1979

# A Test of photogrammetric terrain mapping for ecological land classification in the Lolo Creek drainage Montana

Fred C. Martin
*The University of Montana*

## Recommended Citation

Martin, Fred C., "A Test of photogrammetric terrain mapping for ecological land classification in the Lolo Creek drainage Montana" (1979). *Graduate Student Theses, Dissertations, & Professional Papers*. 8959.
https://scholarworks.umt.edu/etd/8959

# A TEST OF PHOTOGRAMMETRIC TERRAIN MAPPING FOR ECOLOGICAL LAND CLASSIFICATION IN THE LOLO CREEK DRAINAGE, MONTANA

By

Fred C. Martin Jr.

B.S. University of Montana, 1970

Presented in partial fulfillment of the requirements
for the degree of

Master of Science in Forestry

University of Montana

1979

Approved by:

Chairman, Board of Examiners

R C Murray
Dean, Graduate School

6-1-79
Date

Martin, Fred C. Jr., M.S., 1979 Forestry

An Evaluation of Photogrammetric Terrain Mapping for Ecological Land Classification in the Lolo Creek Drainage, Montana (130 pp.)

Director: Frederick L. Gerlach

The area of study was located in the Bitterroot Mountains, Montana, and included 2,883 hectares. Elevations ranged from 1,122 to 2,381 meters. Higher elevations had been glaciated while lower elevations included residual gentle divides and upland slopes and oversteepened slopes along higher order streams. Most slopes had a northern exposure and were covered by dense forest.

The purpose of study was to test the use of land form parameters as determined from aerial photographs for mapping and classifying habitat types. Methods of study consisted of constructing a series of maps, grid sampling each map and statistical analysis of the sampled data. A habitat type map was made from field traverses. A land form map was made from normal color aerial photographs. Existing vegetation was mapped from color infrared aerial photography. Statistical analysis shows that all land form and existing vegetation variables are associated with habitat type. Classification of habitat types from terrain factors ranged from 42 to 90 percent success depending on the classification level. Existing vegetation characteristics contributed little to habitat type classification. The most important land form parameters were elevation, slope plan form, topographic position and watershed order. Normal color photography was considered slightly superior to color infrared for land form mapping, while color infrared was superior to normal color for existing vegetation mapping.

The landscape is discussed in terms of an open system, determined by gravitational and climatic forces. Variations in these forces at different sites result in modification of biological and geomorphic processes. Land from was concluded to be a practical means for landscape classification and mapping, and to provide a suitable basis for ecological land classification.

# ACKNOWLEDGEMENTS

Assistance provided by the U. S. Forest Service during the conduct of this study is gratefully acknowledged, with special thanks to Mr. Charles Tribe, Lolo N. F., for making available aerial photography and financial support for map reproduction, and to Mr. Henry Rosenau, Geometronics Unit, for providing aerial triangulation control data. I would also like to thank Professor Frederick Gerlach, Thesis Committee Chairman, for the encouragement to initially undertake this project and for his support throughout its duration.

# CONTENTS

## TABLES

## ILLUSTRATIONS

Plate

# CHAPTER 1

# INTRODUCTION

From a distance the eastern face of the Bitterroot Mountains appears almost a continuum of tree covered slopes, only occasionally interrupted by deeply incised stream valleys. These linear stream valleys, however, greatly modify the general environment by creating a chevron pattern of paired slopes. A closer examination reveals that these paired slopes are not mirror images, but rather, are sharp contrasts of each other. Generally, north slopes display a cool-moist environment covered by dense forests, while south facing slopes are warmer and drier, often supporting only open forests or scattered trees. Contrast is also evidenced by the overall steepness of south facing slopes compared to the gentler incline of north facing slopes.

Further examination reveals that a number of smaller paired slopes comprise each of the larger slopes. Tributaries rising from the main valley streams divide the main slopes into new slope pairs, while smaller feeder tributaries, in turn, create additional slope pairs. As the tributaries are followed headward, slope steepness begins to decline and the shape of the slopes becomes more rounded. Eventually, the headwater streams are replaced by broad concave hollows or seepage zones separated by rounded convex divides. A causal relationship appears to have developed between the land form1/ and vegetation pattern. The forests of the moister concavities and north slopes are composed of tall mesic species while the drier convexities and south slopes support more xeric open stands. At higher elevations in the Bitterroots, recent glaciation has partially modified the general land form, but even here an interrelationship between land form and vegetation appears to exist.

The general interrelationship between land form and environment has long been recognized, as evidenced by the expression of site in soil catena and forest growth studies. Despite the apparent association between land form and other environmental attributes, little attention has been focused on the use of land form for ecological land classification. Most natural resource inventories have relied on combining individual resource characteristics, i.e. soil, water, vegetation and geomorphic process, into composite ecological units. However, increasing realization of the systems nature of the environment suggests that an integrated framework for classifying ecological conditions is possible.

---

1/ Land form is distinguished from landform according to Savigear (1965) and Young (1972). A landform is a feature of the earth's surface with distinctive form characteristics which can be attributed to the dominance of particular processes or particular structures in the course of its development and to which the feature can be clearly related. Land form, on the other hand, refers to the configuration of the surface of the land and its three dimensional shape.

The purpose of this study was to investigate the suitability of land form parameters derived from aerial photographs for landscape mapping and ecological land classification. The study objectives were:

1. To use aerial photography to classify and map land form parameters
2. To test the ability of land form variables to discriminate and classify habitat types
3. To determine if the addition of photographically interpreted existing vegetation variables to the land form variables increased classification results
4. To statistically evaluate associations between habitat types and the land form and existing vegetation variables

The diversity and variable resolution of mapped information that has generally been produced for land planning have resulted in a multitude of different landscape divisions. If it were possible to delineate single map units to which various resource attributes could be correlated, the inventory and mapping of forest land resources could be significantly improved. It is the supposition of this study that land form units possess sufficient ecological homogeneity to provide a single landscape stratification system.

The value of aerial photography for increasing the efficiency of resource inventory and mapping is widely recognized. A project started in 1973 by the Lolo National Forest sought to examine the application of aerial photography to resource inventory in a multi-discipline planning environment. This study is actually an extension of that project and utilized much of the aerial photography acquired for that effort.

# CHAPTER 2

# LITERATURE REVIEW

Although literature about the interaction of land form with other physical and biological processes is extensive, generally accepted relationships are yet to be fully established. Theoretical concepts are well-grounded in the basic sciences, but practical techniques and relationships are still being developed. Cited references have been selected to document theoretical concepts, to show general land classification techniques and to illustrate some practical applications.

## THEORETICAL CONSIDERATIONS

The basis for considering land form as an indicator of environment lies in the interrelationship between form and natural processes, i.e. geomorphic, climatic and biological processes. Chorley (1962) has advocated an open system framework for conceptualizing form-process interactions, wherein the import and export of energy and materials across and through the land surface are equated by means of an adjustment of form through time. A number of advantages accrue from this concept, including: 1) the focusing of attention on the possible relationships between form and process, 2) the acceptance of a more liberal view of changes of form through time than was fostered by traditional geomorphic thinking, and 3) the directing of attention to the whole of the landscape assemblage, rather than to the often minute elements having supposed historical significance (Chorley, 1962,p. B1).

Long ago Gilbert (1880) recognized that land form and erosional processes were intricately related in a cause and effect relationship. "Of the main conditions which determine the rate or erosion, namely the quantity of running water, vegetation, texture of rock, and declivity, only the last is reciprocally determined by rate of erosion. . . . Wherever by change of any of the conditions the erosive agents come to have locally exceptional power, that power is steadily diminished by the reaction of the rate or erosion upon declivity." (Gilbert, 1880, p. 117). A more recent study by Arnett (1971) confirmed the observations of Gilbert, and showed that slopes could be grouped by distinguishable land torm characteristics and that the effectiveness of denudational processes was largely determined by land form.

Recognition of the influence of land form has been equally strong with regard to climatic processes. The description of this influence given by Geiger is noteworthy.

> If the surface of the ground is sloping, the heat balance will be modified owing to the different angle of incidence of solar radiation. In mountainous regions direct solar radiation may be cut off due to the effect of shadows, in which

> case only diffuse sky radiation is effective. The flow of water down sloping surfaces and also in the ground near the surface, modifies the water balance of the ground. The influence of hills, mountains, and valleys on winds leads to a modification of the amount of precipitation, since raindrops, and even more so, snowflakes, are carried along by the wind. These modifications in the heat and water balance of the ground surface result in a topoclimate which, under otherwise similar conditions, differs widely from the climate on a horizontal surface.
>
> Other, additional, factors are also involved. Owing to the slope of the ground and to differences in height, secondary circulations such as mountain slope winds, valley winds and mountain winds are set up. . . . Such secondary circulations react in turn on the heat and water balance. (Geiger, 1969, p. 105).

The intensity of these climatic modifications has been measured. A south facing 20 degree slope at 50 degrees latitude receives nearly 35 percent more annual insolation than a similarly inclined north facing slope (Lee and Baumgartner, 1966, p. 260), while under cloudless conditions, a 30 degree south facing slope at 50 degrees latitude during the month of May could receive over 100 percent more direct solar radiation than a similar north facing slope (Kaempfert and Morgen, 1952). The shape of the land surface, as well as its slope angle and exposure, is also a major climatic modifier. Insolation losses due to shading can exceed 30 percent of the annual potential on concave land forms. Shading on convex land forms, however, was found to rarely reduce solar radiation by more than two percent (Lee and Baumgartner, 1966, p. 262-264).

The geomorphic significance of land form determined topoclimates in the Bitterroot Mountains was noted by Beaty. "Differences in slope exposure . . . give rise to contrasting microclimates, which led to the operation of different gradational processes on slopes of varying aspect and also to differences in the intensity of operation of similar processes on north and south facing segments." (Beaty, 1962, p. 353). The effect of land form induced solar radiation differences on forest growth were studied by Lee and Sypolt (1974). Differences in solar radiation received on north and south facing slopes affected forest growth, even under conditions of ample soil moisture. North facing slopes had significantly greater tree growth than south facing slopes. The differences in productivity were attributed to radiation and thermal regimes that created leaf water deficits (rates of canopy respiration exceeded rates of absorption by roots) much more severe on south facing slopes than on north facing slopes (Lee and Sypolt, 1974, p. 153).

The interaction of form and process also extends to surface runoff and soil moisture. Hack and Goodlett (1960) concluded that surface runoff distribution is largely determined by land form. Convex forms were described as areas that disperse surface flow and concave forms as areas that concentrate runoff, while the amount of runoff passing any point on a straight slope is proportional to the length of slope above that point. These relationships are modified somewhat because the amount and rate ot runoff is also influenced by soil depth. Because the soil mantle is usually thicker in concavities than on adjacent slopes and convexities (Bunting, 1961; Hack and Goodlett, 1960), raintall sufficient to saturate the mantle of slopes and convexities and to produce runoff may be insufficient to saturate the mantle in concavities. Continued runoff form side slopes and ridges may, however, raise the moisture levels within concavities to field capacity and thus eventually lead to active runoff within concavities. This scenario of runoff and soil saturation developed by Hack and Goodlett is consistent with the variable source, or contributing area, concept of stormflow production proposed by Nutter and Hewlett (1971).

The influence of land form is not confined just to surface water flow, for soil moisture also undergoes gravity movement. Movement of subsurface water can be expected to generally follow the course of surface runoff. Subsurface movements thus act "to keep the soil materials in concavities nearer to field capacity than otherwise would be the case. In effect intervals of relative dryness are shorter for concave areas than in adjacent convex or uniformity sloping areas." (Hack and Goodlett, 1960, p. 30). Troeh (1964) also found that soil drainage was closely correlated with land form and that soil drainage could be predicted with a high degree of reliability from land form parameters.

The development and composition of soils has been closely related to surface and subsurface water movements, as well as to land form in general. According to Young (1972, p. 254) soil drainage affects color and organic matter, while stage of weathering (dependent on rates of denudation) influenced soil texture and cation exchange capacity. Glazovskaya described a geochemical soil sequence, or catena, wherein landscapes and soils which "are adjacent but at different elevations, are united by the lateral migration of chemical elements into a single geochemical landscape." (Glazovskaya, 1968, p. 303). The different soil types of this catena were directly associated with individual land form units.

Vegetation response has also been shown to be related to land form, especially with regard to land form influenced soil moisture conditions. Hack and Goodlett (1960) found not only that tree species and basal area were associated with slope plan form, topographic position and exposure, but also that the distribution and coverages of shrubby and herbaceous species were also associated. They concluded that the presence of certain soil moisture levels during the growing season was a major determinant of plant distribution. Bassett (1964) found that periodic tree growth was closely correlated with the availability of surface soil moisture. A number of other studies have found significant associations between site index and such land form parameters as elevation, topographic position, exposure and slope angle (Cox et al., 1960; Deitschman and Green, 1965; Myers and Van Deusen, 1960).

The interrelationships between land form and other environmental factors, and the adjustment of land form to these factors over time were succinctly summarized by Hack and Goodlett.

> The slope forms and the debris that mantles them are in a steady state, or state of continuous adjustment, dependent on the interrelations between factors such as the kind of bedrock and its resistance to weathering, the relief, the climate, the exposure, and others. Inasmuch as the system is open, some of these factors may be changed through time. As a result, the form as well as other interrelated phenomena must change. For example, as the relief is reduced, the slope must flatten and the texture of the material on the slope must change; . . . The vegetation, its distribution and its composition are, of course, a part of the open system. (Hack and Goodlett, 1960, p. 57).

In addition to geomorphic, climatic and biological processes, the occurrence of wildfire events has also been recently related to land form. Arno (1970, p. 4 and 10) indicated that both the prevalence and intensity of wildland fires were influenced by topographic position and exposure. Habeck (1972) citing data reported by Aldrich and Mutch (1971) presented figures showing that wildfires were five times more numerous on ridge slopes than in valley bottoms, and were about four times more numerous on midslopes than in valley bottoms.

The strong relationships between land form and natural processes and resource attributes presented above provide a theoretical foundation for developing an ecological land stratification based on land form parameters.

## LAND_CLASSIFICATION_TECHNIQUES

Land form classification and mapping is based on acceptance of the concept that distinct, or at least separable, units can be identified within the landscape. The principles of landscape science were reviewed by Isachenko (1973), wherein he proposed that basic physical-geographic land units have been formed by the independent and simultaneous action of zonal (mainly climatic) and azonal (mainly geotectonic) forces. Isachenko presented a hierarchy of landscape division ranging form broad regional units, defined in terms of natural processes acting within these units, to small indivisible units, defined largely upon their composition, i.e. topographic form, soils, vegetation, etc.

In practical applications two general techniques have evolved, each of which addresses a different part of the landscape hierarchy. For regional applications, a "landscape" approach has been used, while for lower more discrete land classification, a "parametric" approach has been suggested (Wertz and Arnold, 1972). The landscape approach is characterized by its use of air photos to identify landscape patterns and a reliance on the recognition of landforms for boundary delineation. No definite criteria are used to define land units in the landscape approach, rather the mapper seeks to recognize patterns wherein the factors of climate, parent material, topography, soil and vegetation are uniform within the limits appropriate to the mapping purpose. Advocates of this approach claim that with an understanding of the genesis of the landforms, landscape units can be defined which will be found, after closer examination, to have consistent resource attributes (Mabbutt, 1968, p. 25).

The parametric approach, on the other hand, is characterized by the use of measured properties to define land units. These measured parameters are associated with selected resource attributes through statistical analysis. The quantitative nature of the parametric approach lends itself to the use of electronic data processing and photogrammetric data collection (Mabbutt, 1969, p. 22).

Most resource inventories to date have relied upon the landscape approach for land classification and mapping (Martinson et al., 1973; Petterson, 1976; U. S. Forest Service, 1976a). Although parametric attributes, such as stream pattern, relief measures and slope shape have been proposed for more detailed land unit classification, in actual practice heavy reliance continues to be placed on identifying the supposed genetic origin of landforms for land unit delineation (U. S. Forest Service, 1976a). The land units delineated in the landscape approach are assigned resource attributes, i.e. soils and vegetation, by empirical inference rather than by statistical association.

Parametric studies to date have concentrated primarily on classifying land units, without considering the association between land form and other resource attributes. Ahnert (1970a) suggested descriptive classifications for slope plan and profile form, and Young (1972) has given quantitative categories for classifying slope angles and slope forms. Speight (1968) devised a system using nine classes of slope angle, four of profile curvature, four of plan curvature and three of unit catchment to classify and map land form units. Savigear (1965) described yet another method of land form classification based upon profile form, slope angle and breaks in slope. Dalrymple et al. (1968) devised a hypothetical nine unit land surface model based primarily on slope profile form and slope position, but also incorporating denudational processes. A characteristic of all of these parametric classifications is the division of a slope into discrete units which are relatively homogeneous with regard to form characteristics. The few parametric land form classifications studies that have attempted to identify resource attribute associations are discussed below.

## RELATED_STUDIES

Previous studies of interest include investigations on air photointerpretation of land form parameters and research on vegetation and land form relationships. One of the few studies that used remote sensing and land form to address forest productivity (Getter and Tom, 1977) found that timber yield classes could be correctly classified over 90 percent of the time. Classification variables used in that study included land form parameters such as elevation, slope angle and topographic exposure, and multi-spectral digital data from LANDSAT-1. A study by Parry and Beswick (1973) used aerial photographs to derive parametric land form indices to describe regional landscape patterns. These indices proved to be sufficiently sensitive to show differences in lithology and geologic structures. Wong et al. (1977) used a combination of topographic maps and aerial photos to derive a number of land form and hydrologic variables, such as slope angle, relief change indices, drainage texture and density, valley depth, etc. These variables were found capable of distinguishing between individual soil types.

Deitschman (1971) reported on a project to map habitat types on the Coeur d'Alene National Forest using land form criteria. The criteria used were elevation, exposure, land configuration (combination of topographic position and profile curvature) and adjacent land features (shadow effects). Data on habitat types were obtained from scattered field samples, which were then plotted onto topographic base maps. The relations between habitat type and land form were based upon an unspecified procedure using the plotted field data and the base map contours. "Using a more-or-less objective extrapolation of the previously determined geographic and topographic relationships to intervening areas, the remaining 96 percent of the forest was then mapped. . ." (Deitschman, 1973, p. 3). Unfortunately, no measures of success of this exercise were provided.

In a study of seral shrub communities in northern Idaho, Mueggler described "the relations of shrub and herb species to environmental factors that affect the composition of these seral stages within the Thuja-Tsuga forest climax zone." (Mueggler, 1965, p. 183). The environmental factors considered included number of years since burning or logging, latitudinal range, elevation, percent slope, topographic position, and seven physical and chemical soil properties. The relation of individual species to environmental factors varied widely by species, but generally, all environmental factors, except six of the seven soil properties, were associated with one or more species. Attempts were also made to relate seral communities to the environmental factors but without success. "There is so little uniformity among communities that classification into discrete groups is hardly justified. However, inability to classify communities into definite species does not prevent prediction of probable species combinations under different environmental conditions." (Mueggler, 1965, p. 178).

In a study of vegetation response to environmental gradients, Kessell (1976) identified six major environmental influences: 1) elevation, 2) topographic moisture and aspect, 3) primary succession, 4) watershed location, 5) alpine wind-snow exposure, and 6) secondary succession. The six factors (or gradients) were used to describe the distribution of plant communities, distribution of fuels and plant succession. Diagrams of fuel categories versus the environmental gradients showed moderate levels of association. However, no statistical measures of the association between the gradients and vegetation and fuels were given.

