Appendix 3C

Examples of Existing Vegetation Mapping Protocols Used to Produce Mid-level Geodatasets

1. **Programmatic overview of the Pacific Southwest Region process.**

2. **Project documentation for the Northern Region Vegetation Mapping Project (R1-VMP).**

Pacific Southwest Region Process

3. CHAPTER 200 - VEGETATION MAPPING

CONTENTS

200 - VEGETATION CLASSIFICATION AND MAPPING

In forestry, the need often arises to map and inventory vegetation, as an assessment of its condition. Conventional methods use manual interpretation of stereoscopic aerial photography to delineate areas of homogeneous vegetation (usually termed stands) using analysis of image tone, texture, and topography. With the availability of computers and satellite imagery, automated procedures have been developed to capture the same attributes for delineating stands.

210 - CONVENTIONAL VERSUS AUTOMATED METHOD

The conventional methodology used to produce vegetation maps begins with the delineation and mapping of forest stands. Natural resource professionals skilled in air photointerpretation techniques use conventional resource photography, typically normal color, 9" x 9" positive prints at a scale of 1:15,840 or 1:24,000, to delineate forest stands by drawing boundaries around homogeneous areas of uniform vegetation. Typically, a minimum size of five acres will be required for delineation. Concurrent with the delineation process, the stand boundaries are transferred manually from the air photos to 7-1/2 minute topographic quadrangles, and labels are affixed to each stand indicating the species composition, height, crown density, and other features of interest for forest management purposes. The stand maps which are thus produced are a basic information resource, widely used at the National Forest and Ranger District levels. Because this process is based on manual photointerpretation, it can be time consuming and costly, as well as inconsistent from analyst to analyst.

The boundaries on the stand maps are then scanned photomechanically and inputted into an automated, computerized data base system which is manipulated through the Geographic Information System, GIS software. Once scanned and edited, the polygons are displayed by map section with a GIS system and stand labels are assigned to the polygons. Unfortunately, the labeling process is, at the present time, relatively costly and labor intensive.

An automated method of mapping forest vegetation has been developed over the last 15 years using image processing and GIS technology. It was designed to overcome the problems of conventional methods, by using computer processing techniques to extract and process tonal, textural, and terrain information. Major sources of informational data input consist of registered Landsat imagery, digital terrain data, and ground based information used in map classification, stand delineations, canopy, size class, and ecological modeling.

Comparison of samples from forest strata identified by the automated method, with strata identified by conventional procedures, showed that both have about the same potential to reduce the variance of timber volume estimates over simple random sampling.

The automated method bypasses manual photointerpretation by using classification of Landsat and registered digital terrain data. Labeling of the automatically defined classes is still required; however, this labeling can be done much more rapidly and efficiently than in the conventional procedure. Furthermore, by utilizing image processing software systems, the classified images, which are the analog of stand maps, can be directly interfaced through software to the polygon-format files into GIS data bases.

220 - AUTOMATED CLASSIFICATION OF FOREST VEGETATION

In mapping existing vegetation for large area inventories, habitat analysis, fire fuels modeling, and other vegetation based information needs, four key attributes characterize each forest stand or region: life form, species types (CalVeg), and for forest types, average visible tree crown size, and canopy closure. Each of these attributes is characterized independently and in a hierarchical fashion. A hierarchical approach that first classes the most general landscape features (life form) results in a foundation onto which more detailed floristic and structural information can be added. Mapping each of these attributes independently minimizes the confusion between attributes that have only slight image tone and texture differences. Additionally, mapping vegetation attributes separately allows for the most appropriate classification technique to be applied. For example, unsupervised classification has been shown to be effective for mapping life forms and tree crown size but relatively poor as a singular technique for vegetation type.

The basis of mapping existing vegetation with remote sensing techniques is to use the same three characteristics of tone, texture, and terrain that the photo interpreter uses in delineating forest stands or region boundaries, as well as life form classification. Landsat imagery reflectance vectors provide tonal information for brightness and greenness, and Digital Elevation Model (DEM) 1:24,000 or Defense Mapping Agency (DMA) 1:250,000 digital terrain data provide the required terrain information. Texture data are derived from Landsat imagery. The computer processing is carried out using ERDAS Imagine, Image Processing Workbench (IPW) or similar image processing systems, in combination with ARC-INFO or other geographic information systems that support raster based layers. Integration of existing GIS layers of water bodies from Cartographic Feature Files (CFFs) and mapped areas of plantations and non-stocked forest land on wildfire areas are used to make the final vegetation maps more accurate.

In a departure from the traditional method of stand delineation, an automated, systematic method of generating spatial, unattributed stands or regions is used. Stand delineations are independent of map attribute classification so as to avoid reducing spatial accuracy by incorporating error inherent in thematic classifications. Through the application of image segmentation algorithms, consistent delineations of landscape features and growth forms are created based on user defined spectral and spatial parameters (See Figure 1.1). This process allows for stand delineations more quickly and efficiently than traditional photo interpretation techniques. Image derived stands are subsequently combined with vegetation attribute maps through GIS software to produce a stand-based, multi-attribute vegetation database (See Figures 1.2,1.3).

Life form mapping is performed using unsupervised classification techniques. Tree size class is also mapped using this technique, or in combination with supervised classification. In either case, a large number of ground observations of stands with different average tree sizes is necessary to produce reliable maps for this attribute.

Typically, in an automated, hierarchical vegetation mapping process, vegetation species is the next level of map information produced following life form classification. Because forest composition varies systematically with terrain, species type can be modeled using terrain data and ancillary GIS data. To quantify the relationship between elevation, slope, aspect, and CalVeg type, field data is required. The simplest method of quantification involves systematically observing each CalVeg type at all aspects, slopes and elevations, and plotting this on a graph. If ecological relationships vary across a Forest, geographical areas or Natural Regions, this needs to be identified and unique mapping rules developed for each Region.

The structural attributes of overstory tree size and tree canopy closure are most typically mapped following the development of life form and vegetation type information. This allows for pre-stratification of tree types into groups with unique and similar physiological characteristics. The intent is to minimize confusion in mapping structural attributes across physically variable populations.

230 - MODELING ECOLOGICAL RELATIONSHIPS

Observations in western coniferous forest areas have shown that forest composition varies systematically with topography in many places. The distribution patterns of coniferous species have long been associated with particular elevation ranges; species are often referred to as "low elevation" or "high elevation" species. Red fir, for example, is usually considered a high elevation species. Compass aspect (direction which a slope faces) has also been recognized as influencing tree growth and species distribution. North to northeast exposures are typically more favorable for tree growth than drier southwestern exposures (in the northern hemisphere). As a result, species that exhibit elevational zonation tend to occur at lower elevations on northeast-facing slopes. These terrain relationships represent climatic influences, in particular moisture and temperature, that control species distributions. Satellite remote sensing is used for mapping the life forms of conifer, hardwood, shrub, meadows, barren, grass and water. However, remote sensing is not particularly strong in differentiating species or groups of species that are similar, since the variation in spectral signatures can be large. Therefore, the terrain variables of elevation, slope and aspect have proven useful in modeling species associations (Macomber et al. 1991).

Natural Regions
Because a large National Forest may exhibit extensive climatic, geologic, and ecological diversity, plant species-habitat relationships and spectral signatures (light reflectance) which characterize particular vegetation types, are not likely to be the same in all portions. Therefore, the project area is divided into Natural Regions in which ecological relationships remain fairly constant and signature extension should be valid within a particular Natural Region. This not only facilitates the accuracy of ecological type modeling within Natural Regions, but also serves as "processing areas" to simplify image processing work areas.

Natural Regions are defined as areas within which the elevation-aspect ranges of the various major vegetation types remain constant. Traditionally, Natural Regions have been designated primarily on the basis of ground reconnaissance, interviews with resource professionals familiar with a particular area, and relevant background material (i.e. geology maps, isohyetal maps, published documentation). With the implementation of the National Hierarchical Framework of Ecological Units (ECOMAP), Section and Subsection divisions of the ECOMAP are now used to determine appropriate natural regions.

Digital Terrain Processing
USGS Digital Elevation Models (DEM) are used to derive classes for elevation and slope/aspect as input to the modeling process with Image Processing software. DEM images are first mosaiced to cover the area of the Landsat TM image, then registered to the Landsat scene and resampled to match the TM image.

