocks) tend to flatten out, dry out, and become less distinct upon crossing the Tertiary basin deposits, perhaps partly because
of the high water-holding capacity and greater depth of these soils.

These differences in topographic expression became important factors in determining the size and resolution of the delineated land units during photointerpretation.

Apparently, differences in geology are reflected not only by soils and landforms, but also by vegetation. In another study conducted near the current study area, Goldin (1976) found that "at similar topographic positions, definite differences occurred in plant distribution and community structure according to the underlying substrate"; habitat types occurring on limestone soils were of a more droughty nature than those found on granitic or quartzitic soils on similar topographic sites.

Almost all of the study area supports, or is capable of supporting, forest vegetation, with the exception of a few isolated areas of riparian zones, rock outcrops and scree slopes, and mining and other disturbances. The principal tree species are (in order of dominance) : Douglas-fir (Pseudotsuga menziesii), ponderosa pine (Pinus ponderosa), lodgepole pine (Pinus contorta), and western larch (Larix occidentalis).
Douglas-fir occurs on all exposures throughout the study area. Ponderosa pine and Douglas-fir form open stands on semi-arid southerly slopes, especially at lower elevations. Lodgepole pine occurs on northerly exposures at lower elevations, becoming increasingly common, on all exposures, at higher elevations. Dense, even-aged stands of lodgepole pine have commonly become established on previously burned areas. Western larch occurs primarily on northerly slopes at all elevations, in combination with varying amounts of Douglas-fir and lodgepole pine. Lubrecht Forest is near the eastern edge of the geographic range of western larch, and while it is a significant component of many stands, it is rarely the dominant overstory species. A few distinctive two-storied stands occur in the eastern half of the study area in which an upper story of relict old-growth larch, apparently survivors of a past fire, overtop a lower story of dense, "dog-hair" lodgepole pine. In the nearly flat terrain around Lubrecht Camp, ponderosa pine, Douglas-fir, and western larch occur in almost equal proportions, apparently even in old-growth situations.

Engelmann spruce (Picea engelmannii) and subalpine fir (Abies lasiocarpa) occur locally in minor amounts along stream bottoms and drainage areas, and on a few northerly slopes and cold pockets at higher elevations.
Small groves of black cottonwood (*Populus trichocarpa*) and quaking aspen (*Populus tremuloides*) are found in very restricted swampy areas, and are a very minor component of the overall forest overstory vegetation.

Most of the study area, and of Lubrecht Forest in general, is second-growth forest. Early logging began during the period 1904-1906, when most of Township 13 North, Range 15 West (including the western third of the study area) was logged by the Anaconda Company. The remainder of the study area was logged during the period 1925-1934, when railroad spur lines were built up Elk Creek, North Fork Elk Creek, and Stinkwater Creek (Cauvin 1961, Steele 1964). Only small experimental and sanitation cuttings have taken place since then, until recently. A major logging operation in the western third of the study area began during the summer of 1982 and is currently in progress.

The early logging practices removed only the largest merchantable timber and left many trees which have since become dominant overstory trees. This has resulted in many stands having a clumpy, uneven appearance, with a scattering of older dominant trees interspersed with lower stories of emerging poles and saplings in various densities. In other areas, the lack of cultural treatments has resulted in stands with erratic overstory patterns and size
distributions, even though the age distribution may be rather uniform. Thus, while it is a common goal in forest management to create uniform stand conditions, and the primary timber species in the area are suitable for even-aged stand management, most of the truly uniform stands in the study area did not arrive at that condition by design of management.

One of the goals of ongoing research at Lubrecht Experimental Forest is to develop more efficient and intelligent timber management practices. It is believed that the type of mapping envisioned in this study will be useful for identifying and prioritizing those stands suitable for various management and research applications.
CHAPTER IV

STUDY DESIGN

The essential problems addressed in this study involved the ability to photogrammetrically map timber stands and to estimate measures of the volume, productivity, and composition of those stands based on their photointerpreted characteristics. These estimates were provided through statistical prediction models based on quantitative relationships between photointerpretation variables and selected ground attributes.

To accomplish the study objectives, four basic task areas were identified: 1) collection of ground data, 2) photointerpretation and mapping, 3) statistical analysis and prediction, and 4) field verification.

GROUND DATA COLLECTION

In order to develop reliable correlations between the photointerpreted variables and actual stand conditions, it was necessary to obtain accurate field data over the range of conditions found in the study area. An intensive field sample was conducted during the 1980 and 1981 field seasons.
Beginning in 1980, a densified network of ground control points with known positional coordinates (X, Y State Plane Coordinates, and Z, elevation) has been implemented and tested in the study area (Gerlach, in progress). Since the ability to accurately locate and map field locations is an important consideration in studies such as this one, field data were collected in coordination with this control system.

Field plots were located at 150-foot (45.7 m) intervals along randomly selected transect lines between control stations (which average 1320 feet (402 m) apart in a roughly square grid system). All plots were variable-radius plots, with appropriate basal area factors chosen within each stand to assure an adequate number of tally trees. Data collection followed standard Forest Survey timber inventory procedures (USFS 1978). Data collected at each plot included basic tree measurements - i.e., height, dbh, radial growth, and age (for site trees) - stand size and structure, physiographic and topographic characteristics, habitat type, and forest type. An example of the field data collection form used is shown in Appendix A. A total of 255 field plots along 25 transects were sampled. Raw field data were transcribed in coded form onto computer files and stored on magnetic tape.
Sample plot locations were accurately pin-pointed in the field on 1:12000 scale color aerial photos. Also, knowing the ground coordinates and calculated bearings between control points allowed for calculation of the ground coordinates of the sample plots. Computer files of these coordinates were compiled which could then be used as input to mapping programs. Control point and sample plot locations were plotted at 1:24000 scale and overlaid to 7.5-minute quadrangle coverage of the study area. This provided a relatively accurate visualization of the field locations against a standard topographic map base, which would become useful during the photointerpretation and mapping phase of this study.

Raw field data were computer processed using equations and algorithms selected for accuracy and applicability to the study area. Volume equations were adapted from Champion Timberlands (1980) and Brackett (1973). Scribner Decimal C board foot volume was calculated for trees six inches dbh and larger, and cubic foot volume (including stumps and tops) was calculated for trees two inches dbh and larger. A volume growth algorithm was developed based on empirically-derived height-diameter relationships observed within the study area. Site index and yield capability equations were adapted from Brickell (1970), with the exception of the site index equation for ponderosa pine,
which was from Tesch and others (1980). Site index figures are for a 50-year base age. Yield capability equations are derived from various functions of site index, and assume fully stocked natural stands (Brickell 1970). Actual yields may be somewhat less in stands with rock outcrops or limiting soil conditions. However, for the purposes of this study, only the unadjusted yield figures were used. Yield capability was expressed in cubic feet per acre per year.

An output file of plot summary data was produced which would be used in calculating ground data statistics and in matching ground data to corresponding photointerpretation data.

**PHOTOINTERPRETATION AND MAPPING**

A flight line of 1:24000 scale panchromatic (black and white) aerial photography of the study area was taken in July, 1980. Eight exposures (providing roughly seven stereomodels) were taken in a strip running east-west. Nominal focal length of the photography was six inches. This type of conventional medium-scale photography, commonly known as "resource photography", is probably the most commonly available, widely used, and least expensive aerial photography used in forestry applications today.
Photointerpretation was done stereoscopically under magnification with an Alan Gordon Enterprises Condor T-22 stereoscope. This instrument provides 1.5- and 3-power magnification, producing approximate working scales on this photography of 1:16000 and 1:8000, respectively. Stand delineation was done over a light table on film diapositives, which were subsequently placed in a Kelsh projection stereoplotter for photogrammetric mapping. These diapositives were printed emulsion-down, allowing stand boundaries to be inked (and easily erased) on the film base, while providing a "right-reading" image to work with.

Selection of photointerpretation criteria was based primarily on two considerations: 1) there had to be a theoretical connection between the photointerpreted variables and the stand attributes to be estimated, and 2) the variables would have to be consistently and objectively measured and observed on the aerial photography. No attempt would be made to directly interpret stand attributes during photointerpretation. The guiding purpose in designing the photointerpretation scheme was that the variables obtained from the aerial photography would be used as independent variables in statistical equations for predicting several (dependent variable) stand attributes.
A further consideration which influenced the nature of the variables chosen was the minimum area limit of the delineated stands. Since delineation stressed the recognition of homogeneous conditions of overstory and topography, the relative definition of "homogeneity" was somewhat dependent on this specification. A five-acre minimum limit was chosen arbitrarily, but was believed to be an appropriate size for most local timber management operations. Smaller areas could have been delineated given the resolution of the photography, but this probably would have resulted in a large number of unworkably small units, at least from the standpoint of practical timber management planning. Only in a few special cases, such as swamps or mines, were smaller units delineated.

The selected photointerpretation criteria are listed in Tables 1 and 2. Two groups of photointerpretation (P.I.) variables were recognized, delineation and descriptive variables. Delineation variables were those that were most useful in detecting and categorizing different stand conditions. Once stands were delineated and coded in terms of the initial eight delineation variables, data were collected for seven more descriptive variables, which, in general, were more easily collected after attention could be focused on a delineated area. In addition, two supplementary variables were collected, photointerpreted
forest type, and geology/parent material (from Brenner 1968), but were not used as independent variables in the statistical analyses. Forest type was subjectively estimated, as is traditionally done in photointerpretation, to compare classification accuracy with that obtained by statistical prediction methods.

Pattern and texture were evaluated by comparison with representative stands of each category. The 'mottled' pattern category was split into two distinct types. Mottled-systematic refers to stands with a repetitive, usually striated pattern which was observed in areas of partial cutting or seepage zones. The mottled-erratic category refers to stands with no apparent order to a partially broken pattern, but with somewhat evenly distributed openings in the canopy. Broken pattern indicates stands with many irregular openings and highly variable tree size distributions. The complex texture category refers to usually two-storied stands with both fine and coarse texture images intermixed. Percent canopy coverage was measured using a standard reference template.
Table 1. Delineation Criteria

<table>
<thead>
<tr>
<th>I. Overstory Pattern</th>
<th>VI. Plan Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Uniform, evenly distributed</td>
<td>1. Notably convex (Rh&lt;80 m.)*</td>
</tr>
<tr>
<td>2. Mottled, systematic</td>
<td>2. Slightly convex (80&lt; Rh&lt;200 m.)</td>
</tr>
<tr>
<td>3. Mottled, erratic</td>
<td>3. Nearly straight (Rh&gt;200 to Rh&lt; -200 m.)</td>
</tr>
<tr>
<td>4. Broken</td>
<td>4. Slightly concave (-80&gt; Rh&gt; -200 m.)</td>
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</tbody>
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<table>
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<tr>
<th>II. Overstory Texture</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Very fine</td>
<td>5. Notably concave (Rh&gt; -80 m.)</td>
</tr>
<tr>
<td>2. Medium fine</td>
<td>6. Undulating</td>
</tr>
<tr>
<td>3. Medium coarse</td>
<td></td>
</tr>
<tr>
<td>4. Coarse</td>
<td></td>
</tr>
<tr>
<td>5. Complex</td>
<td></td>
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<table>
<thead>
<tr>
<th>III. Percent Canopy Coverage</th>
<th>VII. Profile Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Less than 25%</td>
<td>1. Convex</td>
</tr>
<tr>
<td>2. 25 - 40%</td>
<td>2. Straight</td>
</tr>
<tr>
<td>3. 40 - 55%</td>
<td>3. Concave</td>
</tr>
<tr>
<td>4. 55 - 70%</td>
<td>4. Undulating</td>
</tr>
<tr>
<td>5. 70 - 85%</td>
<td></td>
</tr>
<tr>
<td>6. Greater than 85%</td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>IV. Slope Gradient</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. 0 - 5%</td>
<td>1. None</td>
</tr>
<tr>
<td>2. 5 - 15%</td>
<td>2. Logging</td>
</tr>
<tr>
<td>3. 15 - 35%</td>
<td>3. Mining</td>
</tr>
<tr>
<td>4. 35 - 55%</td>
<td>4. Rock outcrops, scree</td>
</tr>
<tr>
<td>5. 55 - 75%</td>
<td>5. High water table</td>
</tr>
<tr>
<td>6. Greater than 75%</td>
<td>6. Hardwoods (&gt;60%)</td>
</tr>
</tbody>
</table>