The most significant related study was conducted by Hack and Goodlett (1960). This investigation evaluated the relationship between land form and soils, vegetation and geomorphic process in a forested watershed of the Central Applachian Mountains. "The most important lesson to be learned from the landforms [land forms] of the Little River area relates to the extraordinary regularity of the landforms, and the nicety of adjustment of the soils and vegetation to them. The close relation between these three terrain elements [land form, soil and vegetation] has been demonstrated over and over again. . . . The correlation extends even to the asymmetry in their distribution pattern." (Hack and Goodlett, 1960, p. 57). Of particular interest was the finding by Hack and Goodlett that the distribution of both overstory and understory forest species, as well as the size and density of the forest stands, were largely coincident with well defined differences in land form.

# CHAPTER 3

## STUDY AREA DESCRIPTION

The study area is located in the Bitterroot Mountains within the Lolo Creek drainage. This area was chosen because of the diversity of terrain and the availability of substantial aerial photographic imagery. The area encompasses 2,883 hectares (7,125 acres) and is shown graphically on plates 1, 2 and 3. Entirely contained within the area are three small drainages: upper Dick Creek, Small Creek and Marshall Creek. Parts of two larger drainages, South Fork Lolo Creek and West Fork Butte Creek, are also within the study area. Elevations range from a low of 1,122 meters (3,680 feet) on South Fork Lolo Creek to a high of 2,381 meters (7,812 feet) at Rocky Point on the crest of the Bitterroot Mountains. Forested slopes with predominately north-easterly and north-westerly exposures characterize the area. Precipitation ranges from a low of 635 mm (25 inches) per year in the lower northern portions to over 2,032 mm (80 inches) per year at elevations over 1,829 meters (6,000 feet) in the southern portion (Soil Conservation Service, 1970). The Elk Meadows Road traverses the entire study area, running through the central portion in a north-south direction.

Three different geologic units have been described in the study area (Nold, 1968). The northern one-quarter of the area is underlain by the Ravalli Group of quartzites, with some interbedded argillites, phyllite and schists. The central half of the area is composed predominately of schist-gneiss and pegmatites. The southern quarter is underlain by the Skookum Butte Stock, composed mainly of granodiorite, quartz diorite and diorite. The varying lithology is not readily apparent in the topography, although subtle differences would normally be expected. This lack of topographic expression probably results from three conditions. First, differences between the Ravalli quartzite and the schists-gneiss units may be masked by a large proportion of phyllite interbedded in the quartzite. This condition was supported by field evidence, wherein substantial amounts of interbedded phyllites were encountered. Second, expected differences in resistance to weathering between the Ravalli quartzite and the presumably more erosive schist-gneiss could not be isolated from geomorphic influences. For example, the steeper slopes associated with the Ravalli quartzite appear to have resulted more from the rapid downcutting of West Fork Butte Creek than from the resistance of the quartzite. Similarly, rapid downcutting by South Fork Lolo Creek has created nearly identical steep slopes along its course in areas underlain by both schist-gneiss and Ravalli quartzite. And third, differences between the Skookum Butte Stock and schist-gneiss are masked by recent glaciation, which deposited a veneer of material over the upper half of the study area.

Geomorphologically the study area can be conceptualized as three areas similar to, but overlapping, the geologic units. The southern third of the area has been greatly modified by alpine glaciation. Mary's Pond and the other ponds in this portion of the area, as well as the U-shaped valley floor of upper Dick Creek, atest to recent glaciation. With the exception of the watershed above Mary's Pond, glacial sculpturing has been confined to the upper and middle portions of the Dick Creek drainage. The central one-third of the study area is characterized by relatively gentle residual headwater slopes and broad divides. Exceptions to this pattern are the steep slopes along the South Fork Lolo Creek and lower Dick Creek, below its junction with Johnny Creek. This central portion appears to have evolved through chemical weathering, or bedrock corrosion as described by Bunting (1961), and by soil creep. Processes acting on the slopes along the South Fork Lolo Creek and lower Dick Creek were probably influenced by the downcutting of these higher order streams. Wash and rill erosion were evident in the field on these steep slopes. The northern one-third of the area consists of both moderate slopes and broad divides, and relatively steep slopes along lower Marshall Creek and West Fork Butte Creek. The downcutting of West Fork Butte Creek appears to have influenced slope angles adjacent to its tributaries, including Marshall Creek, as these streams adjusted to the lower base level of West Fork Butte Creek. Processes in this northern third appear similar to those of the central portion, with bedrock corrosion on the gentler headwater slopes and more active erosion on the steeper slopes. These general observations of geomorphic processes within specific watershed orders are consistent with the findings given by Arnett (1971).

With the exception of a few small areas of rock outcrop, talus and water, all of the study area is in forest or capable of supporting forest vegetation. A substantial portion of the area has been disturbed by logging and thinning operations, and a number ot areas, such as the valley bottom of upper and middle Dick Creek, are entirely devoid of forest cover because of recent logging. The composition of tree species largely follows an elevation and exposure pattern. Low elevation slopes are composed primarily of *Pseudotsuga menziesii* and *Larix occidentalis* on northerly exposures and *Pinus ponderosa* and *Pseudotsuga menziesii* on southerly exposures. As elevation increases *Pinus contorta* replaces both *Pinus ponderosa* and *Larix occidentalis* on all exposures. At higher elevations, above 1,585 meters (5,200 feet), *Pseudotsuga menziesii* is gradually replaced by *Pinus contorta*, which often forms pure dense stands. Mixed stands above 1,525 meters (5,000 feet) are composed of *Abies lasiocarpa*, *Picea spp.*, *Pseudotsuga menziesii* and *Pinus contorta*. As stand age increases, beyond about 90 years, *A. lasiocarpa* and *Picea spp.* increase in coverage at the expense of *Pinus contorta*. At the highest elevations, *Pinus albicaulis* becomes common especially on warmer exposures. *Tsuga mertensiana*, *T. heterophylla* and *Larix lyallii* were not found in the study area.

Forest stands on the slopes are generally pole and saw timber in size, and 60 to 70 years in age. The age similarity of many lower and middle elevation stands suggests that they may have become established following catastrophic fires that swept across much of the Bitterroot Mountains at the turn of the century. Most forest stands have closed canopies, but on southerly exposures, especially at low and mid-elevations, crown coverage is often less than 50 percent.

Vegetation of the valley bottoms along the major streams, and even along some smaller tributaries, is substantially different from the adjacent slopes. In these valley bottom areas, the stands are generally all age and composed of climax tree species. *Picea spp.* and *Abies lasiocarpa* are the principal species along with relics of *Pseudotsuga menziesii*, *Larix occidentalis* and *Pinus* *ponderosa*. *Thuja plicata* and *Abies grandis* were found only in a few locations. *Thuja plicata* was found along South Fork Lolo Creek and lower Dick Creek, and *Abies grandis* was found adjacent to South Fork Lolo Creek, Small Creek and some of the tributaries to Marshall Creek and West Fork Butte Creek. Changes in elevation and exposure produced only minor variations of forest composition or structure on valley bottom sites. Disturbances in the valley bottoms from both past and recent logging have been significant and much more severe and extensive than on the adjacent slopes.

# CHAPTER 4

# STUDY DESIGN

Four separate tasks were completed in pursuit of the objectives: 1) a habitat type map was drawn from field traverses, 2) a parametric land form classification was formulated and a map of land form constructed using aerial photographs, 3) existing vegetation cover was classified and mapped from aerial photographs, and 4) each map was sampled and the sample data statistically analyzed.

## HABITAT TYPE CLASSIFICATION AND MAPPING

As currently practiced in the northern Rocky Mountains, ecological land classification consists of mapping habitat types and landtypes, and combining (overlaying) the mapped units to form composite ecological land units (Buttery, 1978; Martinson, et al., 1973; U. S. Forest Service, 1973 and 1974a). "A habitat type is a *unit of land* having a narrow range of environmental variation. As such, it represents a permanent land stratification system based on potential vegetation development." (Pfister, 1973, p. 121). A landtype is based on the inferred recent geomorphic processes and/or structural control that is expressed in the geomorphology of an area (U. S. Forest Service, 1974a, p. 99).

For purposes of this study, ecological land classification consisted only of a habitat type map. A landtype map was not developed because an accepted taxonomic system for landtypes is not available (U. S. Forest Service, 1976a, p. 12), and because the landtype classification developed for the study area (Petterson, 1976) was considered too general for large scale map applications. In addition, it has been suggested that because the habitat type system utilizes the entire plant community as an integrated indicator of environmental factors, it shows internal consistency with respect to such features as topographic relations, soil type, hydrologic cycle, seral stages of vegetation, susceptibility or resistance to disease, rate of growth, etc. (Daubenmire, 1976, p. 121; Daubenmire and Daubenmire, 1968, p. 51; Pfister, 1975, p. 313).

The habitat type classification used was developed by Pfister et al. (1977). This classification uses indicator species (understory and overstory) for determining the potential of a site or land unit to produce similar plant communities at climax. A field inventory was conducted to identify habitat types, to the phase or most detailed level, and to construct a habitat type map. The field inventory consisted of ground traverses spaced approximately 250 meters apart. Since the intent of the field inventory was construction of a map, and not the sampling of selected plots, a "free" survey was used. In this method of survey, the actual route of traverse was modified by the character of terrain and habitat types encountered. A U. S. Geological Survey topographic map enlarged to 1:12,000 scale with 40 foot (12 meters) contours was used along with a pocket altimeter for determining field location during the inventory. Ecotones (habitat type boundaries) were mapped in the field onto the topographic map base. Habitat type boundaries were extended between traverse lines with the aid of 1:12,000 scale normal color aerial photographs. Since all of the mapped habitat type units were visited, the air photos were used only for extending the ecotone boundaries established in the field. Habitat types occurring between traverse lines were not detected in the field and were not included on the map. Photointerpretive criteria for boundary line placement consisted of general terrain and forest cover similarities between ecotones. Boundary line plotting on the base map was by ocular transfer, while viewing the stereo photo images with a lens stereoscope.

## LAND_FORM_CLASSIFICATION_AND_MAPPING

Development of the land form classification was dependent on the detection and recognition of land form parameters in the stereoscopic aerial photo model. Although the use of air photointerpretation has become widespread in natural resource study, it is important to note that only two terrain elements can be seen on aerial photographs. These are surface morphology and, to a lesser extent, vegetative cover. Surface processes, soil, hydrology and geology can be inferred only indirectly. "It is the form of the ground surface, described as a combination of relative relief, slope form and drainage pattern that is seen on [aerial] photographs." (Young, 1972, p. 5).

The land form classification used in this study consisted of combining a selected number of land form parameters, or variables, to categorize and delineate map units. Variables describing slope morphology included slope profile form, slope plan (contour) form, topographic exposure, slope angle and topographic position. Tables 1, 2, and 3, and plate 2 list the different classes, or values, associated with each slope form variable. Illustrations of a number of these land form parameters are presented in Appendix 4. These morphological factors are similar to those used by Speight (1968) and are generally consistent with other slope morphology classification techniques (Ahnert, 1970a; Curtis et al., 1965; Gregory and Brown, 1966; Young, 1972). In addition to the above slope morphology variables, two other variables--watershed order and elevation--were used for land form classification. Watershed order was defined according to the order of the stream within the delineated watershed. The stream ordering system used was developed by Strahler (1957). Elevation was measured from the topographic base map 40 foot (12 meters) contour intervals. The above land form parameters were selected because of their ease of recognition on aerial photographs and for their general usage in slope form classification.

TABLE 1

SLOPE PROFILE FORM CLASSIFICATION

| FORM DESCRIPTION | RADIUS OF CURVATURE | ANGULAR CURVATURE<br>Degrees |
|---|---|---|
| Moderately Convex | 57.3m to 573m | 10 to 100/100m |
| Nearly Straight | >573m or <-573m | 10 t0 -10/100m |
| Moderately Concave | -57.3m to -573m | -10 to -100/100m |

TABLE 2

SLOPE PLAN FORM CLASSIFICATION

| FORM DESCRIPTION | RADIUS OF CURVATURE | CHANGE IN ASPECT<br>Degrees |
|---|---|---|
| Notably Convex | >50m | 116/100m |
| Slightly Convex | 50m to 500m | 11.6/100m |
| Nearly Straight | 500m to - 500m | - |
| Slightly Concave | -50m to -500m | -11.6/100m |
| Notably Concave | <-50m | -116/100m |

Construction of the land form map consisted of a two-step process: 1) mapping of stream channels and watershed boundaries, and 2) mapping of slope morphology. All mapping was done using a Galileo SMG-4 stereo plotter. With its 4X magnification power, the SMG-4 functioned both as a map plotter and a stereoscope for photointerpretation. A 7 1/2 minute U. S. Geological Survey topographic quadrangle, enlarged to 1:12,000, was used as a base map. All mapping, including the field inventory, used the same base map.

TABLE 3

DESCRIPTION OF SLOPE MORPHOLOGY FORM CLASSES

| MAP CODE1/ | PROFILE FORM | PLAN FORM |
|---|---|---|
| 1 | Nearly Straight | Notably Convex |
| 2 | Moderately Convex | Slightly Convex |
| 3 | Nearly Straight | Slightly Convex |
| 4 | Moderately Convex | Nearly Straight |
| 5 | Nearly Straight | Nearly Straight |
| 6 | Moderately Concave | Nearly Straight |
| 7 | Nearly Straight | Slightly Concave |
| 8 | Moderately Concave | Slightly Concave |
| 9 | Nearly Straight | Notably Concave |

1/ Not all combinations of plan and profile forms occurred in the study area.

Stream channels and watershed boundaries were mapped from 1:24,000 scale, original color infrared transparencies. Photogrammetric mapping control for the color infrared photography was derived from the topographic base map. Two classes of stream channels were mapped: 1) channels with apparent perennial flow or those possessing a clearly defined channelway, and 2) ephemeral streams or linear traces of seepage zones, as defined by Bunting (1961). Watershed boundaries were delineated for each stream segment whenever possible. Boundaries for a number of first order stream segments and seepage zones could not be delineated because of the lack of defined flow lines on the aerial photos. Perennial and intermittent ponds and clearly visible, large springs and seeps were also mapped. Even though a number of smaller springs and seeps could be inferred from the aerial photographs, both within the forest and along roadways, they were not included in the mapped data.

Slope morphology was mapped from original normal color aerial transparencies at 1:24,000 photo scale. Photogrammetric control for the normal color photography was provided through aerial triangulation of wing points using 1:63,360 scale panchromatic photography on a Zeiss C-8 stereoplanigraph. Land form units were delineated by systematically evaluating each parameter listed on plate 2 and in tables 1, 2 and 3. Plan, or contour, curvature was the first parameter considered. A transparent templet with the appropriate radius of curvature inscribed at nominal photo scale (1:24,000) was used for measuring plan curvature. Second, profile curvature was determined by hand plotting a number of representative profiles for selected slopes. These measured slopes were used as benchmarks for classifying other slope profiles. Slope angle was then measured using vertical heights read from the SMG-4 and horizontal distances plotted onto the base map. Topographic exposure was classified by 45 degree intervals. Slopes possessing angles less than five degrees were considered to have a horizontal, or flat, exposure. Finally, a topographic position was given to each morphological unit. Slope units adjacent to streams which had a developed valley bottom, usually fourth and higher order streams, were classified as "talweg" units. Slopes adjacent to tributary streams which did not possess defined valley bottoms, generally stream orders less than three, were considered to be located at "midslope." "Interfluve" slopes were those associated with major drainage divides. Convex ridges separating tributary streams were considered midslope. Talweg and interfluve slopes usually had less than ten degree angles. Topographic position thus provided a basis for differentiating these gently sloping units of significantly different environment.

## EXISTING_VEGETATION_CLASSIFICATION_AND_MAPPING

Existing vegetation characteristics were mapped in conjunction with streams and watersheds from the 1:24,000 scale color infrared photography. Plate 3 and table 5 list the five variables used for vegetation mapping. Crown canopy cover was determined using a transparent crown coverage scale, and crown diameters were measured with circle templets calibrated to nominal photo scale. Crown texture was classified by ocular estimation according to classes relative to the study area. Two-storied texture was based on a minimum of 15 to 20 foot differences in height between upper and lower stand stories. Inter-Society Color Council - National Bureau of Standards, ISCC-NBS system color chips (as reproduced in the Manual of Color Aerial Photography, 1968), were used to identify and classify photographic color. Because of the variation in color between different photographs, and the color drop-off effect near the edges of the color infrared imagery, benchmark areas matching the color chips were established in a single stereo-model. Color classification was then extended by reference to these benchmark areas. The existing vegetation classification was applied only to forest stands where the undisturbed condition could be ascertained. Stands that had been disturbed to such an extent that their pre-disturbance class could not be determined were classified as "disturbed forest stands." Disturbed stands included areas affected by logging, thinning or burning. The presence of a rocky surface was classified when it appeared from the air photos that more than ten percent of the ground surface was covered by rock.

The existing vegetation variables were selected because they have been traditionally mapped from aerial photographs to support timber inventories. The application of these variables to ecological land classification is based on the assumption that current overstory forest characteristics reflect differences in site conditions and can thus aid in ecological land classification.

Species composition was not included as a vegetation delineation criterion because of the difficulty of consistently identifying tree species at the available photo scale, 1:24,000. Generally photo scales substantially larger than 1:24,000 scale are required for individual tree species identification (Heller, et al., 1964). In addition, species composition is usually an inferred characteristics based upon the recognition of such photo characteristics as texture, color and stand location, i.e. exposure and topographic position (Hudson, et al., 1976; Northrop and Johnson, 1970). Average stand height was not included as a vegetation variable because stand height differences in the study area were often too small to adequately measure with the SMG-4.

## AERIAL_PHOTO_SELECTION_AND_APPLICATION

The selection of normal color photography for slope morphology mapping and color infrared for drainage and vegetation mapping was based largely on the results of published studies. Anson (1966) compared normal color and color infrared photography under essentially identical conditions. He found that color infrared showed greater detail for vegetation and drainage mapping because of larger tonal contrasts between dissimilar areas. In the same study normal color photography was deemed superior to color infrared for purposes of soil mapping. Studies comparing color infrared with panchromatic photography have concluded that color infrared is better than panchromatic for separating rock areas from bare soil (Garn et al., 1973), and for identification of surface water features (Malmgren and Garn, 1975). Other studies that compared normal color with panchromatic photography concluded that land form and soil delineations were more accurate when compiled from normal color photography (Anson, 1970; Halliday, 1969; Kuhl, 1970).

In addition to the above published evaluations of aerial film types, an empirical examination of the available imagery was made. As this examination was consistent with the published findings, film type selection was straightforward. Selection of photo scale, however, was decided principally by availability. Although a number of different photo scales had been flown over the study area, only the 1:12,000 scale normal color and 1:24,000 scale color infrared and normal color photography provided complete coverage. Because the 1:24,000 scale photography was the original film processed to a positive image, it was not suitable for field use. But, as the resolution of these original photos was deemed far superior to the 1:12,000 scale normal color prints, they were used for mapping land form and existing vegetation. Table 4 summarizes the types, scales and uses of the aerial photography employed in the study.

TABLE 4

AERIAL PHOTOGRAPHY CHARACTERISTICS

| USE | FILM TYPE | SCALE | DATE |
|---|---|---|---|
| Slope Form Mapping | Normal Color | 1:24,000 | 8/9/73 |
| Streams, Watersheds and Vegetation Mapping | Color Infrared | 1:24,000 | 8/9/73 |
| Habitat Type Boundaries | Color Prints | 1:12,000 | 9/23/75 |
| Aerial Triangulation | Panchromatic | 1:63,360 | 8/6/72 |

NOTE: All photography was taken with 152mm focal length metric cameras.

