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Mapping the undergrowth of forested elk habitat using Remote Sensing and Geographic Information Systems

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The University of Montana

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MAPPING THE UNDERGROWTH OF FORESTED ELK HABITAT
USING REMOTE SENSING
AND GEOGRAPHIC INFORMATION SYSTEMS

By

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B.S., University of Montana, Missoula, 1982

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Chairman, Board of Examiners

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Dean, Graduate School

August 11, 1993
Date
This project involved the application of new methods for mapping the vegetation of forested wildlife habitat. The study area was the Blackfoot-Clearwater Wildlife Management Area of western Montana. The Blackfoot-Clearwater is a winter range used by elk, mule deer, and white-tailed deer and is managed by the Montana Department of Fish, Wildlife, and Parks. The study area is located 70 km northeast of Missoula, Montana, near the confluence of the Clearwater and Blackfoot Rivers. Timber harvesting continues in the study area on land leased from private timber companies.

Wildlife managers need information on the effects of timber harvesting on habitat vegetation structure. Traditional forest inventory methods emphasize the timber overstory and ignore the undergrowth composition. Techniques were applied to the study area that were designed to extend the effectiveness of remotely sensed imagery to the mapping of forest undergrowth.

A vegetation inventory of 204 sample plots was conducted. The inventory data were used to model changes in undergrowth composition as a function of timber canopy coverage, elevation, slope, and aspect. The sample data were also used as ground truth for a classification of a Landsat Thematic Mapper satellite image. The classified image was imported as a layer into a GIS database.

The inventory data indicated that the vegetation of the study area is dominated by a few species. The overstory is primarily douglas fir. The undergrowth is dominated by snowberry, serviceberry, and pine grass. There is an inverse relationship between shrub abundance and timber canopy cover; the fewer trees the more shrubs. However, there was not enough variation in the vegetation between sample plots to predict changes in the presence of browse species as the timber canopy changes. In fact the vegetation of the area is fairly homogenous. In addition, the timber canopy cover is sparse overall.

The implications of the loss of timber cover are discussed. Recommendations are also made on the implementation of remote sensing and GIS in wildlife management.
ACKNOWLEDGEMENTS

This project has been a trial as well as a triumph for me. I have learned a great deal about myself as I have worked to complete this study. Yet, at times the work was like a mountain I could never climb or a river I could never run. Many colleagues and friends helped me get through those times. I want to thank them now for their help.

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INTRODUCTION

Wildlife managers often inventory the habitats of the animals they oversee. The composition and structure of plant communities affect their quality as wildlife habitat. Information about these plant communities is used in the development of management strategies for wildlife populations. Managers also need to know the current and potential condition of wildlife habitat to plan for events that may affect that habitat, such as wildfire or timber harvesting.

As our understanding of natural systems improves, the complexity of these systems becomes more apparent. Today, there is a growing trend toward an ecosystem approach to management (Brooks and Grant 1992). One of the challenges to adopting ecosystem management is the tremendous volume of information that it requires. Effective ecosystem management requires that we visualize many trends simultaneously over a broad area. This is a nearly impossible task for the human mind.

Advances in technology offer some hope that we may integrate ecosystem management into the management of the often conflicting demands on resources. Recently, computer technology has been developing at a rapid pace. Processing power has increased while the cost of equipment has fallen.
Software designed to handle complex spatial analyses of multiple variables has improved in power and ease of use. Earth observation systems have become more sophisticated and their data more affordable. These trends have created a feedback loop between the development and application of new systems. Managers have asked for more information and new ways to put it to use; developers have responded with new tools and new ways of visualizing our environment.

Geographic Information Systems (GIS) are an important part of this new technology. GISs are computer-based systems used for the collection, storage, and analysis of spatial information (Aronoff 1989). GIS is becoming a widely accepted tool in urban planning, facilities management, and resource management. However, GIS should be thought of as a technology in its adolescence. The effective application of GIS requires that large amounts of data be acquired and entered into the system. This demands organizational support and commitment to the long term development of GIS. This support must include the purchase of equipment and training for personnel. Also, the application of GIS to management problems is a maturing process. As we apply GIS to more problems, we find new ways to look at them.

Remote sensing (RS) is an important source of data for
GIS. Advances in sensor design and capability have resulted in the increased use of satellite RS systems in resource management applications. Satellite RS offers broad spatial, spectral, and temporal coverage. For example, the Landsat Thematic Mapper (TM) sensor has a 7 band configuration that measures a wide range of the electromagnetic spectrum useful in studying natural resources. In addition, the Landsat satellite's orbit allows nearly monthly views of any area on the Earth's surface.

My research has explored the application of RS and GIS to ecosystem management. Specifically, I studied the acquisition, processing, and analysis of spatial data to address a problem related to the management of forested elk (Cervus elaphus) habitat.

Literature Review

Winter is a critical season for wild ungulates. During winter, they must cope with the worst environmental conditions, while consuming the poorest quality food (Armleder et al. 1986). The animals must have access to habitats that provide cover as well as food. Trees and tall shrubs can provide cover. Grasses, forbs, shrubs, and trees can provide food.
Ungulates require cover for shelter from winter weather, reduction in snow pack, and protection from predators or human disturbance (Nyberg 1987). Animals will seek sites on their winter range that provide the mixture of cover and food they need to survive. The spatial distribution of favorable habitat patches is an important quality of a winter range. The condition of wintering animals will decline if they must travel over a large or unsuitable area to find both cover and food (Armleder, et al. 1986). In North America today, nearly all successful free-ranging elk herds are associated with forested lands (Allen 1972). As a result, forest management practices may have the greatest potential of any activity for influencing elk populations (Lyon and Ward 1982).

Research in western Montana has quantified the use of different forested habitat structure by ungulates in winter (Beall 1974; Berner et al. 1988; Burcham 1990; Hicks 1990). Other researchers have made recommendations on improving forested habitat structure to benefit wintering ungulates (Armleder, et al. 1986; Johnson 1991; Nyberg 1987). In addition, models have been developed that predict forested habitat structure of winter range (Laursen 1984; Moeur 1986). However, to apply this research, managers must inventory and assess the quality and current condition of winter ranges. RS and GIS are tools that managers of winter
range now have available to aid in the inventory and mapping of these lands.

Paper maps are static documents that use codes and symbols to display spatial information (Burrough 1986). Paper maps are usually made for a single purpose, and they are difficult to revise or update. One major benefit of GIS is its capacity to merge maps with databases (Pamap 1992). This capacity creates a dynamic linkage between spatial information and attributes that may describe or modify conditions of the area in question. This linkage makes possible the manipulation, analysis, display, and editing of spatial data (Congalton and Green 1992). However, a GIS is only as good as the data used to build it. GIS data cannot be mass produced. The data must be specific to the study area and relevant to the goals of the project. This demand for data has increased the use of RS.

RS offers the ability to acquire a snapshot of current vegetative conditions of an area. However, this application has had limited value in studies of forest undergrowth because on forested sites, satellite sensors primarily measure the reflectance of the forest canopy. Winter range managers need information about the forest understory and undergrowth as well as the overstory. Understory is trees regenerating and growing beneath a forest canopy;
undergrowth is the shrubs and herbs growing beneath a forest canopy. Understory and undergrowth can provide browse for wintering ungulates.