Elevation and slope/aspect images are then converted to ARC/INFO grids. Slope is divided into 4 classes and aspect into 3 classes. Refer to Figure 2.1 by clicking on the button below. The resultant combination classes represent incremental levels of solar insolation with class 1 being the coolest and moistest and class 10 the hottest and driest. Slope and aspect also influence parameters such as soil development, which exerts environmental influences on plant species composition. Where significant correlations of species composition to soil type are observed, digital soil layers may also be utilized as a model input.

Building an Ecological Terrain Model
Field training site data is collected to form the basis for the ecological terrain modeling. Observations are made throughout the project area, within each natural region, to sample the range of elevation/slope/aspect combinations. Quad maps and aerial photography are used to collect the data. Observations are recorded for the occurrence of each major vegetation type at different locations to determine the extent of a type within a natural region. Slope angle, elevation and aspect are recorded for conifer, hardwood and shrub types that occur within a natural region.

Particular attention is paid to the elevation/slope/aspect combinations where vegetation changes. For example, a Mixed Conifer - Fir forest type can occur within an elevational band of up to 7000 feet in a particular natural region. On north aspects above 7000 feet, Red Fir becomes the major type. However, Red Fir may not occur on south aspects until an elevation of 8000 feet and may not occur at all on south aspects with greater than 60% slope. In addition to recording the elevation/slope/aspect combinations of different vegetation types, field notes are also collected with more detail on species composition throughout a project area. This facilitates the development of descriptions for vegetation types within a project area, as well as provide additional data needed for crosswalking between classification systems. These notes are also used to address anomolous error remaining in the map following model application.

After field data collection, the data is transferred to a matrix graph which assigns a type to a combination of elevation and slope/aspect class (Figure 2.2). Figure 2.1 illustrates how slope is divided into 4 classes and aspect into 3 classes. These ten classes represent increasing levels of solar insolation with class 1 being the coolest and moistest and class 10 the hottest and driest. In addition to field data, any ancillary data such as old vegetation maps, ecological classification data, silvicultural stand exam data, etc., that exists will be utilized to make decisions about what types occur across a natural region and where vegetation types change within a matrix graph. Each natural region will have three matrix graphs completed, one each for conifers, hardwoods and shrubs. Obviously, there is some generalization about the compositions of each type and the actual "boxes" where change takes place; however, this method can improve the results for mapping vegetation types across large land areas, than with using spectral signatures alone.

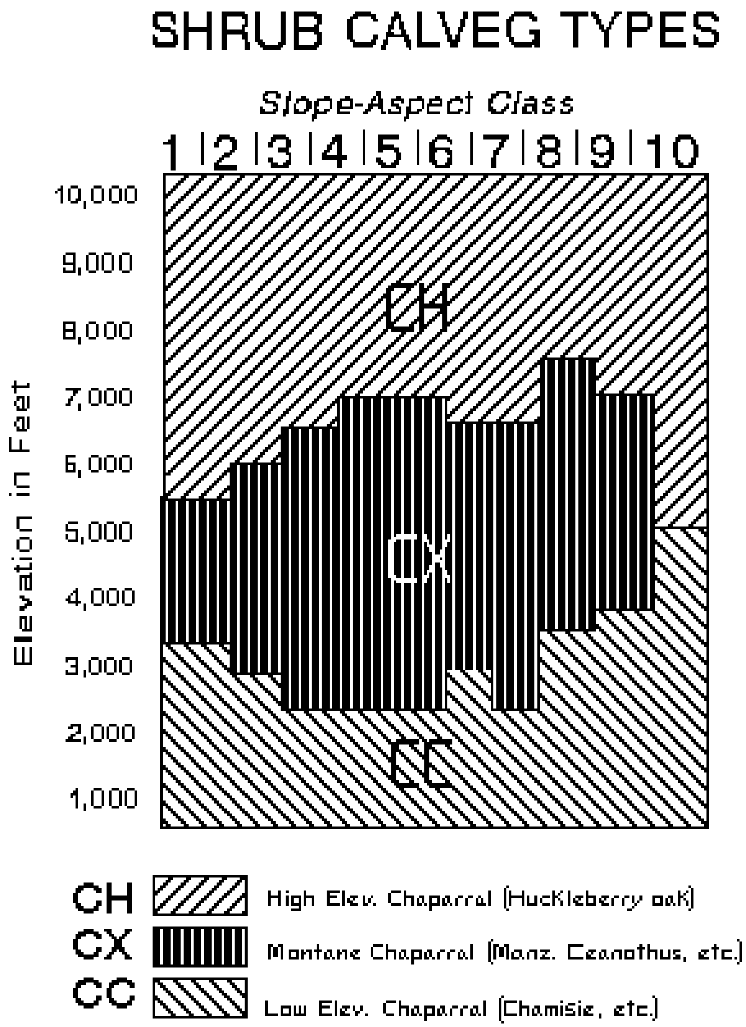

Figure 2.2

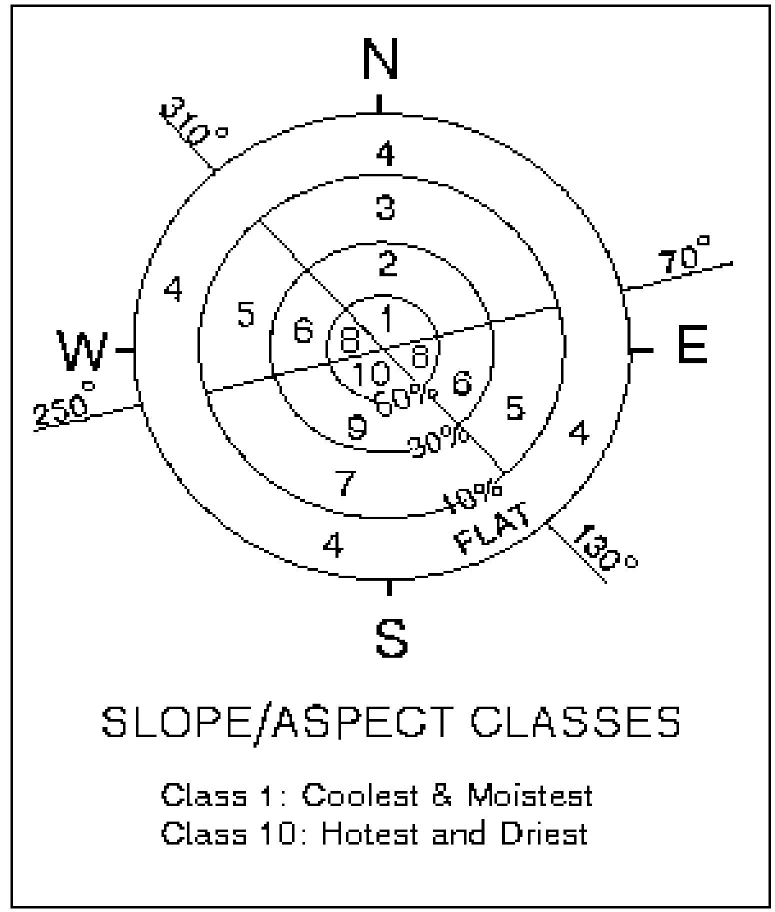

Figure 2.1

Life Form Classification.
Prior to modeling ecological relationships for vegetation type, the Landsat image is classified into several life forms: conifer, hardwoods, mixed, shrub, wet herbaceous, dry herbaceous, barren, water, snow, agricultural and urban. Other more specific vegetation types that have unique spectral properties may be mapped at this time as well.

Cloud areas are also distinguished in this step and are subsequently classified into one of the above life forms, utilizing various techniques. Plantations are added as a separate layer, to distinguish productive forest land from shrub, meadow, grass or barren classes. Water bodies are also added from Cartiographic Feature Files, where available, in order to maintain spatial consistency in lakes.

Image classification produces a "pixel-based" land cover map utilizing an unsupervised classification technique. This technique produces spectral cluster classes known as a "per pixel classification". A large number of classes are produced, which are then processed by an analyst into simpler, smaller sets and labeled with the appropriate life form.