## VARIABLES AND SAMPLING DESIGN

Because a focus of the study was the classification of land units and the production of maps, the maps themselves became the primary data base. Values of the twelve independent variables (i.e. land form and existing vegetation variables) and the classes of the dependent variable (habitat types) were obtained from the maps by grid sampling. Map sampling consisted of overlaying a transparent metric grid over each map--land form (including base contours), existing vegetation and habitat type maps. The grid was oriented to the universal transverse mercator grid markings of the base map in order to provide consistent registration between maps and to preserve the coordinate location for each sample point. The rectangular grid provided a sampling intensity of one point for every four hectares (9.88 acres), for a total of 722 sample points. Data from each sample point were then keypunched onto data cards for computer processing. Table 5 shows the variables collected at each sample point and the level of measurement (scale of measurement) associated with each of the variables.

Transformation of values was necessary for a number of variables to make them more amenable for computer processing and for more consistent representation of actual conditions. The sampled values obtained for the slope profile form, slope plan form, slope angle, topographic exposure, crown canopy coverage and average crown diameter variables were recoded to the quantity representing the midpoint of each of the respective variable classes. Topographic exposure was recoded to a linear order reflecting cold to hot conditions. Table 6 shows the mean azimuth and recoded value for each exposure class. Although there appears to be some loss of resolution in the recoding of exposure, the actual total number of possible values and the relative distance between values has been preserved.

For lack of an accepted standard for ranking the relative influence of interfluve versus talweg slopes, the following values were established: interfluve slopes were coded as 1, midslope positions were valued as 2, and talweg slopes were coded as 5. This ranking is based on the assumption that soil moisture increases in a downslope direction and that talweg slopes are substantially more moist than either interfluve or midslope positions. This assumption is supported by numerous studies that have evaluated the influence of slope position on soil moisture and vegetation response (Bunting, 1961; Cox et al., 1960; Hack and Goodlett, 1960; Troeh, 1965). This recoding of topographic position transformed the variable into an ordered metric level of measure (see table 5).

Elevation values were treated in two different ways depending on the statistical procedure used. First, for contingency table and frequency analysis, elevation was recoded into 152 meter (500 foot) groups. Second, the actual elevation value, to its nearest 40 foot (12 meters) contour interval was used in the discriminant analysis procedure.

Photographic color was considered to have an ordered metric level of measurement based upon the ISCC-NBS system of 267 color values. All other variables were input to the statistical analysis procedures without altering their original level of measurement and without substantive recoding.

## TABLE 5

## DATA BASE VARIABLES

| VARIABLE | LEVEL OF MEASUREMENT1/ |
|---|---|
| Ecological Land Unit Variables | |
| Habitat Types and Phases | Nominal |
| Land Form Variables | |
| Watershed Order | Ordinal |
| Slope Profile Form | Ordered Metric2/ |
| Slope Plan (Contour) Form | Ordered Metric |
| Slope Angle | Interval |
| Topographic Exposure | Interval |
| Elevation | Interval |
| Topographic Position | Ordered Metric |
| Existing Vegetation Variables | |
| Crown Canopy Coverage | Interval |
| Average Crown Diameter | Interval |
| Crown Texture | Ordinal |
| Photographic Color | Ordered Metric |
| Presence of Rocky Surface | Dichotomy - Interval |

1/ Level of measurement after Stevens (1964).

2/ Ordered metric falls, "between the ordinal and interval levels, an ordered metric consists of ordered categories where the relative ordering of the inter-category distances is known even though their absolute magnitude cannot be measured." (Nie et al., 1975, citing Coombs, 1953).

Combination of the numerous values for each of the twelve independent variables results in a large number of possible classes to describe each sample point. Many studies of land form have attempted to deal with the multiplicity of classes by subjectively grouping the potential classes into a few land form elements, e.g., crests, concave foot slopes, back slopes, convex creep slopes, etc. (Acton, 1965; Dalrymple et al., 1968; Walker and Ruhe, 1968). Other investigators have sought to deal with land form complexity by mathematical equations which model various slope forms (Ruhe and Walker, 1968; Troeh, 1964 and 1965). Still others have used data processing and statistical techniques to correlate resource attributes directly with land form parameters (Arnett, 1970; Gregory et al., 1966). In this study electronic data processing and statistical analysis were used to evaluate independent and dependent variable relationships.

## TABLE 6

## RECODING OF TOPOGRAPHIC EXPOSURE

| EXPOSURE | MEAN AZIMUTH<br>DEGREES | RECODING |
|---|---|---|
| NNE | 22 | 1 |
| ENE | 68 | 3 |
| ESE | 113 | 6 |
| SSE | 158 | 7 |
| SSW | 203 | 9 |
| WSW | 248 | 8 |
| WNW | 293 | 4 |
| NNW | 338 | 2 |
| FLAT1/ | - | 5 |

1/ No azimuth assigned, assumed horizontal.

## STATISTICAL ANALYSIS

Data analysis consisted of three general operations: 1) sorting and frequency distribution operations, 2) two-way contingency table evaluation, and 3) discriminant analysis. These analysis steps were conducted to examine variable distributions and variable associations, and to discriminate and classify habitat types from the twelve independent variables.

The nominal level of measurement for habitat type (the dependent variable) and the ordinal level of measurement of some independent variables restricted the types of statistical procedures that were suitable for data analysis. Although two statistical procedures, calculation of eta and discriminant analysis, have generally been used only with interval level independent variables, all of the independent variables (land form and existing vegetation) were included in these procedures. Although such inclusions may contradict traditional applications there are precedents for including all of the variables in the analysis.2/

---

2/ "Abelson and Tukey (1959) argue that the proper assignment of numeric values to the categories of an ordered metric scale will allow it to be treated as though it were measured at the interval level. Labovitz (1970) goes further by arguing that, except for extreme situations, interval statistics can be applied to _any_ ordinal variables as interval. He argues, 'although some small error may accompany the treatment of ordinal variables as interval, this is offset by the use of more powerful, more sensitive, better developed, and more clearly interpretable statistics with known sampling error.'" (Nie et al., 1975, p. 6).

Not all sampled data were included in contingency table and discriminant analysis. An entire sample point was excluded if the habitat type for that point occurred less than five times in the entire sample. This situation reduced the useable sample size from 722 to 696 points. In addition existing vegetation data were not included if the sample point was classified as a disturbed forest stand, although the habitat type and land form data for the sample point were included in the analysis. Sample data available for existing vegetation analysis was thus reduced to 477 observations.

The first analysis step was to sort all the sample data by habitat type to examine the range of land form and existing vegetation characteristics associated with each habitat type. Data was then sorted by land form and existing vegetation characteristics to determine the total number of land form and existing vegetation classes actually sampled. One-way frequency distributions were generated for each variable to determine the actual number of occurrences of each value of each variable. Both absolute and relative frequency counts were made.

Contingency table analysis consisted of examining the joint frequency distribution of each land form and existing vegetation variable (columns) by each habitat type (rows) in a two dimensional table. Chi-square, Cramers V, uncertainty coefficient and eta were calculated for each of the twelve contingency tables generated. The chi-square values were used solely to determine if habitat types were related to land form or existing vegetation variables, and to indicate if further analysis was profitable. Cramers V provided a measure of the strength of the association between habitat type and the other variables. Cramers V makes a correction for the fact that the value of chi-square is directly proportional to the number of cases and adjusts chi-square for both the number of cases and the number of rows and columns in the contingency table. Cramers V ranges from 0 to 1.0, and indicates the degree of association between two nominal level or higher level variables, but does not reveal the manner in which the variables are associated.

The uncertainty coefficient is a measure of the proportion of uncertainty in the dependent variable that is reduced by knowledge of the independent variable. The maximum value of the uncertainty coefficient is 1.0, which denotes the complete elimination of uncertainty, i.e., when each independent category is associated with a single category on the dependent variable. The minimum value is zero, which means no improvement in prediction. Calculation of the uncertainty coefficient is based on the probabilities of a group membership of the dependent variable and the conditional uncertainty of the dependent variable given an independent variable class. Uncertainty coefficient, like

Cramers _V_, assumes nominal levels of measure for both the independent and dependent variable.

Eta is a measure of the association between a nominal level variable and an interval level variable. Values of eta range from 0 to 1.0. High values of eta would suggest that predictable values of land form and existing vegetation variables can be expected to coincide with specified habitat types. Eta is calculated using the means of interval level variables (independent variables) and is an indication of how dissimilar the means of these variables are within the categories of the nominal level variable (dependent variable). The square of eta can be interpreted as the proportion of variance in the land form and existing vegetation variables accounted for within a habitat type class. Eta squared is, therefore, usually expressed as a percentage value (Nie et al., 1975, p. 230).

The twelve contingency tables gave a visible record of the frequency relationships between habitat type and the land form and existing vegetation variables. Chi-square provided a measure of the independence between the variables while Cramers _V_ gave an indication of the strength of this relationship. The uncertainty coefficient indicated the amount by which uncertainty of habitat type prediction is reduced by knowledge of land form and existing vegetation variables. And finally, eta described the degree to which values of land form and existing vegetation could be correlated to habitat types.

The final analytical procedure was the application of discriminant analysis to measure the contribution of each independent variable for habitat type discrimination and classification. Discriminant analysis is a procedure that formulates linear combinations of discriminating (independent) variables which maximize the separation between groups (dependent variables). "The discriminant functions (linear combinations of variables) are derived such that the first function separates the groups as much as possible. The second function separates (the groups) in an orthogonal (right angle) direction given the first separation, the third function provides maximal separation in another orthogonal direction, etc." (Klecka, 1975, p. 444). Each function can be considered as an axis in geometric space (or discriminant space) along which each case can be located. The average value of a group for each function represents its centroid, and the combinations of all such centroids describes the most likely position of a group in discriminant space. The maximum number of discriminant functions which can be derived is either one less than the number of groups (dependent variable groups) or equal to the number of discriminating (independent) variables, whichever is smaller. Because the number of dependent variable groups (habitat types) was greater than the number of independent variables, the number of derived functions equalled the number of independent variables. Seven discriminant functions were derived for the land form variables and five functions were derived for the existing vegetation variables. A combined total of twelve functions were available for discriminant analysis.

The method for selecting the discriminating (independent) variables used in the discriminant functions is a stepwise process. The variable that has the highest value on the selection criterion is chosen for input to the function generator. This variable is then paired with each of the other variables to determine the next best discriminating variable. These two variables are then combined with the third best variable, and so on, until all variables are selected, or until no additional variables provide a minimum level of improvement in separating the dependent variable classes. The criterion used for determining variable selection is the overall multivariate F ratio for each variable. The larger the F value, the greater the discriminating power of the variable. Variables that meet or exceed the minimum selection criterion value are used in developing the discriminant functions which perform group (dependent variable) classification.

The discriminant analysis procedure produces a number of important measures valuable for analyzing the importance of a given independent variable in discriminating between dependent variable groups. An eigenvalue, a special measure computed in the process of deriving the discriminant functions, is a measure of the relative importance of a single function. The sum of all eigenvalues is a measure of the total variance existing in the discriminating variables. "When a single eigenvalue is expressed as a percentage of the total sum of eigenvalues, we have an easy reference to the relative importance of the associated function." (Klecka, 1975, p. 442).

A measure of a functions statistical significance is provided by Wilk's lambda. "Lambda is computed as each function is derived and is an inverse measure of the discriminating power in the original variables which has not yet been removed by the discriminating functions." (Klecka, 1975, p. 442). Since lambda can be transformed into a chi-square statistic it is a means for evaluating the significance of the separation in discriminant space provided by each independent variable.

A measure of the importance of individual variables in the classification of groups is provided by the standardized coefficients derived for each variable in each of the discriminant functions. The absolute value of each coefficient represents the relative contribution of its associated variable to that function. The sign merely denotes whether the variable is making a positive or negative contribution. Since the functions are derived in order of increasing importance, those variables that contribute the most to the first functions play a greater role in discriminating between groups.

Using the derived discriminant functions, a discriminant score on each function for each case can be computed and its location in discriminant space determined. By comparing the location of each case with the centroid location for each group, it is possible to classify unknown cases according to their independent variable values, or to classify known cases. The purpose of classifying known cases is to evaluate the effectiveness of the discriminating variables. From an examination of a generated classification table, the proportion of correct to incorrect classifications can be measured. The plenary test of land form and existing vegetation variables for habitat type discrimination was the construction and evaluation of such a classification table. A major short coming of this classification procedure, however, is the inability to determine reliability levels for the classification results. The significance level of each variable and each function to separate classes is provided, as noted above, but the significance of the classification results as a whole cannot be measured.

# CHAPTER 5

# RESULTS

Plates 1, 2 and 3 illustrate the results of the habitat type, land form and existing vegetation mapping procedures, respectively. Because each map represents an independently conducted inventory, the results of these inventories, along with their frequency distributions, are reported individually. The interrelationships between each of these three data sets are then discussed in terms of both map similarities and the statistical analysis of the sampled data.

## HABITAT TYPE CHARACTERISTICS

A total of 40 different habitat types and phases were mapped within the study area, but only 24 types were statistically analyzed because of limited occurrences. Plate 1 lists the habitat types actually mapped. All of the types normally found within the Bitterroot Mountains in Montana, with the exception of the *Pinus ponderosa* and *Tsuga heterophylla* climax types, were encountered within the study area. Two habitat types--*Picea*/*Physocarpus malvaceus* and *Abies lasiocarpa*/*Vaccinium globulare*--found in the study area are usually found only near or east of the Continental Divide (Pfister et al., 1977, p. 61 and 97). In addition, one new habitat type phase--*Abies lasiocarpa/Menziesia ferruginea-Vaccinium scoparium*--was defined. A few areas could have been mapped and described by a combination of habitat types, i.e. a mosaic or complex map unit description. But, in order to provide a more straight forward appraisal of habitat types, all map units were defined as a single habitat type. To present a better measure of map unit resolution, a new method for stating habitat type map "accuracy" was employed.

Throughout the following sections, habitat types (and phases) are occasionally referenced by their accepted abbreviations. The full habitat type names and abbreviations are listed in Appendix 1. For a complete definition and typical description of each habitat type, the reader is referred to Pfister et al. (1977).

## HABITAT TYPE DISTRIBUTION

The distribution and character of habitat types (h.t.s) of the *Pseudotsuga menziesii* series generally agreed with the descriptions given by Pfister et al. (1977). A number of notable exceptions were encountered in the field which were later recognizable in the statistical analysis. Separation of the two phases of the *Physocarpus malvaceus* h.t. was often difficult under field conditions. According to Pfister et al. (1977) the *Physocarpus malvaceus* (*PHMA*) phase is characterized by the dominance of *P. malvaceus* in the undergrowth on cool moist sites, while the *Calamagrostis rubescens* (*CARU*) phase occupies warm-dry sites where *Larix occidentalis* and *Pinus contorta* are absent. In the field a number of steep cool sites possessed dense layers of *P. malvaceus* and some *Pinus contorta*, while similar sites with *Pinus contorta* and *Larix occidentalis* had comparatively little coverage of *P. malvaceus* but substantial coverages of *C. rubescens* and *Carex geyeri*. Little environmental difference could be detected between these sites, and their classification to a single phase could not be consistently assigned. Of course, the typical moist site *PHMA* phase and the drier *CARU* phase sites were encountered, but the middle ground where neither phase appeared appropriate was common place.

The second exception was distinguishing between some *Pseudotsuga menziesii* h.t.s and some *Abies lasiocarpa* h.t.s. Broad transitions where the eventual climax--*P. menziesii* or *Abies lasiocarpa*--was uncertain occupied many interfluve and upper slopes. Phases of *Pseudotsuga menziesii/Vaccinium globulare* and *Abies lasiocarpa/Xerophyllum tenax* were particularly difficult to separate at times. In many areas there was a complete absence of forest regeneration under a mature closed canopy of *P. menziesii* and *Pinus contorta*, while in other areas *Picea spp.* was the only reproducing tree species. Most areas such as these, were classified into *Abies lasiocarpa* h.t.s, depending on either the presence of Picea spp. reproduction or the presence of any amount of A. lasiocarpa. Stands with a complete absence of Picea spp. or A. lasiocarpa were classified as Pseudotsuga menziesii h.t.s.

The transition between P. menziesii and A. lasiocarpa climax habitat types appeared to be highly correlated with elevation. This altitudinal transition was observed to occur about 1,584 meters (5,200 feet) throughout the study area. Variations were noted, as on cool exposures where the upper level dropped to 1,465 meters (4,600 feet), and on warmer exposures where the transition extended up to 1,705 meters (5,600 feet).

In addition to the two exceptions cited above, a number of Pseudotsuga menziesii habitat types were found to be quite similar to each other and often to grade into one another without definite boundaries. Phases of Pseudotsuga menziesii/Linnaea borealis were found to often grade into Abies lasiocarpa/Linnaea borealis or Abies grandis/Linnaea borealis h.t.s on moister sites and to grade into the PSME/PHMA-PHMA phase or PSME/VAGL h.t.s on drier sites. Likewise, although the PSME/CARU h.t.s are readily distinguishable from the phases of PSME/VAGL and the PSME/PHMA-PHMA phase, the boundaries between PSME/CARU h.t.s and these other two habitat types were often broad transition zones.

The *Picea/Physocarpus malvaceus* h.t. occurred at only two locations. Both sites were cool moist hollows adjacent to the headward extension of first order stream courses at an elevation of 1,370 meters (4,500 feet). A dense shrubby layer of *P. malvaceus* and all ages of *Picea spp.* characterized each site. *Abies lasiocarpa* was poorly represented. This habitat type appeared to represent an extension of the *PSME/PHMA-PHMA* phase into an even moister environment.

*Abies grandis* h.t.s occurred sporadically on warm-moist sites below 1,585 meters (5,200 feet). A number of *A. grandis* h.t.s were sampled but not enough for statistical analysis. *Abies grandis* h.t.s occupied hollows or cool exposures adjacent to *Abies lasiocarpa* h.t.s, but generally upslope from stream bottoms and possible frost pockets or cold air drainage ways. *Abies grandis* h.t.s appeared to represent a transition between *Abies lasiocarpa* h.t.s on cool moist sites and *Pseudotsuga menziesii* h.t.s on drier sites.

*Thuja plicata* h.t.s were found only in the higher order stream valleys of lower Dick Creek and South Fork Lolo Creek. The valley bottom of the extreme lower portion of South Fork Lolo Creek was classified and mapped as a *Thuja plicata* h.t., even though no *T. plicata* was found in this area. Environmentally, no differences were evident between this area and sites further upstream which supported dense stands of T. plicata. The vegetation in this lower area has been continuously disturbed for many decades. This disturbance has reduced crown canopy coverage to 50% and has caused intervening openings to become occupied by dense sod. The valley bottom of West Fork Butte Creek has been similarly disturbed and represents nearly identical environmental conditions. But, because no T. plicata was found anywhere along West Fork Butte Creek, this area was classified according to the vegetation types present, as an Abies lasiocarpa h.t.

A majority of the study area was classified as Abies lasiocarpa h.t.s, with 20 different types identified. With one exception, the Abies lasiocarpa h.t.s generally conformed to the descriptions of Pfister et al. (1977). The exception was the occurrence of Abies lasiocarpa/Vaccinium globulare h.t. This type is usually found only in areas near or east of the Continental Divide. The ABLA/VAGL h.t. occupied cool north midslope exposures of moderate slope angle between 1,585 meters (5,200 feet) and 1,770 meters (5,800 feet). Except for the absence of Xerophyllum tenax no major environmental differences could be detected between this type and adjacent similar sites occupied by the Abies lasiocarpa/Xerophyllum tenax-Vaccinium globulare phase. The Abies lasiocarpa/Vaccinium globulare h.t. may, however, be slightly moister and a little more sheltered than ABLA/XETE-VAGL. The ABLA/VAGL h.t. is also quite similar environmentally, and often found adjacent to the *Abies lasiocarpa*/*Alnus sinuata* h.t. The *ABLA*/*ALSI* h.t. appears to occupy sites slightly more moist than *ABLA*/*VAGL*, and is usually found downslope from *ABLA*/*VAGL* on slopes having a more concave plan form. The *ABLA*/*VAGL* h.t. may represent a subtle, wide transition zone between the *ABLA*/*XETE*-*VAGL* phase and the *ABLE*/*ALSI* h.t.