Stenback and Congalton (1990) offer a review of work that addressed the effects of understory vegetation on reflectance values in satellite imagery. They report that little research has been conducted dealing with this problem outside of agricultural studies. Research dealing with forest understory indicated that there was an influence on reflectance values by understory vegetation, but the effect had not been quantified. Stenback and Congalton (1990) went on to perform a study of the feasibility of detecting the presence or absence of vegetative undergrowth with RS data. They looked at sites having a range of forest canopy closures within the Sierran mixed conifer zone using TM data. They were able to distinguish between sites that had no undergrowth vegetation and sites with undergrowth vegetation with 55-69% accuracy. This result is not promising, but it points out that further study and development of different procedures are needed to apply RS to the mapping of undergrowth vegetation.
Problem Definition

The Blackfoot-Clearwater Wildlife Management Area (BCWMA) is an important winter range for elk, mule deer (Odocoileus hemionus), and white-tailed deer (O. virginianus). The Montana Department of Fish, Wildlife & Parks (MDFWP) has managed the area to benefit elk since 1948. In addition to deeded land, the BCWMA includes grazing leases on land owned by Champion International Corporation, Plum Creek Timber Company, and the Montana Department of State Lands. The grazing leases are used to provide forage for wildlife. Livestock do not graze on these units but timber harvesting continues on the leased lands at the landowners' discretion.

Timber harvesting can affect the quality of the winter range in several ways. Removal of the timber overstory may benefit ungulates by increasing shrub production (Laursen 1984). However, timber harvesting also reduces cover, a loss to wintering big game (Beall 1974; Nyberg 1987). Cutting units exist in a diversity of ages and intensity of removal on the BCWMA.
Research Objective

The BCWMA managers do not have an accurate or current map of the cutting units or forest cover types of the study area. As a result, it is difficult to predict the effects of timber harvesting on the big game population. The primary objective of this study was to develop and test new procedures to quantify changes in undergrowth vegetation in relation to changes in forest overstory composition.

This research objective was divided into the following four tasks:
1) develop a model describing the relationship between timber canopy cover and undergrowth vegetation,
2) classify a TM image of the study area to depict the vegetation cover types,
3) apply the vegetation model to the classified cover type map to produce a map of the distribution of timber cover types and undergrowth browse,
4) produce digital maps and linked databases that will aid the MDFWP in the management of the area.
BACKGROUND

Study Area

The BCWMA is located 70 km northeast of Missoula, Montana, near the confluence of the Clearwater and Blackfoot Rivers (Figure 1). The study area corresponds to Montana Hunting District 282, and covers nearly 11,000 ha.

Elevation in the study area ranges from 1150 m to 1725 m. Topography varies from gently rolling slopes at the lower elevations to steep terrain at the higher elevations. The vegetation types include rangeland, irrigated hay meadows, riparian areas, and forestland. My research focused on the forested areas.

Forest habitat types (Pfister et al. 1977) are predominantly in the Douglas fir (Pseudotsuga menziesii) climax series, but some of the higher elevation stands are in the sub-alpine fir (Abies lasiocarpa) series. Douglas fir and western larch (Larix occidentalis) are the most abundant trees, ponderosa pine (Pinus ponderosa) is common on the drier sites.
Figure 1. Location of the study area in western Montana.
Timber Harvesting History

The present forests are all second growth timber. Logging began in this area in the late 19th century when the construction of the transcontinental railroads created a demand and market for timber (Butcher 1967). The low elevation of the study area made the timber easily accessible. In the early years the timber was floated down the Blackfoot River to the sawmill at Bonner (where the Blackfoot River flows into the Clark Fork River). Later, a narrow gauge railway network was developed that linked the forests of the Blackfoot drainage with the mill. Timber harvesting has continued to be an important use of the area. An extensive road system has been constructed over the years to support the timber harvest. Cutting units and haul roads remain obvious features of the landscape in the study area. In recent years the study area has been logged extensively as many of the second growth stands have matured to merchantable size.

Fire History

Changes in the fire regime have affected the plant community. The forest habitat types of the study area are
in fire group six (Fischer and Bradley 1987); moist douglas fir habitat types. This group is characterized by a pre-settlement fire free interval of 15-40 years. Studies by Barrett and Arno (1982) have shown that ignitions by Native Americans decreased the fire free interval to 7-9 years in lower elevation forests in and near the major valleys of western Montana. This information indicates that the mean fire free interval for the study area would have ranged from 7-40 years before the 1930's.

Frequent fires would not have allowed dead fuels to accumulate and understory trees to develop. As a result, fires would tend to be of low intensity and result in stands with open understories.

The increase in fire suppression activity after 1930 resulted in much longer fire free intervals. In fact many forest stands in the area have not experienced fires in more than 60 years. The result has been a buildup of woody fuels and densely stocked understories (Gruell 1983). Longer fire free intervals are also responsible for shifting the timber type to douglas fir and sub-alpine fir from ponderosa pine, western larch, and lodgepole pine (*Pinus contorta*). Timber harvesting also has contributed to this shift in timber type.
In October 1991, a wildfire started along highway 83 at the southwest corner of the study area. This fire was driven by high winds and burned nearly 3000 ha of state and private land in about 24 hours. The fire started in rangeland and burned into forested areas at the southern end of the study area. The effects of this fire will not be directly addressed in this project because it occurred after the vegetation inventory was complete.

Grazing History

The rangeland communities of the Intermountain West evolved with little significant grazing pressure (Bedunah 1992). The vast herds of bison (*Bison bison*) found on the open plains did not occur in the mountain valleys of western Montana. Scattered herds of elk and deer probably had little impact on rangeland composition. The introduction of agriculture, accompanied by the plow, domestic livestock, exotic plants, and fire control drastically altered the ecological balance of these rangelands (Harris 1967). These changes altered the plant composition, introduced weed and pest species, and in some cases eliminated native plant communities.
A major portion of the study area was managed as a cattle and sheep ranch before 1948 by the Boyd family. The range was heavily grazed and in some areas hay crops were cut (Geis, et al. 1955). When the MDFWP acquired the property, all domestic livestock were removed. However, hay is still cut on three fields around the Boyd ranch headquarters. The lack of livestock grazing makes the study area a very unusual community in western Montana. The area may be the closest example of pre-settlement range condition existing today. However, the heavy use by wild ungulates, fire suppression, and weed infestations represent some of the changes civilization has brought to the area.

It is this relatively intact rangeland community that is primarily responsible for holding the large number of elk on the BCWMA. The adjacent forestland provides alternative forage for elk when snow conditions make the bunchgrasses unavailable (MDFWP 1989). This combination of plant communities provides the wintering elk with choices that enable them to adjust their behavior as winter conditions vary.
The Issue of Scale

When planning a GIS project, scale is an important consideration. The acquisition of digital spatial data is a major expense. It is important to consider what spatial data is needed, what is available, and at what scale.

The scale at which ecological processes are examined may affect the outcome of the investigation. Landscape ecologists have shown that ecologic processes are scale dependent. Landscapes are described in terms of their structure, function, and change (Forman and Godron 1986). Landscapes are by definition spatially heterogeneous. Therefore, the measurement of spatial pattern depends on the scale at which the measurements are made (Turner, 1989). A landscape may appear to be heterogeneous at one scale but homogeneous at another scale (Meentemeyer and Box, 1987). Also a dynamic landscape may exhibit a stable mosaic at one scale but not at another (Turner, 1989).

A scale must be selected for GIS projects that adequately displays the ecologic processes to be studied while keeping the costs of data acquisition manageable. For this project a scale of 1:24,000 was chosen. This scale is used by the MDFWP managers working in the area. At this scale changes in land cover type are readily observable
without overwhelming detail. Also, digital elevation data for the study area were available at this scale.