Image classification occurs with individual pixels, not stands. Therefore, an additional step utilizes an image segmentation procedure which delineates stand boundaries, based on spectral similarities. When combined with the per pixel classification, a "stand based" land cover map is produced. This map is then passed through a decision rule process, which utilizes analyst specified decision rules to label the stands or polygons, based on the per pixel classification. Although life forms classification is based on spectral differences, decision rules are utilized to determine conifer, hardwood and shrub polygons from each other. The decision rules are determined by the classification system and further influenced by the analyst who compensates for class variation within a specific classification product. The decision rules are to label a polygon as conifer if 10% of the tree canopy cover is conifer. If there is at least 10% conifer cover then a polygon is labeled as conifer. If there is less than 10% conifer canopy cover, but at least 10% hardwood cover, the polygon is labeled as hardwood. If less than 10% tree cover exists, and there is at least 10% cover of shrubs, the polygon is labeled as shrub. Otherwise it will be labeled as one of the other categories based on plurality. Editing is then carried out on these stands or polygons to resolve any ambiguous results for life form. This stand life form map is then used as input to the ecological terrain model.

In subsequent processes, stand polygon boundaries are drawn between non-conifer areas, and between conifer areas which are at least one size class and or density class apart. The minimum mapping unit is 5 acres for contrasting types, and 10 acres for non-contrasting types, where size or density of the inclusion area is only one class different than the surrounding area.

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CalVeg is the classification system being used for the mapping of existing vegetation. After the types are plotted on matrix graphs and separated in slope-aspect-elevation space, rules for the prediction of CalVeg types are developed. The input for the rules are the elevation maps and the slope/aspect maps that were already created in IPW and ARC. These "rules" produce a separate "map" for conifers, hardwoods and shrubs within each natural region. This map represents the potential for finding a particular existing vegetation type at the specified elevation and slope/aspect class, based on field training site data and ancillary ecological information.

The final step is to combine these layers with the stand based cover map which represents life form for the area. These layers become the inputs to which the modeling rules are applied. The actual model application is performed in ARC/GRID using ARC macro language (AML) scripts which can be easily modified if rule refinements are necessary. Subsequent AML outputs become the draft vegetation type or CALVEG layers that are field reviewed and, if necessary, revised before integration into the final map products. In this way, all conifers, hardwoods and shrubs, within a natural region, are assigned a specific type or series level label of the CALVEG classification system based on these rules. Meadows and dry grass were previously broken out during life form image classification and polygon formation, and do not undergo more specific identification. The basic process is to intersect separate layers in a geographic information system; the life form layer together with each model layer representing the potential types for conifers, hardwoods and shrubs.

Not all vegetation types can be modeled with terrain data. Examples include: vegetation growing on serpentines, and those with specific moisture or soil requirements, such as Lodgepole Pine. In these cases, ancillary information is sought out which can delineate where these areas can occur. Resource professionals from the National Forests very often have mapped these areas or know where they occur. In such cases, these are brought in as another GIS layer which then "supercedes" the results of the ecological terrain model. The quality of vegetation type maps produced from remote sensing can be greatly improved with specific information derived from ancillary data, both in the use of building the terrain model, and to delineate types which are not as directly influenced by terrain variables. In some cases, ecological modeling may consider differences in soils or geology as variables to be input into type modeling, particularly in areas where terrain does not strongly influence vegetation compositions. Increasingly, environmental variables known to drive vegetation distribution are being captured and maintained as digital information. As these data are developed and become available, there exists the potential for increasing the predictive accuracy of ecological models.

CALVEG Classification System.

The CalVeg Classification of California Vegetation system was initiated in January, 1978 by the Region 5 Ecology Group of the U.S. Forest Service with headquarters in San Francisco. The acronym means **C**lassification and **A**ssessment with **L**andsat of **V**isible **E**cological **G**roupings. The CalVeg team's mission was to classify California existing, rather than potential, vegetation communities for use in statewide resource planning considerations. This was accomplished with the use of color infrared satellite imagery and field verification of types by current soil-vegetation mapping efforts as well as professional guidance through a network of contacts throughout the state. Maps were produced at a statewide scale of 1:1,000,000 in electronic format as well as regional maps at scales of 1:250,000 produced as overlays to existing baseline or "sheet" maps at that scale. It was one of the earliest statewide vegetation coverages easily available for computerized mapping efforts and was considered to be useful for landscape level, watershed level or coarser scale applications, such as forest level planning and analysis. The first maps produced under this classification using current remotely sensed imagery and methods were those of the southern Sierra national forests in the mid-1980s at an image resolution of 30 meters or greater. Some of these older maps have been updated one or more times in the interim period.

Whereas regional forest types are groupings used for forest canopy modeling, inventory and general planning, the CALVEG classification can be more suitable for multiple-use resource information needs of the National Forests. The key in Appendix B can serve as criteria for separating CALVEG types from each other. More detailed descriptions are available in the U.S. Forest Service document **CALVEG: A Classification of California Vegetation**. Some descriptions have been refined further than what is in this document, to provide more specificity of type descriptions for particular National Forest mapping projects.

Regional Forest Type. Regional forest type is a level of classification used to divide forests into broad categories based on species composition. The underlying reason for the differentiation of regional types is that forest stands of tree size and canopy density characteristics, but different regional types, will have different timber volumes. Regional types are typically defined by the dominant species in the stand; for example: red fir, Douglas-fir, ponderosa pine, or simply mixed conifer. This broader grouping has been found to be useful in modeling forest canopy geometry, where average crown width and length for a regional forest type with a common mix of tree species, can be estimated.

The field graphs used to define CALVEG types by natural regions are also used in modeling regional forest type, by grouping closely related CALVEG types into regional types.

231 - FIELD NOTES RECORD

MAJOR VEGETATION TYPE - FIELD NOTES

Date: ____________________ Observer: ____

Observation Point No. : _______________ Quad No.: _________________ Photo No.: _________________

Slope: ________________ Aspect: _________________ Elevation: ________________

Overstory Total Tree Canopy Cover % : ___________________

Overstory Total Conifer Canopy Cover % : ______________________

Overstory Total Hardwood Canopy Cover % : ____________________

Total Shrub Cover % : _______________

Total Herb Cover %: ________________ (Forbs/Graminoids/Ferns)

Species	%Cover	Species	%Cover
Overstory Conifers _______________	________________	Shrubs _________________	________________
_______________	________________	_________________	________________
_______________	________________	_________________	________________
_______________	________________	_________________	________________
_______________	________________	_________________	________________

______________ ______________ ______________ ______________

Hardwoods______________ ______________ Forbs ______________ ______________

Ferns

______________ ______________ Grasses ______________ ______________

______________ ______________ ______________ ______________

______________ ______________ ______________ ______________

______________ ______________ ______________ ______________

______________ ______________ ______________ ______________

CalVeg Type ______________________ WHR Type ______________________

240 - FOREST CANOPY MODELING

The Canopy Model. Canopy modeling is accomplished using geometric modeling procedures. The canopy model is used to obtain estimates of "treeness" or values of "M", which are in turn inverted to give estimates of canopy closure as percent cover values for each forest stand or region. The canopy model is a four component model consisting of; sunlit tree crowns, sunlit background, shaded tree crowns and shaded background (See Figure 2.3). This is essentially a mixture model, that mimics the light sources (or lack of light) contributing to reflectance values for each 30 meter pixel area of a Landsat image brightness-greenness band combination, and how it varies between pixels within a stand.

Compensating for Illumination. For most National Forest land, the area being classified contains rugged terrain. Terrain effects how the sunlight is reflected or absorbed by an object or surface and the intensity of the sunlight received, which causes increased variance in the spectral values of the Landsat image. The variation is produced by differential illumination of slopes (shadows) caused by high topographic variation combined with low sun angle at the time, about 10:00 AM for our location, of the Landsat overpass. To minimize this effect, mid to late summer image dates are obtained, when the sun angle is the highest, and the shaded slopes receive the most sunlight. Even so, the more densely stocked forest areas with normal illumination have the same spectral reflectance as more sparsely stocked areas in poorly illuminated or shaded areas. This problem rules out the separation of forest canopy attributes based solely on spectral reflectances. Thus, it is necessary to develop a means of separating the image into categories based on illumination conditions at the time of the Landsat overpass.