Two habitat types occurred over extremely broad ranges of environment. The *Abies lasiocarpa*/*Menziesia ferruginea* h.t. occupied sites ranging from moist lower slope hollows at low elevations (1,370 meters, 4,800 feet), to drier cold middle and upper slopes at high elevations (1,980 meters, 6,500 feet). At the higher elevations, *ABLA*/*MEFE* took on a distinctive appearance which permitted definition of a new phase unique to the study area. This new phase--*Abies lasiocarpa*/*Menziesia ferruginea*-*Vaccinium scoparium*--was created to separate stands with minimal coverage of *M. ferruginea* that occurred on some high elevation sites. The *ABLA*/*MEFE*-*VASC* phase was characterized by scattered *M. ferruginea*, dense coverages of *V. scoparium* and the absence of almost all other typical undergrowth species. Overstory coverage in this phase consisted almost solely of *Pinus contorta* with *A. lasiocarpa* reproduction. *Pinus albicaulis* was absent. The *ABLA*/*MEFE*-*VASC* phase was mapped as a single continuous relatively large map unit. It was boardered by the more typical high elevation *ABLA*/*MEFE* h.t. (termed the *ABLA/MEFE-MEFE* phase) at lower elevations, and by *Abies lasiocarpa/Luzula hitchcockii-Menziesia ferruginea* at higher elevations. The *ABLA/MEFE-VASC* phase may represent a broad transition between the typical *ABLA/MEFE* h.t. and *ABLA/LUHI-MEFE*. Even with the creation of *ABLA/MEFE-VASC*, the *ABLA/MEFE-MEFE* phase occupied a broad range of sites from moist lower slopes at low elevations to cold upland slopes at high elevations.

The *Abies lasiocarpa/Xerophyllum tenax-Vaccinium globulare* phase was also found to occur over a broad range of sites, from cool damp gentle north slopes at moderate elevations to steep high energy sites to cold high elevation slopes. This wide range of *ABLA/XETE-VAGL* is evident on plate 1, where this phase extends contiguously from steep south facing slopes, over gently sloping wide divides to moderately sloping north facing cool slopes. The broad range of both the *ABLA/XETE-VAGL* and *ABLA/MEFE-MEFE* phases is consistent with the descriptions given by Pfister et al. (1977).

Although most of the *Abies lasiocarpa* h.t.s were readily recognized in the field, the placement of boundaries between types was often difficult and somewhat arbitrary. Relatively wide transitions were often encountered between *ABLA/XETE-VAGL* and *ABLA/MEFE-MEFE* on cold-moist sites and between *ABLA/XETE-VAGL* and *Abies lasiocarpa/Linnaea borealis* h.t.s on warm-moist sites. A narrow transition was found to occur between *ABLA/LIBO* h.t.s and *Abies lasiocarpa/Clintonia uniflora* h.t.s, especially with the *ABLA/CLUN-CLUN* phase. Environmental differences between *ABLA/ALSI* and *ABLA/MEFE-MEFE* were not obvious on a number of occasions, particularly where the two types were found adjacent to each other. The occurrence of transition zones was more common at middle elevations. At the higher elevations, however, fewer habitat type classes occurred, but the types then extended over a broader range of sites. For example, the *ABLA/LIBO* h.t.s were generally absent above 1,675 meters (5,500 feet). Sites expected to be occupied by *ABLA/LIBO* h.t.s above this elevation were often classed as *ABLA/CLUN* h.t.s or *ABLA/MEFE-MEFE* phase.

## HABITAT TYPE MAPPING

A comparison of the habitat type map, plate 1, with the land form and existing vegetation maps, plates 2 and 3, shows obvious differences in detail between the maps. While the resolution of the habitat type map is comparable to similar maps (Daubenmire, 1973; Klinka and Skoda, 1977; Pfister, 1976), plate 1 is not nearly as detailed as plates 2 or 3. The difference in detail resolution of plate 1 is the direct result of a ground observer's inability to adequately locate and map small units of land without the aid of a more detailed field map, more precise traverse methods and substantially greater traverse density.

The importance of an adequate base map cannot be overemphasized. As noted by others (Daubenmire, 1973; Morisawa, 1957) the standard topographic quadrangle often fails to portray adequate detail for the natural scientist. Problems in mapping habitat types onto existing maps have been described by Daubenmire:

> Often ecotones were associated with minor changes in direction of slope that either were undetectable on the aerial photos from which the map was made, or that the cartographer felt must be ignored because of time and money limitations. It is frustrating to stand beneath a cover of trees and find no match for slope direction on the map at that elevation. . . . (Daubenmire, 1973, p. 90).

Such conditions often result in the mapper simplifying the desired portrayal of ground detail to fit the resolution of the base map.

The use of aerial photos aided the extension of boundary lines between habitat type boundaries (ecotones), but did not entirely substitute for a more detailed base map. In most instances, the location of an ecotone detected on the ground could be associated with an image or line visible on the air photo. The exact nature of the photographic expression for a habitat type boundary was quite variable and no consistent pattern or criteria were identified. In some cases the ecotone was recognizable on the air photo as a distinct or subtle change in exposure or plan form, while in other instances boundaries were expressed as changes in crown canopy coverage, stand height, canopy texture or photographic color. As suggested by Colwell (1967), what is often seen in the air photo as an ecological boundary is the response of the forest overstory to a change in the complex of ecological factors that govern forest growth. The inability to characterize all the many subtle terrain difference portrayed by aerial photographs and to select only those elements that correspond to ecotone boundaries limited the use of photointerpretation to directly identify and map habitat type boundaries. It is important to note that a detailed study of an aerial photo can yield a multitude of nuances and subtle lines that can be interpreted as habitat type boundaries. The selection of the correct image characteristics for a specific ecotone was possible in this study only when prior knowledge had first been obtained in the field.

In order to provide others with some indication of the reliability level of the habitat type map, two measures of resolution were recorded on plate 1. These measures are the density of field traverse and the percentage of mapped stands field visited. The density of field traverse specifys the number of traverses made through an area, i.e. the linear distance traversed for each areal unit of land mapped. The traverse density for this study--four linear kilometers per square kilometer (6.4 miles per square mile)--appears comparable to densities used for other similar mapping projects (Daubenmire, 1973; Klinka and

Skoda, 1977). Both of these investigators listed mapping density strictly in terms of the area covered per day, approximately 75 hectares (185 acres). This daily areal density is comparable to a density of three kilometers (1.85 miles) of linear traverses per day, which was the average rate of mapping in this study.

The percentage of mapped stands visited informs the map user of the number of map units that were actually field visited, and conversely, how many units were placed on the map by inference from other factors. This measure provides an estimate of the confidence that a user can have in actually finding a specified habitat type within the mapped unit. Traditionally, accuracy estimates of habitat type maps have been based on a subjective appraisal by the map maker, and have given the map user little quantitative information about the field work actually completed.

## LAND_FORM_CHARACTERISTICS

The classification of the study area into land form classes consisted of combining the slope morphology units mapped on plate 2 with the appropriate watershed order and elevation at each sample point. For practical purposes, the slope morphology units shown on plate 2 can be considered as land form units. As can be seen on plate 2, most slope morphology units do not overlap different watershed order classses. This situation is expected since slope form greatly influences surface flow dynamics. In addition, only rarely do slope morphology units extend over a wide elevation range.

The slope morphology characteristics listed on plate 2 yield a possible 1,152 combinations. By combining the potential slope form classes with the six different watershed orders and the nine different elevation classes, 62,208 different land form classes are possible within the study area. The grid sample of plate 2 produced only 155 different slope morphology types, of which 54 occurred once and only 48 types were sampled on five or more occasions. Combining the 155 different slope morphology types with the watershed and elevation classes created a total of 331 different land form classes. Of the 176 new classes created by the addition of watershed order and elevation to slope morphology, 89 classes differed only by a single watershed order.

## LAND FORM DISTRIBUTION

Appendix 2 lists the frequency distributions for all sampled variables. With few exceptions, land form variables exhibit normal or at least expectable distributions. Watershed order presents the most curious distribution, with a small sampling of first, fourth and sixth order watersheds and a large number of second and third order watersheds. Because each sample point represents a unit area, an exponential progression should occur when the areas of lower order watersheds are summed. This obviously does not occur. A partial explanation for the observed distribution is that the study area does not represent a complete drainage basin. Also, problems in mapping watersheds (described in the next section) resulted in an under representation of first order watersheds.

The two-fold number of talweg slopes compared to interfluve slopes can also be explained, in part, by the absence of a complete drainage basin for study. The inclusion of partial areas of third and higher order stream valleys, without including the accompanying upper slope drainage areas, increases the area of talweg areas without a corresponding increase in interfluve areas. In addition, the areal extent of valley bottoms appears greater than the area of divides. Examination of plate 2 confirms that drainage divides (interfluves) are extremely narrow and thus occupied areas much smaller than the valley bottoms (talweg slopes), or were too narrow to even be mapped as separate units.

The frequency tables also show an irregularity between convex and concave slope forms. Concave areas, both in plan and profile dimensions, are substantially more numerous than convexities. An explanation for the large areas of concave plan form is that midslope ridges are so broadly rounded that they were classified as straight in plan form. An examination of the base map contours shows that most midslope ridges have broadly rounded contours, while stream channels are shown by more "V" shaped contours. Concave profiles are also more numerous than convex profiles. Like concave plan forms, concave profiles are associated with stream channels, particularly along the edge of the glaciated valley floor of upper Dick Creek. Convex profiles, however, are found largely on upper slopes. As with plan form the greater changes in slope curvature are associated with the occurrence of stream bottoms, while the upper slopes exhibit more gradual changes in slope curvature. Upper and midslope areas having larger radii of curvatures thus are usually classified as straight, while lower slope areas generally have smaller radii of curvatures and are are classified as concave.

## LAND FORM MAPPING

Overall, the land form units shown on plate 2 agree closely with the topography as represented by the base map contours. The land form units, however, show numerous topographic features which are not detectable from the base map contour lines. Small drainage features, areas of concave form and changes in exposure are particularly more evident from the photographically interpreted land form units than from the base map contours. The slopes adjacent to the middle portions of Dick Creek clearly illustrate these features. Some differences between the photogrammetrically mapped land forms and the base map resulted from errors in the original base map. Errors on the base map probably occurred because of the heavy forest cover over most of the study area. Recent logging in some areas permitted a clearer interpretation of terrain on the aerial photographs used for this study than was probably possible on the original photography used for base map compilation. Such errors illustrate the need for high resolution film and precision viewing optics when analyzing subtle terrain in densely forested regions.

The slope angles measured using the aerial photographs and classified on plate 2 generally agreed with angles interpreted from the base map contours. Other investigators have demonstrated that slope angles measured from air photos are slightly better than slope angles measured from contour maps (Moessner and Choate, 1966 and 1968). During the field inventory of habitat types, slope angles were measured with a hand held Brunton pocket transit. A comparison of 144 of these measurements with the slope angle groupings listed on plate 2, showed that 88% of these spot ground angles agreed with the slope groups, or were within one degree of these groupings. Of the 12% of spot angles not in agreement, the largest deviation from the group bounds was four degrees.

Stream orders for selected stream segments are listed in table 7. These stream orders are generally two to three orders higher than expressed on the original base map because of the addition of first and second order streams to the base map from the aerial photographs. Morisawa (1968) has also shown that drainage densities depicted on published topographic maps do not adequately represent the drainage network. Many first order streams that were visible on the air photos could not be identified from the base map, i.e., contour crenulations for these drainage lines were absent. Although ephemeral streams were considered first order streams, it was not always possible to delineate a watershed area for these segments. In such cases, the adjacent slopes were classified according to the stream order at the base of the slope. This situation was particularly common with feeder streams to South Fork Lolo Creek. The smaller than expected watershed area for first order streams and larger than expected area for second and fifth order streams may, in part, be related to the absence of these delineated first order watersheds.

Identification of profile curvature presented two mapping problems. First, the necessity to hand plot elevation points to construct a profile was extremely time consuming. Second, at the scale of the photography, 1:24,000, and the scale of map compilation, 1:12,000, convex and concave profiles were difficult to recognize and plot because of the limited map area occupied by these slope units. As an example, classification of convex slopes requires a rate of curvature greater than ten degrees per 100 meters. If a convex slope is encountered with an initial slope of 15 degrees and a rate of curvature of 20 degrees per 100 meters, within a slope length of 100 meters the slope angle would have increased to 35 degrees, and within 300 meters the angle would be 75 degrees. Most convex or concave profile slope segments are therefore quite short, horizontally. In the case of the above example, the horizontal length of the 100 meter slope segment would be 90 meters, or 0.75 cm (0.3 inches) at map compilation scale, and only 0.375 cm (0.15 inches) at photo scale. Profile plotting and subsequent mapping of such small slope units is a task appropriate only at larger map scales, at least as large as 1:6,000.

TABLE 7

SELECTED STREAM ORDERS BY STREAM SEGMENT

| STREAM SEGMENT | STREAM ORDER |
|---|---|
| Seepage Line or Ephemeral Stream | 1 |
| Small Creek | 3 |
| Marshall Creek | 4 |
| Upper Dick Creek | 3 |
| Middle Dick Creek | 4 |
| Lower Dick Creek (Below Johnny Creek) | 5 |
| West Fork Butte Creek | 5 |
| South Fork Lolo Creek | 6 |

The use of two different sets of photography for land form mapping--color infrared for watersheds and normal color for slope morphology--did not produce significant advantages. In fact, the need to examine and plot data from two sets of imagery caused problems in registering different sets of terrain data to the base map, as well as increased mapping time. Neither form of imagery was considered to be superior to the other. Drainages appeared slightly more visible on the color infrared than on the normal color, while the familiar color relationships on the normal color permitted easier recognition of ground features. Problems of dense shadows on infrared photography reported by Colwell (1960) were not significant on the color infrared used in this study. Shadow and color drop-off problems outside the center of a color infrared photo presented few difficulties as long as adequate stereo overlap, at least 60%, was available. An important attribute of both forms of imagery was the fact that all film was original. Color integrity, color differentiation and resolution was substantially greater on this original film than on the color prints that were used for habitat type boundary extension. In summary, this investigator preferred the normal color for land form mapping because of the familiar color relationships. The color infrared did occasionally provide greater color differentiation valuable in some circumstances. The value of the color infrared appeared to decrease as familiarity with ground conditions increased. Similarly, it appears that the value of the color infrared would decrease as photo scale increases.

## EXISTING VEGETATION CHARACTERISTICS

According to the criteria listed on plate 3, a possible 144 combinations of existing vegetation types could be defined. Out of these possible types, 31 types were actually sampled, of which only 24 types occurred on five or more occasions.

The principle result from the mapping of existing vegetation was an empirically derived relationship between color infrared (CIR) photographic color and vegetation condition. Table 8 summarizes these relationships. Areas labeled as "9" on plate 3 were generally wet sites occupied by low vegetation, either grasses or shrubs. These areas were associated with moist areas along streams, seeps or springs within the forest canopy or with brushy seepage areas adjacent to talus slopes. Forest areas having the identical photographic color tone as these wet non-forest areas were usually moist sites where tree growth was vigorous due to increased soil moisture availability. These areas were usually located in the center of a hollow or on a bench adjacent to a stream. Old growth forest stands also had a distinctive photographic color and were readily detected. Often an understory of vigorous reproduction was recognizable by its brighter color tone and gave some old growth stands a two-tone appearance. The one occasion of a boggy site with a perched water table, but still vigorous tree growth, had a distinctive "deep purple pink" color. These relationships were based on general observations made during the field inventory.

TABLE 8

EXISTING VEGETATION AND CIR PHOTOGRAPHIC COLOR

| COLOR AND NUMBER1/ | SIGNIFICANCE | MAP CODE |
|---|---|---|
| 257 Very Deep Purple Pink | Old Growth Forest | 2 |
| 256 Deep Purple Red | General Forest | 3 |
| 255 Soft Pink Red | General Forest | 4 |
| 248 Deep Purple Pink | Wet Forest Stand | 8 |
| 254 Very Purple Red | Moist Forest Stand | 5 |
| 254 Very Purple Red | Moist Grass or Brush | 9 |

1/ Number codes and color names from ISCC-NBS System (American Society of Photogrammetry, 1968).

The above relationships between photographic color and vegetation condition were not evident on the normal color photography. Although the mapped stands could be detected on both the normal color and the color infrared, the normal color photography provided little color differentiation for stand separation. Stands that were only slightly different in color on the normal color photos were readily separated on the color infrared photography. Similarly, areas of rock versus bare soil or grass, and areas of wet grass versus dry brush or grass, were readily identified on the color infrared but only marginally recognizable on the normal color photography. These results are consistent with other studies (Anson, 1966; Garn et al., 1973).

## MAP COMPARISONS

A visual comparison of plates 1, 2 and 3 reveals only a general resemblance between all three maps. Plates 1 and 2, however, exhibit a greater degree of correspondence even though the amount of detail portrayed on each map is substantially different. For example, areas having complex delineations on one map are also complex on the other map, while the areas of less detail are generally coincident on both maps. Likewise, areas of rough topography exhibit increased land form variability as well as increased habitat type variability, while areas of smooth topography exhibit a more simplified land form and habitat type pattern. A high degree of parallelism is also evident between plates 1 and 2, particularly along ridges and stream channels. This parallelism follows the actual topographic pattern, whether or not it is visible in the base map contours. The habitat types mapped in the field along drainages and ridge slopes that were not visible on the base map match surprisingly well with the portrayal of these land form features as mapped from the aerial photography. The areas along lower

Small Creek and middle Dick Creek, in particular, illustrate these relationships. The similarity between plates 1 and 2 also extends to moisture relationships. The concave areas (hollows) associated with the upper watersheds of tributary streams to West Fork Butte Creek and Marshall Creek are clearly evident on both maps, even though such areas are not always recognizable from the base contours. Although the above noted conditions are most obvious on plates 1 and 2, these same relationships also occur, but to a lesser degree, on plate 3. The slopes adjacent to lower Small Creek provide a good example of these subtle likenesses.

## STATISTICAL COMPARISONS

Because of the often complex visual appearances of the maps and their different degrees of detail, a statistical evaluation provides a more satisfying measure of the interrelationships between habitat type and the land form and existing vegetation variables. Contingency table analysis of each independent variable (land form and existing vegetation variables) by habitat type produced chi-square values significant to at least the 99.9% level for all variables. These values indicate that all of the land form and existing vegetation variables are indeed related to habitat types. Values for Cramers $\underline{V}$, a measure of the strength of relationships between two variables, generally show only a moderate degree of association between habitat type and the independent variables. The highest value of V was 0.623 for elevation followed by 0.522 for topographic position. Values for Cramers V for each variable, as well as the values for the uncertainty coefficient, are shown in table 9.