**METHODS**

**Vegetation Inventory**

I completed a vegetation inventory of the study area during the summer and fall of 1991. The forested portions of the study area were the focus of the inventory because information about their structure was lacking. Traditional forest mapping methods emphasize the timber overstory and ignore the understory and undergrowth. I selected a procedure for this project that would describe the variation in undergrowth plants in relation to timber canopy coverage.

I delineated stands that represented a range of timber coverage and aspect on color aerial photos. I sampled 34 stands with 6 plots of 8 m radius in each stand for a total of 204 plots (Figure 2). The sampling procedure was based on a method described by O'Brien and VanHooser (1983). An important feature of this method was the division of the
Figure 2. Map of the study area showing the sample plots and stands in Hunting District # 282.
plants into 4 life forms (trees, shrubs, forbs, and graminoids) and 3 height classes (< 0.4 m, 0.5-2 m, and > 2 m).

The position of browse plants in the canopy influences their availability to wintering ungulates. For this study, plants < 0.4 m tall were not considered available because they would tend to be covered by snow. Plants > 2 m tall would usually be out of the reach of the animals and so were not considered available either. Availability is independent of abundance because a species could be common but unavailable because of its lifeform or distribution.

I recorded the forest habitat type, % timber canopy coverage (± 10 %), % slope (± 5%), and aspect (± 5°) at each plot. The vegetation at each plot was described in four ways. First, a species list was compiled of all plants present with > 5% coverage. The canopy coverage class and height class of each species was tallied. An ocular estimate was used to tally % cover; height class was measured with the aid of a 2.1 m pacing stick. Second, the coverage class for each life form by height class was recorded. Third, a count was made of trees by species and DBH (diameter at breast height) class (< 2.5 cm, 2.6-7.5 cm, 7.6-12.5 cm, 12.6-23.0 cm, 23.1-35.5 cm, and > 35.6 cm). Fourth, a variable radius plot of the trees > 7.5 cm DBH was
established using either a 10 or 20 basal area factor (BAF). A BAF was selected for each stand based on the stand density in the aerial photos.

The variable radius plot is a standardized technique used to determine the amount of standing timber occupying a site. In this procedure, a tree is counted as an "in" tree depending on its DBH and its distance from the sampling location. In my inventory, the sample point was the center of each 8 m plot. The number of "in" trees per plot times the BAF gives a basal area of timber per plot in ft²/acre (Dilworth and Bell 1986), which was then converted to m²/ha.

Analysis of Inventory Data

I created a separate database file for each part of the inventory (species list, life form by height class, tree count, variable plot cruise, and site features) using the FoxPro database management system. I used a 386 class microcomputer to perform all automated analyses and mapping procedures.

I performed a discriminant function analysis of the variables using the statistical analysis package SYSTAT.
Database files can be imported directly into SYSTAT for analysis. The sample data were used to construct a model to predict the relationship between shrub undergrowth, timber overstory, and topography. The independent variables were aspect, slope, timber basal area, forest canopy cover, and elevation. The dependent variable was the abundance of browse species. Relative abundance of browse species was tallied in canopy cover classes: 0 = absent, 1 = present (≥ 0% cover), 2 = common (≥ 1% cover), 3 = well represented (≥ 5% cover), 4 = abundant (≥ 25% cover), and 5 = very abundant (≥ 50% cover). These cover classes were used as the predicted groups for the discriminant function analysis. The hypothesized model was: 

\[ y = f(x_1, x_2, x_3, x_4, x_5) \]

where: 
- \( y \) = browse canopy cover class
- \( x_1 \) = elevation
- \( x_2 \) = slope
- \( x_3 = (\text{slope} \times \text{sine(aspect)}) \)
- \( x_4 \) = timber basal area
- \( x_5 \) = timber canopy cover.

**Geographic Information System**

I created a map in metric units, in the Universal Transverse Mercator (UTM) projection and the 1927 North American Datum (NAD 27), using the Pamap GIS software.
package. A Digital Elevation Model (DEM) at 1:24000 was acquired from the U. S. Geological Survey (USGS) based on 7.5' quad maps. The DEM consisted of a series of points with x, y, z coordinates in a 30 m grid. The DEM was imported directly into Pamap GIS as a raster cover level.

In raster format, data are arrayed in cells (referred to as pixels) in a column and row structure. The location of objects or conditions are defined by the row and column position of the pixels. The value stored for each pixel indicates the type of object or condition that is found at that location (Aronoff 1989).

In Pamap GIS, raster data can be stored as either a surface or polygonal cover. The surface cover is the simpler form; the data are represented by x and y coordinates and a single z value. This z value may represent any attribute that varies spatially, such as elevation, slope, snow depth, or population density. The polygonal cover in Pamap GIS is linked to a database record that contains many attributes that relate to the polygons overlaying the pixels. These attributes might be land ownership, timber volume, land cover type, value/ha, animal home ranges, or any other variable that may be relevant. Information about the area, perimeter, and neighboring polygons is stored for each polygon on the cover.
Also, I digitized the vegetation sample plot locations and stand polygons boundaries into a Pamap GIS map file. This digitizing linked the sample data to the other data sets I developed for this project. I determined the elevation for each sample point by querying the DEM.

I also digitized the boundary of Hunting District #282 into the map. This boundary formed a planning ring and was used as the domain of the study area for spatial analysis. The planning ring is overlayed on the active polygonal cover. Reports can be generated on the area of the polygons and their attributes inside the ring (Pamap 1992).

**Image Processing**

I classified a Landsat TM (TM) image of the study area to display timber coverage classes. The TM data were a subset of the Missoula scene, sampled on 2 June 1991. TM imagery is a set of pixel reflectance values ranging from 0-255 for each of 7 bands covering a wide range of the electromagnetic spectrum. The pixel resolution is 30 m x 30 m of ground surface. I used bands 2, 3, 4, 5, and 7 in the classification. These bands measured wavelengths of radiant
energy associated with green plants (Table 1). This combination of bands was also the one found to be most effective in measuring undergrowth vegetation by Stenback and Congalton (1990). The software package VGA ERDAS was used to perform the image processing.

Table 1. Spectral Characteristics of the selected TM bands

<table>
<thead>
<tr>
<th>Band</th>
<th>Spectral Range (μm)</th>
<th>Spectral Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0.52 - 0.60</td>
<td>green</td>
</tr>
<tr>
<td>3</td>
<td>0.63 - 0.69</td>
<td>red</td>
</tr>
<tr>
<td>4</td>
<td>0.76 - 0.90</td>
<td>reflective infrared</td>
</tr>
<tr>
<td>5</td>
<td>1.55 - 1.74</td>
<td>mid-infrared</td>
</tr>
<tr>
<td>7</td>
<td>2.08 - 2.35</td>
<td>mid-infrared</td>
</tr>
</tbody>
</table>

VGA ERDAS used an iterative procedure to classify each pixel in the image. The ISODATA procedure repeatedly performed an entire classification and recalculated the associated descriptive statistics. In this procedure, pixels were examined one at a time by the ERDAS software. The spectral distances between each analyzed pixel and the means of previously defined clusters were calculated. Each
pixel either contributed to an existing cluster, or began a new cluster, based on the spectral distances (ERDAS 1991).

The output of this procedure was a signature file that I displayed over the unclassified image and compared with the vegetation inventory data. The clusters were then interactively identified and assigned to ground cover classes. The signatures of the identified clusters were then used to create a final land cover image. This classified image was imported as a surface cover into the PAMAP GIS map of the study area. I converted this surface cover into a polygonal cover so I could calculate the area of each cover type.
RESULTS

Vegetation Inventory

Eight tree species were present in the sample. They were douglas fir, western larch, ponderosa pine, lodgepole pine, sub-alpine fir, aspen (*Populus tremuloides*), engelmann spruce (*Picea engelmannii*), and cottonwood (*Populus trichocarpa*). Douglas fir was the most common tree (Figure 3). Douglas fir was present at nearly 3 times as many plots as western larch, the next most abundant tree species. Douglas fir was also the dominant tree species in all size classes. It was particularly abundant in the 0-2.5 cm DBH class (Figure 4).