<table>
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<tr>
<th>V. Aspect (° Az.)</th>
<th>VIII. Landscape Modifiers</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. N (338 - 22)</td>
<td>1. None</td>
</tr>
<tr>
<td>2. NE (23 - 67)</td>
<td>2. Logging</td>
</tr>
<tr>
<td>3. E (68 - 112)</td>
<td>3. Mining</td>
</tr>
<tr>
<td>4. SE (113 - 157)</td>
<td>4. Rock outcrops, scree</td>
</tr>
<tr>
<td>5. S (158 - 202)</td>
<td>5. High water table</td>
</tr>
<tr>
<td>6. SW (203 - 247)</td>
<td>6. Hardwoods (20-60%)</td>
</tr>
<tr>
<td>7. W (248 - 292)</td>
<td>7. Hardwoods (&gt;60%)</td>
</tr>
<tr>
<td>8. NW (293 - 227)</td>
<td>8. Two-storied stand</td>
</tr>
<tr>
<td>9. Flat (Less than 5% slope)</td>
<td>9. Unknown/other</td>
</tr>
</tbody>
</table>
Table 2. Descriptive Criteria

I. Average Stand Height (feet)
1. Less than 30
2. 31 - 45
3. 46 - 60
4. 61 - 75
5. Greater than 76

VI. Drainage Order
1. First order
2. Second order
3. Third order
4. Fourth order
5. Fifth order

II. Average Crown Diameter (feet)
1. Less than 7
2. 7 - 14
3. 14 - 21
4. 21 - 30
5. Greater than 30

VII. Average Photographic Tone
1. Light
2. Medium
3. Dark

III. Physiographic Class
1. Main ridge, interfluve
2. Flat, bench
3. Midslope ridge
4. Midslope facet
5. Midslope drain
6. Stream bottom

Ancillary Variables

VIII. Photointerpreted Forest Type
1. Ponderosa pine
2. Douglas-fir
3. Douglas-fir/western larch/ponderosa pine
4. Douglas-fir/western larch
5. Lodgepole pine
6. Engelmann spruce/Subalpine fir
7. Hardwoods

IV. Local Slope Position
1. Lower slope
2. Midslope
3. Upper slope

IX. Parent Material*
1. Quaternary gravels
2. Tertiary basin deposits
3. Limestone
4. Precambrian bedrock
5. Igneous bedrock

V. Elevation (feet m.s.l.)
1. 3800 - 4000
2. 4000 - 4200
3. 4200 - 4400
4. 4400 - 4600
5. 4600 - 4800
6. 4800 - 5000
7. 5000 - 5200
8. 5200 - 5400
9. 5400 - 5600
10. 5600 - 5800
11. 5800 - 6000

*(from Brenner 1968)
The combination of overstory (image) pattern and texture, and percent canopy coverage, was believed to be most useful for recognizing particular overstory conditions. The perceived texture of a stand on a given scale of photography is a function of the size, shape, and spacing of the individual tree crowns (ASP 1960). Unless the stand is truly uniform in terms of size, age, site conditions, etc., there will probably be breaks in the forest canopy, resulting in a less than uniform overstory pattern. On medium to small scale photography, pattern and texture have long been used by photointerpreters to provide clues to stand structure and composition (ASP 1960, 1975). For instance, dense stands of even-aged lodgepole pine appear on aerial photos as uniform, fine-textured, and "carpet-like", while old-growth stands of ponderosa pine on dry exposures tend to have coarse textures and broken patterns. While percent canopy coverage provides information about the amount of area occupied by vegetation, it provides no indication by itself of the pattern or density of the vegetation. It was felt that using all three variables, pattern, texture, and canopy coverage, provided an efficient means of initially stratifying overstory conditions, which could then be measured in more detail for average stand height and crown diameter.
Aspect was measured directly from the photos and topographic maps. Plan form was evaluated in terms of relative concavity or convexity with reference templates drawn to scale. The selected values for radius of horizontal curvature were based on field observations and previous studies (Young 1972, Martin 1979). A similar measure of profile form, though possible, would have been very cumbersome to evaluate on aerial photography (as noted by Martin 1979), and the slightly more subjective categories of profile form were evaluated visually. The landscape modification variable was chosen mainly to sort cases in later analyses and was not meant to be used as an independent variable. Local slope position and general physiographic location, while lacking quantitative values, could be used to characterize stands fairly consistently once delineations were made.

Drainage order refers to the order of the stream adjacent to or drained by a stand. The smallest, ephemeral stream courses were classified as first order. The confluence of two first-order streams produced a second-order stream, two second-order streams combine to form a third-order stream, and so on. The confluence of a given stream with a lower-order stream, however, would not change the classification of the first stream (i.e., a first-order stream joining a second-order stream would not
raise the order of the second-order stream) (after Strahler 1957). As would be expected, most cases involved first-order drainages, with decreasing proportions in each higher order. In the context of this study, the highest order attained was fifth-order, in the lower reaches of Elk Creek. The rationale for using this variable was that the size of the stream channel adjacent to a stand would be related to soil moisture, and hence parameters such as volume, growth, site quality, and floristic composition. Most streams regarded as first-order were actually dry most of the year, while those above third order usually had at least intermittent stretches of running water throughout the year. Also, this variable was rather easily determined from maps and aerial photography, and most of the stands could be classified without much ambiguity. Stands located on benches or ridgetops that were not clearly in any particular drainage were assigned a missing value code for this variable.

An attempt was made to measure the average tone of stands with a reference gray scale. Tone is usually used in photointerpretation to identify species, but the intention here was to obtain a measure of relative reflectance, resulting from the combined effects of tree foliage and ground reflectance. However, as has been found in many other studies (ASP 1960, 1975), tone varied too much across
a single photograph, for a number of reasons, to be of much use. Thus, the categories of this variable that finally were used only represent gross differences evaluated by visual comparison.

In making stand delineations, attention was usually focused first on areas reflecting distinctive overstory conditions. Within these areas, further subdivisions could usually be made along breaks in slope, aspect, or topographic form. Of course, drastic breaks in topography, such as sharp ridgelines, provided natural lines for stand delineation regardless of overstory appearance (although such drastic changes were usually also reflected in the vegetation).

The relatively short focal length of the photography enhanced vertical exaggeration when viewing in stereo, thus accentuating topography, which was desirable in delineation. In many areas, however, topography was rather weakly expressed, and delineations were based primarily on the appearance of the overstory.

Most photointerpretation data was obtained while working on the stereoscope. However, a few variables were more easily and accurately obtained while mapping on the Kelsh plotter. Pattern, texture, canopy coverage, aspect, plan and profile form, landscape modifiers, slope position,
drainage order, physiographic class, and average tone were obtained during preliminary photointerpretation on the stereoscope. Slope gradient, average stand height, average crown diameter, and elevation were measured on the Kelsh plotter.

The range of values and the type of categories recognized for each of the photointerpretation variables were designed in such a way that the correct classification could be determined rapidly and consistently, given the inherent variability of the stands themselves and the limitations of the equipment, while maintaining a certain amount of resolution in the criteria. For example, very precise tree height measurements could be obtained on the Kelsh plotter (i.e., within five feet) but the variation around the average height of most stands was probably greater than this level of precision.

As the stands were interpreted and delineated, they were assigned a unique identification number. The photointerpretation data was recorded in code and stored, along with the identifier number, in a computer file. A sample of a computer printout listing stands by identifier number with their associated P.I. variables is shown in Appendix B.
After the diapositives were delineated and annotated, they were placed in the Kelsh plotter, with an adjacent stereomate, for photogrammetric mapping of stand boundary detail. Ground control points were located and marked on the diapositives. A base map with plotted control points was produced on a Calcomp drum plotter at a scale of 1:4800 (the stereomodel is magnified five times by the Kelsh projectors). The control on the photos was then used to precisely orient and scale the stereomodel to the base map. Also, 7.5-minute quadrangle tick marks were plotted onto the base map to allow for registration of the stand map with topographic quadrangle coverage of the study area during final map compilation. Use of the Kelsh stereoplotter allowed for mapping at a precision not normally found in natural resource mapping projects.

STATISTICAL ANALYSIS

A preliminary step in data analysis involved matching field data to corresponding photointerpretation data and compiling a data base from which further analyses could be performed. This began with carefully transferring field plot locations from the 1:12000 scale color photography to the 1:24000 scale panchromatic diapositives. A number of plots either fell on stand boundary delineations, could not be reliably located, or were unsuitable for some other
reason, reducing the field data set from 255 to 227 plots. Data from these 227 plots were then matched with corresponding photointerpretation data from 93 delineated stands (some stands had several plots) and were stored as a combined data set in a computer file. Further analysis of this data set depended on the type of dependent variable (stand attribute) under consideration, whether continuous or interval-level (volume, growth, site index, or yield capability), or categorical or nominal-level (habitat or forest type). In either case, though, statistical analysis was conducted in basically two steps: 1) measures of association and tests of statistical significance were calculated for each of the independent P.I. variables against the dependent attributes, and 2) predictive models were developed for the dependent attributes based on information from step 1 and from theoretical considerations. All statistical calculations were done using the SPSS statistical package (Nie, et.al. 1975) on the University of Montana Decsystem-20 computer.

Interval-level Attributes

In cases where several field plots were located within a delineated stand, field plot data for interval-level stand attributes were averaged. It was believed that this would reduce the effect of chance fluctuations in field plot data
and strengthen the correlations between the field data and corresponding photointerpretation data.

For each of the independent P.I. variables, a one-way analysis of variance (univariate F-test) was conducted to detect significant differences among category means on each of the dependent variables. The eta-squared statistic, calculated as the ratio of between-groups sum of squares to total sum of squares, provided a measure of the total variance (linear and nonlinear) in the dependent variable explained by the independent variable. Eta-squared values can range from zero to a maximum of +1, where all variation in the dependent variable would be accounted for by the independent variable.

Multiple regression analysis was used to obtain predicted values of the interval-level stand attributes. In conventional regression analysis, an equation is derived wherein predicted values of a single interval-level dependent variable are calculated from a linear combination of interval-level independent variables, each multiplied by an associated coefficient. The equation also usually contains a constant, or intercept, term. The coefficients are based on the correlations between the independent variables and the dependent variable, and the equations are derived in such a way (least squares method) that the
differences between the predicted and observed values of the dependent variable are minimized over all cases in the analysis. The degree to which this error is minimized is indicated by certain diagnostic statistics, such as R-squared. Thus, given the independent variable values of any particular case, the dependent attribute of interest can be calculated with a known reliability.

Since all of the independent P.I. variables used in this study were broken into categories and recorded as such, they were not truly interval level of measurement. Several of the variables (canopy coverage, average stand height, average crown diameter, elevation, percent slope, and a transformation of aspect) were interval-level by nature and could be treated as roughly continuous scale by using their midpoint values. However, the remaining variables (pattern, texture, tone, plan and profile form, slope position, drainage order, and physiographic class), while perhaps not beyond measurement, lacked numerical values in this study. To incorporate these variables into the analysis, the technique of regression with dummy variables was employed. Dummy variables are created by treating each category of a nominal-level variable as a separate variable and assigning arbitrary scores of one or zero to all cases depending on the presence or absence of each of the categories. These variables can then be treated as interval-level and entered
into a regression equation of the form

\[ Y' = a + b_1 D_1 + b_2 D_2 + \ldots + b_n D_n, \]

where \( Y' \) is the predicted dependent variable, \( a \) is the intercept term, \( b_1, b_2, \ldots, b_n \) are coefficients, and \( D_1, D_2, \ldots, D_n \) are dummy variables. For cases containing only the reference category, this equation reduces to \( Y' = a \). For cases containing the category represented by dummy variable 1, the equation reduces to \( Y' = a + b_1 \); for cases with dummy variable 2, \( Y' = a + b_2 \), and so on (since the other dummy variables would be entered as zero).