The registered terrain data are used to model illumination conditions for each pixel within a stand or region. The angle between a normal-to-the-land surface and the sun at the time of the Landsat overpass is calculated. For a diffuse (Lambertian) reflector, the apparent brightness of a surface under constant illumination at an angle z will be proportional to cos(z). Thus, a cos(z) image displays the brightest values for pixels directly facing the sun and the darkest values for pixels in shade. From the cos(z) image, a mask is created to divide the image into two categories based on illumination: well-illuminated, and poorly-illuminated (shaded). The cutoff between these two categories is a zenith angle of 60 degrees; areas with angles greater than 60 degrees are considered poorly-illuminated.

The mask of shaded and well-illuminated pixels is created and serves to divide the area being mapped into its shaded and unshaded components. Since only a small percent of the image will be shaded, however, many classes remain undivided. The result of this action is to reduce within-class variation effectively and remove a potentially adverse effect on the predictive process.

Canopy Model Inputs. The canopy model requires several kinds of information; Landsat imagery, time and location of the satellite when the image was taken, topography of the stands, average crown length to crown radius by regional forest type, and component signatures from known locations with known values for the model components.

Figure 2.3 – Canopy Model

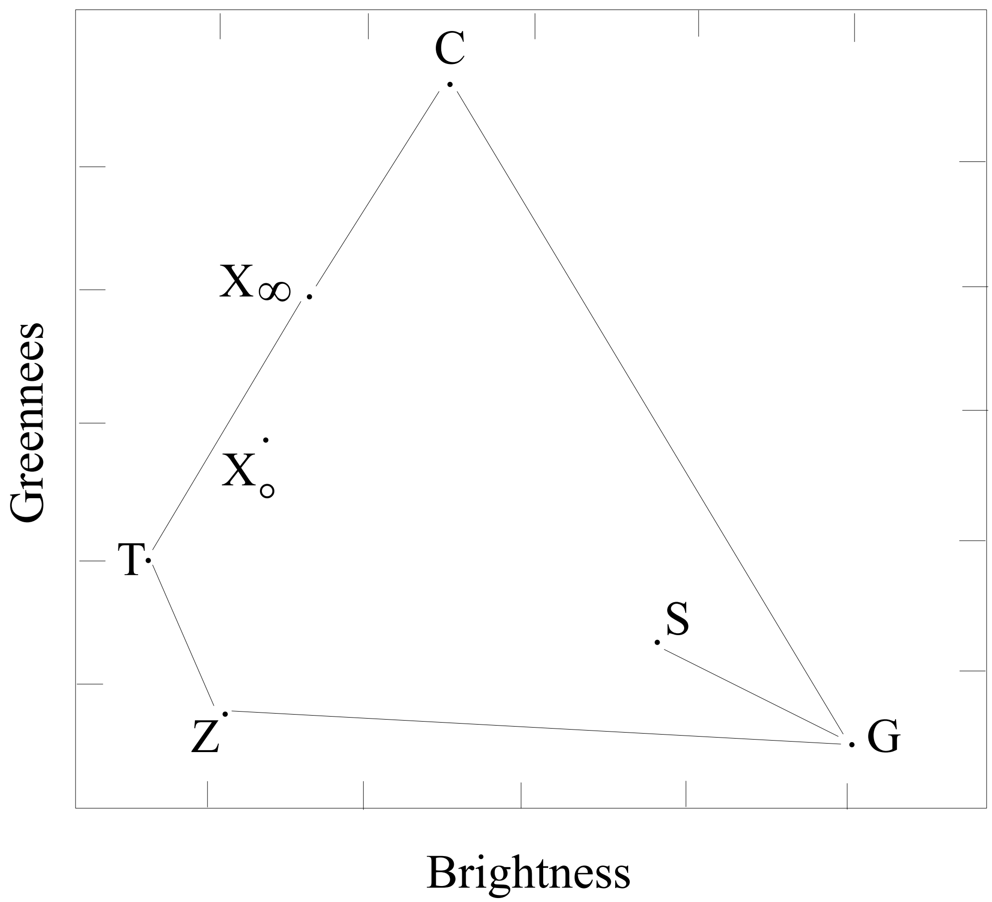


Figure 2.3 - Hypothetical location in feature space of the four components of the model: illuminated crown (C), shadowed crown (T), illuminated background (G), shadowed background (Z), and the coverage trajectory from the backgound (G) to X_∞.

The Landsat image is re-combined into two transformations, brightness and greenness. These are used in both the signature estimation procedure, as well as values for each pixel in a forest stand.

The time and location of the satellite are used to calculate the local solar zenith, and are used in combination with the slope and aspect information to determine the surface geometry of each stand.

Data collected from a number of individual stands are used to calibrate the component signatures of the canopy model; shaded and sunlit crowns and background for each regional forest type, as well as to develop the tree geometry parameters of crown length to crown radius, b to r ratio (See Figure 2.4).

After the crown model is calibrated using detailed information for known stands, the model is run across the entire map area for all pixels within stands. This is done for each regional forest type. For all stands labeled with the same regional type, an estimate of "M" or treeness is determined for each pixel, and then inverted to obtain estimates of canopy cover for each stand. (See Figure 2.5, Forest Vegetation Mapping Scheme.)