TABLE 9

NOMINAL LEVEL MEASURES OF ASSOCIATION

BETWEEN HABITAT TYPE AND THE INDEPENDENT VARIABLES

| INDEPENDENT VARIABLE | CRAMERS V | UNCERTAINTY COEFFICIENT |
|---|---|---|
| Land Form Characteristics | | |
| Slope Profile Form | .331 | .027 |
| Slope Plan Form | .426 | .112 |
| Slope Angle | .374 | .110 |
| Topographic Position | .344 | .143 |
| Elevation | .623 | .328 |
| Watershed Order | .404 | .122 |
| Topographic Position | .522 | .094 |
| Existing Vegetation Characteristics | | |
| Crown Canopy Coverage | .516 | .101 |
| Average Crown Diameter | .401 | .085 |
| Crown Texture | .401 | .085 |
| Photographic Color | .368 | .081 |
| Presence of Rocky Surface | .269 | .014 |

The values for the uncertainty coefficient listed in table 9 indicate that knowledge of any given land form variable increases habitat type prediction generally about 12%, while knowledge of any single existing vegetation variable increases predictive ability by only eight percent.

Elevation had the highest uncertainty coefficient, and decreased uncertainty of habitat type prediction by nearly one third. Although all of these values, except for the elevation value, are quite small, they utilize only a nominal level of measure for the independent variable. Therefore, a substantial amount of information provided by the independent variables has not been considered by this measure of association.

TABLE 10

INTERVAL LEVEL MEASURES OF ASSOCIATION

BETWEEN HABITAT TYPE AND THE INDEPENDENT VARIABLES

| INDEPENDENT VARIABLE | ETA | ETA SQUARED |
|---|---|---|
| Land Form Characteristics | | |
| Slope Profile Form | .442 | 19.5% |
| Slope Plan Form | .607 | 36.8% |
| Slope Angle | .533 | 28.4% |
| Topographic Exposure | .480 | 23.0% |
| Elevation | .897 | 80.5% |
| Watershed Order | .538 | 28.9% |
| Topographic Position | .662 | 43.8% |
| Existing Vegetation Characteristics | | |
| Crown Canopy Coverage | .645 | 41.6% |
| Average Crown Diameter | .561 | 31.5% |
| Crown Texture | N/A | N/A |
| Photographic Color | .394 | 15.5% |
| Presence of Rocky Surface | .269 | 7.2% |

The values for eta and eta squared are shown in table 10 and indicate that there is a great deal of association between some land form and existing vegetation variables and some habitat types. In particular, most habitat types appear to occur within a narrow altitudinal range. Similarly, topographic position and slope plan form are moderately associated with habitat types, as are crown canopy coverage and average crown diameter.

The discriminant analysis procedure was applied using the independent variables in three ways. First, only the land form variables were evaluated, second, only the existing vegetation variables were evaluated, and third, all independent variables were included. The classification of habitat types to the phase level using only the land form variables resulted in 42% of the cases correctly classified. The discriminant analysis procedure also computed the second most probable class for each case. Combining the first and second most probable classifications, yielded a correct classification result of 63% using the land form variables. Using only existing vegetation variables produced a correct classification of 16% for the habitat types at the phase level. When both the first and second most probable classes were counted, the percentage of classification was 27%. The percentage of correct classification when all the independent variables were entered into the analysis was only 48%. For both the first and second most probable cases, the classification percentage was 67%. Thus, the land form and existing vegetation characteristics produced largely overlapping results, and their combination did not substantially increase prediction capability. Because of the missing data the number of cases evaluated using land form variables was 696, while only 477 cases could be evaluated using all of the variables together, or using just the existing vegetation variables.

Table 11 summarizes the classification results obtained at the habitat type phase level when only the land form variables were analyzed. Classified habitat types which occurred less than eight percent of the time, or which occurred less than five times, were not listed in table 11. Although the cases for each habitat type were classified into several different types, the range of classified types is relatively narrow.

## TABLE 11

## DISCRIMINANT ANALYSIS CLASSIFICATION -

## PREDICTED HABITAT TYPES FOR KNOWN HABITAT TYPES

| KNOWN HABITAT TYPES1/ | PREDICTED HABITAT TYPES | NUMBER OF CASES | TOTAL % OF CASES |
|---|---|---|---|
| PSME/PHMA-PHMA (30) | PSME/PHMA-PHMA | 12 | 40.0% |
| | PSME/PHMA-CARU | 4 | 13.3 |
| | PSME/LIBO-CARU | 5 | 16.7 |
| | PSME/CARU-ARUV | 3 | 10.0 |
| | | -- | ----- |
| | | 24 | 80.0% |
| PSME/PHMA-CARU (31) | PSME/PHMA-PHMA | 6 | 19.4% |
| | PSME/PHMA-CARU | 20 | 64.5 |
| | | -- | ----- |
| | | 26 | 83.9% |
| PSME/VAGL-ARUV (19) | PSME/PHMA-PHMA | 3 | 15.8% |
| | PSME/PHMA-CARU | 2 | 10.5 |
| | PSME/VAGL-ARUV | 6 | 31.6 |
| | PSME/VAGL-XETE | 4 | 21.1 |
| | PSME/CARU-ARUV | 2 | 10.5 |
| | | -- | ----- |
| | | 17 | 89.5% |
| PSME/VAGL-XETE (19) | PSME/VAGL-ARUV | 2 | 10.5% |
| | PSME/VAGL-XETE | 6 | 31.6 |
| | PSME/LIBO-VAGL | 2 | 10.5 |
| | PSME/CARU-ARUV | 4 | 21.1 |
| | ABLA/XETE-VAGL | 2 | 10.5 |
| | | -- | ----- |
| | | 16 | 84.2% |
| PSME/LIBO-CARU (18) | PSME/PHMA-PHMA | 4 | 22.2% |
| | PSME/LIBO-CARU | 6 | 33.3 |
| | ABLA/LIBO-VASC | 7 | 38.9 |
| | | -- | ----- |
| | | 17 | 94.4% |
| PSME/LIBO-VAGL (25) | PSME/LIBO-CARU | 3 | 12.0% |
| | PSME/LIBO-VAGL | 9 | 36.0 |
| | PSME/CARU-ARUV | 3 | 12.0 |
| | ABLA/LIBO-XETE | 4 | 16.0 |
| | ABLA/LIBO-VASC | 3 | 12.0 |
| | | -- | ----- |
| | | 22 | 80.0% |

TABLE 11--Continued

| KNOWN HABITAT TYPES1/ | PREDICTED HABITAT TYPES | NUMBER OF CASES | TOTAL % OF CASES |
|---|---|---|---|
| PSME/CARU-ARUV (15) | PSME/PHMA-CARU | 5 | 33.3% |
| | PSME/VAGL-ARUV | 2 | 13.3 |
| | PSME/LIBO-VAGL | 2 | 13.3 |
| | PSME/CARU-ARUV | 4 | 26.7 |
| | | 13 | 86.6% |
| THPL/CLUN-CLUN (11) | THPL/CLUN-CLUN | 10 | 90.9% |
| | ABLA/CLUN-ARNU | 1 | 9.1 |
| | | 11 | 100.0% |
| ABLA/CLUN-CLUN (24) | THPL/CLUN-CLUN | 4 | 16.7% |
| | ABLA/CLUN/CLUN | 7 | 29.2 |
| | ABLA/CLUN-ARNU | 3 | 12.5 |
| | ABLA/CLUN-XETE | 2 | 8.3 |
| | ABLA/LIBO-LIBO | 2 | 8.3 |
| | | 18 | 75.0% |
| ABLA/CLUN-ARNU (24) | ABLA/CLUN-CLUN | 3 | 12.5% |
| | ABLA/CLUN-ARNU | 14 | 58.3 |
| | ABLA/CLUN-XETE | 3 | 12.5 |
| | ABLA/ALSI | 3 | 14.3 |
| | | 23 | 97.6% |
| ABLA/CLUN-XETE (21) | ABLA/CLUN-XETE | 8 | 38.1% |
| | ABLA/CLUN-MEFE | 4 | 19.0 |
| | ABLA/VAGL | 4 | 19.0 |
| | | 16 | 76.1% |
| ABLA/CLUN-MEFE (63) | ABLA/CLUN-ARNU | 6 | 9.5% |
| | ABLA/CLUN-MEFE | 28 | 44.4 |
| | ABLA/CACA-CACA | 6 | 9.5 |
| | ABLA/MEFE/MEFE | 6 | 9.5 |
| | ABLA/ALSI | 5 | 7.9 |
| | | 51 | 80.8% |

TABLE 11--Continued

| KNOWN HABITAT TYPES1/ | PREDICTED HABITAT TYPES | NUMBER OF CASES | TOTAL % OF CASES |
|---|---|---|---|
| ABLA/CACA-CACA (9) | ABLA/CACA-CACA | 6 | 66.7% |
| | ABLA/MEFE-VASC | 1 | 11.1 |
| | ABLA/LUHI-LUHI | 2 | 22.2 |
| | | -- | ------ |
| | | 9 | 100.0% |
| ABLA/LIBO-LIBO (15) | ABLA/LIBO-LIBO | 8 | 53.3% |
| | ABLA/LIBO-VASC | 2 | 13.3 |
| | | -- | ----- |
| | | 10 | 66.6% |
| ABLA/LIBO-XETE (68) | PSME/VAGL-XETE | 12 | 17.6% |
| | ABLA/LIBO-LIBO | 8 | 11.8 |
| | ABLA/LIBO-XETE | 27 | 39.7 |
| | ABLA/VAGL | 6 | 8.8 |
| | | -- | ----- |
| | | 53 | 77.9% |
| ABLA/LIBO-VASC (5) | PSME/LIBO-CARU | 2 | 40.0% |
| | ABLA/CLUN-CLUN | 1 | 20.0 |
| | ABLA/LIBO-VASC | 2 | 40.0 |
| | | -- | ------ |
| | | 5 | 100.0% |
| ABLA/MEFE-MEFE (70) | ABLA/MEFE-MEFE | 24 | 34.3% |
| | ABLA/MEFE-VASC | 5 | 7.1 |
| | ABLA/XETE-VAGL | 7 | 10.0 |
| | ABLA/LUHI-VASC | 6 | 8.6 |
| | ABLA/LUHI-LUHI | 9 | 12.9 |
| | | -- | ----- |
| | | 51 | 72.9% |
| ABLA/MEFE-VASC (6) | ABLA/MEFE-VASC | 5 | 83.3% |
| | ABLA/LUHI-LUHI | 1 | 16.7 |
| | | -- | ------ |
| | | 6 | 100.0% |

TABLE 11--Continued

| KNOWN HABITAT TYPES1/ | PREDICTED HABITAT TYPES | NUMBER OF CASES | TOTAL % OF CASES |
|---|---|---|---|
| ABLA/XETE-VAGL (142) | PSME/VAGL-XETE | 11 | 7.7% |
| | ABLA/LIBO-XETE | 7 | 4.9 |
| | ABLA/MEFE-MEFE | 16 | 11.3 |
| | ABLA/MEFE-VASC | 5 | 3.5 |
| | ABLA/XETE-VAGL | 56 | 39.4 |
| | ABLA/VAGL | 7 | 4.9 |
| | ABLA/ALSI | 19 | 13.4 |
| | ABLA/LUHI-VASC | 6 | 4.2 |
| | ABLA/LUHI-LUHI | 7 | 4.9 |
| | | 134 | 94.2% |
| ABLA/VAGL (6) | ABLA/VAGL | 6 | 100.0% |
| ABLA/ALSI (7) | ABLA/LIBO-XETE | 1 | 14.3% |
| | ABLA/XETE-VAGL | 2 | 28.6 |
| | ABLA/VAGL | 2 | 28.6 |
| | ABLA/ALSI | 2 | 28.6 |
| | | 7 | 100.0% |
| ABLA/LUHI-VASC (35) | ABLA/CACA-CACA | 4 | 11.4% |
| | ABLA/MEFE-VASC | 4 | 11.4 |
| | ABLA/XETE-VAGL | 3 | 8.6 |
| | ABLA/LUHI-VASC | 14 | 40.0 |
| | ABLA/LUHI-LUHI | 5 | 14.3 |
| | PIAL-ABLA | 5 | 14.3 |
| | | 35 | 100.0% |
| ABLA/LUHI-LUHI (23) | ABLA/CACA-CACA | 5 | 21.7% |
| | ABLA/MEFE-VASC | 4 | 17.4 |
| | ABLA/XETE-VAGL | 3 | 13.0 |
| | ABLA/LUHI-VASC | 6 | 26.1 |
| | ABLA/LUHI-LUHI | 5 | 21.7 |
| | | 23 | 99.9% |
| PIAL-ABLA (10) | PIAL-ABLA | 10 | 100.0% |

1/ Numbers in parenthesis are total number of cases analyzed.

An attempt was made to combine the numerous habitat types and phases into groups to improve the percentage of correct classifications. The classification results obtained from the land form variables were examined to identify natural groupings of habitat types. Groupings were developed by lumping together those habitat types which tended to be confused in the classification process. The groups identified by this process were identical to the grouping suggested by Pfister et al. (1977, p. 141). Using only the land form variables to predict these habitat groups, a correct classification of 53% was obtained. Because each of the habitat types overlap one another in a number of dimensions of discriminant space, grouping did not substantially increase the percentage of correct classification.

Classification of habitat types was also calculated for different levels, i.e. the habitat type level (one step less detailed than the phase level) and the series level (only overstory climax species considered). Using only the land form variables, classification results were 53% at the habitat type level and 90% at the series level. For both the first and second most probable cases, classification results at the habitat type level increased to 71% using only the land form variables. Using just the existing vegetation variables, classification results were 26% at the habitat type level and 76% at the series level. When all the independent variables were used, correct classification occurred 57% of the time at the habitat type level and 89% of the time at the series level. Again, the addition of existing vegetation variables did not substantially increase the classification results. Table 12 summarizes these results.

TABLE 12

DISCRIMINANT ANALYSIS SUMMARY RESULTS

| VARIABLES INCLUDED | HABITAT TYPE CLASSIFICATION LEVEL<br>PHASE | TYPE | SERIES |
|---|---|---|---|
| Land Form | 42.5% | 53.0% | 89.9% |
| Existing Vegetation | 15.7% | 25.8% | 76.1% |
| All Variables | 47.8% | 57.2% | 89.1% |

A total of seven functions were derived for the discriminant analysis of land form variables, one for each variable. Table 13 lists the order of variable entry into the analysis, and their F values. The importance of a specific variable is slightly different than that suggested by the values of the uncertainty coefficient and the other contingency table statistics. Slope angle became less important in the discriminant analysis, while plan form increased its importance when all variables were considered together in the discriminant analysis. The Wilk's lambda calculated for each variable shows that all variables produced significant separation in discriminant space for habitat type classification. Table 14 shows the discriminant function number, the eigenvalue and relative eigenvalue percentage. These percentages show the relative importance of each function for habitat type prediction. Table 14 shows that 87.3% of the total variation has been accounted for by just the first two functions. The Wilk's lambda value for each function indicated, however, that all functions produced significant separation results to at least the 95% level. The importance of each variable in each function is given by its standardized coefficient. These coefficients are listed in Appendix 3. The coefficient values indicate that the land form variables most important for habitat type prediction, in order of decreasing importance are: 1) elevation, 2) slope plan form, 3) topographic position, 4) watershed order, 5) topographic exposure, 6) slope angle, and 7) slope profile form.

## TABLE 13

## VARIABLE ENTRY SEQUENCE AND F VALUE

| STEP NUMBER | VARIABLE | F VALUE |
|---|---|---|
| 1 | Elevation | 131 |
| 2 | Topographic Position | 24 |
| 3 | Slope Plan Form | 10 |
| 4 | Topographic Exposure | 9 |
| 5 | Slope Angle | 8 |
| 6 | Watershed Order | 6 |
| 7 | Slope Profile Form | 3 |

## TABLE 14

## DISCRIMINANT FUNCTION EIGENVALUES

| DISCRIMINANT FUNCTION | EIGENVALUE | RELATIVE PERCENTAGE |
|---|---|---|
| 1 | 5.01 | 69.5 |
| 2 | 1.29 | 17.8 |
| 3 | .38 | 5.3 |
| 4 | .27 | 3.7 |
| 5 | .15 | 2.1 |
| 6 | .07 | 1.0 |
| 7 | .04 | .6 |

# CHAPTER 6

# DISCUSSION

A number of characteristics of the habitat type and land form classifications warrant further discussion because of their influence upon study results and their significance to other studies. Similarly, a presentation of some of the shortcomings and credits of the techniques and variables used herein may help to illuminate opportunities for future applications. And finally, additional research needs are suggested.

## HABITAT TYPE CLASSIFICATION EVALUATION

Many of the situations encountered during development of the habitat type map have already been presented. But several observations of species occurrences and mapping difficulties deserve further mention.

The occurrence of *Thuja plicata* in middle and upper South Fork Lolo Creek and its absence in lower South Fork Lolo Creek and West Fork Butte Creeks is puzzeling. The disappearance of *T. plicata* in South Fork Lolo Creek is abrupt and coincides with man's disturbance. The abrupt disappearance and absence of *T. plicata* in other areas under similar conditions has been noted by others (personal communication, Floyd Pond, U. S. Forest Service, Missoula, MT). The absence of T. plicata in South Fork Lolo and West Fork Butte Creeks may be caused by the dense sod and higher solar insolation in these disturbed areas. A lack of root penetration and susceptibility to full sunlight of T. plicata seedlings has been reported (U. S. Forest Service, 1965) and supports these observations. Had most of the valley of West Fork Butte Creek been classified as THPL/CLUN-CLUN instead of ABLA/CLUN-CLUN h.t., classification results for the ABLA/CLUN-CLUN h.t. may have been higher (see table 11). Such a possibility is quite likely because of the differences in environment between most ABLA/CLUN-CLUN h.t.s and the valley of West Fork Butte Creek. Most ABLA/CLUN-CLUN h.t.s were found in hollows and seepage zones or on benches and slopes adjacent to and above the wet bottoms boarding stream channels.

Picea spp. and Abies lasiocarpa were generally considered to be ecological equivalents for habitat type classification. In western Montana, this equivalence has also been accepted by most other habitat type investigators (personal communication, Stephen F. Arno, Intermountain Forest and Range Experiment Station, Missoula, MT). Many areas classified as either ABLA/XETE-VAGL or ABLA/LIBO-XETE contained no Abies lasiocarpa, but did support numerous Picea spp. seedlings and saplings. Such areas generally supported a mature overstory of Pseudotsuga menziesii and Pinus contorta about 60 years in age. The presence of Picea *spp.* in these stands, generally located upslope from available *A. lasiocarpa* seed sources, may be explained by differences in seed characteristics between *A. lasiocarpa* and *Picea spp.* The seeds of *Picea spp.*, *Picea engelmannii* and *Picea glauca*, are less than one half the size of *A. lasiocarpa* seeds, have substantially more wing area and are four to eight times lighter in weight than *A. lasiocarpa* seeds (U. S. Forest Service, 1974b). Seed dispersal should be substantially greater for *Picea spp.* and may account for the more rapid succession of *Picea spp.* in upslope areas. The lack of *A. lasiocarpa* in these mature stands may also indicate their marginal environment for this species, particularly with regard to seedling establishment.

The difficulty of classifying a site based on its potential to support and develop a given climax plant community should be obvious. Both, areas that have been continuously disturbed and transitional sites that are in a successional stage do not lend themselves to habitat type classification. The situations presented above illustrate the difficulty in consistently classifying habitat types.

Although habitat type classification has been widely accepted in the northern Rocky Mountains as a means for classifying ecosystems (Daubenmire and Daubenmire, 1968; Hoffman and Alexander, 1976; Pfister et al., 1977), a number of shortcomings were noted. The most significant problem was the use of habitat type classification criteria--threshold canopy coverages of selected indicator species--as a basis for map unit boundary delineation. Daubenmire states: "For all practical purposes habitat types have fixed characteristics and boundaries." (Daubenmire, 1976, p. 128). This investigator found the contrary to be the rule. Although many sites could be found that fit a given habitat type description, only rarely could boundaries be readily placed around a specific site or between habitat types. The difficulty of boundary placement around a site has been noted by others: "What is clear and precise in a vegetation type is always its center, not its margin, and that it characteristically may not have sharp boundaries." (Kuchler, 1972, p. 514, citing Tuxen, 1955).