As an example using variables from this study, if only pattern and texture dummy variables were used, the prediction equation would have the form

\[ Y' = a + b_1 D_{\text{Pat}_1}(\text{uniform}) + b_2 D_{\text{Pat}_2}(\text{mottled-systematic}) + b_3 D_{\text{Pat}_3}(\text{mottled-erratic}) + b_4 D_{\text{Tex}_1}(\text{very fine}) + b_5 D_{\text{Tex}_2}(\text{medium fine}) + b_6 D_{\text{Tex}_3}(\text{medium coarse}) + b_7 D_{\text{Tex}_4}(\text{coarse}). \]

For a stand having uniform pattern and medium fine texture, this equation reduces to

\[ Y' = a + b_1 D_{\text{Pat}_1} + b_5 D_{\text{Tex}_2}. \]

/3 Actually, one dummy variable, representing a sort of reference category, must be coded only as zero to allow solution of the least squares normal equations.
The procedure followed in this study was to code all of the independent P.I. variables as dummy variables, selectively using those deemed appropriate for each analysis. Also, interval-level variables were included in the equations when appropriate, and several interval-level variables were created (such as, a cosine transformation of aspect, and various transformations and combinations of average height, average crown diameter, and canopy coverage). Although it is likely that some significant interaction terms exist involving the dummy variables, none were found in the several attempts that were tried, and exploring this possibility could be a formidable job in itself (from 13 independent P.I. variables, 78 dummy variables were created, with roughly 2 billion possible interaction terms). Independent variables were entered into, and removed from, the equations in a step-wise manner, depending on their relative contribution to the explained variation and whether meeting specified limiting criteria for entry and removal.

Several statistical measures were provided to evaluate the regression equations. The R-squared statistic indicates the proportion of variation accounted for in a dependent variable by the independent variable(s). Adjusted R-squared
is an R-squared statistic adjusted for the number of independent variables in the equation and the number of cases (Kim and Kohout 1975, p.358). It is a more conservative estimate of the percentage of variation explained, and is generally thought to be a more sensitive measure of the reliability of an equation. The standard error of the estimate is a measure of the dispersion of the actual Y values from the predicted Y' values. As the regression line (or surface) can be thought of as a kind of "moving average", the standard error of the estimate is analogous to the standard deviation of a sample mean, and when expressed as a percentage of the mean of the cases used in the analysis, is directly comparable to the coefficient of variation (in percent).

Nominal-level Attributes

Since nominal-level attributes cannot be rationally averaged, as can interval-level attributes, statistical analyses involving nominal attributes had to be conducted on a plot-by-plot basis. For instance, where two different habitat types were found within a delineated stand, the two habitat type codes could not be combined to form an "average" habitat type. Thus, ground-sampled nominal attributes had to be matched plot-by-plot to the P.I. data describing the stands in which they fell, resulting in some
stands having identical sets of P.I. data but different nominal attribute ground data.

Chi-square tests were conducted to determine if P.I. variables were independent of nominal attributes. A measure of association was provided by the asymmetric lambda statistic. Asymmetric lambda measures the percentage improvement in the ability to predict a nominal dependent variable given the value of a nominal independent variable and, like eta-squared, ranges in value from zero to one.

Discriminant analysis was the multivariate statistical procedure used to predict nominal stand attributes given several independent P.I. variables. The central concept of discriminant analysis is that maximization of between-group variation relative to pooled within-group variation (i.e., maximum group separation) can be achieved through suitable weighted linear combinations of independent, or "discriminating", variables. "The mathematical objective of discriminant analysis is to weight and linearly combine the discriminating variables in some fashion so that groups are forced to be as statistically distinct as possible" (Klecka 1975).
The weighted linear combination is known as the discriminant function and is of the form

\[ D_i = d_1 Z_1 + d_2 Z_2 + \ldots + d_p Z_p, \]

where \( D_i \) is the discriminant score on function \( i \), the \( d \)'s are weighting coefficients, and the \( Z \)'s are the standardized values of the original \( p \) variates (Klecka 1975, p.435). The mean discriminant score on each function within a particular group defines its group centroid, or most typical location for a case from that group in \( n \)-dimensional space. Classifying a case by discriminant analysis basically involves assigning it the membership of the group represented by the nearest centroid. The overall classification accuracy can be evaluated by classifying cases of known group membership, such as the original cases used in the analysis, and finding the percentage correctly classified.

Discriminant functions are derived in such a way that the overall multivariate \( F \)-ratio for testing differences between group centroids is maximized. This involves solving the characteristic equation

\[ W^{-1} B - \lambda I = 0, \]

where \( W^{-1} \) is the inverse matrix of the pooled within-groups sum of squares and cross-products, \( B \) is the between-groups sum of squares and cross-products matrix, \( \lambda \) is an eigenvalue (or latent root), \( I \) is an identity matrix, and 0 is a 0
vector (Green 1976, Cooley and Lohnes 1962). Several discriminant functions may be generated by solution of this matrix equation and the eigenvalues are measures of the relative discriminating power of their corresponding functions. Eigenvectors associated with these eigenvalues are the discriminant function coefficients. A standardized discriminant function coefficient provides an index of the relative contribution of its associated independent variable, similar in interpretation to beta weights in regression analysis.

The discriminant functions may be thought of as defining axes in geometric space, with discriminant scores representing the positions of individual cases along those axes. The first function is derived such that, given the discriminating variables, maximum group separation occurs along that axis. One "best" function may not exhaust the predictive power of the discriminating variables, and a second function may be derived which separates groups along an orthogonal axis, given the separation already achieved. The final result may be several functions, each providing maximum group separation, in decreasing order, along mutually orthogonal axes. An examination of the coefficients associated with the first function(s) may thus indicate which variables are most important for discriminating between groups.
The number of possible functions derived is equal to the number of discriminating variables or one less than the number of groups, whichever is less. The dependence on the number of variables results from the mathematical impossibility of creating more linear functions than there are variables comprising them. The dependence on the number of groups stems from the basic geometric principle that the maximum number of dimensions needed to describe a set of points is one less than the number of points (the points in this case being the group centroids).

It is often the case that most of the discrimination between groups can be achieved with less than the total possible number of discriminant functions. Statistical significance of discriminant functions (actually, their eigenvalues) can be tested with Wilk's lambda. "Lambda is an inverse measure of the discriminating power in the original variables which has not yet been removed" (Klecka 1975). This may be demonstrated intuitively in the case of only one function, where lambda is equal to 1/(1+λ). Wilk's lambda may be converted to a chi-square statistic for testing significance. Another useful measure in evaluating discriminant functions is the relative eigenvalue percentage. Since an eigenvalue is an index of the amount of between-group variation accounted for by a function, expressing it as a percentage of the sum of all possible
eigenvalues provides an easily interpreted measure of the relative importance of a function. The number of discriminant functions derived was controlled by setting the minimum acceptable cumulative eigenvalue percentage at 95%, and the maximum significance level of Wilk's lambda at 0.25.

A requirement of discriminant analysis is that the discriminating variables are at least ordinal level of measurement. Several of the P.I. variables (pattern, texture, tone, and slope position) were actually recorded as nominal-level variables, but it was felt that their classes could be ordered in a way reflecting their approximate relation to each other ("ordered metric" level, as described by Nie, et.al. 1975, p.6). No approximate ordering could be formulated for plan form, profile form, or physiographic class, and these variables were excluded from the analysis. The remaining variables were considered roughly interval-level, using their class midpoints, or ordinal-level.

In a manner analogous to regression analysis, high degrees of collinearity among independent variables lead to unstable discriminant function coefficients, not truly reflecting the contribution of a variable. This problem can be avoided by using a step-wise procedure, where variables are entered into the analysis in the order of their
discriminating ability, given the variables already entered, and variables falling below a certain criteria are excluded from the analysis.

Using the step-wise option of the SPSS DISCRIMINANT program, the selection criterion used here was minimization of Wilk's lambda (or, equivalently, maximization of the overall multivariate F-ratio for the test of differences among the group centroids). Significance levels of multivariate F-to-enter and F-to-remove were specified at 0.20 and 0.25, respectively.

The general classification rule is to assign an observation to the group whose centroid is closest to that observation in discriminant space. This rule, however, does not take into account prior probabilities of group membership; that is, the probability of drawing at random a member of each group from a mixed population. Prior probabilities provide an adjustment based on the relative frequency of the groups in the population. If nothing is known of the group distributions, it is probably safest to assume equal prior probabilities. However, if the total sample is reasonably large (i.e., greater than 30 cases) and was randomly selected, using the relative frequencies of the groups in the sample as a priori probabilities may lead to a substantial reduction in misclassification (Morrison 1967).
In the analyses done in this study, prior probabilities were specified using the relative frequencies of the groups in the sample.

The classification accuracy was checked empirically by classifying the original cases of known group membership used in deriving the discriminant functions. A classification table showing predicted versus observed memberships can reveal the overall accuracy of the discriminant functions, as well as groups which apparently cannot be distinguished from others in terms of the discriminating variables. It is important to keep in mind that the classification accuracy is not a test of statistical significance, and one cannot make inferences regarding the reliability of the classifications.

FIELD VERIFICATION

During the summer of 1982, field data were collected on nine previously unsampled stands, providing a check against the predicted attribute values for these stands. Selection was based on distinct image characteristics (vegetative and topographic) thought to clearly represent a few typical stand conditions. The method of sampling these stands was slightly different from previous field sampling. A transparent grid was overlaid to the delineated stand and a
grid point was located near the center of the stand, and pinpointed on the aerial photography. This pinpointed location became the center of a four-point, diamond-shaped cluster of sample plots, spaced 150 feet apart. By this method, with all four plots located intentionally within the most representative part of the stand, a good (or at least better) estimate of the attributes of interest for that stand would be assured. Also, this data would eventually be added to the final data set; whatever correlations existed between the sampled attributes and the P.I. variables for these stands would be free of error due to borderline plots or inadequate sampling, and the final predictive models might be strengthened somewhat.

/4 Bias may be introduced into a sampling scheme when plots are chosen subjectively. This danger was circumvented by the fact that the grid was placed arbitrarily over the photo. Thus, there was no control over where the grid points fell, and the sample point location was essentially random, within a desired area. Also, pinpointing was actually done on aerial photo paper prints (not diapositives) since these photos would be needed for field use.
CHAPTER V

RESULTS

Study results are presented here in four basic categories: field sampling, photointerpretation and mapping, analysis of photointerpretation variables and predictions, and field verifications.

FIELD SAMPLING

Descriptive statistics for the continuous scale ground-sampled stand attributes are presented in Table 3. These figures are based on data from 255 sample plots. Standard errors of less than 10% of the mean were obtained for all attributes and was greater than 5% of the mean for only one attribute, board foot volume per acre. This was considered to be an acceptable level of sampling accuracy for the purposes of this project. These statistics provided a standard against which further analytical results could be compared. The relatively high standard deviation for board foot volume is believed to be a reflection of the highly variable tree size distributions in the stands of the study area.
Table 3. Descriptive Statistics for Ground-Sample Data

<table>
<thead>
<tr>
<th>Stand Attribute</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error</th>
<th>%Std. Error</th>
<th>Min.</th>
<th>Max.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cubic foot volume/acre</td>
<td>1965.1</td>
<td>1375.7</td>
<td>86.7</td>
<td>4.4</td>
<td>0.0</td>
<td>8553.0</td>
</tr>
<tr>
<td>Board foot volume/acre</td>
<td>5526.7</td>
<td>5454.9</td>
<td>343.6</td>
<td>6.2</td>
<td>0.0</td>
<td>37152.0</td>
</tr>
<tr>
<td>Cubic foot growth/acre</td>
<td>34.0</td>
<td>21.6</td>
<td>1.4</td>
<td>4.1</td>
<td>0.0</td>
<td>143.0</td>
</tr>
<tr>
<td>Board foot growth/acre</td>
<td>143.3</td>
<td>104.6</td>
<td>6.6</td>
<td>4.6</td>
<td>0.0</td>
<td>731.0</td>
</tr>
<tr>
<td>Average Site Index</td>
<td>52.3</td>
<td>11.2</td>
<td>0.7</td>
<td>1.3</td>
<td>20.0</td>
<td>103.0</td>
</tr>
<tr>
<td>Average Yield Capa.</td>
<td>65.7</td>
<td>25.0</td>
<td>1.6</td>
<td>2.4</td>
<td>19.0</td>
<td>222.0</td>
</tr>
</tbody>
</table>

The minimum values of 0.0 for the per acre attributes (cubic and board foot volume and growth) are somewhat misleading. This may have occurred in cut-over stands, or in sparse, open stands where no tally trees could be obtained by variable-radius (BAF) plot sampling. In some seedling-sapling stands, a number of trees were indeed tallied but the maximum dbh recorded was less than the minimum limit for the volume equations used (2.0 inches for cubic foot and 6.0 inches for board foot volume). In either case, values for these attributes may have been quite low, but rarely would these per acre figures be truly zero.
Table 4 presents a frequency tabulation of the nominal-level stand attributes encountered. A total of 23 different habitat types and eight different forest types were identified. Only four habitat types occurred more than 5% of the time, and these were all in the *Pseudotsuga menziesii* series. Three dominant habitat types, Psme/Vaca, Psme/Libo-Vagl phase, and Psme/Syal-Caru phase each occurred about 20% of the time.