Figure 2.4 - Calibration of Crown Model

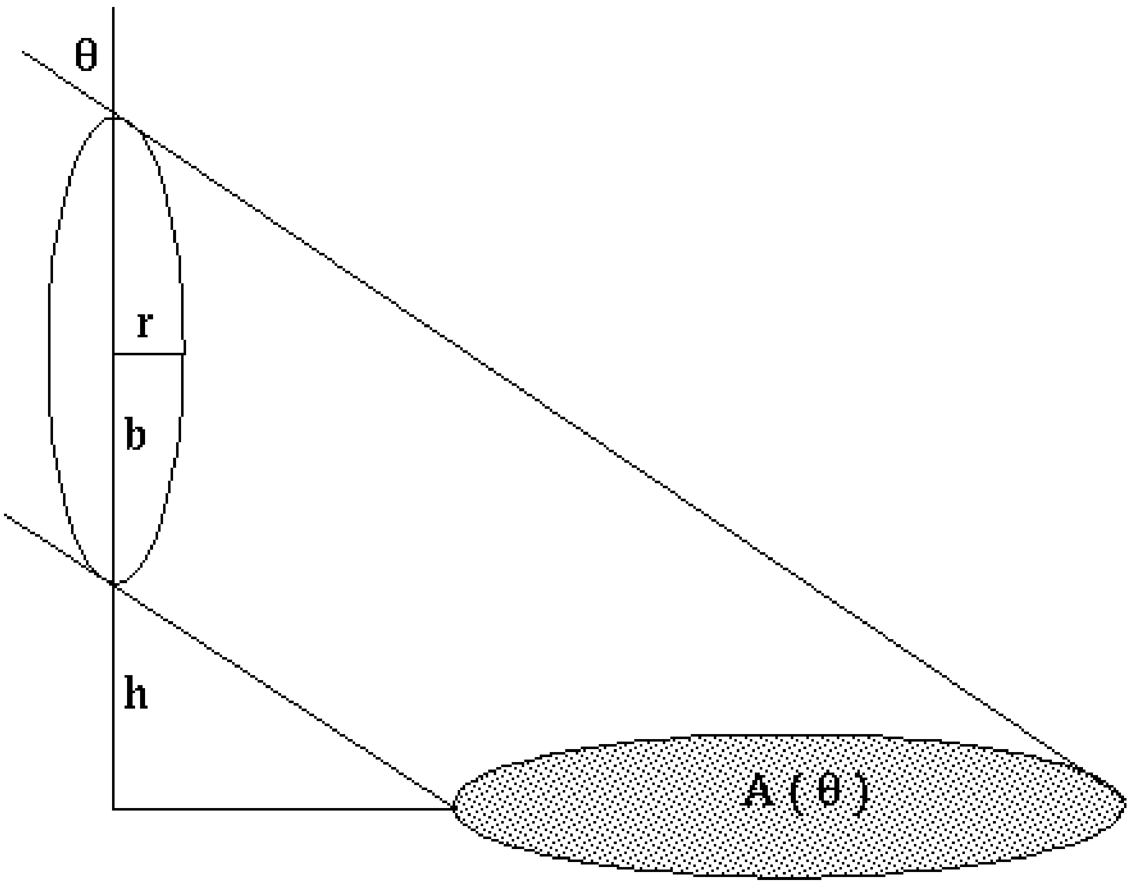
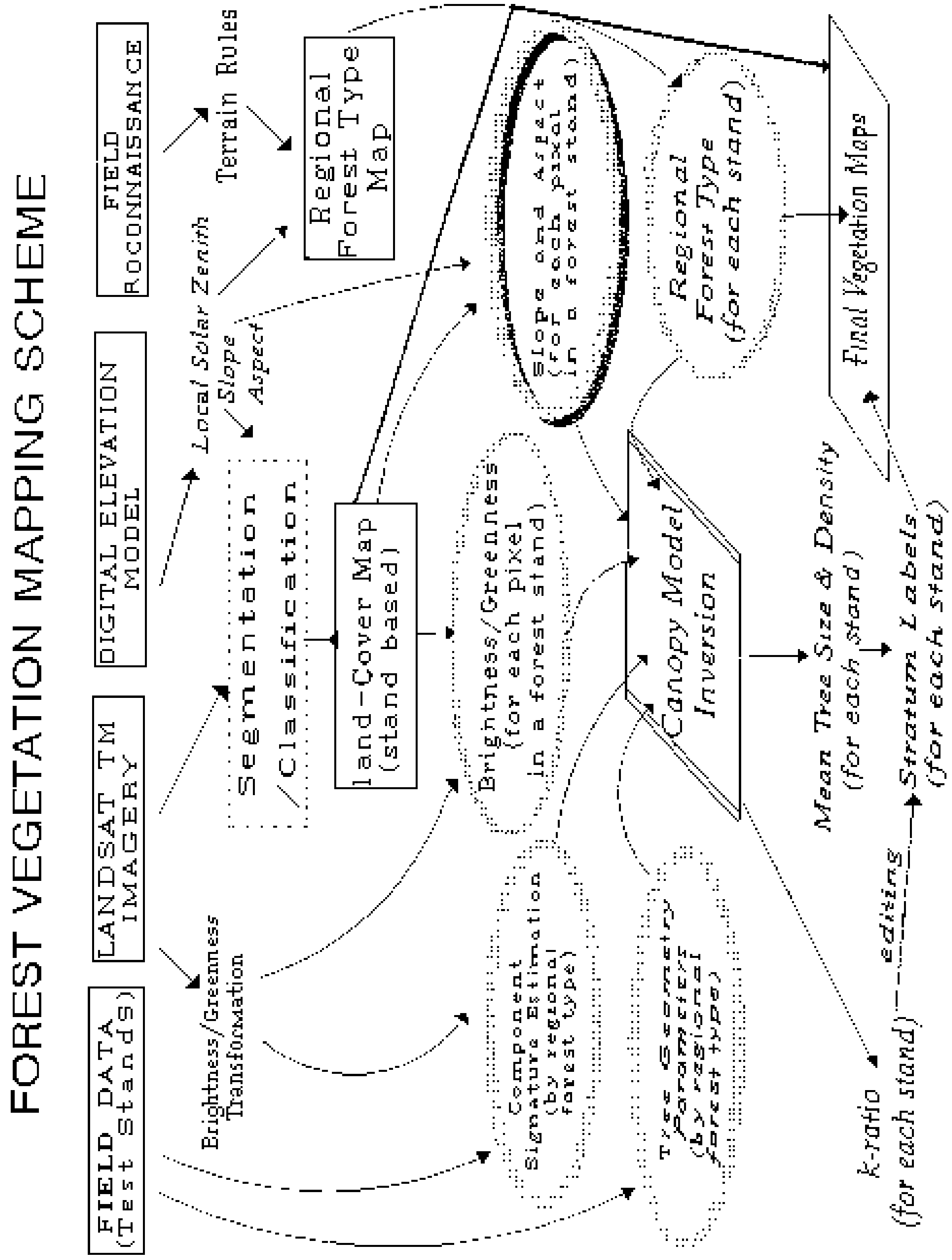


Figure 2.4 - Simple spheroid model of a conifer tree in the canopy reflectance model. r=radius of crown; b=half-height of crown; h=height of stem; θ = solar zenith angle; A(θ) =area of shaded background.

Figure 2.5 - Forest Vegetation Mapping Scheme



250 - TREE SIZE CLASS ESTIMATIONS

Estimating average tree size class is the hardest stand attribute to obtain from image processing techniques, or directly from aerial photos. This is due to several factors, none of which are totally independent. What is seen from aerial photos is the visible crowns from a "birds eye view". Trees and portion of tree crowns are hidden from view by the shadowing and overlapping of trees in the upper canopy, and thus, only part of what is actually in a forest stand can be measured directly on aerial photos. What can be directly measured is the visible crown diameter of the top story trees. Because crown diameter and tree diameter at breast height (DBH) are highly correlated, estimates of tree size can be made by measuring their crowns. However, crown width to DBH relationships do vary by species, especially for hardwoods compared to conifers. The other key factor causing estimation errors in average tree size is where stands are made up of trees of different sizes, from large to small. This is the case for many stands found in California due to fire, pests and harvesting history.

When estimating tree size using Landsat imagery, a large number of training stands are required to overcome this problem. Most of the reflected light received from the ground to the satellite is a function of tree canopy cover, not tree size. Although tree size does affect the texture of the image, it also affects the measure of variance of neighboring pixel values where the larger the variance value, the larger the trees; this same effect can be from clumped small trees with bright background areas between the clumps. This problem causes the worst kind of confusion, large trees confused with small trees.

The most reliable procedure to map average tree size is to use unsupervised classification. For all pixels classified as trees, these areas are now re-classified for tree size using the information from known stands that are homogenous in tree size. The focus of the classification is to concentrate on separating the small pole size trees from the large timber size trees, and default the remaining into the medium size class. Although this procedure is not as exacting as doing detailed measurements on aerial photos or in-place stand exams, it does produce a useable map when combined with the plantation layer for the smaller seedling, sapling and pole stand sizes.

260 - COLLECTING TRAINING SITE INFORMATION

Field Data Collection - Canopy/Size

It is important to have accurate field data in each of the major forest types in order to model canopy cover and conduct unsupervised classification for size classes. Our approach is to model canopy cover based on the geometry of forest canopies and the position of the sun. This approach allows for variation in the bi-directional reflectance of forest canopies and the effects of sun angles, surface topography, background vegetation and shadowing. Field data therefore, must reflect the range of conditions that are encountered within a project area.

Based on field reconnaissance, published material, and discussion with knowledgeable local experts, major forest types (conifers and hardwoods) for the project area are identified. Major forest types correspond to CALVEG Series Level types; for example: Red Fir, Eastside Pine, Blue Oak, etc. Training stands are chosen as a representative sample of each major forest type, on illuminated, shaded and flat slopes. Illuminated slopes are those at a south-southeast aspect

and greater than 30% slope; shaded are on north-northwest aspects and greater than 30% slope; and flat are those with less than 20% slope. This describes the mid-range of possible illumination conditions (flat) and the two extremes (shaded and illuminated) for calibrating the canopy model. Training stands are further stratified by canopy cover class: 10-30%, 31-69%, and greater than 70% canopy closure. Training stands are chosen with aerial photography interpretation to determine if they meet the sets of condition described above. In addition, they should be at least 10 acres in size and homogenous in canopy cover. Further verification of training stands that meet the above set of conditions occurs in the field before data collection.

For each canopy model training site, a 16-point grid is installed (Quick Plot Stand Exam, See Section 374 for plot configuration), with points located at equal distances from each other. The distance between points varies with the size of the stand, to sample all portions of the area. At each point, information on elevation, slope and aspect is recorded. A variable-radius plot is used, and for all trees that fall in the plot, species, crown position, crown ratio and diameter at breast height (DBH) are recorded. At each point, one tree (first tree from north) will also have height and crown diameters measured. Two site trees are located within each training site, to core for age and determine the site index for the stand. Information is also collected on "background" found beneath the canopy, including percent cover of seedlings, saplings, shrubs, forbs and grasses, and any ground material (rock, duff, etc.) that may be present.

Size canopy training sites must also include a range of all major forest types in the project area on illuminated, shaded and flat conditions across 4 size class groups. These classes are for poles (6-12" DBH), small trees (12-24" DBH), medium trees (25-36" DBH) and large trees (greater than 40"). Again, each training site must be at least 10 acres in size, and fairly homogenous with regards to size class. Stands should also be single-storied, even-aged stands, with moderate crown density. No field data are collected, since they are used for an unsupervised classification, not a modeling technique. The stand is delineated on aerial photographs and topographic quadrangles, and information on type (species composition), tree size class and illumination angle are recorded.