Another mapping difficulty was the occurrence of a habitat type over a number of different environments. As noted previously the *ABLA/XETE-VAGL* phase is found in a number of different environments. Floristic composition of the *ABLA/XETE-VAGL* phase was quite varied from site to site. Moist site forbs, such as *Coptis occidentalis*, *Thalictrum occidentalis* and *Viola orbiculata*, were associated with this phase on cooler sites, while dry site graminoids, such as *Calamagrostis rubescens* and *Carex geyeri*, were associated with this phase on drier sites. Examples of other habitat types with similar broad environmental ranges have been previously presented. The use of a single set of indicator species to describe a habitat type appears to result in many types having an excessively broad environmental range. Kuchler (1972, citing Godron, 1964) suggested that all species are of diagnostic value, and it is only that the indicator value of some species have not yet been discovered.

The need for deriving more satisfactory mapping criteria for habitat type mapping is analogous to a similar need in soil mapping. The mapping of soil boundaries defined solely on the basis of profile characteristics is similarly difficult. Curtis (1962 and 1973) has advocated that the soil series be related to landscape units, defined by features such as drainage pattern, slope form and angle, and micro-relief. These landscape units would then be correlated with groups of soil series possesssing a limited range of profiles and parent materials. Thus, a separation of taxonomic units and mapping units is proposed. Such an approach may be worthwhile for habitat type mapping, wherein the mapping units are described in terms of observable and measurable surface features and are then correlated with a limited number of similar habitat types.

## LAND_FORM_CLASSIFICATION_EVALUATION

Three aspects of the land form classification warrant additional comment. First, the relation between individual land forms and specific geomorphic processes and regions occurring within the study area are presented.

Second, additional land form variables are described and recommendations for their future use are suggested. And third, opportunities for applying photogrammetric and digital methods to land form classification are considered.

## LAND FORM AND PROCESS

A number of relationships between individual land form characteristics and specific areas of differing evolutionary history were recognized within the study area. Many concavities, both in plan and profile, are found in and adjacent to valley bottoms which have a stable stream base level. The base level of both Upper Dick Creek and lower West Fork Butte Creek appear to be stable, as evidenced by their meandering stream channels. Also, the slopes boardering each stream are quite steep and possibly oversteepened. These conditions appear to give rise to the occurrence of concave land forms. According to Young (1972, p. 95) a concave slope profile is a transportational slope subject to control by removal of the regolith, and requiring a restriction in the rate of lowering of the slope base. The forms adjacent to these two drainages appear to satisfy these requirements, and to be inherited features, the result of past glaciation and associated processes. South Fork Lolo Creek, on the other hand, appears to be currently downcutting its valley and producing rectilinear transportational slopes. These rectilinear slopes may be caused by the continuous undermining of the slope bases by South Fork Lolo Creek. The occurrence of convex slopes are usually associated with upper slope positions where the slopes are subject to denudational processes, such as soil creep and wash. These upper slopes also appear to have been influenced less by changing geomorphic conditions over time compared to the valley bottom (talweg) areas. Thus, the slope forms of the study area appear the result of: 1) current geomorphic processes, 2) historic forms, and 3) longstanding continual processes. These observations are consistent with the conclusion expressed by Ruxton (1968), that most land is disordered. The fact that the land form classification used herein permits recognition of possible disequilibrium and disorder in the landscape, suggests that a parametric approach is sensitive to the complexity of form and process interactions through time.

## ADDITIONAL LAND FORM PARAMETERS

Analysis of the various land form variables was based solely on their individual values. The combination of variables into new measures was not undertaken due to time limitations, nor were additional land form elements gathered to further refine the initial discriminant analysis classification. Previous studies indicate that the inclusion of additional land form variables could be beneficial. Schumm et al., (1970) has suggested that slope angle be used in the form of a sine-cosine product. It was proposed that this product would provide an index to express the susceptibility of a given slope segment to erosion. Stage (1976) has also suggested use of a combined variable defined as the product of the tangent of slope angle times the sine-cosine product of topographic exposure. "In this way, plots on flat ground will have a zero value for these two variables, but plots on steep ground will have weights for sine and cosine of aspect." (Stage, 1976, p. 457-458).

Lee (1963 and 1964) has given equations for calculating a radiation index derived from slope and exposure measures. These equations (derived from Okanoue, 1957) utilize the slope and exposure values for a given slope, along with its geographic latitude to compute the period of sunlight (ignoring shading by adjacent slopes) and the daily maximum potential insolation. Similarly, Nash (1963) has proposed a method of combining potential evapotranspiration and average solar radiation to yield a measure of soil moisture deficits on a given slope. Measures such as those of Lee and Nash would provide data directly related to elements influencing the growth and development of plants.

In addition to variables derived from slope and exposure, other land form parameters appear to have potential for improving the land form classification. The length of slope above a given point has already been discussed with regard to runoff and soil water movements. Slope length has also been used in both soils and vegetation studies. Site index has been correlated with the distance up the slope as a percentage of total slope length (Meyers and Van Deusen, 1960), while the thickness of the soil mantle has been positively correlated with slope length (Ahnert, 1970b). Part of the value of watershed order as used in this study, may be its partial measure of slope length. According to Strahler (1950) the length of slope is a function of drainage basin size and as the order of watershed increases, the associated slopes lengthen accordingly.

A consideration of additional hydrologic elements also appears to have value in land form classification. Speight (1968) used unit catchment area, along with four other parameters, in a large scale study of land form classification. Unit catchment area was defined by the number of flow lines passing within a specified distance of a point. This parameter thus provided an indication of drainage density as well as slope length, particularly in areas where the drainage density was relatively constant. Kuska and Lamarra (1973) used drainage density and pattern to evaluate large land areas at small map scales. Inferences about the diversity of surface materials and potential vegetation were then made on the basis of the total number, size and densities of the various drainage basin studied. Other hydrologic parameters have been used in geomorphic analysis including stream length, basin area, basin perimeter and variously defined indices (Strahler, 1957). Almost all of these various measures can be derived from aerial photographs in quantitative form.

A further possible refinement of the land form classification is the stratification of land from units by landform or parent material. As noted above, various slope forms are closely related to specific landforms, e.g. concave slopes and glaciated valleys. The combination of land form units and parent material has been used as a basis for soil mapping in the forested Cascade Mountains of Oregon and Washington (personal communication, E. C. Steinbrenner, Senior Soil Scientist, Weyerhauser Company, Western Forestry Research Center, Centralia WA).

Experience from this study suggests that topographic exposure and slope angle should be considered in terms of a combined variable. As was previously stated, use of angle and exposure as separate variables contributed little to habitat type classification. Calculation of a sine-cosine product from slope angle and exposure or the generation of a radiation index would require no additional data collection and little additional computation. The addition of slope length or unit catchment area to the land form classification is believed to also warrant consideration. Collection of this variable could be difficult with manual methods, but might be easily derived from digital terrain data (described in the next section). Grouping, or stratifying, land form variables by parent material might be beneficial where major lithological differences are encountered. Stratification of variables by lithology or landforms in this study probably would not have substantially increased classification results. While stratification by parent material may be of some merit, stratifying by landforms appears less important because of the natural association between land form and geomorphic processes. And finally, the addition of hydrologic parameters appears worthwhile, but may be so closely correlated with unit catchment area or slope length as to negate their value. Also, collection of hydrologic variables, especially for small watersheds, may require considerable extra effort.

## PHOTOGRAMMETRIC AND DIGITAL APPLICATIONS

The use of land form characteristics for classifying the landscape, be they the ones used in this study or possible additional elements, has one vital attribute significant for mapping--they are all visible on aerial photographs and they all can be quantified. Most land form variables could also be derived from digital terrain models, which provide a dense grid of horizontal and vertical coordinates that describe surface topography and configuration. The use of digital terrain data for generating slope angle and exposure maps and for constructing perspective drawings of landscapes has become commonplace (Gossard, 1978; Sharpnack and Akin, 1969; U. S. Forest Service, 1976b). And, Troeh (1965) described methods for calculating plan and profile forms from digital coordinates.

The ability to use precision photogrammetric devices for efficiently gathering terrain data over large areas in digital form creates new opportunities for measuring land form parameters. Computer processing of this data and construction of maps by computer controlled electro-mechanical plotters would permit replicable results with known precision. In addition, new variables could be defined and then generated from the original digital data without re-examination of either the air photos or the ground.

## EVALUATION OF STUDY RESULTS

Comparison of the current study with other investigations is difficult for lack of comparative measures. Of the related studies previously discussed, only Mueggler (1965) and Getter and Tom (1977) provided statistical measures of success. The results of this study, 90% correct classification at the broadest level of classification (series level), are comparable with the classification results for timber productivity obtained by Getter and Tom. Mueggler attained good statistical association between individual species occurrence and land form parameters, but not for the more variable community groupings. Likewise in this study, some habitat types, generally those restricted to narrowly defined environments, were highly discriminated, while the more variable habitat types were often classified among a number of similar types. The lack of statistical measures for the studies by Deitschman (1973) and Kessell (1976) makes comparison with the results of those studies difficult. It was apparent, however, that both Kessell and Deitschman were satisfied with the procedures and results that they obtained.

A characteristic of all of these related studies was the comparison of field sample plot data with land form variables. Even in the mapping study by Deitschman, the habitat type and terrain relationships were initially obtained from individual sample plots. In this study, however, all data was derived from a sampling of mapped data. The inherent differences between boundaries of the three separately constructed maps created numerous opportunities for mismatching of boundary lines. The severity of potential misregistration of boundaries between maps was not initially recognized, yet this mismatch is considered a major shortcoming of the current study. Boundary integrity may indeed be a major reason for the lack of coincidence between land form and vegetation boundaries that has so often been noted in operational studies. The lack of coincident of boundary lines does not necessarily mean a lack of correspondence between resource attributes. As can be seen from an examination of plates 1 and 2, coincidence of lines is a rare occurrence, whereas the correspondence of habitat types and land form exceeds 40% at the phase level and approaches 90% at the series level.

The results of this effort are considered successful despite the relatively low classification value of 42% for habitat types, to the phase level. As previously presented, the classification of habitat type from land from variables increased to 53% at the habitat type level and to 90% at the series level. Further, as shown in table 11 most habitat types were classified into three or four similar types 80% or more of the time. The overlap between numerous habitat types is evident from this table, wherein for example, the PSME/XETE-VAGL phase was predicted in five different habitat types. It has been shown that the habitat types with the poorest classification results were also the types that occupied extremely varied environments or presented special mapping problems. The gradation between specific habitat types, as well as their varied floristic composition, is evident in the classification manual of Pfister et al. (1977). The fact that habitat types can be evaluated only as nominal levels of measurement, and the inability to assign more quantitative values to each habitat type, made it particularly difficult to adequately determine similarity or overlap between individual habitat types.

## IMPLICATIONS FOR FURTHER STUDY

Rowe (1971) listed two technical means for improving land inventory systems: 1) by more quantified descriotions of the land surface for greater consistency in its definition, and 2) by more sophisticated measurement of environmental attributes for characterizing land units. Jones (1969) proposed that, "so far as forestry is concerned, the primary purposes of site classification or ordination [including mapping] are 1) to identify productivity, and 2) to provide a frame of reference for silvicultural diagnosis and prescription." (Jones, 1969, p. 16). Classification systems for these purposes may not, however, provide an adequate means for defining map boundaries, as has been shown for habitat type classes in this study. But, assignment of forest characteristics to a map unit does not necessarily require that the same criteria be used for both recognizing and characterizing map units. As stated by Beckett, "if we map the natural resources of a region we do so in order to be able to make more precise statements about the mapped subdivisions than we can make about the region as a whole." (Beckett, 1968, p. 53). The ability to adequately characterize an area of land by its map units requires the units to be consistently recognized and precisely located. The use of criteria, such as vegetation coverages in habitat type classification or of qualitative or inferred characteristics in the landscape approach, cannot provide consistency or precision. The land form parameters used in this study provide quantitative criteria for map unit definition that can be precisely measured through photogrammetric procedures.

The use of parametric measures also provides greater flexibility and longevity for the map units than is provided by vegetation classifications. In synecological classifications (like habitat type classification) other environmental factors are associated in an unknown and unadjustable way (Jones, 1969, p. 17). The association of environmental factors to land form parameters, however, is based on knowledge of ecosystem interactions and statistical associations. As knowledge of ecosystem dynamics increase, land form parameters can be adjusted and refined to incorporate new relationships much more easily than can synecological classifications. Future improvements in mapping natural resources are suggested by refining the land form parameters used for delineating map units and by identifying the type and extent of natural resource attributes that can be correlated within delineated map units.

# CHAPTER 7

## SUMMARY AND CONCLUSIONS

The use of habitat types as a basis for land classification and mapping was found difficient in a number of ways. First, disturbed areas and transitional environments were extremely difficult to classify. Second, placement of boundary lines between units was often arbitrary because of the gradual transition of species representation and distribution. And third, the use of only a few indicator plant species for habitat type determinations resulted in different environments and plant communities being classified as the same habitat type. Had the habitat type system incorporateed a greater number of indicator species and classes, it is believed that the relationship between land form and habitat type would have been much stronger.

The use of aerial photography for land form classification and mapping proved highly successful. With the exception of slope profile form and a few first order watershed boundaries, all land form variables were readily interpreted and mapped from the photos. Although slope profile form was easily recognizable, instrument limitations and mapping scale reduced the ability to adequately measure and map slope profile form. All of the variables, except profile form, were considered valuable for landscape classification. But in the future, topographic exposure and slope angle should be combined to form a single variable, in addition to their use individually. The ability to derive land form variables from photogrammetric digital terrain models promises to substantially increase opportunities to acquire detailed land form information over large areas, while the ability to computerize data analysis should improve classification and mapping efficiency.

The addition of existing vegetation variables to the land form variables did not substantially increase habitat type discrimination or classification results. Existing vegetation variables were, however, significantly associated with habitat types and by themselves did produce moderately successful discrimination of habitat types, up to 76% correct classification at the series level.

Improvements in the use of land form characteristics for landscape classification are suggested in three areas. First, the addition of combined slope angle-topographic exposure variable and a measure of slope length, such as unit catchment area, is believed worthwhile. The combined angle-exposure value would provide an index of solar insolation received by a landscape unit, while the measure of slope length could indicate the amount of upslope soil moisture storage that might be available to a land unit. Second, the collection of resource attributes should be based on a sampling of ground points rather than on a sampling from map sources. Problems of line coincidence and line placement precision on the maps create numerous chances for error in sampling land form and resource attribute observations. And third, comparison between land form characteristics and resource attributes should utilize attributes which can be precisely measured and determined. Simple class data (nominal measures) such as habitat types, limit the type of statistical procedures that can be applied to data analysis, thus restricting opportunities for quantifying relationships. To the extent possible, all variables, including land form, should be measured using continuous scales of measure.

The use of land form characteristics to describe and delineate land units appears to provide a more sensitive classification of environment than does habitat type. In addition, because land form can be expressed as measurable quantities and can be derived from precisely determined topographic coordinates, land form units are easily and consistently mapped. 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. The desirability of using land form for ecological land classification and stratification comes not only from theoretical acceptability and land mapping advantages, but also because land form is readily applicable in the field, being based entirely upon visually apparent features of the landscape.

# CITED REFERENCES

Abelson, Robert P. and Tukey, John W. 1970. "Efficient Conversion of Non-Metric Information into Metric Information." In: Tufte, Edward R., ed. The Quantitative Analysis of Social Problems. Reading, Mass.: Addison Wesley. pp. 407-417. Cited by: Nie et al., q.v., p. 6.

Acton, D. F. 1965. "The Relationship of Pattern and Gradient of Slopes to Soil Type." Canadian Journal of Soil Science, Vol. 45: 96-101.

Ahnert, Frank. 1970a. "An Approach Towards a Descriptive Classification of Slopes." Zeitschrift fur Geomorphology, Vol. 14, Supp. 9: 71-84.

Ahnert, Frank. 1970b. "A Comparison of Theoretical Slope Models with Slopes in the Field." Zeitschrift fur Geomorphologie, Vol. 14, Supp. 9: 88-101.

Aldrich, D. and Mutch, R. W. 1971. "White Cap Fire Study - A Progress Report." Bitterroot National Forest, U. S. Forest Service. Cited by: Habeck q.v., p. 30.

American Society of Photogrammetry. 1968. Manual of Color Aerial Photography. Falls Church, Virginia: American Society of Photogrammetry.

Anson, Abraham. 1966. "Color Photo Comparison." Photogrammetric Engineering, Vol. 32(2): 286-297.

Anson, A. 1970. "Color Aerial Photos for Soils and Rocks." Photogrammetric Engineering, Vol. 36: 343-359.

Arnett, R. R. 1971. "Slope Form and Geomorphological Process: An Australian Example." In: Embleton, C., ed. Slopes Form and Process. Special Publication No. 3. London, England: Institute of British Geographers. pp. 81-91.

Arno, Stephen F. 1976. The Historical Role of Fire on the Bitterroot National Forest. USDA For. Serv. Res. Pap. INT-187. Ogden, Utah: Intermountain Forest and Range Experiment Station.

Bassett, John R. 1964. "Tree Growth as Affected by Soil Moisture Availability." Soil Science Society Proceedings, Vol. 28(3): 436-438.

Beaty, C. R. 1962. "Asymmetry of Stream Patterns and Topography in the Bitterroot Range, Montana." Journal of Geology, Vol. 70: 347-354.

Beckett, P. H. T. 1968. "Method and Scale of Land Resource Surveys, in Relation to Precision and Cost." In: Stewart, G. A., ed. Land Evaluation. Macmillan of Australia. pp. 53-63.

Bunting, B. T. 1961. "The Role of Seepage Moisture in Soil Formation, Slope Development and Stream Initiation." American Journal of Science, Vol. 259(7): 503-518.

Buttery, Robert T. 1978. "Modified ECOCLASS - A Forest Service Method for Classifying Ecosystems." In: Integrated Inventories of Renewable Natural Resources: Proceedings of the Workshop. USDA For. Serv. Gen'l Tech. Rpt. RM-55. Ft. Collins, Colo.: Rocky Mountain Forest and Range Experiment Station.

Chorley, Richard J. 1962. Geomorphology and General Systems Theory. Geological Survey Professional Paper 500-B. Washington, D. C.: U. S. Government Printing Office.

Colwell, Robert N. 1960. "Some Uses of Infrared Aerial Photography in the Management of Wildland Areas." Photogrammetric Engineering, Vol. 27(5): 774-785.

Colwell, Robert N. 1967. "Remote Sensing as a Means of Determining Ecological Conditions." Bioscience, Vol. 17(7): 444-449.

Coombs, Clyde H. 1953. "Theory and Methods of Social Measurement." In: Festinger, Leon and Katz, Daniel, ed. Research Methods in the Behavioral Sciences. New York: Holt, Rinehart, and Winston. pp. 471-535. Cited by: Nie et al., q.v., p. 6.

Cox, G. S.; McConnell, R. C.; and Matthew, L. M. 1960. "Ponderosa Pine Productivity in Relation to Soil and Landform in Western Montana." Soil Science Society of America Proceedings, Vol. 24(2): 139-142.

Curtis, L. F. 1962. "Soil Classification and Photo Interpretation." In: Commission VII, International Society of Photogrammetry, ed. Transactions of the Symposium on Photo Interpretation, Vol. 14. Delft, The Netherlands: International Archives of Photogrammetry. pp. 153-158.