Table 4. Frequency Table of Nominal-level Attributes

<table>
<thead>
<tr>
<th>Habitat type</th>
<th>abs. freq.</th>
<th>rel. freq. (%)</th>
<th>Forest type</th>
<th>abs. freq.</th>
<th>rel. freq. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scree</td>
<td>2</td>
<td>0.8</td>
<td>Ponderosa pine</td>
<td>14</td>
<td>5.5</td>
</tr>
<tr>
<td>Psme/Vaca</td>
<td>48</td>
<td>19.2</td>
<td>Douglas-fir</td>
<td>102</td>
<td>40.0</td>
</tr>
<tr>
<td>Psme/Phma-Phma</td>
<td>6</td>
<td>2.4</td>
<td>Douglas-fir/</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Psme/Phma-Caru</td>
<td>1</td>
<td>0.4</td>
<td>Western larch/</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Psme/Vagl-Vagl</td>
<td>6</td>
<td>2.4</td>
<td>Ponderosa pine</td>
<td>43</td>
<td>16.9</td>
</tr>
<tr>
<td>Psme/Vagl-Aruv</td>
<td>4</td>
<td>1.6</td>
<td>Douglas-fir/</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Psme/Vagl-Xete</td>
<td>4</td>
<td>1.6</td>
<td>Western larch</td>
<td>70</td>
<td>27.5</td>
</tr>
<tr>
<td>Psme/Libo-Syal</td>
<td>10</td>
<td>4.0</td>
<td>Lodgepole pine</td>
<td>13</td>
<td>5.1</td>
</tr>
<tr>
<td>Psme/Libo-Caru</td>
<td>4</td>
<td>1.6</td>
<td>Engelmann spruce/</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Psme/Libo-Vagl</td>
<td>49</td>
<td>19.6</td>
<td>Subalpine fir</td>
<td>8</td>
<td>3.1</td>
</tr>
<tr>
<td>Psme/Syal-Agsp</td>
<td>16</td>
<td>6.4</td>
<td>Engelmann spruce</td>
<td>3</td>
<td>1.2</td>
</tr>
<tr>
<td>Psme/Syal-Caru</td>
<td>55</td>
<td>23.0</td>
<td>Hardwoods</td>
<td>2</td>
<td>0.8</td>
</tr>
<tr>
<td>Psme/Caru-Agsp</td>
<td>3</td>
<td>1.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Psme/Caru-Caru</td>
<td>11</td>
<td>4.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Psme/Caru-Pipo</td>
<td>2</td>
<td>0.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Psme/Cage</td>
<td>1</td>
<td>0.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Psme/Aruv</td>
<td>1</td>
<td>0.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Picea/Gatr</td>
<td>6</td>
<td>2.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abla/Gatr</td>
<td>5</td>
<td>2.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abla/Libo-Libo</td>
<td>3</td>
<td>1.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abla/Libo-Xete</td>
<td>2</td>
<td>0.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abla/Libo-Vasc</td>
<td>1</td>
<td>0.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abla/Mefe</td>
<td>10</td>
<td>4.0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The Douglas-fir forest type was by far the most common one observed, followed by Douglas-fir/western larch, and Douglas-fir/western larch/ponderosa pine. Ponderosa pine and lodgepole pine forest types each occurred about 5% of the time. The remaining forest types, Engelmann spruce, Engelmann spruce/subalpine fir, and hardwoods (aspen and cottonwood), each occurred less than 5% of the time.

PHOTOINTERPRETATION AND MAPPING

The finished stand map is presented in Plate 1. A total of 1260 stands were delineated, with an average unit size of 11.6 acres (4.7 ha). The relative ease of stand delineation varied considerably over the study area. In the eastern portion, with more accentuated topography and contrasting stand conditions, delineation was usually rather straightforward. In the western portion, however, especially near Lubrecht Camp, there was a definite lack of contrast in topographic and overstory parameters. Although differences were clearly evident, here the changes between stand conditions were much more gradual, and delineation was somewhat more difficult. The approach in this area was to start by splitting out broad differences, mainly in terms of overstory variables, and sometimes more subtle subdivisions would become apparent. However, most delineations here were
the result of numerous trials and revisions and the average delineated stand size in this area tended to be somewhat larger.

Overall, the photointerpretation criteria, with the exception of one or two categories, appeared to provide a suitable and efficient means of identifying and describing different stand conditions. The process of interpretation, stand delineation, and data recording required about 20 hours of work per stereomodel.

Mapping of stand boundary detail was done on the Kelsh plotter in a continuous strip; that is, the drafting mylar and base map (with control) were moved across the plotting table with each set-up of a stereomodel. The final manuscript map, at a scale of 1:4800, measured about 11 feet long by 3 feet wide. This map was photographically reduced to a final compilation scale of 1:12000. A chronoflex print (black-line on mylar) of the USGS quadrangle coverage of the area was enlarged from 1:24000 to 1:12000 scale and registered precisely to the stand detail map. Final map compilation involved exposing three separate negative overlays (the stand and quad maps, and an overlay of map nomenclature and scribed boundary lines framing the detail) onto a photographic mylar print. The quadrangle detail (contours, section lines, roads, etc.) was screened back
50\%. The final mylar print is suitable for printing diazo reproductions - Plate 1 is a black-line diazo print.

ANALYSIS OF P.I. VARIABLES AND PREDICTIONS

The distribution of photointerpretation variables for those stands used in statistical analysis is presented in Appendix C. Since there was no attempt to optimize sampling allocation, as in stratified sampling schemes, some of the categories may well be under- or over-sampled. During photointerpretation, it became evident that perhaps a few of the categories ought to be restructured. The mottled-systematic category of overstory pattern was only observed a few times, and t-tests revealed that this category was not significantly different from the mottled-erratic category. Since the difference in interpretation was usually only slight, this category was combined with mottled-erratic to form a single mottled category in subsequent analyses. This is not to say that the mottled category could not be subdivided somehow; a more sensitive measure of pattern may be highly desirable, but a consistent visual criteria for finer divisions could not be found in this study.
The landscape modification variable also could be restructured. In particular, there was no need for two hardwood coverage categories. As it turned out, dense hardwood groves usually also indicated areas of high water table and swamps, and some cases could have gone into either category (swamps or hardwoods). This was considered a minor problem, though, and since the modifier P.I. variable was not used as an independent variable, from the standpoint of statistical analysis it was only important that non-modified cases be separated from those with obvious departures from normal stand conditions.

**Analysis of Interval-level Attributes**

Table 5 presents the results of the univariate F-tests and eta-squared measures of association. As might be expected, the volume per acre attributes appear to be relatively strongly related to overstory-type independent variables. The growth per acre attributes also show significant relationships with some overstory variables, but also reveal some significant effects of topographic parameters; in particular, aspect and slope position. The site quality attributes, average site index and yield capability, appear to be least related to most of the P.I. variables. Only plan form, profile form, and texture show any statistical significance or degree of association.
Table 5. Tests of Significance and Measures of Association for Interval-level Attributes.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Cubic foot volume/acre</th>
<th>Board foot volume/acre</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
<td>sig.</td>
</tr>
<tr>
<td>Pattern</td>
<td>6.20</td>
<td>.001</td>
</tr>
<tr>
<td>Texture</td>
<td>0.89</td>
<td>.474</td>
</tr>
<tr>
<td>Canopy coverage</td>
<td>8.16</td>
<td>.000</td>
</tr>
<tr>
<td>Average stand height</td>
<td>3.54</td>
<td>.010</td>
</tr>
<tr>
<td>Average crown dia.</td>
<td>0.90</td>
<td>.443</td>
</tr>
<tr>
<td>Aspect</td>
<td>1.75</td>
<td>.100</td>
</tr>
<tr>
<td>Slope (%)</td>
<td>0.92</td>
<td>.455</td>
</tr>
<tr>
<td>Plan form</td>
<td>1.18</td>
<td>.327</td>
</tr>
<tr>
<td>Profile form</td>
<td>0.11</td>
<td>.956</td>
</tr>
<tr>
<td>Elevation</td>
<td>3.11</td>
<td>.004</td>
</tr>
<tr>
<td>Slope position</td>
<td>1.39</td>
<td>.254</td>
</tr>
<tr>
<td>Physio. class</td>
<td>2.53</td>
<td>.035</td>
</tr>
<tr>
<td>Drainage order</td>
<td>0.72</td>
<td>.608</td>
</tr>
<tr>
<td>Ave. tone</td>
<td>10.19</td>
<td>.000</td>
</tr>
<tr>
<td>Modifier</td>
<td>1.18</td>
<td>.324</td>
</tr>
<tr>
<td>Parent material</td>
<td>1.95</td>
<td>.110</td>
</tr>
<tr>
<td>P.I. Variable</td>
<td>Cubic foot growth/acre</td>
<td></td>
</tr>
<tr>
<td>--------------------</td>
<td>------------------------</td>
<td>---</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>sig.</td>
</tr>
<tr>
<td>Pattern</td>
<td>4.14</td>
<td>.009</td>
</tr>
<tr>
<td>Texture</td>
<td>1.81</td>
<td>.134</td>
</tr>
<tr>
<td>Canopy coverage</td>
<td>5.12</td>
<td>.000</td>
</tr>
<tr>
<td>Average stand height</td>
<td>0.44</td>
<td>.779</td>
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<tr>
<td>Average crown dia.</td>
<td>0.48</td>
<td>.696</td>
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<tr>
<td>Aspect</td>
<td>2.49</td>
<td>.018</td>
</tr>
<tr>
<td>Slope (%)</td>
<td>2.09</td>
<td>.089</td>
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<tr>
<td>Plan form</td>
<td>0.73</td>
<td>.601</td>
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<td>Profile form</td>
<td>3.93</td>
<td>.011</td>
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<td>1.20</td>
<td>.307</td>
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<td>Slope position</td>
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<td>.020</td>
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<tr>
<td>Physio. class</td>
<td>0.70</td>
<td>.626</td>
</tr>
<tr>
<td>Drainage order</td>
<td>1.92</td>
<td>.099</td>
</tr>
<tr>
<td>Ave. tone</td>
<td>6.95</td>
<td>.002</td>
</tr>
<tr>
<td>Modifier</td>
<td>2.30</td>
<td>.042</td>
</tr>
<tr>
<td>Parent material</td>
<td>1.10</td>
<td>.363</td>
</tr>
</tbody>
</table>
Table 5. Tests of Significance and Measures of Association for Interval-level Attributes.
(cont.).

<table>
<thead>
<tr>
<th>P.I. Variable</th>
<th>Average site index</th>
<th>Average yield capability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
<td>sig.</td>
</tr>
<tr>
<td>Pattern</td>
<td>0.34</td>
<td>.797</td>
</tr>
<tr>
<td>Texture</td>
<td>3.60</td>
<td>.009</td>
</tr>
<tr>
<td>Canopy coverage</td>
<td>0.43</td>
<td>.827</td>
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<tr>
<td>Average stand height</td>
<td>1.78</td>
<td>.140</td>
</tr>
<tr>
<td>Average crown dia.</td>
<td>1.06</td>
<td>.369</td>
</tr>
<tr>
<td>Aspect</td>
<td>0.47</td>
<td>.874</td>
</tr>
<tr>
<td>Slope (%)</td>
<td>0.96</td>
<td>.434</td>
</tr>
<tr>
<td>Plan form</td>
<td>2.94</td>
<td>.017</td>
</tr>
<tr>
<td>Profile form</td>
<td>2.62</td>
<td>.056</td>
</tr>
<tr>
<td>Elevation</td>
<td>0.35</td>
<td>.943</td>
</tr>
<tr>
<td>Slope position</td>
<td>2.14</td>
<td>.124</td>
</tr>
<tr>
<td>Physio. class</td>
<td>1.11</td>
<td>.363</td>
</tr>
<tr>
<td>Drainage order</td>
<td>1.29</td>
<td>.278</td>
</tr>
<tr>
<td>Ave. tone</td>
<td>0.12</td>
<td>.889</td>
</tr>
<tr>
<td>Modifier</td>
<td>1.41</td>
<td>.220</td>
</tr>
<tr>
<td>Parent material</td>
<td>3.18</td>
<td>.017</td>
</tr>
</tbody>
</table>
Interestingly, the ancillary parent material variable appears to be significantly related to the site quality attributes. This factor was obtained from a separate map and is only shown here for the sake of comparison. Since it was not a directly observable photointerpretation variable, it was not used as an independent variable in the prediction equations. A more thorough investigation would be needed to establish a link between the geology and site quality of the area; however, this simple result, and other evidence already cited (Goldin 1976), supports the theoretical contention of a relationship and hints at the value of this factor in a more comprehensive inventory of forest productivity.