Twenty-two shrub species (Appendix C) were present in the sample. Of these, five are considered important to elk as browse. They were serviceberry (*Amelanchier alnifolia*), mountain maple (*Acer glabrum*), willows (*Salix spp.*), snowbrush ceanothus (*Ceanothus velutinus*), and chokecherry (*Prunus virginiana*). Oregon grape (*Berberis repens*) is considered to be an important browse species for deer. Serviceberry was the most common browse species and the dominant available browse species (Figure 5). Plants were considered available if they occurred in height class 2 (0.5
Figure 3. The relative abundance of the 7 most common tree species.
Figure 4. Distribution of sample trees by species and diameter class.
Figure 5. The relative abundance and availability of 11 important shrub species.
m-2 m). Other shrub species abundant (> 25 % cover) in the sample included snowberry (*Symphoricarpos albus*), spirea (*Spirea betulifolia*), Wood's rose (*Rosa woodsii*), honeysuckle (*Lonicera utahensis*), and globe huckleberry (*Vaccinium globulare*).

Twenty-four species of forbs were present (Appendix C) in the sample. Of these, strawberry (*Fragaria virginiana*), meadowrue (*Thalictrum occidentale*), twinflower (*Linnaea borealis*), yarrow (*Achillea millefolium*), and spotted knapweed (*Centaurea maculosa*) were the most common (Figure 6). None of the other forb species were present at more than 40 plots.

Twelve species of graminoids were present in the sample (Appendix C). Pine grass (*Calamagrostis rubescens*) and elk sedge (*Carex geyeri*) were the most abundant (Figure 7).

Forest habitat types were represented by 28 types (Appendix D). The douglas fir climax series predominated. The five most abundant habitat types were: Pseudotsuga menziesii/Symphoricarpos albus-Calamagrostis rubescens (PSME/SYAL-CARU), PSME/Linnaea borealis-SYAL (PSME/LIBO-SYAL), PSME/Vaccinium caespitosum (PSME/VACA), PSME/LIBO-Vaccinium globulare (PSME/LIBO-VAGL), and PSME/SYAL-SYAL (Figure 8). Of the remaining 23 habitat types, none were
Figure 6. The relative abundance of the 10 most common forb species.
Figure 7. The relative abundance of the 10 most common graminoid species.
Figure 8. The relative abundance of the 8 most common forest habitat types.
sampled at more than 10 plots.

The inventory data indicate that the vegetation of the study area is dominated by a few species. The overstory is primarily douglas fir. The undergrowth is composed primarily of snowberry, serviceberry, and pine grass. These four species are the only ones that were well represented at more than 25% of the sample plots. This composition is consistent with the dominant habitat type of PSME/SYAL-CARU.

Data Analysis

The variable plot timber sample revealed that the mean timber basal area was significantly lower than those found for similar habitat types in undisturbed stands (Pfister et al. 1977). The mean timber basal area for all sample plots was 15.6 m²/ha (67.2 ft²/ac) and the maximum basal area was 51 m²/ha (220 ft²/ac) (Table 2). Pfister et al (1977) reported a mean timber basal area of 40 m²/ha (172 ft²/ac) for PSME/SYAL habitat types and 52 m²/h (226 ft²/ac) for PSME/LIBO habitat types. The study area sample plots in the PSME/SYAL habitat types had a mean timber basal area of 14 m²/ha (61 ft²/ac) and 16 m²/ha (70 ft²/ac) in the PSME/LIBO habitat types. The mean sample plot timber basal areas were
31-35% of the potential mean timber basal area for the habitat type.

### Table 2. Summary statistics of sample data (n = 204)

<table>
<thead>
<tr>
<th></th>
<th>BASAL AREA (m²/ha)</th>
<th>CANOPY COVER (%)</th>
<th>TREES / HA</th>
</tr>
</thead>
<tbody>
<tr>
<td>MINIMUM</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>MAXIMUM</td>
<td>51.10</td>
<td>80.00</td>
<td>32.00</td>
</tr>
<tr>
<td>MEAN</td>
<td>15.63</td>
<td>27.92</td>
<td>9.96</td>
</tr>
<tr>
<td>STANDARD DEV</td>
<td>12.01</td>
<td>19.32</td>
<td>7.15</td>
</tr>
</tbody>
</table>

Timber canopy cover was also low in the study area as would be expected with the low timber basal areas. Timber canopy cover and timber basal area were positively associated ($r = 0.665$, Table 3). The timber canopy cover of the sample plots ranged from 0-80% with a mean of 28%. The number of trees (> 12.5 cm DBH) / ha on the sample plots ranged from 0-32 with a mean of 10 (Table 2).
Table 3. PEARSON CORRELATION MATRIX (n = 204)

<table>
<thead>
<tr>
<th></th>
<th>SERVICE BERRY</th>
<th>BASAL AREA</th>
<th>CANOPY COVER</th>
<th>TREES / HA</th>
</tr>
</thead>
<tbody>
<tr>
<td>SERVICEBERRY</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BASAL AREA</td>
<td>-0.264</td>
<td>1.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CANOPY COVER</td>
<td>-0.275</td>
<td>0.665</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>TREES / HA</td>
<td>-0.224</td>
<td>0.817</td>
<td>0.652</td>
<td>1.000</td>
</tr>
</tbody>
</table>

There was a negative relationship between timber cover and shrub abundance (Table 3). As timber canopy cover and basal area decreased, the cover class of serviceberry increased (Figure 9).

I used a discriminant function analysis to quantify the relationship between the abundance of browse and changes in timber cover. This analysis revealed a relationship between changes in timber cover and the abundance of serviceberry, the most abundant browse species. However, the relationship was weak. When I tested models with combinations of the different independent variables, the F-statistics of the multivariate tests ranged from 2.42 to 3.62 (Table 4). These results were significant, but the low values of the F-statistics did not support proceeding with model construction.
Figure 9. The relationship between timber basal area, canopy cover, and the cover class of serviceberry.
The full model had the lowest F-statistics. The model: 

\[
\text{serviceberry cover class} = \text{constant} + \text{timber basal area} + \text{timber canopy cover},
\]

had the highest F-statistics. Lumping the predicted classes for serviceberry improved the F-statistics slightly. The lumped classes used were: 0 (0-5% cover), 1 (5-50% cover), and 2 (> 50% cover).