Curtis, L. F. 1973. "Applications of Photography to Soil Mapping from the Air." Photographic Techniques in Scientific Research, Vol. 1: 57-110.

Curtis, L. F.; Doornkamp, J. C.; and Gregory, K. J. 1965. "The Description of Relief in Field Studies of Soils." Journal of Soil Science, Vol. 16: 16-30.

Dalrymple, J. B.; Blong, R. J.; and Conacher, A. J. 1968. "An Hypothetical Nine Unit Landsurface Model." Zeitschrift fur Geomorphologie, Vol. 12, Series 2: 60-76.

Daubenmire, R. 1973. "A Comparison of Approaches to the Mapping of Forest Land for Intensive Management." Forestry Chronicle, Vol. 48(2): 87-91.

Daubenmire, R. 1976. "The use of Vegetation in Assessing the Productivity of Forest Lands." Botanical Review, Vol. 42(2): 115-143.

Daubenmire, R. and Daubenmire, J. B. 1968. Forest Vegetation of Eastern Washington and Northern Idaho. Washington Agricultural Experiment Station, Technical Bulletin 60. Pullman, Washington: Washington State University.

Deitschman, Glenn H. 1973. Mapping of Habitat Types Throughout a National Forest. USDA For. Serv. Gen'l. Tech. Rpt. INT-11. Ogden, Utah: Intermountain Forest and Range Experiment Station.

Deitschman, Glenn H. and Green, Alan W. 1965. Relations Between Western White Pine Site Index and Tree Height of Several Associated Species. USDA For. Serv. Res. Pap. INT-22. Ogden, Utah: Intermountain Forest and Range Experiment Station.

Garn, Herbert S.; Logan, Leon D.; and Malmgren, Robert C. 1973. "Color Infrared Photography as a Land Management Tool." Mimeographed report. Missoula, Montana: USDA Forest Service.

Geiger, R. 1969. "Topoclimates." In: Flohn, H. ed. General Climatology, 2, World Survey of Climatology Volume 2. Chapter 3: 105-138.

Getter, James R. and Tom, Creighton H. 1977. "Forest Site Index Mapping and Yield Model Inputs to Determine Potential Site Productivity." Resource Inventory Notes, BLM-7. Denver, Colorado: USDI, Bureau of Land Management.

Gilbert, G. K. 1880. Report on the Geology of the Henry Mountains, 2nd ed. Washington D. C.: Government Printing Office.

Glazovskaya, M. A. 1968. "Geochemical Landscapes and Types of Geochemical Soil Sequences." Transactions of the 9th International Congress on Soil Science, Vol. 4: 303-312.

Godron, M. 1964. "Carte Phyto-Ecologique, Argent-Sur-Sauldre, Sologne." C.N.R.S., Centre d'Etudes Ohytosociologiques et Ecologiques, Montpellier. Cited by: Kuchler q.v., p. 521.

Gossard, Terry W. 1978. "Applications of DTM in the Forest Service." Photogrammetric Engineering, Vol. 44(12): 1577-1586.

Gregory, K. J. and Brown, E. H. 1966. "Data Processing and the Study of Land Form." Zeitschrift fur Geomorphologie, Vol. 10: 237-263.

Habeck, James R. 1972. Fire Ecology Investigations in Selway - Bitterroot Wilderness. Publication No. R1-72-001. Missoula, Montana: U. S. Forest Service.

Hack, J. T. and Goodlett, J. C. 1960. Geomorphology and Forest Ecology of a Mountain Region in the Central Applachians. USGS Professional Paper, 347. Washington, D. C.: USDI Geological Survey.

Halliday, James. 1969. "Applications of Color Aerial Photographs in Topographic Mapping." In: New Horizons in Color Aerial Photography. Falls Church, Virginia: American Society of Photogrammetry and Society of Photographic Scientists and Engineers.

Heller, P. C.; Doverspike G. E.; and Aldrich, P. C. 1964. Identification of Tree Species on Largescale Panchromatic and Color Aerial Photographs. Agriculture Handbook No. 261. Washington, D. C.: USDA Forest Service.

Hoffman, George R. and Alexander, Robert R. 1976. Forest Vegetation of the Bighorn Mountains, Wyoming: A Habitat Type Classification. USDA For. Serv. Res. Pap. RM-170. Ft. Collins, Colorado: Rocky Mountain Forest and Range Experiment Station.

Hudson, William, D.; Amsterburg, Robert J.; and Meyers, Wayne L. 1976. Identifying and Mapping Forest Resources From Small-Scale Color-Infrared Airphotos. Agricultural Experiment Station Research Report 304. East Lansing, Michigan: Michigan State University.

Isachenko, A. G. 1973. Principles of Landscape Science and Physical-Geographic Regionalization. Translated by R. S. Zatorski, edited by John S. Massy. Melbourne, Australia: Melbourne University Press.

Jones, John R. 1969. Review and Comparison of Site Evaluation Methods. USDA For. Serv. Res. Pap. RM-51. Ft. Collins, Colorado: Rocky Mountain Forest and Range Experiment Station.

Kaempfert, W. and Morgen, A. 1952. "Die Besonnung." Z. Meteorol., Vol. 6: 138-146. Cited by: Geiger q.v., p. 109.

Kessell, Stephen R. 1976. "Wildland Inventories and Fire Modeling by Gradient Analysis in Glacier National Park." Proceedings Tall Timbers Fire Ecology Conferencee and Intermountain Fire Research Council and Land Management. Tallahassee, Fla.: Tall Timbers Res. Sta.

Klecka, William R. 1975. "Discriminant Analysis, Chapter 20." In: Nie et al. SPSS Statistical Package for the Social Sciences, Second Edition. New York: McGraw Hill. pp. 434-467.

Klinka, Karel and Skoda, Lou. 1977. "Synecological Map of the University of British Columbia Research Forest." The Forestry Chronicle, Vol. 53(6): 348-352.

Kuchler, A. W. 1972. "Problems in Classifying and Mapping Vegetation For Ecological Regionalization." Ecology, Vol. 54: 512-523.

Kuhl, Arthur. 1970. "Color and Infrared Photos for Soils." Photogrammetric Engineering, Vol. 36(5): 475-482.

Kuska, James and Lamarra, Vince A. 1973. "Use of Drainage Patterns and Densities to Evaluate Large Scale Land Areas for Resource Management." Journal of Environmental Systems, Vol. 3(2): 85-100.

Labovitz, Stanford. 1970. "The Assignment of Numbers to Rank Order Categories." American Sociological Review, Vol. 35: 515-524. Cited by: Nie et al., q.v., p. 6.

Lee Richard. 1963. Evaluation of Solar Beam Irradiation as a Parameter of Mountain Watersheds. Colo. State Univ. Hydrol. Paper No. 2. Ft. Collins, Colo.: Colo. State Univ.

Lee Richard. 1964. "Potential Insolation as a Topoclimatic Characteristic of Drainage Basins." Bulletin of International Association Scientific Hydrology, Vol. 9(1): 27-41.

Lee, R. and Baumgartner, A. 1966. "The Topography and Insolation Climate of a Mountainous Forest Area." Forest Science, Vol. 12(3): 258-267.

Lee R. and Sypolt, C. R. 1974. "Toward a Biophysical Evaluation of Forest Site Potential." Forest Science, Vol. 20(2): 145-154

Mabbutt, J. A. 1968. "Review of Concepts of Land Classification." In: Stewart, G. A., ed. Land Evaluation. Macmillan of Australia. pp. 11-28.

Malmgren, Robert C. and Garn, Herbert S. 1975. "Use of Color Infrared Photography for Forest Land Inventories." Journal of Soil and Water Conservation, Vol. 30(3): 125-128.

Martinson, Albin H.; Delk, Robert; and Venturini, Dennis. 1973. Spotted Bear Country. Publication No. R1-73-010. Missoula, Mont.: USDA Forest Service.

Moessner, K. E. and Choate, G. A. 1964. Estimating Slope Percent for Land Management From Aerial Photos. USDA Forest Service Res. Note INT-26. Ogden, Utah: Intermountain Forest and Range Experiment Station.

Moessner, K. and Choate, G. A. 1966. "Terrain Slope Estimation." Photogrammetric Engineering, Vol. 32: 67-75. blank 1

Morisawa, Marie. 1957. "Accuracy of Determination of Stream Lengths from Topographic Maps." Transactions of the American Geophysical Union, Vol. 38(1): 86-88.

Mueggler, Walter F. 1965. "Ecology of Seral Shrub Communities in the Cedar-Hemlock Zone of Northern Idaho." Ecological Monographs, Vol. 35: 165-185.

Myers, Clifford A. and Van Deusen, James L. 1960. "Site Index of Ponderosa Pine in the Black Hills from Soil and Topography." Journal of Forestry, Vol. 58(7): 548-555.

Nash, A. J. 1963. "A Method for Evaluating the Effects of Topography on the Soil Water Balance." Forestry Science, Vol. 9(4): 413-422.

Nie, Norman H.; Hull, C. Hadlai; Jenkins, Jean G.; Steinbrenner, Karin; and Bent, Dale H. 1975. SPSS Statistical Package for the Social Sciences, Second Edition. New York: McGraw-Hill.

Nold, John. 1968. "Geology of the Northeastern Border Zone of the Idaho Batholith, Montana and Idaho." Ph.D Dissertation, University of Montana.

Northrop, Kenneth G. and Johnson, Evert W. 1970. "Forest Cover Type Identification." Photogrammetric Engineering, Vol. 36(5): 483-490.

Nutter, Wade L. and Hewlett, John D. 1971. "Stormflow Production from Permeable Upland Basins." In: Monke, E. J., ed. Biological Effects on the Hydrological Cycle. Proc. of the Third International Seminar for Hydrology Professors. West Lafayette, Indiana: Dept. of Agricultural Engineering, Agricultural Exper. Sta., Purdue, Univ.

Okanoue, M. 1957. "A Simple Method to Compute the Amount of Sunshine on a Slope." Journal of Japanese Forestry (Nov. 1957): 435-437. (Transl. by K. Miyadawa, Colo. State Univ.). Cited by: Lee q.v., p. 16.

Parry, J. T. and Beswick, J. A. 1973. "The Application of Two Morphometric Terrain-Classification Systems Using Air-Photo Interpretation Methods." Photogrammetria, Vol. 29(5): 153-186.

Petterson, Stan. 1976. Land Types. Mimeographed report. Missoula, Mont.: USDA For. Service, Lolo National Forest.

Pfister, Robert D. 1973. "Habitat types and Regeneration." Western Forestry and Conservation Association Proceedings." Portland, Ore. pp. 120-125.

Pfister, Robert D. 1975. "Land Capability Assessment by Habitat Types." America's Renewable Resource Potential - 1975: The Turning Point. 75th Annual Convention Proceedings. Washington, D. C.: Society of American Foresters. pp.312-325.

Pfister, R. 1976. "Summary of Selected Detailed Habitat Type Mapping Projects in the Northern Rocky Mountains." (Mimeographed table.)

Pfister, Robert D.; Kovalchik, Bernard L.; Arno, Stephen F.; and Presby, Richard C. 1977. Forest Habitat Types of Montana. USDA For. Serv. Gen'l. Tech. Rpt. INT-34. Ogden, Utah: Intermountain Forest and Range Experiment Station.

Rowe, J. S. 1971. "Why Classify Forest Land?" The Forestry Chronicle, Vol. 47(3): 144-148.

Ruhe, R. V. and Walker, P. H. 1968. "Hillslope Models and Soil Formation. I. Open Systems." Transactions of the 9th International Congress on Soil Science, Vol. 4: 551-560.

Ruxton, Bryan P. 1968. "Order and Disorder in Land." In: Stewart, G. A., ed. Land Evaluation. Macmillan of Australia. pp. 29-39.

Savigear, R. A. G. 1965. "A Technique of Morphological Mapping." Annals of the Association of American Geographers, Vol. 55(3): 514-538.

Schumm, S. A.; Vird, J. B.; and Starkel, L. 1970. "Report of Work Group on Classification of Hillslopes." Zeitschrift fur Geomorphologie, Vol. 14, Supp. 9: 85-87.

Sharpnack, David A. and Akin, Garth. 1969. "An Algorithm for Computing Slope and Aspect From Elevations." Photogrammetric Engineering, Vol. 35(3): 247-248.

Speight, J. G. 1968. "Parametric Description of Land Form." In: Stewart, G. A., ed. Land Evaluation. Macmillan of Australia. pp. 239-250.

Stage, A. R. 1976. "An Expression for the Effect of Aspect, Slope, and Habitat Type on Tree Growth." Forest Science, Vol. 22(4): 457-460.

Stevens, S. S. 1946. "On the Theory of Scales of Measurement." Science, Vol. 103: 667-680. Cited by: Nie et al., q.v., p. 4.

Strahler, A. N. 1950. "Equilibrium Theory of Erosional Slopes Approached by Frequency Distribution Analysis." American Journal of Science, Vol. 248: 673-646. Cited by Arnett q.v., p. 84.

Strahler, A. N. 1957. "Quantitative Analysis of Watershed Geomorphology." Transactions of American Geophysics Union, Vol. 38: 913-920.

Troeh, Frederick R. 1964. "Landform Parameters Correlated to Soil Drainage." Soil Science Society of America Proceedings, Vol. 28(6): 808-812.

Troeh, F. R. 1965. "Landform Equations Fitted to Contour Maps." American Journal of Science, Vol. 263: 616-627.

Tuxen, R. 1955. "Das System der Nordwestdeustschen Pflanzengesellschafter." Mitt. Florist.-soziol. Arveitsgem, 5: 155-176. Cited by: Kuchler q.v., p. 514.

U. S. Forest Service. 1965. Silvics of Forest Trees of the United States. Agriculture Handbook No. 271. Washington, D. C.: U. S. Dept. of Agriculture.

U. S. Forest Service. 1973. ECOCLASS - Method for Classifying Ecosystems - A Task Force Analysis. Missoula, Montana: USDA Forest Service.

U. S. Forest Service. 1974a. Land Use Planning. Sandpoint, Idaho: USDA Forest Service, Idaho Panhandle National Forests.

U. S. Forest Service. 1974b. Seeds of Woody Plants in the United States. Agriculture Handbook No. 450. Washington, D. C.: USDA Forest Service.

U. S. Forest Service. 1976a. Land System Inventory Guide. Missoula, Montana: USDA Forest Service.

U. S. Forest Service. 1976b. Topographic Analysis System: User's Guide, Second Edition. Washington D. C.: USDA Forest Service.

Soil Conservation Service, in cooperation with the Montana Water Resources Board. 1970. "Average Annual Mountain Precipitation Map." Bozeman, Montana: USDA Soil Conservation Service.

Walker, P. H. and Ruhe, R. V. 1968. "Hillslope Models and Soil Formation: Closed Systems." Transactions of the 9th International Congress on Soil Science, Vol. 4: 561-568.

Wertz, W. A. and Arnold, J. F. 1972. Land Systems Inventory. Ogden, Utah: USDA Forest Service, Intermountain Region.

Wong, Kam W.; Thornburn, T. H.; and Khoury, M. A. 1977. "Automatic Soil Identification from Remote Sensing Data." Photogrammetric Engineering, Vol. 43(1): 73-80.

Young, Anthony. 1972. Slopes. Edinburgh: Oliver and Boyd.

# APPENDIX 1

## HABITAT TYPE NAMES AND ABBREVIATIONS

| ABBREVIATION : | HABITAT TYPES AND PHASES |
|---|---|
| | PSEUDOTSUGA MENZIESII CLIMAX SERIES |
| PSME/AGSP h.t. | Pseudotsuga menziesii/Agropyron spicatum |
| PSME/PHMA h.t. | Pseudotsuga menziesii/Physocarpus malvaceus |
| -PHMA phase | -Physocarpus malvaceus |
| -CARU phase | -Calamagrostis rubescens |
| PSME/VAGL h.t. | Pseudotsuga menziesii/Vaccinium globulare |
| -VAGL phase | -Vaccinium globulare |
| -ARUV phase | -Arctostaphylos uva-ursi |
| -XETE phase | -Xerophyllum tenax |
| PSME/LIBO h.t. | Pseudotsuga menziesii/Linnaea borealis |
| -CARU phase | -Calamagrostis rubescens |
| -VAGL phase | -Vaccinium globulare |
| PSME/SYAL h.t. | Pseudotsuga menziesii/Symphoricarpos albus |
| -CARU phase | -Calamagrostis rubescens |
| PSME/CARU h.t. | Pseudotsuga menziesii/Calamagrostis rubescens |
| -AGSP phase | -Agropyron spicatum |
| -ARUV phase | -Arctostaphylos uva-ursi |
| | PICEA CLIMAX SERIES |
| PICEA/PHMA h.t. | Picea/Physocarpus malvaceus |
| | ABIES GRANDIS CLIMAX SERIES |
| ABGR/CLUN h.t. | Abies grandis/Clintonia uniflora |
| -CLUN phase | -Clintonia uniflora |
| -ARNU phase | -Aralia nudicaulis |
| -XETE phase | -Xerophyllum tenax |
| ABGR/LIBO h.t. | Abies grandis/Linnaea borealis |
| -LIBO phase | -Linnaea borealis |
| -XETE phase | -Xerophyllum tenax |
| | THUJA PLICATA CLIMAX SERIES |
| THPL/CLUN h.t. | Thuja plicata/Clintonia uniflora |
| -CLUN phase | -Clintonia uniflora |
| -ARNU phase | -Aralia nudicaulis |
| -MEFE phase | -Menziesia ferruginea |

## APPENDIX 1--Continued

| ABBREVIATION : | HABITAT TYPES AND PHASES |
|---|---|
| | ABIES LASIOCARPA CLIMAX SERIES |
| ABLA/CLUN h.t. | Abies lasiocarpa/Clintonia uniflora |
| -CLUN phase | -Clintonia uniflora |
| -ARNU phase | -Aralia nudicaulis |
| -XETE phase | -Xerophyllum tenax |
| -MEFE phase | -Menziesia ferruginea |
| ABLA/VACA h.t. | Abies lasiocarpa/Vaccinium caespitosum |
| ABLA/CACA h.t. | Abies lasiocarpa/Calamagrostis canadensis |
| -CACA phase | -Calamagrostis canadensis |
| -GATR phase | -Galium triflorum |
| ABLA/LIBO h.t. | Abies lasiocarpa/Linnaea borealis |
| -LIBO phase | -Linnaea borealis |
| -XETE phase | -Xerophyllum tenax |
| -VASC phase | -Vaccinium scoparium |
| ABLA/MEFE h.t. | Abies lasiocarpa/Menziesia ferruginea |
| -MEFE phase | -Menziesia ferruginea |
| -VASC phase | -Vaccinium scoparium |
| ABLA/XETE h.t. | Abies lasiocarpa/Xerophyllum tenax |
| -VAGL phase | -Vaccinium globulare |
| -VASC phase | -Vaccinium scoparium |
| ABLA/VAGL h.t. | Abies lasiocarpa/Vaccinium globulare |
| ABLA/ALSI h.t. | Abies lasiocarpa/Alnus sinuata |
| | Upper subalpine h.t.s |
| ABLA-PIAL/VASC h.t. | Abies lasiocarpa-Pinus albicaulis/Vaccinium scoparium |
| ABLA/LUHI h.t. | Abies lasiocarpa/Luzula hitchcockii |
| -VASC phase | -Vaccinium scoparium |
| -MEFE phase | -Menziesia ferruginea |
| | Timberline h.t.s |
| PIAL-ABLA h.t.s | Pinus albicaulis-Abies lasiocarpa |