Training site data are processed and summarized using the USFS Region 5 Forest Inventory and Analysis System software for input into the canopy model and size classification.

270 - INTEGRATING REMOTE SENSING PRODUCTS IN GIS

Unlike the conventional method of vegetation mapping where the stand maps must be photo-to-map transferred, scanned or digitized and labeled, the automated classification data file is converted from pixel format (raster), to polygon format (vector). Most GIS software can accommodate this as a standard routine. The resultant vegetation map is now a layer in the GIS data base which may be overlaid with administrative, compartment, and/or watershed boundaries. If plantations, non-stocked forest areas from fires, and/or water bodies have not been incorporated during the mapping phase, they can now be used to over-ride these areas, by using the GIS software to update the vegetation maps. Once the map update and overlay process is complete, net National Forest acre values can be calculated for each unique vegetation label or attribute of interest, broad life form or CALVEG type. Maps can be easily produced for use in forest inventory, land management planning, watershed analysis or landscape analysis projects.

280 - ACCURACY ASSESSMENT

All vegetation type maps contain errors. It is impossible to create absolutely accurate delineations between vegetation types, largely because vegetation does not grow in homogenous patches or stands. By nature, vegetation boundaries are likely to be diffuse, or fuzzy, rather than sharp and contrasting. Errors can be of several types. Errors of omission occur when "conifers are mapped as something other than conifers". Conversely, an error of commission occurs when "shrubs are mapped as conifers". Registration errors can affect large areas of a map, causing the boundary lines to be shifted in one direction.

Accuracy assessment of maps improves their utility by providing the user of the maps with information about the nature, magnitude, frequency and source of errors. If the user knows that some of the conifers are mapped as something other than conifer, it will help explain why the total acreage of conifer falls short of expected values. On the other hand, if the acreage of conifer seems excessive, it could well be because many of the shrubs were mapped as conifer. An accuracy assessment can be conducted in a variety of ways, but the two primary methods are the Error Matrix, and the Fuzzy Set.

An error matrix involves comparing mapped labels with on-the-ground conditions at the site. The observer has only to determine if the mapped label is right or wrong. If the mapped unit is "conifer" and the observer finds shrubs, it counts as an error. A matrix table is constructed using mapped labels on one axis, and observed conditions on the other axis. The higher the proportion of "matches" there are, the more accurate the map is. The error matrix is sometimes referred to as a "Confusion Table" because it can highlight the types that are often confused. If 25% of the sites labeled conifer actually contain shrubs, then it can be inferred that there is a high level of confusion between conifer and shrubs.

Fuzzy Set theory goes a step beyond looking at right vs. wrong and confusion. It requires that the observer, without knowledge of the map label, make an unbiased evaluation of the site and rate all possible labels on a relative scale from "absolutely right" to "absolutely wrong". For example, if the observer was evaluating a pure red fir stand, he/she would rate a label of "hardwoods" as absolutely wrong, but might rate "mixed conifer-fir" as wrong, but close. Or a shrub/hardwood site might get an OK rating for either the "shrub" or "hardwood" label, but would receive "absolutely wrong" for a conifer label.

The benefit of using Fuzzy Set accuracy assessment is that it provides more information about the nature of errors, their magnitude and where they are likely to occur. Below is an example from the accuracy assessment recently completed on a forest mapping project.

> "Polygons labeled conifer can reliably be expected to be conifers except on steep, northwest-facing slopes where confusion with hardwoods may occur."

Regardless of how carefully a vegetation map is prepared, there will always be errors. An accuracy assessment is essential to provide the map user with the necessary information to interpret the map wisely. Forest inventory information can be used in the preparation of accuracy assessments, as long as all unique vegetation types and conditions are sampled in a non-biased fashion.

Contents

Note: Page numbers reflect original document not this Tech. Guide example)

Executive Summary

Existing vegetation is the primary natural resource managed by the USDA Forest Service and by most forest landowners and land management agencies. The agency is charged with managing vegetation for a variety of human uses while maintaining the integrity of ecosystem components and processes at national, regional, and local scales. One of the most fundamental information needs to support ecosystem assessment and land management planning is consistent and continuous current vegetation data of sufficient accuracy and precision to address the principal issues and resource concerns. Many of the analyses needed to address multiple resource issues are essentially analyses of vegetation pattern and process relationships. These vegetation analyses are used to support a variety of Forest Service business needs including:

- Forest planning, including revision and amendment of existing plans
- Forest-level and regional fuels assessments for implementation of the National Fire Plan
- Ecosystem assessment at the watershed scale that assess all lands within a watershed ($4^{th}/5^{th}$ HUC EAWS) independent of ownership
- Resource Planning Act reporting requirements
- Forest and rangeland assessments
- Post-fire assessments
- Project-level cumulative effects analyses

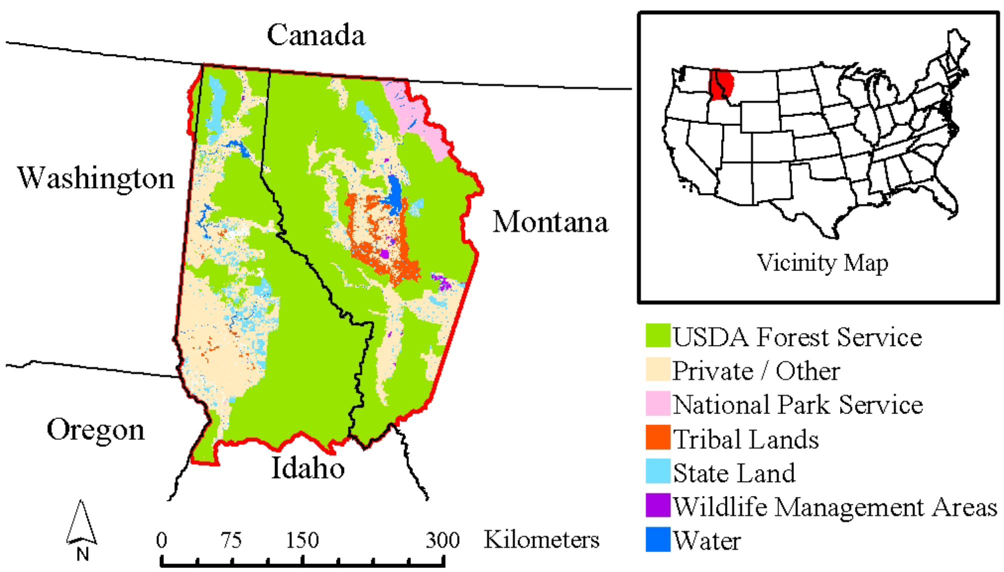


Figure 1. Northern Region Vegetation Mapping Project area.

Responding to these business needs, the Regional Forester's Team tasked the Northern Region, Resource Information Management (RIM) Board, to develop a plan to map current vegetation west of the Continental Divide. The Northern Region Vegetation Mapping Project, hereafter referred to as R1-VMP, was designed to meet this identified need (Figure 1).

The Regional Forester's Team had two programmatic objectives for R1-VMP:

1. Produce a consistent and continuous geospatial database for existing vegetation and associated attributes covering the northern Idaho and western Montana portions of the Northern Region. These data will be continuous across all ownerships and be produced following a consistent methodology. These data will also be compatible with the recently completed SILC3 vegetation-mapping project for the eastside of the Northern Region as well as recent national standards for vegetation classification and mapping.
2. Develop remote sensing and spatial analysis skills on each Forest to facilitate long-term use and maintenance of these datasets. The skills and experience gained by Forest-level employees will provide the basis for Forest specific refinements of the Regional data and specialized analysis support.