Statistics from the regression analyses are presented in Table 6. Although only cubic foot growth per acre appeared to be significantly affected by the modifier variable (Table 5), all of the regression analyses were performed only on non-modified cases (i.e., no sign of stand disturbance). This was done to avoid error that could be introduced by using data from disturbed stands, and allowed for a "cleaner" analysis. This reduced the number of usable cases from 93 to 77 stands.
Table 6. Summary Regression Statistics.

<table>
<thead>
<tr>
<th>Stand Attribute</th>
<th>$R^2$</th>
<th>adj. $R^2$</th>
<th>Std. Error</th>
<th>%Std. Error</th>
<th>c.v. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cubic foot volume/acre</td>
<td>.73</td>
<td>.69</td>
<td>717.5</td>
<td>33.8</td>
<td>60.4</td>
</tr>
<tr>
<td>Board foot volume/acre</td>
<td>.89</td>
<td>.86</td>
<td>2180.2</td>
<td>35.0</td>
<td>92.4</td>
</tr>
<tr>
<td>Cubic foot growth/acre</td>
<td>.58</td>
<td>.51</td>
<td>12.7</td>
<td>36.3</td>
<td>52.1</td>
</tr>
<tr>
<td>Board foot growth/acre</td>
<td>.67</td>
<td>.61</td>
<td>52.0</td>
<td>35.4</td>
<td>56.8</td>
</tr>
<tr>
<td>Average Site Index</td>
<td>.65</td>
<td>.56</td>
<td>6.6</td>
<td>12.6</td>
<td>19.1</td>
</tr>
<tr>
<td>Average Yield Capa.</td>
<td>.53</td>
<td>.46</td>
<td>15.7</td>
<td>23.8</td>
<td>32.5</td>
</tr>
</tbody>
</table>

F-tests for all of the regression equations were significant beyond the .0001 level. Clearly, though, some equations were more reliable than others. Relatively high R-squared values were obtained for cubic and board foot volume per acre, while growth and site quality equations were somewhat less successful. These results might have been anticipated given the basic ground-sample statistics (Table 3) and the univariate tests of significance and measures of association (Table 5). The ground sample data indicated a relatively large amount of variation in the
volume per acre attributes and the univariate F values and eta-squared statistics suggest strong correlations exist between some of the P.I. variables and these attributes. Thus, a high multiple correlation coefficient could be expected. Conversely, the site quality attributes showed only a small amount of variation in the ground data statistics, and only a few significant correlations were indicated between the P.I. variables and these attributes. The growth per acre attributes showed a fairly high degree of variation in the ground data statistics, but slightly weaker relationships (than the volume per acre attributes) with the P.I. variables. This is reflected in the moderately successful regression statistics. In both volume and growth equations, the board foot attribute was more successfully predicted, perhaps because of a particularly strong relationship with average stand height, and a moderately significant effect of crown diameter (which was insignificant with cubic foot volume and growth).

As a further means of comparison, the percent standard error and coefficient of variation are provided in Table 6.5. The difference between the two values provides an indication of the relative efficiency of the regression equation.
In formulating the regression equations, a theoretical connection (admittedly slight in some cases) could be postulated between each of the dependent variable attributes and the independent P.I. variables. Hence, a nearly complete set of dummy variables was included in each analysis. It is usually more efficient, though, to make use of interval-level independent variables as much as possible in regression analysis, and specialized continuous variables were formulated for each of the analyses based on experimentally or empirically demonstrated correlations. As expected, variables involving average height and canopy coverage were found to be highly significant for explaining variation in volume-related attributes. An interaction term, height squared times canopy coverage squared (after Pope 1962), was found to be particularly useful, accounting for about 60% of the variation in both cubic and board foot volume per acre. Also as expected, crown diameter was found to be a less important variable but did account for a significant amount of variation in board foot volume per acre, as crown diameter squared and in the triple interaction term (average height X crown diameter X canopy

/5 These figures are based on the non-modified cases used in the regression analyses (n=77). Slightly different coefficients of variation would be obtained from the original data used in producing Table 3.
coverage) (after Paine 1981). The ratio of height to crown diameter, as described by Spurr (1960) and Smith (1965), was tried as an independent variable in the site index and yield equations but was found to be insignificant.

To control variable entry and removal in the step-wise process, probabilities of F-to-enter of 0.20 and F-to-remove of 0.25 were specified. While it was undesirable to have independent variables in the equations with levels of significance as low as 0.20, it was found that optimum combinations of variables could be obtained by setting this lenient cut-off value. Sometimes it appeared that the combined effect of two or more variables accounted for more of the variation than a single related variable entered early on in the step-wise process, which would become insignificant and be removed from the equation. For instance, elevation, entered originally as an interval-level variable, would be replaced by several of the more important elevation dummy variables. Equations which were derived using more stringent cut-off criteria, while perhaps having less "noise" in the independent variables, did not attain the better results possible by letting the equations "run their full course" with the more lenient criteria. Fortunately, in all of the final derived equations, only a few independent variables tested below the 0.10 level of significance, and this was considered to be tolerable given
the better regression statistics. Summaries of the regression equations are presented in Appendix D.

Analysis of Nominal-level Attributes

Contingency table analysis revealed that chi-square tests of significance for all of the P.I. variables against the nominal-level attributes were significant beyond the .0001 level. This indicates that the distribution of the P.I. variables in relation to habitat and forest type occurrence could not have happened by chance. Measures of association between the nominal attributes and the P.I. variables (asymmetric lambda) are presented in Table 7. Overstory variables texture and canopy coverage and topographic variables elevation and slope position were found to be most highly associated with habitat type distribution. Also, aspect and average stand height show relatively high lambda values, but it is difficult to theoretically justify the association of stand height and habitat type, and this result was believed to be mostly coincidental. Aspect appeared to be the P.I. variable most highly associated with forest type occurrence, followed by physiographic class, elevation, and canopy coverage.
Table 7. Asymmetric Lambda - Measure of Association for Nominal-level Attributes.

<table>
<thead>
<tr>
<th>P.I. Variable</th>
<th>Habitat type</th>
<th>Forest type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pattern</td>
<td>.090</td>
<td>.031</td>
</tr>
<tr>
<td>Texture</td>
<td>.163</td>
<td>.063</td>
</tr>
<tr>
<td>Canopy coverage</td>
<td>.247</td>
<td>.100</td>
</tr>
<tr>
<td>Ave. stand height</td>
<td>.151</td>
<td>.113</td>
</tr>
<tr>
<td>Ave. crown dia.</td>
<td>.078</td>
<td>.050</td>
</tr>
<tr>
<td>Aspect</td>
<td>.157</td>
<td>.200</td>
</tr>
<tr>
<td>Slope gradient (%)</td>
<td>.072</td>
<td>.025</td>
</tr>
<tr>
<td>Plan form</td>
<td>.120</td>
<td>.075</td>
</tr>
<tr>
<td>Profile form</td>
<td>.099</td>
<td>.044</td>
</tr>
<tr>
<td>Elevation</td>
<td>.229</td>
<td>.100</td>
</tr>
<tr>
<td>Slope position</td>
<td>.169</td>
<td>.006</td>
</tr>
<tr>
<td>Physio. class</td>
<td>.133</td>
<td>.113</td>
</tr>
<tr>
<td>Drainage order</td>
<td>.139</td>
<td>.044</td>
</tr>
<tr>
<td>Average tone</td>
<td>.127</td>
<td>.013</td>
</tr>
<tr>
<td>Parent material*</td>
<td>.090</td>
<td>.131</td>
</tr>
</tbody>
</table>

*(from Brenner 1968)

An important consideration in the use of the lambda statistic is that it is assumed that both dependent and independent variables are nominal-level. A substantial amount of information contained in the interval-level
independent variables may be disregarded by treating them as nominal-level. This points out a fundamental disadvantage in the statistical analysis of nominal-level variables: they are generally limited to less powerful analytical methods.

Using discriminant analysis, an overall correct classification of 57.8% was obtained for habitat type, and 65.6% was obtained for forest type. Classification tables for habitat and forest type are presented in Table 8. Discriminant function coefficients are presented in Appendix E.

For the habitat type analysis, habitat types (to the phase level) which were observed in the field only once were considered most apt to be originally misclassified, and were excluded from the analysis. This reduced the number of habitat types considered to 17 and the number of cases to 218. Seven discriminant functions, out of a total possible of nine, were statistically significant for discriminating between groups, given the discrimination possible with the original independent variables. The relative importance of the independent variables, as suggested by the coefficients of the first two discriminant functions, seems fairly consistent with the lambda measures of association obtained, and with general landscape associations observed in the
field. Aspect, elevation, and canopy coverage appear to be the most important variables in the first two functions, followed by slope position, tone, and slope gradient. A slope-aspect interaction term contributes quite highly in both functions. Based on the asymmetric lambda values, one would also expect texture and drainage order to be useful discriminating variables, but this was not found to be the case. In fact, drainage order did not even meet the minimum significance level for entry into the analysis. It is quite possible, though, that the somewhat arbitrary orderings assigned to these variables (i.e., drainage order was simply ordered 1,2,3,..., etc.) did not suitably represent the true relationships of their categories. Thus, one is cautioned against making interpretations about such variables based on their discriminant function coefficients. However, in the case of more continuous-scale variables, such as aspect, elevation, and canopy coverage, it is reasonable to believe that these coefficients provide a more valid confirmation of their relative importance.

An examination of the classification table shows that most of the observed habitat types were correctly classified better than 60% of the time by discriminant analysis. Most of the misclassifications fell into the three largest groups, Psme/Vaca, Psme/Libo-Vagl, and Psme/Syal-Caru. Of these three, Psme/Syal-Caru was the least distinct (34.6%
correctly classified), being misclassified equally as Psme/Vaca and Psme/Libo-Vagl (15.4%). Psme/Vaca was correctly classified 62.5% and Psme/Libo-Vagl was correctly classified 78.6% of the time.

Since it is of interest to be able to classify areas by habitat type which have been disturbed or deforested, a separate analysis was conducted using only topographic independent variables. A correct classification of 41.7% was obtained. Using only overstory-type independent variables, a correct classification of 44.0% was obtained. Hence, the topographic and vegetation P.I. variables were not completely additive in their ability to discriminate habitat types, but better results could be obtained using elements of both, rather than either factor alone. It is interesting that a certain amount of statistical discrimination between habitat types can be achieved based on the photointerpreted appearance of the overstory vegetation.