Serviceberry, the dominant shrub species, was well represented (> 5% cover) to abundant (> 25% cover) at nearly all the sample plots. The vegetation of the study area is fairly homogenous. Therefore, classifying the TM image to display forest overstory classes will adequately describe the distribution of the major undergrowth browse species, serviceberry.
Table 4. MULTIVARIATE TEST STATISTICS

<table>
<thead>
<tr>
<th>Model Description</th>
<th>Equation</th>
<th>WILKS' LAMBDA</th>
<th>F-STATISTIC</th>
<th>DF</th>
<th>PROB</th>
</tr>
</thead>
<tbody>
<tr>
<td>full model</td>
<td>$y = f(\text{ba}, \text{cc}, \text{el}, \text{sl}, \text{ss})$</td>
<td>0.784</td>
<td>2.472</td>
<td>20, 647</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F-STATISTIC</td>
<td>DF</td>
<td>PROB</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.418</td>
<td>20, 792</td>
<td>0.001</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>THETA = 0.140</td>
<td>S = 4, M = 0.0, N = 96.5</td>
<td>0.001</td>
<td></td>
</tr>
<tr>
<td>model 2: with basal area + canopy cover</td>
<td>$y = f(\text{ba}, \text{cc})$</td>
<td>0.886</td>
<td>3.091</td>
<td>8, 396</td>
<td>0.002</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F-STATISTIC</td>
<td>DF</td>
<td>PROB</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.054</td>
<td>8, 398</td>
<td>0.002</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>THETA = 0.100</td>
<td>S = 2, M = 0.5, N = 98.0</td>
<td>0.002</td>
<td></td>
</tr>
<tr>
<td>model 3: with basal area + canopy cover</td>
<td>$y_1 = (\text{ba}, \text{cc})$</td>
<td>0.931</td>
<td>3.624</td>
<td>4, 400</td>
<td>0.006</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F-STATISTIC</td>
<td>DF</td>
<td>PROB</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.587</td>
<td>4, 402</td>
<td>0.007</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>THETA = 0.066</td>
<td>S = 2, M = -0.5, N = 99.0</td>
<td>0.005</td>
<td></td>
</tr>
</tbody>
</table>

where: $y = \text{cover class of serviceberry}$
$y_1 = \text{lumped cover classes of serviceberry}$
$\text{ba} = \text{timber basal area}$
$\text{cc} = \text{timber canopy cover}$,
$\text{el} = \text{elevation}$
$\text{sl} = \text{slope}$
$\text{ss} = \text{slope} \times \text{sine(aspect)}$
I classified the TM image of the study area into 8 land cover types: closed timber, moderate timber, open timber, aspen/shrubs, moist meadows, rangeland, hay fields, and water. I used the sample plot data to stratify the timber cover types. The closed timber type consisted of those stands with timber basal areas > 10 m²/ha (> 43 ft²/ac): moderate timber, 7 - 10 m²/ha (30 - 43 ft²/ac): and open timber < 7 m²/ha (< 30 ft²/ac). The rangeland, aspen/shrubs, moist meadows, and hay fields types were identified by comparing the classification signatures to aerial photos.

The rangeland type is a mixture that could be further delineated with additional field work. This type includes sites that have been converted to grasslands by timber harvesting. It would be useful, in the future, to be able to distinguish these converted grasslands from native rangeland.

The open timber type covers the most land in the study area (Figure 10). This type also has the largest average polygon size (Figure 11). The average polygon size of a land type is one measure of fragmentation. The open timber type covers more land area with fewer polygons than any other type. Therefore it is the most continuous. The
Figure 10. Area of 7 land cover types.
Figure 11. Average polygon size of land cover types.
closed and moderate timber types, by contrast, have low
average polygon sizes. These types are more fragmented.

DISCUSSION

Deer, Elk, and Trees

The current research reveals the extent of the timber
harvesting in the study area. This harvesting has
fragmented the remaining forest cover into scattered
remnants. This fragmentation means that cover may be the
limiting factor on this winter range for deer and elk.

Hicks (1990) found that forest canopy closure
significantly affects snow interception. In his study area,
white-tailed deer use was negatively correlated with snow
depth except when snowpack was light (<13 cm). Hicks (1990)
considered snow interception cover to be stands with > 40%
canopy closure. Snow cover hinders animal movement,
increases their energy needs, and reduces forage
availability (Johnson, 1991). Forest canopy cover reduces
snow depth by intercepting snow fall and moderating
temperatures. Warmer winter temperatures under a forest
canopy promote snow melt and the reduction of snow pack.

Beall (1974) found that elk depend on timbered sites, when they are available, to respond to changes in thermal and solar radiation. A majority of elk bed sites on his study area in southwestern Montana were associated with dense timber clumps on the upper one third of a slope. Beall (1974) also found that elk in his study area had a tendency to bed near the largest tree available within the stand. These larger trees would create a more uniform thermal environment because of their greater surface area and mass.

On the BCWMA, elk benefit from having a choice of habitats available. The large, open bunchgrass communities provide ideal forage. When deep or crusted snow conditions make this forage unavailable, the elk move onto the adjacent timbered slopes. In addition, the timbered hills provide elk a potentially wide range of sites where they can find shelter from extreme weather.

On the BCWMA the average canopy closure for the sample plots was 28% with a standard deviation of 19%. Most of the timber stands are not acting as snow interception cover. The low canopy cover also is providing little thermal cover. In addition, the majority of the existing trees are in the
smaller size classes. These smaller trees are less desirable for elk bed sites. These factors reduce the quality of the winter range for elk and deer.

Hillis et al. (1991) have developed guidelines (the Hillis paradigm) for retaining elk security areas during hunting season in western Montana. They consider 100 ha to be the minimum size for elk security areas. These areas should be large, connected, vegetative communities > 0.8 km from open roads. In addition, they recommend that these security areas make up ≥ 30% of the analysis area.

Although hunter numbers on the BCWMA are controlled by permit, the Hillis paradigm offers managers a guideline for assessing the quality of elk habitat. The value of the Hillis paradigm in this discussion is that it quantifies the relationship between elk and their use of timber for cover. If a winter range meets the guideline for hunting season security cover, it would also provide much better thermal and snow interception cover.

The BCWMA falls far short of meeting this guideline for elk security during hunting season. There is only one unit of remaining forest cover that meets the size requirements. This unit is 248 ha in size but it makes up only 2.5% of the analysis area.
The current condition of the forest stands puts the function of the study area as an ungulate winter range at risk. There remain few areas that provide snow interception, thermal, and security cover for deer and elk. The wildfire during October of 1991 is a good example of an event that could eliminate a significant portion of the remaining forest cover. If the winds had been out of the south that day, the fire would have burned into the best of the remaining forest stands. As it happened, the fire burned 10% of the closed and moderate timber stands and 15% of the open timber stands (Figure 12).

Forest Habitat Management

An effort should be made to improve the amount of forest cover available on the BCWMA, although the divided ownership will make this a difficult task. The MDFWP owns a significant portion of the open forest type, but none of the closed forest type (Figure 13). The remaining lands in the closed forest type are owned by the Champion Timberlands Corporation and the Montana Department of State Lands (MDSL) (Figure 14). The MDFWP should continue their current efforts to exert greater influence over timber management on the BCWMA. Additional land exchanges, purchases, or
Figure 12. Area of land cover types affected by the October, 1991 wildfire.
Figure 13. Area of the open timber and rangeland cover types in the study area by ownership.
Figure 14. Area of the moderate and closed timber cover types in the study area by ownership.
easements would improve the prospects for maintaining forest cover in the area.

Not all timber harvesting is detrimental to wildlife. Indeed, timber management can be used to improve or maintain wildlife habitat. However, the current condition of the forest cover in the study area makes it advisable to defer timber harvesting until timber canopy cover has significantly increased.

Increases in timber cover will come from regeneration and growth in the open forest stands. The MDFWP is at an advantage in this regard because the agency currently owns a sizeable portion of these stands. The managers may want to consider further evaluating the effects of the lack of cover on the ungulate populations of the BCWMA. However, I believe that it would be desirable to set goals for thermal and snow interception cover based on current knowledge. One goal might be to attain at least 40% forest canopy closure on > 30% of the area. This would significantly increase thermal and snow interception cover. These increases are particularly needed in the stands that are adjacent to the bunchgrass areas heavily used by elk. Another goal could be to increase the average size class of the timber stands to provide more large trees for bed sites.
Once targets for forest cover and structure have been accepted, timber harvesting could resume if the harvest contributed toward meeting the desired conditions. Ample guidelines exist for designing timber harvest that benefits deer and elk habitat (Arno, et al. 1987; Berner, et al. 1988; Hicks 1990; Hillis, et al. 1991; Jonson 1991; Marcum, et al. 1984 ). Future timber management plans should strive to incorporate these guidelines.