Based on an extensive foundation of remote-sensing applications, R1-VMP was developed with the following design elements:

- Utilization of ECOMAP section-level delineations to limit the variance associated with vegetation types within the study area
- Extensive use of ancillary data and ecological modeling to improve classification results
- Extensive use of summer and fall Landsat TM data to exploit seasonal variation in vegetation and other land cover classes
- Utilization of TM image segmentation and merge procedures to create base classification units
- Utilization of hierarchical classification to provide a consistent linkage between the lower levels commonly used by the agency and the upper levels required by the Federal Geographic Data Committee (FGDC) vegetation classification standards
- Generation of training and accuracy assessment data through a structured aerial photo interpretation process

The result of R1-VMP is a geospatial database used to produce four primary map products. Lifeform, tree canopy cover class, tree diameter, and dominance type are each displayed in separate maps. Map products have a variable minimum map unit (MMU) size varying from 1 acre for water features, 2.5 acres for grass-forb and shrub, to 5 acres for tree land cover. The geospatial database can be used as needed to construct user-specified map themes at varying MMU to aid in the analysis of management questions related to forest vegetation. The details of database and map product development and accuracy assessment are included in the project report.

A maintenance and update strategy has been designed to annually identify areas of changed conditions for systematic updates of the R1-VMP data.

1.0 Introduction

Existing vegetation is the primary natural resource managed by the USDA Forest Service and most forest landowners and land management agencies. The agency is charged with managing vegetation for a variety of human uses while maintaining the integrity of ecosystem components and processes at national, regional, and local scales. One of the most fundamental information needs to support ecosystem assessment and land management planning is consistent and continuous current vegetation data of sufficient accuracy and precision to address the principal issues and resource concerns. The primary ecosystem component managed is vegetation. Other ecosystem components, such as water, soil, fuels and air quality, as well as terrestrial and aquatic fauna, are managed indirectly by way of vegetation management and/or access management. Many of the analyses needed to address multiple resource issues are essentially vegetation pattern and process analyses. These vegetation analyses are used to support a variety of Forest Service business needs including:

- Forest planning, including revision and amendment of existing plans
- Forest-level and regional fuels assessments for implementation of the National Fire Plan
- Ecosystem Assessment at the Watershed Scale (EAWS) that assess all lands within a watershed ($4^{th}/5^{th}$ HUC EAWS) independent of ownership
- Resource Planning Act reporting requirements
- Forest and rangeland assessments
- Post-fire assessments
- Project-level cumulative effects analyses

Maps are the most convenient and universally understood means to graphically represent the spatial arrangement and relationships among features on the earth's surface (Mosby 1980). A map is indispensable for recording, communicating, and facilitating analysis of such information relating to a specific area. Accurate and up-to-date maps of existing vegetation are commonly used for inventorying, monitoring, and managing numerous resources on National Forests (*e.g.*, wildlife habitat) including the business requirements listed above. Recognition of the importance of map products to support this wide variety of business needs was a primary consideration in identifying existing vegetation as a national Geographic Information System (GIS) layer for the Forest Service. This same recognition resulted in the development of the Existing Vegetation Classification and Mapping Technical Guide (Brohman and Bryant 2003) to establish Forest Service standards and procedures for classification and mapping of existing vegetation. This technical guide is authorized by Forest Service Manual (FSM) 1940 and has been developed according to direction in Forest Service Handbook (FSH) 1909. These standards were developed to guide the development of future classification and mapping products following the Federal Geographic Data Committee (FGDC) vegetation classification standards and provide a hierarchical approach to map unit design.

Ecosystem assessment and land management planning at national and regional scales require consistent standards for classification and mapping of existing vegetation. Such standards have never been developed because, until recently, most Forest Service planning and management have focused on issues at the local scale. The breadth of the Forest Service mission necessitates that classification and mapping protocols be designed to deal with a wide range of issues. The agency cannot develop a separate classification and/or map for every question land managers face. The agency must, therefore, describe and map fundamental units of vegetation that can be interpreted to address numerous questions. This requires hierarchical classification and multi-scale mapping so existing vegetation can be described and mapped at the appropriate level of detail for each issue.

Historically, vegetation inventory and mapping has been conducted through some form of two-stage sampling of forest stands. The term *stand* has long been used to refer to the basic unit of forest management (Toumey 1937); therefore, it has been used as the basic unit of mapping and inventory (Graves 1913). A *stand* is defined as "a community, particularly of trees, possessing sufficient uniformity as regards composition, age, spatial arrangement, or condition, to be distinguishable from adjacent communities, so forming a silvicultural or management entity" (Ford-Robertson 1971). This process normally consisted of the delineation of “timber stands” with stereo, vertical aerial photography. The basis for delineation of stands was discontinuities in texture (reflecting stocking and crown size differences) or apparent tree height (Stage and Alley 1972). The second stage was normally field sampling of the delineated stands or field sampling of a stratified random sample of the stands with subsequent inference of field sampled strata characteristics to unsampled stands within the strata. This process also involved transferring the photo delineations to a base map. These stand delineations reflected management considerations as well as vegetative composition and structure. They often included several vegetation types that were different in terms of composition and structure, but were similar in terms of management implications and/or history. The term stand was also extended to specifically describe conditions other than forested stands, such as non-forest vegetation, rock or barren areas, or water bodies. It should be noted that while extending the stand-mapping concept made these maps more comprehensive, they did not map fundamental units of vegetation that could be interpreted to address numerous questions. Additionally, these maps represent a dynamic ecosystem component and have a finite period of currency. The intent with this inventory and mapping strategy was to regularly update the data, normally every decade. Figure 1 illustrates the status of stand exam based inventory data for the Northern Region and the “decay curve” associated with trends in inventory data by displaying a 10-year periodic total that filters out “stale” inventory data from the total. These data apply almost exclusively to the suitable timber base, as defined by the National Forest Management Act of 1976 (US Public Law 94-588 1976). The remaining areas outside the suitable base have few stand exam inventory data even though many of the questions and issues apply to all lands. In addition, there are no specific design considerations for the collection and storage of these data to facilitate their use by other land management agencies or private landowners.

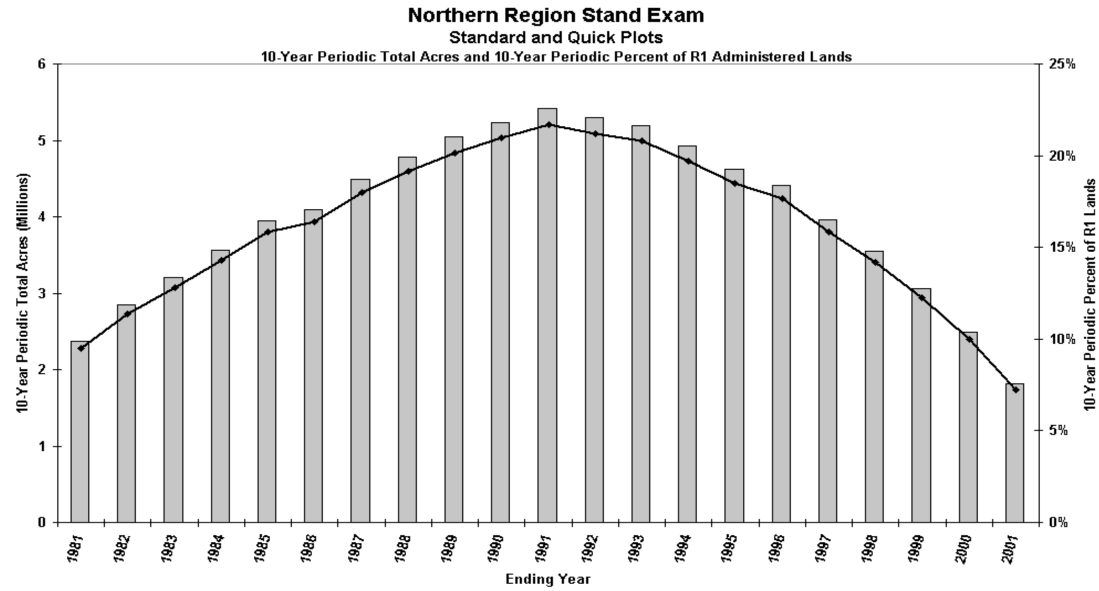


Figure 1. USDA Forest Service, Northern Region, stand exam program status summary for 1980-2001.

Responding to this information need the Northern Region Resource Information Management (RIM) Board developed a plan to focus the Region's efforts and invest in a business plan that will provide for a Regional resource information capability. This plan committed the Region to a prioritized set of projects for the next 3 years. The Regional Forester's Team approved the RIM Board's recommended plan. The RIM Board identified a number of corporate datasets and information systems as priorities. Among other national commitments, resource mapping and development of a GIS core layer for current vegetation was identified. The Northern Region Vegetation Mapping Project, hereafter referred to as R1-VMP, was designed to meet this identified need. The project design was accepted by the RIM Board to be completed as a 3-year project beginning in March of 2001.