Discriminant analysis for habitat type classification was also tried in two other ways. First, habitat types which were observed less than five times (less than about 2%) were excluded from the analysis, further reducing the number of groups to ten. It was thought that running an analysis on the more commonly occurring groups might provide
### Table 8. Discriminant Analysis Classifications: Habitat Types

#### Classification results

<table>
<thead>
<tr>
<th>Actual group</th>
<th>Predicted group membership</th>
<th>No. of cases</th>
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<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
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<td>7</td>
<td>8</td>
<td>9</td>
<td></td>
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<td>0</td>
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<td>0</td>
<td></td>
</tr>
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<td></td>
<td>FSE-HACA</td>
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<td>Group 2</td>
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<td>0</td>
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<td>0</td>
</tr>
<tr>
<td>Group 3</td>
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<td>0</td>
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<td>Group 4</td>
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<td>0</td>
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<td>0</td>
</tr>
<tr>
<td></td>
<td>FSE-PHME</td>
<td></td>
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<td>0</td>
<td>0</td>
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<td>0</td>
<td>0</td>
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<td>0</td>
</tr>
<tr>
<td>Group 5</td>
<td>FSE-PHAE</td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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Percent of "grouped" cases correctly classified: 57.49%
Table 8. Discriminant Analysis Classifications: Forest Types

Classification results -

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<th>Actual group</th>
<th>No. of cases</th>
<th>Predicted group membership</th>
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<tr>
<td>D.FIR</td>
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<td>67.7% 4.2% 1.0% 5.2% 10.4% 11.5% 0.0% 0.0%</td>
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<tr>
<td>P.PINE</td>
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<tr>
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<td>LARCH-D.FIR</td>
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<tr>
<td>P.P.-D.F.-W.L.</td>
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<td>16.1% 9.7% 0.0% 0.0% 22.6% 51.6% 0.0% 0.0%</td>
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<tr>
<td>LODGEPOLE</td>
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<td>8.6% 0.0% 0.0% 0.0% 31.4% 60.0% 0.0% 0.0%</td>
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Percent of "grouped" cases correctly classified: 65.64%
a better indication of the discriminating power of the independent variables. Optimum discrimination was achieved with only six functions (out of a total possible of nine), but a correct classification of 60.0% was obtained, only 2.2% better than the analysis using 17 groups. This suggests a cleaner analysis, but apparently not a substantial gain in discrimination between groups.

In the second type of analysis, habitat types were aggregated according to the habitat group classification adopted for planning purposes by the Lolo National Forest (USFS 1980). By using this classification, five different groups were recognized: non-commercial, warm and dry, moderately warm and dry, moderately cool and dry, and moist. A correct classification of 69.1% was obtained. Considering the fact that using fewer groups tends to result in better classifications, this improvement was viewed as only modest.

For discriminant analysis of forest types, five significant discriminant functions, out of a total possible of seven, were derived using ten independent variables. Texture, crown diameter, elevation, slope gradient, and aspect were the most important variables of the first three functions. However, there was a notable amount of confusion between the relative importance indicated by the lambda measures of association and the discriminant function
coefficients. Surprisingly, average stand height appeared to be a less important variable and canopy coverage did not even meet the minimum significance specification for variable entry in discriminant analysis. However, when only overstory-type independent variables were used in a separate analysis, canopy coverage did appear to be an important variable. The relative showings of average stand height and crown diameter were contrary to the asymmetric lambda values obtained, but seemed more logical based on field observation. For instance, one would expect average crown diameter to be a better variable for discriminating typically dense stands of lodgepole pine from other forest types.

Unfortunately, this was not borne out in the classification table. The lodgepole pine forest type was surprisingly poorly discriminated — none of the observed cases were correctly classified. In general, there appears to be a lack of discrimination between the Douglas-fir, Douglas-fir/western larch, and Douglas-fir/western larch/ponderosa pine forest types, and most misclassifications were into these three groups. Separate analyses using only overstory or topographic independent variables showed a similar trend, with a higher proportion of misclassifications into the Douglas-fir type. This may be due in part to the very uneven sample sizes and the prior
probabilities specification. Using only overstory-type independent variables, a correct classification of 55.5% was obtained, and a correct classification of 57.3% was obtained using only topographic variables. Because of the smaller number of groups and the lopsided sample sizes, though, these results (including the overall classification) may be somewhat misleading and really represent primarily the classification accuracy for the larger groups, especially the Douglas-fir forest type.

As a comparison of statistical prediction and traditional visual techniques, the forest types estimated directly during photointerpretation were crosstabulated against actual forest types. By this technique, 45.3% of the plots were correctly classified. The Douglas-fir and Douglas-fir/western larch/ponderosa pine forest types were rather poorly differentiated, but the distinctive lodgepole pine forest type was correctly identified 75% of the time.

As mentioned earlier, the design of the photointerpretation system occasionally caused different nominal attributes (occurring within a single stand) to be matched with the same set of P.I. variables. In many instances, two similar habitat or forest types would occur closely intermixed within a stand, but in discriminant analysis, only one could be considered in calculating the
classification accuracy. For many operational purposes, knowing the presence of two similar types in a stand may be adequate for planning purposes. The discriminant analysis program used provided the first and second most probable group membership for each case. If both first and second most probable groups have similar interpretations and can be reasonably grouped into a broader category, the classification of stands with unknown group membership can be facilitated. In the analyses done here, considering both first and second most probable groups provided a classification accuracy (against cases of known group membership) of 82.6% for habitat types and 87.2% for forest types. These figures would probably drop slightly if the first and second most probable groups were required to be similar, but would likely still be much higher than the figures based on only the the most probable category. This type of classification might also be useful for identifying all stands where a certain condition is likely to exist, or, conversely, eliminating stands from consideration where a condition is not likely to be found.
FIELD VERIFICATION

Results of the field verification tests are presented in Tables 9 and 10.

Observed and predicted values of the interval-level stand attributes are presented in Table 9. The predicted values are broken into two types: those from the original regression equations (n=77), and those obtained after the data from these stands were included in the analyses (n=86). Observed and predicted habitat and forest types for these stands are presented similarly in Table 10. These predicted types are further broken into first and second most probable groups.

The general statistical results obtained after inclusion of the extra data (i.e., R-squared values, classification accuracies, etc.) were not appreciably different from the original models. However, at least for the nine stands used in this cursory test, most of the predictions were closer to the true values when the larger data set was used.
Table 9. Field tests: Predicted and Observed Interval-level Attributes.

<table>
<thead>
<tr>
<th>Stand #</th>
<th>Cubic foot volume/acre</th>
<th>Board foot volume/acre</th>
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<td></td>
<td>obs.</td>
<td>pred.</td>
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<tr>
<td></td>
<td>(n=77)</td>
<td>(n=86)</td>
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<td>869.5</td>
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Table 9. Field tests: Predicted and Observed Interval-level Attributes (cont.).

<table>
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<th>Stand #</th>
<th>Cubic foot growth/acre</th>
<th>Board foot growth/acre</th>
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<td>pred. (n=86)</td>
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Table 9. Field tests: Predicted and Observed
Interval-level Attributes (cont.).

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Table 10. Predicted and Observed Habitat Types.

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<th>predicted</th>
<th>(n=253)</th>
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<td>2nd prob.</td>
<td>1st prob.</td>
<td>2nd prob.</td>
</tr>
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<td>Psme/Vaca</td>
<td>Psme/Libo-Vagl</td>
<td>Psme/Vaca</td>
</tr>
<tr>
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<td>Abla/Mefe</td>
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<tr>
<td>2</td>
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<td>Psme/Syal-Caru</td>
<td>Psme/Vaca</td>
<td>Psme/Syal-Caru</td>
</tr>
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<td>3</td>
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<td>Psme/Vaca</td>
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<tr>
<td></td>
<td>Abla/Gatr</td>
<td></td>
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<td>Psme/Syal-Caru</td>
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<td>Psme/Syal-Agsp</td>
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<td>Psme/Syal-Caru</td>
<td>Psme/Syal-Agsp</td>
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</tr>
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Table 10 (cont.). Predicted and Observed Forest Types.

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<th>2nd prob.</th>
<th>predicted</th>
<th>1st prob.</th>
<th>2nd prob.</th>
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</tr>
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<td>DF/WL</td>
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<td>DF/WL</td>
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</tr>
<tr>
<td>4</td>
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<td>DF/WL</td>
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<td>DF/WL</td>
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</tr>
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<td>DF/WL/PP</td>
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<td>DF/WL</td>
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<td>DF/WL</td>
<td>LPP</td>
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CHAPTER VI

DISCUSSION

The results obtained indicate that specific land units, suitable for local forest management operations and representing real differences in stand conditions, can be reliably delineated, mapped, and evaluated by the described photointerpretation system. It should be emphasized that the mapped units are not volume, growth, or site quality classes, or habitat or forest types, but entities (stands) which can be characterized, in varying degrees, by each of these resource attributes.

During the course of the project, several shortcomings, assets, and means of improvement were noted. Comments will be presented here regarding the stand attributes themselves, the photointerpretation and mapping system, statistical analysis and results, and future applications and research.
BASIC STAND ATTRIBUTE CONSIDERATIONS

Measurement, Classification, and Estimation

Since the success of the stand attribute predictions depended on the strength of the correlations between the attribute values themselves and the P.I. variables, it was essential that this data be as accurate and consistent as possible. While every effort was made to keep errors of measurement and classification to a minimum in collecting the raw data, it is important to remember that the actual values of volume, growth, site index, and yield capability used as dependent variables in the regression analyses were estimates themselves from equations which in turn were subject to a certain inherent amount of error. Thus, error may be compounded when trying to correlate P.I. variables to dependent ground attributes which may be slightly inaccurate to begin with. The volume equations used in the original field data reduction (Champion Timberlands 1980) are commonly used operationally in the local area and are probably quite reliable, as is the ponderosa pine site index equation, which was developed specifically for the Blackfoot River drainage (Tesch, et.al. 1980). The remaining site index, yield capability, and growth equations, however, may be somewhat suspect. The growth calculations involved the use of a "shrink-back" algorithm, based on local
height/diameter relationships which were known to be rather variable for some species. The site index equations were mathematically fitted to previously constructed site index curves, and the yield capability equations were linear functions of the site index equations (Brickell 1970)./6

Also, the yield capability equations assume full (unimpeded) stocking, not always a reasonable assumption at Lubrecht Forest.

The fact that the calculated value of (current) annual cubic foot growth per acre exceeded the potential yield capability estimate for a few stands suggested that at least one of the estimates was inaccurate. However, this may be due to a sampling problem quite common at Lubrecht Forest. As a result of past disturbances, particularly logging and fire, many stands have a sparse or erratic overstory of overmature trees and a lower canopy level of second- or third-growth younger trees. Finding suitable site trees in these stands can be difficult. Most of the older trees were once understory trees and have not had a steady, even rate

/6 Brickell (1970) states: "However, all variation in yield capability from one site to another cannot be explained by conventional "site index". Short of direct measurement of stand growth itself, it is not generally known what stand parameter(s) could be used to account for variation not explainable by site index".
of growth throughout their lives. These trees would tend to underestimate site index. On the other hand, the younger trees are often still in a stage of juvenile growth and, because site index curves converge toward the origin, site index indicated by from these trees could be overestimated. In fact, substantial differences were noted in a few stands between young and old trees of the same species.

Similar problems exist in measuring actual stand growth. If a tree's growth rate changed greatly within the last ten years (the growth estimates were based on ten-year radial increments), it could provide an erroneous estimate. Data from permanent growth plots, if available, would be more reliable and desirable, and this should be a consideration in the design of a study such as this. A few permanent plots are located within the study area, but data from these plots were not used due to time limitations. It might be worthwhile in the future, however, if permanent plots were targeted prior to aerial photographic overflights and/or surveyed to from local control points. Knowing the locations of these points on aerial photography or X,Y, and Z spatial coordinates could allow for some interesting types of analyses. For instance, plots located on successive sets of photography, several years apart, may allow for a controlled multi-date type of growth analysis. Aerial photographic coverage of the study area in 1:12000 scale
color and 1:24000 scale panchromatic photography has been obtained twice (for each type) within the past ten years, and it is almost certain that this type of coverage will be repeated in the future.

Another source of error involved the averaging of growth, site index, and yield capability by plot and by stand. Tree species respond differently to site conditions, and the current and potential growth indicated for one species may not apply to another on a given site. In field sampling, the selected site trees were dominant or codominant, healthy, and ecologically suited to the given site, but there were often two or more species of suitable site trees on a plot, such as Douglas-fir, western larch, and ponderosa pine. Clearer correlations and more reliable prediction equations (with the P.I. variables) might be obtained by conducting separate analyses for each species. This could, however, become a massive data processing job. Simpler measures or indices are certainly easier to work with.

This is one of the assets of the habitat type classification system — each habitat type represents a specific type of environment with a number of ecological and management implications. The problem here is one of misclassification. Although most of the time the correct
habitat type could be keyed out with confidence, there were notable cases where it was not so straightforward. Recently disturbed areas often presented problems, as did broad ecotones and mosaics of two or more habitat types, which often occurs in undulating terrain. Considering the fact that a number of plots could not be classified with absolute certainty, the discriminant analysis results are not surprising and, in fact, rather encouraging. It is questionable whether one could (without extreme familiarity of the landscape) accurately distinguish between 17 different habitat types better than 60% of the time by direct interpretation of stereoscopic aerial imagery.