# APPENDIX 2

## FREQUENCY DISTRIBUTIONS

| CATEGORY LABEL | ABSOLUTE FREQUENCY | RELATIVE FREQUENCY (PERCENT) | ADJUSTED FREQUENCY (PERCENT) |
|---|---|---|---|
| HABITAT TYPES | | | |
| SCREE | 2 | 0.3 | 0.3 |
| PSME-AGSP | 1 | 0.1 | 0.1 |
| PSME-PHMA-PHMA | 30 | 4.2 | 4.2 |
| PSME-PHMA-CARU | 31 | 4.3 | 4.3 |
| PSME-VAGL-VAGL | 1 | 0.1 | 0.1 |
| PSME-VAGL-ARUV | 19 | 2.6 | 2.6 |
| PSME-VAGL-XETE | 19 | 2.6 | 2.6 |
| PSME-LIBO-CARU | 18 | 2.5 | 2.5 |
| PSME-LIBO-VAGL | 25 | 3.5 | 3.5 |
| PSME-CARU-AGSP | 2 | 0.3 | 0.3 |
| PSME-CARU-ARUV | 15 | 2.1 | 2.1 |
| ABGR-CLUN-CLUN | 3 | 0.4 | 0.4 |
| ABGR-CLUN-ARNU | 2 | 0.3 | 0.3 |
| THPL-CLUN-CLUN | 11 | 1.5 | 1.5 |
| THPL-CLUN-ARNU | 1 | 0.1 | 0.1 |
| THPL-CLUN-MEFE | 1 | 0.1 | 0.1 |
| ABGR-LIBO-LIBO | 4 | 0.6 | 0.6 |
| ABGR-LIBO-XETE | 1 | 0.1 | 0.1 |
| ABLA-CLUN-CLUN | 24 | 3.3 | 3.3 |
| ABLA-CLUN-ARNU | 24 | 3.3 | 3.3 |
| ABLA-CLUN-XETE | 21 | 2.9 | 2.9 |
| ABLA-CLUN-MEFE | 63 | 8.7 | 8.7 |
| ABLA-VACA | 1 | 0.1 | 0.1 |
| ABLA-CACA-CACA | 9 | 1.2 | 1.2 |
| ABLA-CACA-GATR | 1 | 0.1 | 0.1 |
| ABLA-LIBO-LIBO | 15 | 2.1 | 2.1 |
| ABLA-LIBO-XETE | 68 | 9.4 | 9.4 |
| ABLA-LIBO-VASC | 5 | 0.7 | 0.7 |
| ABLA-MEFE-MEFE | 70 | 9.7 | 9.7 |
| ABLA-MEFE-VASC | 6 | 0.8 | 0.8 |
| ABLA-XETE-VAGL | 142 | 19.7 | 19.7 |
| ABLA-XETE-VASC | 1 | 0.1 | 0.1 |
| ABLA-VAGL | 6 | 0.8 | 0.8 |
| ABLA-ALSI | 7 | 1.0 | 1.0 |
| ABLA:PIAL-VASC | 4 | 0.6 | 0.6 |
| ABLA-LUHI-VASC | 35 | 4.8 | 4.9 |
| ABLA-LUHI-MEFE | 23 | 3.2 | 3.2 |
| PIAL:ABLA | 10 | 1.4 | 1.4 |
| Out of range | 1 | 0.1 | Missing |
| | ------- | ------- | ------- |
| Totals | 722 | 100.0 | 100.0 |

## APPENDIX 2--Continued

```
 Valid cases      721        Missing cases      1

                                   RELATIVE    ADJUSTED
                       ABSOLUTE   FREQUENCY   FREQUENCY
 CATEGORY LABEL       FREQUENCY   (PERCENT)   (PERCENT)

PROFILE FORM
 CONCAVE RV<-573M         36          5.0         5.0
 STRAIGHT RV<573M        684         94.7        94.7
 CONVEX RV>573M            2          0.3         0.3
                      -------     -------     -------
Totals                   722        100.0       100.0

 Valid cases      722        Missing cases      0

                                   RELATIVE    ADJUSTED
                       ABSOLUTE   FREQUENCY   FREQUENCY
 CATEGORY LABEL       FREQUENCY   (PERCENT)   (PERCENT)

PLAN FORM
 CONCAVE RH>-50M          61          8.4         8.4
 CVE RH=-50TO-500M       137         19.0        19.0
 STRAIGHT  RH>500M       375         51.9        51.9
 CVX RH=50TO500M         132         18.3        18.3
 CONVEX RH<50M            17          2.4         2.4
                      -------     -------     -------
Totals                   722        100.0       100.0

 Valid cases      722        Missing cases      0

                                   RELATIVE    ADJUSTED
                       ABSOLUTE   FREQUENCY   FREQUENCY
 CATEGORY LABEL       FREQUENCY   (PERCENT)   (PERCENT)

SLOPE ANGLE
 0-2 DEGREES              17          2.4         2.4
 2-5 DEGREES              42          5.8         5.8
 5-10 DEGREES             99         13.7        13.7
 10-18 DEGREES           322         44.6        44.6
 18-30 DEGREES           202         28.0        28.0
 30-45 DEGREES            38          5.3         5.3
 45-70 DEGREES             2          0.3         0.3
                      -------     -------     -------
Totals                   722        100.0       100.0

 Valid cases      722        Missing cases      0
```

APPENDIX 2--Continued

| CATEGORY LABEL | ABSOLUTE FREQUENCY | RELATIVE FREQUENCY (PERCENT) | ADJUSTED FREQUENCY (PERCENT) |
|---|---|---|---|
| TOPO EXPOSURE | | | |
| NNE | 138 | 19.1 | 19.1 |
| NNW | 112 | 15.5 | 15.5 |
| ENE | 88 | 12.2 | 12.2 |
| WNW | 84 | 11.6 | 11.6 |
| FLAT | 59 | 8.2 | 8.2 |
| ESE | 106 | 14.7 | 14.7 |
| SSE | 83 | 11.5 | 11.5 |
| WSW | 21 | 2.9 | 2.9 |
| SSW | 31 | 4.3 | 4.3 |
| | ------- | ------- | ------- |
| Totals | 722 | 100.0 | 100.0 |

Valid cases 722 Missing cases 0

| CATEGORY LABEL | ABSOLUTE FREQUENCY | RELATIVE FREQUENCY (PERCENT) | ADJUSTED FREQUENCY (PERCENT) |
|---|---|---|---|
| ELEVATION | | | |
| 3500' | 6 | 0.8 | 0.8 |
| 4000' | 59 | 8.2 | 8.2 |
| 4500' | 94 | 13.0 | 13.0 |
| 5000' | 128 | 17.7 | 17.7 |
| 5500' | 150 | 20.8 | 20.8 |
| 6000' | 159 | 22.0 | 22.0 |
| 6500' | 94 | 13.0 | 13.0 |
| 7000' | 24 | 3.3 | 3.3 |
| 7500' | 8 | 1.1 | 1.1 |
| | ------- | ------- | ------- |
| Totals | 722 | 100.0 | 100.0 |

Valid cases 722 Missing cases 0

## APPENDIX 2--Continued

```
                                         RELATIVE    ADJUSTED
                           ABSOLUTE     FREQUENCY   FREQUENCY
 CATEGORY LABEL           FREQUENCY     (PERCENT)   (PERCENT)

WATERSHED ORDER
 1ST ORDER                     27          3.7         3.7
 2ND ORDER                    239         33.1        33.1
 3RD ORDER                    235         32.5        32.5
 4TH ORDER                     58          8.0         8.0
 5TH ORDER                    113         15.7        15.7
 6TH ORDER                     50          6.9         6.9
                           -------      -------     -------
Totals                        722        100.0       100.0

  Valid cases      722      Missing cases      0

                                         RELATIVE    ADJUSTED
                           ABSOLUTE     FREQUENCY   FREQUENCY
 CATEGORY LABEL           FREQUENCY     (PERCENT)   (PERCENT)

TOPO. POSITION
 INTERFLUVE                    62          8.6         8.6
 MIDSLOPE                     527         73.0        73.0
 TALWEG                       133         18.4        18.4
                           -------      -------     -------
Totals                        722        100.0       100.0

 Valid cases      722      Missing cases      0

                                         RELATIVE    ADJUSTED
                           ABSOLUTE     FREQUENCY   FREQUENCY
 CATEGORY LABEL           FREQUENCY     (PERCENT)   (PERCENT)

ROCK PRESENCE
 NORMAL SURFACE               686         95.0        95.0
 ROCKY SURFACE                 36          5.0         5.0
                           -------      -------     -------
Totals                        722        100.0       100.0

 Valid cases      722      Missing cases      0
```

## APPENDIX 2--Continued

```
                                    RELATIVE   ADJUSTED
                         ABSOLUTE  FREQUENCY  FREQUENCY
 CATEGORY LABEL         FREQUENCY  (PERCENT)  (PERCENT)

CROWN COVER
 <40% CROWN CVR               88       12.2       17.6
 40-80% CROWN CVR            132       18.3       26.4
 >80% CROWN CVR              280       38.8       56.0
 Out of range                222       30.7    Missing
                         -------    -------    -------
Totals                       722      100.0      100.0

 Valid cases       500        Missing cases     222

                                    RELATIVE   ADJUSTED
                         ABSOLUTE  FREQUENCY  FREQUENCY
 CATEGORY LABEL         FREQUENCY  (PERCENT)  (PERCENT)

CROWN DIAMETER
 <7" CROWN DIA               158       21.9       31.6
 7-14" CROWN DIA             233       32.3       46.6
 >14" CROWN DIA              109       15.1       21.8
 Out of range                222       30.7    Missing
                         -------    -------    -------
Totals                       722      100.0      100.0

 Valid cases       500        Missing cases     222

                                    RELATIVE   ADJUSTED
                         ABSOLUTE  FREQUENCY  FREQUENCY
 CATEGORY LABEL         FREQUENCY  (PERCENT)  (PERCENT)

CROWN TEXTURE
 2-STORY CROWNS                8        1.1        1.6
 COARSE CROWNS               101       14.0       20.2
 MID-TEX CROWNS              233       32.3       46.6
 FINE CROWNS                 158       21.9       31.6
 Out of range                222       30.7    Missing
                         -------    -------    -------
Totals                       722      100.0      100.0

 Valid cases       500        Missing cases     222
```

## APPENDIX 2--Continued

```
                                        RELATIVE   ADJUSTED
                          ABSOLUTE     FREQUENCY  FREQUENCY
 CATEGORY LABEL           FREQUENCY    (PERCENT)  (PERCENT)

PHOTO COLOR
 248 (WET STAND)               1          0.1        0.2
 254 (VIGOROUS STAND)         11          1.5        2.2
 254 (LOW VEG)                 5          0.7        1.0
 255 (GEN'L FOREST)          157         21.7       31.1
 256 (GEN'L FOREST)          312         43.2       61.8
 257 (OLD GROWTH)             19          2.6        3.8
 Out of range                217         30.1     Missing
                          -------      -------    -------
Totals                       722        100.0      100.0

 Valid cases      505       Missing cases    217
```

# APPENDIX 3

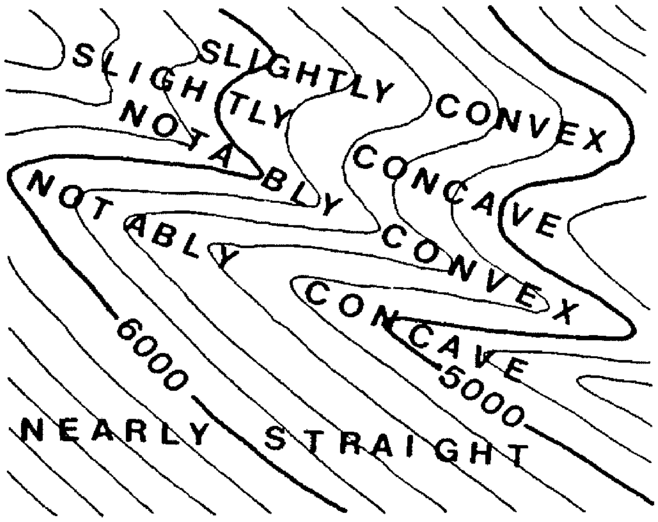
## STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS

| | FUNC 1 | FUNC 2 | FUNC 3 | FUNC 4 |
|---|---|---|---|---|
| Profile | 0.01346 | -0.17200 | 0.09595 | -0.10098 |
| Plan | -0.03903 | -0.50132 | -0.04268 | -0.12086 |
| Angle | 0.10379 | -0.25071 | -0.26422 | 0.44139 |
| Exposure | 0.07219 | -0.09220 | -0.33148 | -0.93225 |
| Elevation | -0.99923 | -0.01571 | -0.27921 | 0.15792 |
| WO | -0.01210 | 0.03306 | -0.76869 | 0.35530 |
| Position | -0.09264 | 0.46685 | -0.16772 | -0.09735 |

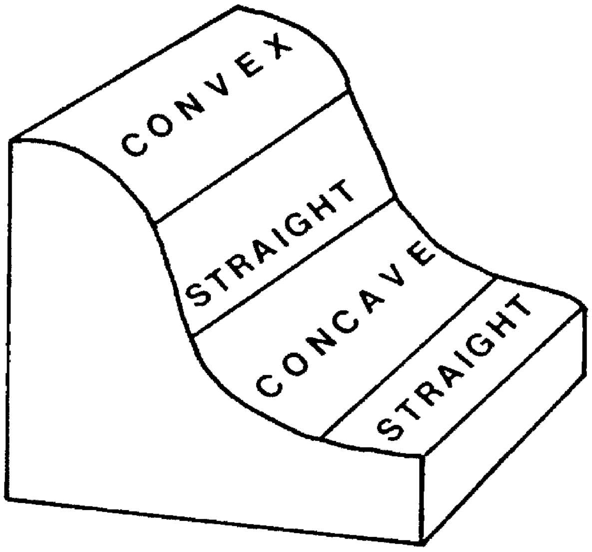
| | FUNC 5 | FUNC 6 | FUNC 7 |
|---|---|---|---|
| Profile | 0.49470 | -0.99837 | -0.06310 |
| Plan | -0.70986 | -0.41541 | -0.58775 |
| Angle | 0.52301 | 0.26014 | -0.74744 |
| Exposure | 0.21604 | 0.11099 | -0.12692 |
| Elevation | 0.09077 | -0.02994 | 0.05081 |
| WO | -0.11210 | -0.30314 | 0.71932 |
| Position | 0.01472 | -0.66014 | -1.09674 |

# APPENDIX 4

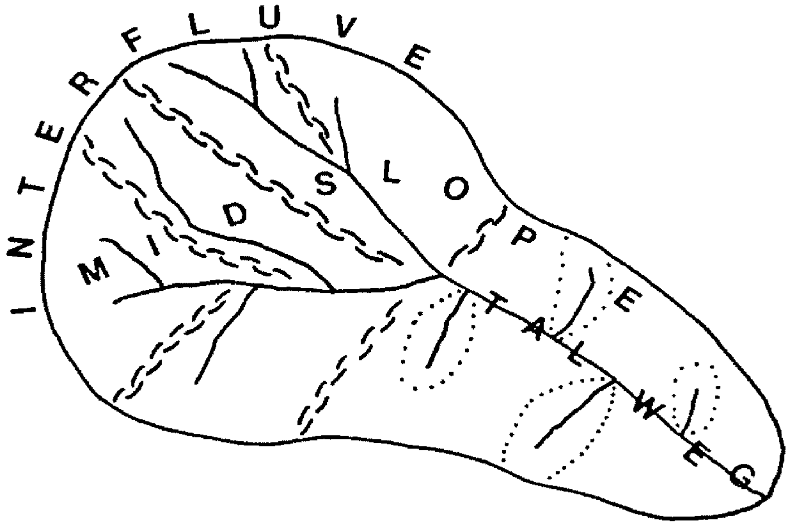
## ILLUSTRATIONS OF LAND FORM PARAMETERS



PLAN FORM CONFIGURATION

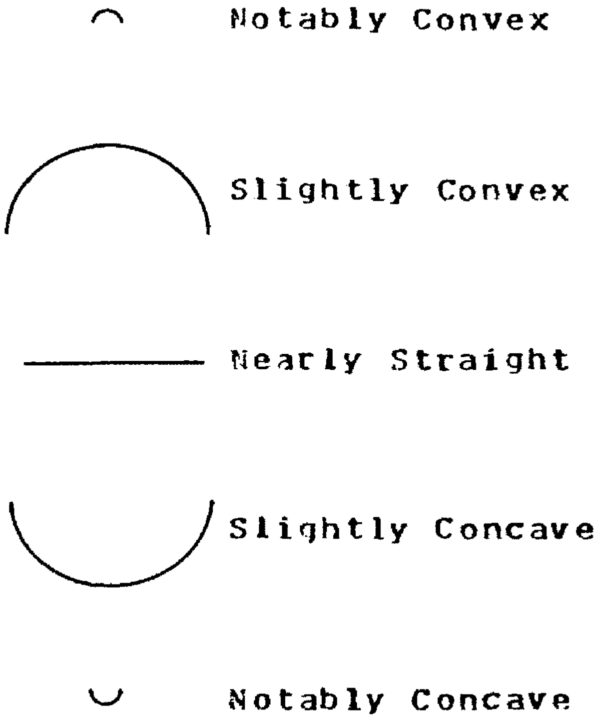


PROFILE FORM CONFIGURATION

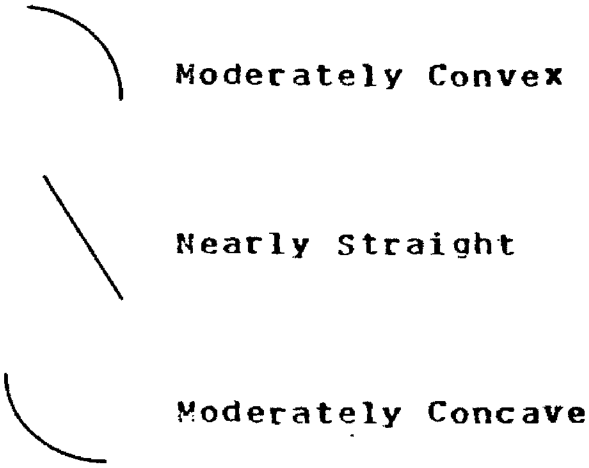


TOPOGRAPHIC POSITION

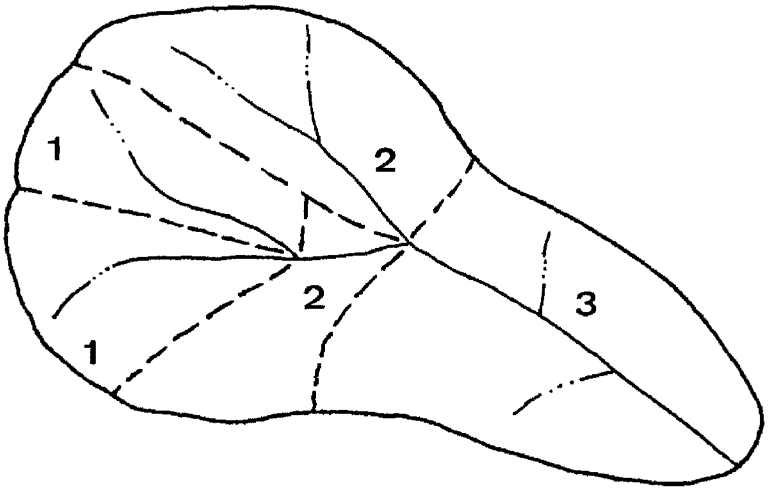
## APPENDIX 4-Continued



PLAN FORM CLASSES
(1:24,000 scale)



PROFILE FORM CLASSES
(1:24,000 scale)



WATERSHED ORDERS

# INDEX