GIS Implementation

Change is often difficult for people and organizations. New technology may improve the job we do, but the growing pains may cause problems. In order to successfully implement GIS, an organization must clearly understand how the new technology fits in with its goals and objectives. The mission and structure of an organization must influence the design of its GIS.

Almost all of the issues the MDFWP deals with have some spatial component. Resources (fish, wildlife, and parks) are distributed across the state. Resource users have a different distribution. MDFWP is charged with satisfying the users while maintaining the resources. Conflict is
often the result. GIS will certainly help the MDFWP do its job, but what will the MDFWP's GIS look like?

The MDFWP is a diverse organization. There are 8 regional offices and the headquarters. Personnel at the different offices have different goals and needs. There are state-wide functions and local functions. The MDFWP's GIS must be flexible to accommodate these different functions.

An appropriate GIS structure would have two levels. The first would provide each region with some GIS capability to meet local needs. The second level would be a centralized GIS capability to address state-wide planning and management.

In general, a GIS consists of hardware, software, data, and people. The hardware and software are the easiest components to acquire. Commercial vendors now offer a wide variety of software packages and computing platforms. The ideal configuration is often a mixture of these software packages and computing platforms.

The current trend toward the adoption of industry standards increasingly enables users to transfer files between software packages and computer operating systems. This makes it possible for an organization to chose those
systems that best meet their needs, without great concern for portability and compatibility. However, an important consideration must be that the system be accessible and useable by the organization.

The most limiting factors in GIS implementation are people and data. An investment in GIS will be wasted without an adequate staff trained in its use and operation (Congalton and Green 1992). GIS limitations are primarily personnel limitations (Oliff 1992). This fact must be acknowledged and dealt with early in the planning for GIS. There is currently a shortage of qualified GIS analysts in the job market. This shortage can be addressed partly by offering GIS training to some existing MDFWP personnel. However, the current staff will be unable to add many additional duties to their present workload. Another option is to form cooperative agreements with both the University of Montana and the Montana State University, where active GIS facilities exist.

For the long term, the MDFWP should plan to add staff who are trained and knowledgeable in both GIS and natural resource management. A good strategy would be to have a GIS analyst at each regional office and the headquarters. In addition, there should be a GIS coordinator to address the planning, unification, and design of the system. This
coordinator could be a post that rotated among the members of a GIS steering committee or the GIS analysts.

In the end, it is important to remember that most difficulties in GIS implementation are the result of institutional or political issues, not technical matters (Anderson 1992). Participation from all levels of the organization is critical in the GIS development process. The method for integrating GIS into an organization should include participation, vision creation, evaluation, change, and implementation (Anderson 1992).

CONCLUSION

Winter range must offer food and cover to be of value to ungulates. Forested winter ranges have the potential to provide a mixture of both food and cover. One measure of the quality of a winter range is how well it provides this mixture. RS and GIS give wildlife managers new ways to inventory and monitor the vegetative condition of winter ranges.

The application of RS to mapping forested wildlife habitat has been limited to measuring differences in the
forest canopy. One of the objectives in my research was to test the hypothesis that the utility of RS can be extended to measuring conditions under a forest canopy by quantifying the relationship between undergrowth and overstory vegetation.

The BCWMA may not have been the best area to develop and test my hypothesis. The vegetation is fairly homogenous, and the remaining forest cover is thin. It would be worthwhile to apply this procedure to other forested wildlife habitats to test the hypothesis under other conditions.

However, I believe that the procedure I have described will be useful to any one interested in mapping a management unit that ranges in size from 5,000 to 50,000 ha. The inventory process is rapid and informative. The classification process is straightforward and is easy to duplicate.

The procedures followed in this project have made it possible to assess and quantify the current condition of the vegetative communities on the BCWMA. In addition, a GIS database has been created that will enable the managers to monitor events and activities in the area and evaluate their impact on management objectives. They can now calculate the
area of land cover types owned by the different parties. They can overlay animal home ranges over the land cover types and topography to gain more knowledge of how the animals use the habitat. They will be able to use the GIS to respond to changes in timber cover or events such as wildfire.
REFERENCES CITED


A. GIS procedures

This section is intended to give the reader an overview of the GIS procedures used in this project. I hope the reader finds this outline useful in planning their own GIS projects. This material is presented only as a guide and is not a cookbook. You will have to consult the manuals and other users of your software to determine the exact procedures for your project. In the following outline, PAMAP commands (PAMAP 1992) are shown in capital letters and the PAMAP module in parenthesis, and ARC/INFO (ESRI 1990) commands are shown in brackets.

A) Software used in this project

1) PAMAP v3.0 - primary GIS
2) ERDAS v7.5 - image processing
3) PC ARC/INFO v3.4D - interchange files
4) Trimble Pathfinder - GPS data processing

B) Map file Management

1) use PAMAP VIEW screen to keep track of graphics, raster, and database levels

PAMAP uses a variety of nested side bar menus to give the user access to tools used for the display, input, editing, and querying of spatial information. One of these tools is the VIEW screens. VIEW provides the PAMAP user with a series of screens where the available vector, database, and raster levels can be named and organized. In addition, these levels may be grouped into 16 different views that may be quickly recalled to display different thematic information. This feature is particularly useful when a map is shared with other users. A new user can browse the VIEW screens and quickly obtain the location of the data of interest.

2) backup often

3) record projection and datum of input data and final maps
C) Data Input

1) data sources for this project

   a) USGS: 1:24000 DEMs

   b) Champion Timberlands: roads, ownership, and, public land survey in Intergraph (IGDS format) (see E below)

   c) NRIS: hydrology and forest boundary as ARC/INFO interchange files (see D below)

   d) Trimble GPS: fences and MDFWP permanent range plots as DXF files (see D, 6-9 below)

   e) Landsat TM: land cover classes (see Appendix B)

   f) digitizing from USGS 7.5’ quads

2) data conversion

   a) PAMAP file translators used: DXF, DLG, IGDS, USGS, ERDAS

   b) ancillary files needed: todos, lanedit, *.prj

   c) rubber sheeting of Champion data (see E below)

3) file transfer

   a) the USGS DEMs and Landsat TM data are supplied on 9-track 2400 ft tape reels. The VGA ERDAS Tapes Module offers the tools needed to transfer this data to files on a hard disk to be used in GIS or image processing.

   b) Once files are downloaded from the tape, they must be transferred to the computers where the maps and images can be displayed and analyzed. One way to do this is to use the program Fastback to back up the files onto many floppy diskettes. This can be a very cumbersome process, but is often the only option available.

   c) In 1992 a wide area network became available to this project. Computer networks facilitate the transfer
of files between locations and machines. This network improved file management and transfer for this project.

D) Translation of ARC/INFO files to PAMAP
ARC/INFO commands are shown in brackets <command>

1) import ARC/INFO interchange files into PC ARC/INFO <import>. If the source file comes from a UNIX environment and is going to a DOS environment, the format of the file must be changed. Rohn Wood of the School of Forestry has written an easy to use program named TODOS, that inserts the needed carriage returns.