Forest type was definitely the most subjective stand attribute studied. The general guideline is to classify a stand after the overstory species with a plurality of the stocking on that site. Like habitat types, typical examples of each recognized forest type could be found, but in the sometimes broad transitional areas between types, many plots could not be clearly classified into one forest type or another. The distinction between the Douglas-fir forest types was particularly obscure at times. Since, by definition, forest types may be in various stages of succession and tend to have broad ecological ranges, a number of cases were found which appeared to be in the process of changing from one forest type to another, such as
from lodgepole pine to Douglas-fir/western larch or Engelmann spruce/alpine fir forest types.

Although the discriminant analysis results for forest type classification were encouraging, certain types apparently could still be better identified by direct image interpretation, especially the lodgepole pine type. Experience gained through this study suggested that the lodgepole pine, Douglas-fir/western larch, and ponderosa pine forest types were fairly distinctive, but that the Douglas-fir and Douglas-fir/western larch/ponderosa pine forest types were difficult to separate, both on the aerial photography and on the ground.

**Sampling**

In most of the previous studies concerned with statistical estimation of stand attributes by aerial photointerpretation, ground data was collected on fixed-area plots. If fixed plots can be reliably located and superimposed on the aerial photos, a one-to-one correspondence between ground data and photointerpretation data is established. In this study, tree and stand data was collected by point-sampling (variable-radius plot), using a relaskop. While this type of sampling may be efficient for obtaining general stand inventory data and statistics, fixed-plot sampling is probably better suited to
this type of photointerpretation study. Although the sampled plots were pinpointed in the field and could usually be placed within a delineated stand, it became evident during photointerpretation that the matching of ground and photointerpretation data could be improved if attention could be focused on a particular, standardized photo-plot area. This might also allow the use of a tree-count variable in the photointerpretation criteria. Determination of average stand height and crown diameter would definitely be easier. An important consideration in such a design, though, is that the criteria describing the plot might not apply to the entire stand. Certain variables are apt to change depending on the part of the stand being considered.

An improved method of plot distribution is recommended in future similar studies. The basic method used in this study—locating plots along randomly selected transect lines—resulted in a substantial number of plots occurring along stand boundaries and ecotones, and data from several plots could not be used in further analyses. Advantages to

/7 Sometimes, the actual plot (usually fifth-acre) may be drawn on the photos using a drafting compass or template, adjusted for scale. On medium-scale photography, though, this image area may be too small to work with, and more commonly, one-acre circles are drawn, providing the acre represents a homogeneous condition.
this system were that a wide range of stand conditions was randomly sampled, and coordinates for these plots could be readily calculated. The field verification tests in 1982 appeared to better sample the stands which were selected and was a more appropriate technique for establishing correlations between ground and photointerpretation data. An improved technique might involve intensively sampling all of the stands within small areas (blocks) located throughout the study area. These sampling blocks could be selected such that the range of variation in the study area is represented, and might include permanent plots, and be encompassed by ground control points. Concentrating sampling on a few stands in a limited area would also be a more efficient allocation of field work.

The salient point, though, is that for this type of study, where a clear correspondence between ground and image characteristics is essential, plots should be distributed such that the most representative part of a stand (with it's inherent variability) is adequately sampled, away from edge effects which confound the relationships being sought.
PHOTOINTERPRETATION

Experience in the use of the photointerpretation scheme showed that rather fine distinctions between stands could be made in terms of the formulated criteria. The detail of the finished stand map attests to this fact. Based on the statistical results obtained, it appears that a versatile prediction capability is provided by criteria describing both overstory vegetation and topographic parameters. Almost all of the P.I. variables were shown to be significantly related to at least one stand attribute (Tables 5 and 7), and most of the relationships conform to basic theoretical premises. However, several variables presented difficulties in practical application. While the intention was to use P.I. variables which could be consistently observed and measured, several important exceptions were noted.

Overstory pattern and texture were important P.I. variables used extensively in stand delineation, but recording them was hindered by a lack of quantification and ambiguous class boundaries. Formulation of the categories was based on recognizable image characteristics known to occur repeatedly on the aerial photos. Most of the stands could be classified without much difficulty but a substantial number did not fit neatly into the specified
categories. Perhaps because of past history, many stands contained elements of several different pattern and texture categories, none very well expressed. In stands with an upper story of older relicts and various lower stories of poles, saplings, and seedlings, the pattern may have been classified as uniform if the total coverage was considered, or mottled or broken if considering primarily the main overstory; the texture of the lower stories may have been fine, while the larger trees lent a coarse appearance. Extreme cases, such as definitely two-storied stands, were classified as complex.

Because of these difficulties, and the fact that these variables appear to be related to certain stand attributes, quantification of pattern, texture, and tone by automated image analysis would seem to be a worthwhile pursuit. Sayn-Wittgenstein (1970) suggests that characteristic patterns of vegetation could be identified by analyzing measurements, such as microdensitometer traces of image density, or stand profiles, for various statistical or mathematical parameters, such as central tendency and dispersion, or periodicity. "The influences that govern plant growth are admittedly many and complex, but the resulting patterns of plant distribution are neither chaotic nor beyond mathematical description. Furthermore, they can include distinctive, identifying features" (Sayn-Wittgenstein
A few of the topographic P.I. variables were also more difficult to use than previously thought. Plan and profile form were originally meant to define stand boundaries, but were actually used more often to describe stands already delineated. Some concavities and convexities made obvious breaks with the general land surface, but usually changes in topographic form were more subtle and did not provide the contrast needed to identify distinct land units. This was somewhat of a paradox: topographic shape is one of the most obvious landscape characteristics visible on stereoscopic aerial photography (is even accentuated), and within a specific area can usually be measured and described quite thoroughly. However, when imposing topographic form categories onto a complex, undifferentiated landscape as a means of delineating individual land units, confusion arises concerning the spatial extent and amount of acceptable variation within each category. Strict adherence to delineating along points of inflection between concave, straight, and convex surfaces does not necessarily produce meaningful land units, besides being a difficult photogrammetry problem. In the end, it was decided that consideration of plan and profile form tends to complicate the stand delineation process, and these variables were more easily evaluated after delineation. However, problems in
the evaluation of these variables could not be totally resolved in this study.

Slope position was another topographic variable which could be simple in concept but deceptively difficult to evaluate. Originally, a measure of distance upslope as a percentage of total slope length (after Myers and Van Deusen 1960) was tried. On long, rectilinear slopes, with well-defined ridgelines and stream channels, this variable seemed workable. However, this ideal situation was found only occasionally, and many slopes contained various benches, knolls, and depressions throughout their length, and lacked definite end points for measuring slope length. Aandahl (1948) noted this problem in a study on the effects of slope on soil properties: "One's first reaction is to measure from the crest of the ridge or top of the knoll. However, the nature of the gradients between the slope position and the top of the ridge has a very definite effect on the influence of (slope) length on soil properties".

A more subjective classification was then tried, using relative main slope position and relative local slope position. Main slope position referred to location relative to the major interfluve or drainage divide above a point, while local slope position referred to location on secondary slopes occurring on the main slope. Eventually it became
obvious that identification of the main slope lacked consistency - secondary ridges and broken topography confused the definition and made it's relevance questionable. But local slope position could be identified reasonably consistently, and was thus retained. A problem encountered with local slope position, though, was that on smaller, tributary slopes, a delineated stand would sometimes cover the entire slope, from bottom to top. Also, the location of a stand on a secondary slope should be qualified somehow by the position of the secondary (local) slope on the primary slope. This problem may have been mitigated somewhat by the combination of local slope position and physiographic class. Once again, though, the classification problem could not be clearly resolved in this study.

Two fundamental problems in the use of variables such as slope curvature and position are that detailed topographic measurements are difficult and tedious by manual photogrammetric methods, and uncertainty exists about the particular measurements which should be used for correlating with stand attributes. A more convenient and objective means of evaluating topographic parameters might be possible through the use of digital terrain models (DTM's) - dense arrays of points which describe the land surface in horizontal and vertical coordinates. Using numerical
coordinate data, computer routines can be used to rapidly identify and evaluate particular topographic parameters quantitatively. Digital terrain data has found application in calculation of earthworks (Young 1972), soil moisture (Troeh 1964), and plan and profile forms (Troeh 1965), and is becoming increasingly common now in automated mapping systems in forestry (Gossard 1978, USFS 1981, USFS 1982). If stand boundaries can be digitized and registered with control to the terrain model, algorithms could be developed for calculating quantitative measures of slope curvature, position, length, etc., which would be difficult to obtain by manual photogrammetric methods.

Although several of the P.I. variables could be restructured and/or improved through the use of automated techniques, the study results do show that visually estimated, subjective photointerpretation variables can be useful for discerning statistically significant differences among certain stand attributes. The problems encountered indicate areas in need of further research.
STATISTICAL CONSIDERATIONS

The significance of the individual P.I. variables, and the linear combinations thereof, has already been well covered. A few observations on the statistical use of these variables, and the general techniques employed warrant further comment.

The strong correlations of average height and canopy coverage with volume per acre provided perhaps the clearest and most successful example of relating measured photointerpretation variables to ground conditions. Crown diameter was found to be significantly correlated with board foot, but not cubic foot, volume per acre. This makes sense, as board foot volume is much more dependent on average dbh, which is in turn reflected by average crown diameter. Canopy coverage was also found to be significantly related to site index, yield capability, and habitat type.

Aspect was significantly related to most of the attributes, either as dummy variables or as various trigonometric transformations (i.e., taking the cosine of aspect azimuth, a continuous variable is created ranging from 1 for north, 0 for east or west, and -1 for south). Slope gradient was not highly significant by itself, but
interaction terms of slope and transformed aspect (after Stage 1976) were found significant, and are recommended as a way of expressing the combined effects of slope and aspect.

Plan and profile form were found significant in explaining variation in site index and yield capability and, to a lesser extent, cubic foot growth per acre. Local slope position was found significantly related to cubic foot growth. It is likely that improved relationships would be obtained with more quantified measures of these variables.

Interestingly, physiographic class explained a significant amount of variation in cubic and board foot volume and site index. The relatively good showing of this more subjective P.I. variable suggested that it accounted for variability in the landscape that was missed by the more objective P.I. variables. This variable was probably the least quantifiable of the P.I. variables.

Pattern, texture, and tone have been used extensively in the past to describe vegetation in photointerpretation schemes (Spurr 1960, Kuchler 1967, ASP 1960, 1975, Stage and Alley 1972, Paine 1981) but have only recently been applied as independent variables for predicting stand attributes (Martin 1979, Martin and Gerlach 1981, USFS 1982). In this study, pattern and tone were found significantly related to volume per acre, but only tone was a useful regression
variable. Pattern was excluded perhaps because of likely collinearity with canopy coverage. Texture appeared to be especially related to site index and yield capability.

A possible alternative approach to site index assessment with P.I. variables could involve estimating the average age of dominant and codominant trees in a stand by regression and relating this predicted value to the average stand height, which can be measured directly. The average age of a stand could well be highly correlated with certain overstory P.I. variables, but is theoretically independent of topography. This fact could simplify analysis by limiting the number of independent variables considered. On the other hand, site index (the height attainable at a given base age) is a measure of productivity, and presumably would be influenced by topographic factors, and manifested in the vegetative appearance of a stand. Consequently, estimating site index from P.I. variables is likely to be a more complex operation than merely estimating stand age.

Considering the narrow range of variability in site index in the study area, independent variables more refined and sophisticated than those used in this study would probably be needed to produce highly accurate prediction results. However, factorial approaches to site quality assessment using photointerpreted data are not likely to be
any more successful than more comprehensive ground-based designs, which are not always particularly successful. Complex and subtle interactions may exist among site-forming factors which are either difficult to quantify or little understood. "Because of these interactions, the simple regression technique of estimating site quality from an evaluation of a few important site factors, important as it is in practical forest ecology, can only be approximate" (Spurr and Barnes 1980).

Statistical analysis and prediction with the nominal-level attributes was hindered by a lack of numerical values for both dependent and independent variables. Automated image and terrain analysis may be especially useful in this case. Independent dummy variables cannot be used in discriminant analysis; independent variables must be at least ordinal-level. The approximate orderings applied to the less objective P.I. variables used in the analyses here may not have been numerically accurate. Also, plan and profile form could not be adapted for use in discriminant analysis, but definite associations were noted in the field, especially between these variables and habitat type distribution. Quantified indices of these topographic forms would probably be useful in habitat type discrimination.
Regression analyses of stand attributes would also benefit from more quantified independent variables for several reasons. The use of dummy variables may be conceptually valid, but equations may quickly become very complicated when several different types of dummy variables are entered. Simpler interval-level variables are more easily interpreted, and may provide satisfactory results with fewer terms. A danger in multiple regression, realized in this study, is that although better statistics may be obtained with more complex equations, estimates may be derived which have no basis in reality (i.e., the negative values of board foot volume in Table 9). It was concluded that simplicity in regression equations is something to strive for, and one should focus attention on the use of a few highly significant interval-level variables and combinations thereof. Dummy variables may help explain significant amounts of variation, but their use should be avoided or limited to a few important independent variables. Results of a recent similar study in western Montana (USFS 1982) showed that a very reliable prediction equation for board foot volume (adjusted R-squared = .94) could be derived using various forms of canopy coverage, stand height, crown size, and a ranked index of texture.
Even though the individual predicted values generated in this study may often appear erroneous (as in Tables 9 and 10), the prediction equations are only meant to give the best approximation of expected average stand attribute values, given a specified set of independent factors. For planning purposes, stands are usually grouped into one of several classes with specified value ranges. For instance, non-productive stands are generally regarded as those producing less than 20 cubic feet per acre annually, while a stand producing over 80 cubic feet per acre per year would be considered rather productive in western Montana. Thus, increments of 20 cubic feet would be a logical breakdown of cubic foot growth classes. By assigning to stands the classes indicated by the predicted attribute values, an overall classification sufficiently accurate for area planning would likely be provided.

**FURTHER COMMENTS AND RECOMMENDATIONS**

An examination of the stand map (Plate 1) reveals a very dense amount of information per map area. During the mapping phase of the study it became evident that, given the specifications of the aerial photography and the equipment, and time limitations, a smaller study area might have sufficed for meeting the study objectives and demonstrating
the mapping technique. As a research study, perhaps relatively more emphasis should have been placed on developing and validating a workable photointerpretation/prediction system, and proportionately less emphasis on the operational mapping technique. The planning of a mapping project must take into account many specifications and constraints, but no matter how well planned, unforseen factors inevitably arise. It is recommended that when considering the operational implementation of a technique such as that presented here, a pilot study should first be conducted on a limited area to firmly establish the viability and limitations of the proposed system. Experience gained from this study suggested that, given the specified design, the scale of the photography was best suited to mapping areas in the range of 1,000 to 10,000 acres. Smaller scale photography has recently been shown to provide comparable results on larger areas, but in less detail (Martin and Gerlach 1981, USFS 1982) On the other hand, using the 1:12000 scale photography of the study area, highly precise tree and stand measurements are possible and species can usually be observed directly under magnification. However, many more exposures would have been required to cover the study area with this type of photography. Deciding on the imagery and mapping system appropriate for a given purpose depends on
the level of detail required, image resolution, size of area, availability of mapping control, and other details which should be worked out well in advance of the operational application.

Despite the ambiguities in the photointerpretation scheme, it is believed that most of the mapped delineations do indeed reflect real lines on the ground. That these lines represent meaningful differences in stand conditions is supported by the statistical results, but further substantiation of boundary integrity could be the subject of another study in itself. Draeger and Jaakkola (1971) describe a method of detecting differences in stand conditions along a transect using principal components analysis. Numerous analyses are possible in a comparative study between the mapped output of the recent Forest Service stand mapping study (USFS 1982) and that provided by this study. Future forest inventory studies could benefit from the various stratifications possible using the mapped output and data set provided by this study.

Above all, this type of mapped information should be used in the context of a flexible, dynamic information system. Because of changing stand conditions, operational systems should allow for a program of continuously updating stand boundaries and attributes (both predicted and actual)
as more ground data becomes available. Further refinement of site quality prediction is of particular merit, being a relatively permanent aspect of the landscape. Volume and growth, however, can only be related to aerial imagery for the time that it was taken - predictions at one time will eventually become obsolete. Depta (1974) describes an information system devised by the Weyerhaeuser Company wherein in-place stand data is periodically updated through the use of a "stand-table generator". The use of a stand prognosis model to simulate the growth of mapped stands (which have been adequately ground-sampled) may be a viable means of keeping in-place stand inventories current.

The ability to spatially overlay various other types of data to the delineated stands should also be encouraged in a comprehensive inventory system. Information on soils, geology, ownership, and other factors not readily visible on aerial photography is often critically important from a management standpoint.

A drawback to the map produced in this study is that consideration of data from other sources cannot be easily accommodated. Information from field sampling, other maps, and other types of imagery can only be suitably overlaid manually when plotted or mapped at a common scale and level of precision. Compiling such information stand by stand
into an existing data base can be a tedious and cumbersome process.

Increasingly, systems for storing and handling in-place resource information with mappable ground coordinates is becoming commonplace in forestry (USFS 1981, 1982). When a data base of landscape information is referenced to a common positional coordinate system (such as the State Plane Coordinate system), various features may be mapped and overlaid, at specified scales, relatively easily by computer plotting routines. Also, the registration of digital terrain models to the coordinate system can allow for a quantitative analysis of the landscape surface (Tom and Miller 1980), and the analytical photogrammetric adjustment of image coordinates on aerial photography. A substantial amount of computer software is needed for this type of mapping system; however, with the rapid advances in computer technology in recent years, such systems will inevitably become more efficient and available in the future.

Since the stand map produced in this study is already orthographically corrected, only a simple transformation would be required to register digitized stand boundary (map) coordinates to the (ground) State Plane Coordinate system. Storing delineated stand boundaries as polygons (sets of
coordinates) would allow for increased flexibility in mapping. In particular, the ability to display levels of various attributes (singly or in combination) by computer graphics could be especially useful. At present, delineated stands are only designated by an identifier number; attribute values for those stands must be found from a list. If specified (but adjustable) categories of an attribute could be color-coded or shaded and displayed graphically, visualization of that attribute would be greatly facilitated. Other possibilities include graphic display of one particular type (i.e., habitat type) or level (i.e., less than 20 cubic feet growth per acre) of attribute, aggregation of adjacent stands with identical attribute category values, and display of combinations of attributes (i.e., various color combinations). These refined cartographic techniques would greatly enhance the value of the existing stand map as a planning tool. However, translating the stand map into digital form and refining the computer mapping technique could be a sizeable project in itself and is not without certain problems. Digitizing the stand map is recommended, but perhaps first on a small portion of the map as a trial test.
From the standpoint of the practicing forester who may not have access to photogrammetric or computer mapping facilities, the ability to accurate map stands is probably less important than being able to predict stand attributes from aerial photography. The photointerpretation variables used in this study are certainly not beyond the grasp of most trained foresters, and as computer analysis becomes more feasible locally with micro- and minicomputers, stand attribute prediction should be a very feasible activity. It should be stressed, however, that predicted attribute values can not be a replacement for actual stand inventory data. The main intent of this research was to provide an aid to efficient planning and organization of forest management activities.
CHAPTER VII

SUMMARY AND CONCLUSIONS

This study has successfully demonstrated a workable technique for stand delineation, evaluation, and mapping using conventional photogrammetric methods and materials. The use of a photointerpretation criteria recognizing overstory vegetation and topographic parameters was found to be useful for evaluating stands in terms of eight different attributes: cubic and board foot volume per acre, cubic and board foot growth per acre, average site index and yield capability, habitat type, and forest type. Most of the photointerpretation variables were significantly related to at least one of the stand attributes. Expansion of ground data to delineated stands was accomplished using the photointerpretation variables as independent variables in regression and discriminant analysis. If predicted stand attribute values are used to assign delineated stands to one of several categories, this technique can provide in-place stand information suitable for forest planning purposes. Information relating to several different stand attributes, with varying degrees of reliability, can be accommodated through the flexibility of the photointerpretation system.
Volume per acre was the most successfully predicted stand attribute, possibly because of the strong dependence of this attribute on directly measurable overstory characteristics. Prediction equations for growth per acre and site quality were statistically significant but less successful. This is likely due to less straightforward relationships between the photointerpretation variables and ground data, but probably also partly because of difficulties in obtaining accurate estimates of these attributes on the ground. Estimation of growth per acre might be improved through the use of permanent growth plot data and possibly multi-date imagery. Based on ground data statistics, there is apparently little variation in site index and yield capability in the study area. Either more sensitive measures of site quality, or more sophisticated photointerpretation variables would probably be needed to better evaluate these attributes from aerial imagery.

While more accurate prediction capabilities may be desirable for certain attributes, it is believed the stand delineations do represent actual and meaningful units on the ground. It is recommended that the mapped output, and associated in-place information, generated by this type of system be incorporated into a dynamic land information system, continuously being updated and improved as more information becomes available.
The technique presented here could undoubtedly be improved, both from a statistical and remote sensing standpoint, by incorporating automated image and terrain analysis. There is convincing evidence some of the photointerpretation variables could be more useful if they could be better quantified. Also, newly developed capabilities in computer graphics and cartography could greatly enhance the usefulness of the stand map. Nevertheless, stand delineation itself is likely to remain an essentially manual task, its success very much dependent upon the experience and judgement of the photointerpreter. Often, the criteria and methodology proposed for mapping stands, or any other natural resource, are based on ideal, well-defined situations which in reality occur only occasionally in natural populations. Apparently, certain stand conditions (such as certain types of species composition) can be evaluated more readily by subjective visual means than by statistical prediction, and an optimal system may well contain elements of both methods. Automated techniques should only be regarded as tools to more precisely characterize manually delineated stands.

It follows that the information generated by this type of stand mapping scheme is in no way meant to replace field-sampled stand inventory data. Operational stand prescriptions and prognoses should be solidly based on
detailed on-the-ground assessments. However, in developing the planning strategy for relatively undeveloped or unsampled forest areas, this mapping technique may be especially helpful in visualizing the general distribution of stand conditions, and locating those conditions of interest to management.


Bickford, C.A. 1953. Increasing the efficiency of airphoto forest surveys by better definition of classes. USDA For. Serv. Sta. Pap. 58, NE For. Exp. Sta., Upper Darby, PA.


Brenner, R.L. 1968. The Geology of Lubrecht Experimental Forest. Lubrecht Series One, Montana Forest and Conservation Experiment Station, School of Forestry, University of Montana, Missoula, MT.


Martin, F.C., and F.L. Gerlach. 1981. Forest stand mapping and evaluation on State and private land in Montana. Bulletin 46, Montana Forest and Conservation Experiment Station, School of Forestry, University of Montana, Missoula, MT.


APPENDICES

A. Sample Field Data Collection Form

B. Sample Printout: Stand Photointerpretation Data

C. Distributions of Photointerpretation Variables for Sampled Stands

D. Regression Equations

E. Discriminant Function Coefficients
### TREE DATA SHEET

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### REMARKS

1. This table is a sample of the data collection form used for recording information about trees.
2. Each column represents a specific field of data that can be collected during a tree survey.
3. The form is used to gather detailed information about the location, characteristics, and condition of each tree.
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<th>Plan form</th>
<th>abs. freq.</th>
<th>rel. freq. (%)</th>
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Appendix C. Distributions of Photointerpretation Variables for Sampled Stands (cont.).

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Appendices D and E: Key to Independent Variables

CANCOVER = Percent canopy coverage

COMBO = Ave. stand height X Ave. crown dia. squared X Percent canopy coverage

COSASP = Cosine (Aspect azimuth)

CWNDIA = Average crown diameter

CWNDSQ = Ave. crown dia. squared

DRNORD = Drainage order

HT2CC2 = Ave. stand height squared X Percent canopy coverage squared

LSPOS = Local slope position

PIELEV = Elevation

PIHEIGHT = Ave. stand height

PIHT2 = Ave. stand height squared

PISLOPE = Percent slope

STAGE = Cosine (aspect) X Percent slope

Dummy variable codes correspond to the category numbers of the original photointerpretation criteria.

Example: Pattern category 1 (uniform) = DPAT1
Cubic foot volume per acre

Variables in the equation

<table>
<thead>
<tr>
<th>Variable</th>
<th>B</th>
<th>Se B</th>
<th>95% Confidence interval B</th>
<th>Beta</th>
<th>F</th>
<th>Sig F</th>
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Board foot volume per acre

Variables in the equation
Cubic foot growth per acre

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Average yield capability

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Appendix E. Discriminant Function Coefficients

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