2) build cover <build cover line> and <build cover>

3) change projection from Albers Equal Area to Universal Transverse Mercator (UTM), PAMAP expects UTM, <project cover input output file>. A projection file (usually *.prj, where * might denote the output projection) is needed. That is a text file, that gives the program the input and output projection. A projection file can be created in any text editor.

4) build new cover (same as 2)

5) export as DXF format <arcdxf dxffile incover # # decimals header>

6) import to PAMAP translator map, using DXF TO PAMAP (FILE TRANSLATORS)to create a translator map. DXF TO PAMAP always puts input on vector level # 1 of target map.

7) merge vector level # 1 of translator map to target map using neat lines for clipping, and give each new vector level a new line index.

8) delete the translator map, and use same the configuration for next DXF translation if any.

9) format the new levels and line indexes.
E) Rubber Sheet in PAMAP

RUBBER SHEETING (UTILITIES) is used to adjust the position of map elements in situations where a map's relative positions are incorrect. This was the case with the data that was supplied to me by Champion Timberlands. The internal structure of this data was accurate, but the data had not been related to a coordinate system. When the data was imported into PAMAP, the data structure remained accurate, but the features were not in the correct location.

RUBBER SHEETING allowed me to reposition these features to correspond with the reference coordinates. This transformation is controlled by user supplied control points in the map. These control points are defined in pairs, one to define the existing (old) location, the second to define the desired location (new). These control points are entered as text elements, where the strings have the same format:

Oi (O = old location, i = a number)
Ni (N = new location, i = a number).

Once the control points are entered, each element's coordinates will define the elements old and new geographic positions. The transformation is a least squares polynomial. The order of the polynomial is specified by the user as the order of fit. An order of 1 requires at least 4 control points; an order of 2, at least 7 points; an order of 3, at least 11 points, and so on.

F) Data Analysis (PAMAP steps)

1) topography
   a) in TOPOGRAPHER create DEM, slope, and aspect surface levels.
   b) in MAPPER query DEM surface level for elevations of sample plots.
   c) in TOPOGRAPHER create perspective views.

2) import classified land cover from VGA ERDAS to PAMAP
   a) use LANEDIT program to convert ERDAS GIS file from ERDAS version 7.4 to 7.3 (PAMAP version 3.0 expects ERDAS version 7.3). Lanedit is a Foxpro program written by Michael Sweet and available at the School of Forestry, GIS Lab.
b) in FILE TRANSLATORS use ERDAS TO PAMAP to create a surface raster level of land cover types

3) in ANALYZER convert surface raster level to a polygonal level.

4) create a planning ring

   a) in MAPPER - INPUT digitize or import planning ring boundary. In this project the planning ring was the boundary of hunting district # 282.

   b) in UTILITIES, DEFINE DATABASE SCHEMA to contain planning ring query report; database must have at least two additional fields, one indicates which polygons are within the planning ring, the other indicates the area of that polygon in the planning ring.

   c) with the polygonal level and database level of interest active, query the planning ring to generate a report.

   d) in UTILITIES, EXPORT DATABASE ATTRIBUTES, invoke external database management system, DO GISBASE, use database level file, query dbase file for sums of areas in planning ring and lists of polygons in planning ring.

5) in ANALYZER overlay ownership and land cover type polygonal levels.

6) create planning report of land cover types by ownership.
B. Digital Image Processing using VGA ERDAS

This section is intended to give the reader an overview of the digital image processing procedures I used in this project. This discussion should help in the planning of an image processing project by giving the reader an introduction to the subjects and materials needed. For more information, Jensen (1986) provides an excellent introduction into sensor characteristics and the benefits and limitations of the application of digital imagery to natural resource management.

The image processing techniques discussed here are specific to VGA ERDAS (ERDAS 1991) so as to classify Landsat Thematic Mapper (TM) imagery.

In the discussion below, VGA ERDAS commands are written in upper case followed by the VGA ERDAS module to which they belong in parentheses. In VGA ERDAS, unclassified image files have a .LAN extension, and classified files have a .GIS extension. It may be useful to think of .LAN files as inputs or data, and .GIS files as products. The goal of digital image processing is to classify data (.LAN files) into a format (.GIS files) that provides information about the area or problem being investigated. The necessary steps are as follows:

1) Subset the scene

Use SUBSET (Core) to capture a rectangular area of a .LAN file and reduce the number of bands. TM files are very large. Therefore, file management is an important consideration. Use only the portion of the image that is relevant to the project. In addition, it is important to have an understanding of the data that digital images contain before proceeding with any image processing. Some of the 7 bands of the TM imagery may be more useful than others. The nature of your project will determine which bands to select.

2) Georeference the scene

If available, query the digital map of the study area to find UTM coordinates of features visible in the imagery (in PAMAP, use: QUERY-LOCATION). Otherwise, the 7.5 ' quads can be used to determine ground coordinates.

   i) use GCP (Image Processing) to enter coordinates of ground control points into VGA ERDAS. In this procedure, a
feature, site, or group of pixels are selected on the display screen, and then the coordinates of that feature are entered at the keyboard. Accurate ground control points are essential to an accurate georectification. The rectified coordinates for all other points in the image are extrapolated from the coordinates of the ground control points. The ground control points should be located throughout the scene. The more dispersed the ground control points are, the more reliable the rectification. A transformation matrix is computed from the ground control points. The goal, in calculating the coefficients of the transformation matrix, is to derive the polynomial equations for which there is the least possible amount of error when they are used to transform the source coordinates of the ground control points into the reference coordinates. The degree of complexity of the polynomial is expressed as the order of the polynomial. The order is simply the highest exponent used in the polynomial. A 1st-order transformation is a linear transformation. Transformations of the 2nd-order or higher are nonlinear transformations. Higher orders of transformation can be used to correct more complicated types of distortion. However, to use a higher order of transformation, more ground control points are required. The minimum number of points required to perform a transformation of order $t$ is $(t + 1)(t + 2)/2$. You should use more than the minimum number of ground control points whenever possible. When you use the minimum number, a perfect fit is always possible, even if one or more of the ground control points are in error.

In most cases, a perfect fit for all ground control points would require an unnecessarily high-order transformation. Instead of increasing the order, you have the option to tolerate a certain amount of error. VGA ERDAS, expresses this error as a RMS value. RMS error is the average distance between the input locations of points and the transformed locations for the same points. RMS error is expressed as a distance in pixel widths. For example, an RMS error of 2 means that the reference pixel is 2 pixels away from the transformed pixel, which is acceptable for most applications.

ii) Use COORDN (Image Processing) to create a transformation matrix of 1st- through 10th-order.

iii) Use LRECTIFY (Image Processing) to perform a linear transformation or NRECTIFY (Image Processing) to perform a nonlinear transformation of a LAN or GIS file. The output of this process is a new file that has been rectified to the ground coordinate system.

At this time it is important to mention the need for
developing a naming convention for your files. Image processing in VGA ERDAS results in a series of new files that have been altered, transformed, or analyzed in some fashion. A naming convention is a very useful technique for keeping track of these new files. If, for example, your original subset .LAN file was called black.lan, your georectified file could be called blackg.lan. A short root name is a good idea, so that one letter could be added to the new file name with each step.

3) Image Classification

Use ISODATA (Image Processing) to perform an iterative statistical clustering of the input image. This clustering method uses the minimum spectral distance formula to create clusters of pixels with similar spectral means. ISODATA prompts the user to select a convergence threshold, a maximum number of iterations, and the number of clusters to identify. The convergence threshold is the maximum percentage of pixels whose cluster assignments remain unchanged between iterations, 95% is a recommended value. This threshold prevents the program from running indefinitely. The program also will stop once it reaches the maximum number of iterations specified, 24 is a recommended value. The number of specified clusters directs the routine to create that number of unique classes of data. A number of clusters between 45 and 90 is recommended. A large number of clusters ensures that the data will be adequately stratified. Once the signatures of the clusters are identified, they can be lumped into meaningful classes. If the clusters contain pixels of two different classes (i.e. water and timber), the ISODATA program will have to be repeated on those clusters to separate these classes.

The output of ISODATA is a signature file (*.sbd), a name file (*.nam), and a GIS file (*.gis) with the preliminary clusters. In this GIS file, the data values correspond to the cluster number that contains that pixel. These clusters are a unique distribution of reflectance values and represent the signatures of an unsupervised classification of the image.

4) Signature Manipulation

Use SIGMAN (Image Processing) to view statistics and histograms of the clusters created from the input file in step 3. It is useful to print a copy of these statistics to reference during cluster identification. The statistics report includes the minimum, maximum, mean and standard deviation of reflectance values in each band, the covariance
matrix of the pixels in the cluster, and the number of pixels in the cluster.

5) Cluster Identification

Use CLASOVR (Core) to display the GIS file output by ISODATA over the source LAN file. CLASOVR allows the user to display all the pixels of one cluster at one time. This enables the user to compare the statistics for each cluster with any ground truth information available, and identify the corresponding ground cover class. It is useful, as a first look at the classification, to toggle through all the signatures, and observe how the clusters are grouped and migrate through the scene. The first clusters created have the lowest mean data values. The mean data values of the clusters increase as subsequent clusters are created. The process of grouping clusters into land cover types is interactive. The user should plan to view all the clusters many times in order to become more familiar with the signatures, and fine tune cluster assignments.

It is very likely that a few clusters will contain pixels that belong in very different classes. For example, bodies of water and timber stands on north slopes both tend to have very low reflectance values. In most cases, the first few clusters will contain pixels from both of these types. It is necessary to separate these clusters more finely in order to accurately classify the scene.

6) Cluster Separation

Use MASK (Core) to pull out specific clusters (signatures) from the GIS file created in step # 3. The data values of that GIS file now correspond to the cluster numbers created in ISODATA. For example, if you were to query various pixels in that GIS file, the data values would range from 1 to n, where n = the number of clusters specified in ISODATA. In order to separate clusters in that file, a new LAN file must be created that contains only those clusters. Remember to pay attention to your file naming convention. Once these clusters are split into meaningful classes, they will be recombined into the final .GIS file for the project.

MASK uses a .GIS file to select (mask) specific areas from a corresponding .LAN file and use those areas to create one or more new .LAN files. The areas to mask are selected by class value. For example, you may need to separate clusters 1 - 3 from your ISODATA created .GIS file because
they contained both water and forest pixels. In MASK, class values 1 - 3 would be assigned a recode value of 1. The .LAN file output by MASK would contain only those areas having a recode value of 1. Any areas assigned a recode value of 0 will not be included in the output. It is possible to create several output .LAN files with MASK, so that if there were more than one group of clusters to bust you need only run MASK once. This would be accomplished by assigning these other groups different recode values.

Once the new .LAN files are created, run ISODATA on them following step # 3. In this case, you may create a lower number of clusters, 12 - 24 is usually adequate.

7) Create Classes

Use MAXCLAS (Image Processing) to create classes from the LAN file based upon the signatures created in ISODATA.

8) Smoothing

Use SCAN (Raster GIS) to filter and smooth the classified file. This is useful to remove the salt and pepper appearance from the file. Filtering gives a more realistic transition between classes and creates a more uniform look. VGA ERDAS allows the user to chose circular, rectangular, and doughnut-shaped scanning and filtering windows. In addition, the size of the scanning window can be controlled as well as the type of filter to be performed.

9) Recombine Files

Use OVERLAY (Core) to recombine classes. OVERLAY creates a composite output GIS file by combining two to four input GIS files based on the minimum or maximum values of the input files. This procedure is necessary to recombine classes from the cluster separation files. Input class values are recoded and combined into one output GIS file.

10- Import Classified File into PAMAP

Use PAMAP File Translator: ERDAS to PAMAP to import the classified file into PAMAP. The import procedure is outlined in Appendix A, part 5 - B of this thesis. The classified file becomes a surface level and is now available for analysis with the other levels in your map.
C. Vegetation Species List.

FORBS

Achillea millefolium
Actaea rubra
Antennaria racemosa
Arnica cordifolia
Arnica latifolia
Aster conspicuus
Astragalus spp.
Balsamorhiza sagitta
Centauraea maculosa
Cirsium undulatum
Cirsium arvense
Clematis pseudoalpina
Epilobium angustifolium
Equisetum arvense
Fragaria virginiana
Galium boreale
Geranium viscosissimum
Linnaea borealis
Lupinus spp.
Senecio triangularis
Smilacina streptopoides
Thalictrum occidentale
Verbascum thapsus
Xerophyllum tenax

SHRUBS

Acer glabrum
Alnus sinuata
Amelanchier alnifolia
Arctostaphylos uva-ursi
Berberis repens
Ceanothus velutinus
Cornus stolonifera
Crataegus douglasii
Lonicera utahensis
Menziesia ferruginea
Physocarpus malvaceus
Prunus virginiana
Ribes montigenum
Rosa woodsii
Rubus parviflorus
Salix spp.
Shepherdia canadensis
Sorbus sitchensis
Spiraea betulifolia
Symphoricarpos albus
Vaccinium caespitosum
Vaccinium globulare

GRAMINOIDS

Agropyron spicatum
Bromus inermis
Bromus tectorum
Calamagrostis canadensis
Calamagrostis rubescens
Carex geyeri
Elymus canadensis
Festuca idahoensis
Festuca scabrella
Koeleria cristata
Phleum pratense
Poa pratense

TREES

Abies lasiocarpa
Larix occidentalis
Picea engelmannii
Pinus contorta
Pinus ponderosa
Populus tremuloides
Populus trichocarpa
Pseudotsuga menziesii
### Sample Plot Habitat Types

<table>
<thead>
<tr>
<th>Habitat Type</th>
<th># of sample plots</th>
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<tbody>
<tr>
<td>Pinus Ponderosa/Symphoricarpos albus</td>
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<tr>
<td>-Symphoricarpos albus phase</td>
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<tr>
<td>-Berberis repens phase</td>
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<td>Picea/Smilacina stellata</td>
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### Habitat Type

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<tr>
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<tr>
<td>Abies lasiocarpa/Alnus sinuata</td>
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**Totals:** 28 habitat types and phases 204 plots
E. Sample Plot Inventory Field Form.

Date: _____ Stand: _____ Plot: _____ Elevation: _____
Slope %: _____ Aspect: _____ Habitat type: _____ Canopy cover: _____

<table>
<thead>
<tr>
<th>Part 1 - Species List by Cover Class and Layer</th>
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<tr>
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<td>Forbs</td>
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Crown canopy class cover codes:

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<td>76-95</td>
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F. Color Plates.

1- Classified Landsat Image showing 8 land cover types

2- Perspective view of the study area with land cover types

3- Landownership for the study area

4- Perspective view with landownership

5- Perspective view with land cover types showing the extent of the October, 1991 wildfire
F1. Classified Landsat Image showing 8 land cover types for the study area. North is along the left margin.
F2. Perspective view of the study area with land cover types.
F3. Landownership for the study area. North is along the left margin.
F4. Perspective view with landownership.
F5. Perspective view with land cover types showing the extent of the October, 1991 wildfire.