The Regional Forester's Team had two programmatic objectives for R1-VMP:

1. Produce a consistent and continuous geospatial database for existing vegetation and associated attributes covering the northern Idaho and western Montana portions of the Northern Region. These data will be continuous across all ownerships and be produced following a consistent methodology. These data will also be compatible with the recently completed SILC3 vegetation-mapping project for the eastside of the Northern Region, as well as recent national standards for vegetation classification and mapping.
2. Develop remote sensing and spatial analysis skills on each Forest to facilitate long-term use and maintenance of these datasets. The skills and experience gained by Forest-level employees will provide the basis for Forest specific refinements of the Regional data and specialized analysis support.

The first objective of R1-VMP was to provide the Northern Region and cooperating agencies with a geospatial database of vegetation and land cover produced following consistent analytical logic and methods and mapped continuously across all ownerships. This geospatial database with its associated inventory data supports land management planning and sustainable forest management at regional, sub-regional, and landscape assessment scales. These data also provide the analytical basis for vegetation pattern and process analyses associated with forest management planning. It is also explicitly designed to provide for project-level analyses using the same analytical logic and scale-appropriate methods. This design element facilitates establishing the relations among individual projects and Forest-wide or Regional management direction. These data should also facilitate cumulative effects analyses for many projects. The project area for R1-VMP covers all ownerships and encompasses approximately 27,000,000 acres (11,000,000 hectares) of the USDA Forest Service, Northern Region (Figure 2). The area extends from the Continental Divide to the Washington and Oregon borders, and from the Salmon River to the Canadian border.

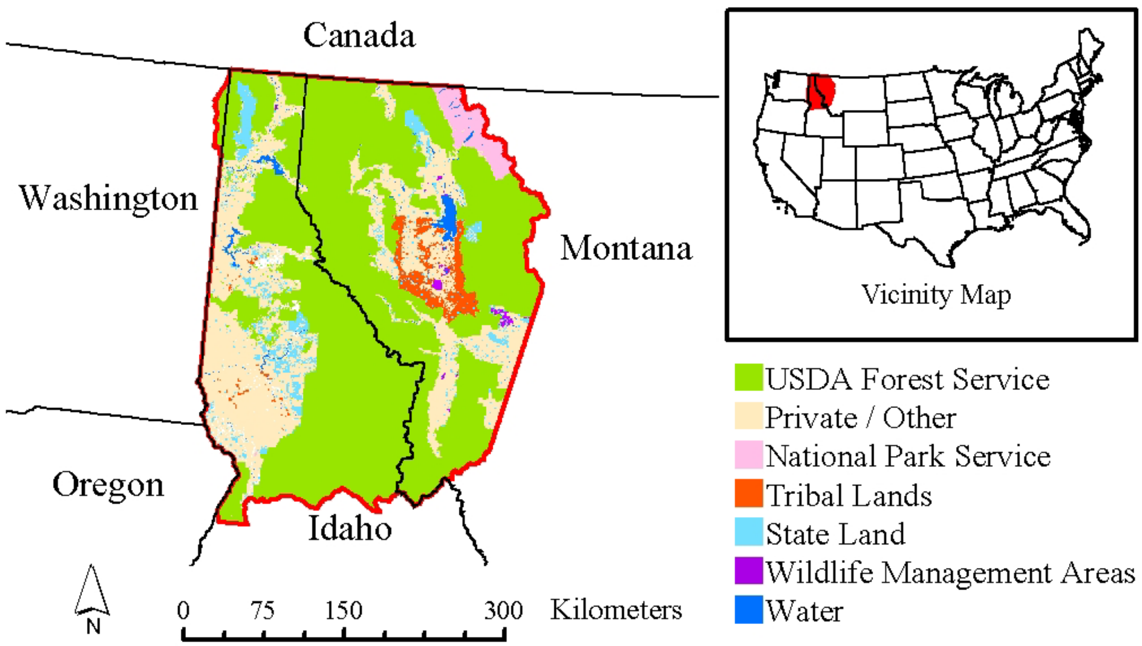


Figure 2. Northern Region Vegetation Mapping Project area.

The second objective was accomplished through a team concept that includes multiple organizational levels within the Region. Within this structure, Regional Office personnel provide overall project coordination and oversight, as well as technical assistance, training, and specialized skills. Forest personnel provide the local field experience and specialized skills needed to produce a quality product and develop the knowledge and experience needed to effectively utilize and improve these data for Forest- and project-level analysis objectives.

In the early stages of the project it became increasingly obvious that R1-VMP was not a mapping project but, in fact, a classification, mapping, and inventory project. The R1-

VMP team needed to facilitate the discussion with the Northern Region Vegetation Council regarding the evaluation and adjustment of the existing Regional classification logic. Numerous problems had been identified with the classification logic and associated algorithms used in the SILC projects and concerns had been expressed that the classes were not exhaustive and/or mutually exclusive. Additional concerns regarding the eventual integration of the map products with some form of inventory data were also raised. Coordination with the Northern Region Vegetation Council and the Regional Forest and Rangeland Staff resulted in the modification of this project to accomplish these longer-term objectives. Accordingly, this project documentation describes the general relationship of vegetation classification, mapping, and inventory followed by sections describing each of these processes relative to R1-VMP. The following project documentation tiers to and expands on the Existing Vegetation Classification and Mapping Technical Guide (Brohman and Bryant 2003). Particularly relevant sections of the technical guide are included here directly, rather than incorporating by reference.

2.0 General Relationship of Classification, Mapping, and Inventory

As discussed in the introduction, one of the most fundamental information needs for implementing any sustainable forest management strategy is consistent and continuous current vegetation data of sufficient accuracy and precision to address the principal issues and resource concerns. Many of the analyses needed to address multiple resource issues are essentially analyses of vegetation pattern and process relationships. All of these analyses rely on the data models produced from vegetation classification, mapping, and/or inventory. R1-VMP is designed to utilize these three types of data models to provide robust existing vegetation information for a wide variety of analysis applications. It is important, however, to remember the caution of the distinguished statistician George Box who observed “All models are wrong-but some models are useful”. Useful is therefore defined by the ability of these data models to address an intended analysis application. The following sections describe the classification, mapping, and inventory logic/methods of the R1-VMP data. Users of these data should evaluate R1-VMP in the context of the intended use.

A number of significant terms are commonly associated with vegetation classification, mapping, and inventory. These terms are subsequently defined in order to ensure a clear and consistent discussion of the concepts and relationships presented in this project documentation.

Existing vegetation is the plant cover, or floristic composition and vegetation structure, occurring at a given location at the current time.

Classification is the process of grouping of similar entities into named types or classes based on shared characteristics. A **vegetation type** is a named category of plant community or vegetation defined on the basis of shared floristic and/or physiognomic characteristics, which distinguish it from other kinds of plant communities or vegetation. **Taxonomic units** are the basic set of classes or types that comprise a natural or scientific classification. Taxonomic units can be developed for physiognomic classifications (*e.g.*, tree dominated classes or shrub dominated classes) or floristic classifications (*e.g*., dominance type classes or plant association and alliance classes). Taxonomic units represent a conceptual description of ranges and/or modal conditions in vegetation characteristics. **Technical groups** are the basic set of classes or types that comprise a technical classification. Technical groups can be developed for structural classifications (*e.g*., canopy cover classes and/or tree size classes). Technical groups represent a conceptual description of ranges and/or modal conditions in vegetation characteristics.

Vegetation mapping is the process of delineating the geographic distribution, extent, and landscape patterns of vegetation types and/or structural characteristics. A **vegetation map unit** is a collection of areas with a common definition and name reflecting their component taxonomic units and/or technical groups. Map units depicted on maps within individual areas or delineations that are non-overlapping and geographically unique are referred to as **map features** (*e.g*., polygon delineations or region delineations). **Thematic resolution** is the level of categorical detail present within a given set of map units. In a general sense, increased thematic resolution is represented by an increase in the number of map units and fewer map units conversely represent coarser thematic resolution. While thematic resolution is often implied by geographic or spatial resolution, a direct relationship is not inherent.

Vegetation inventory is the process of applying an objective set of sampling methods to quantify the amount, composition, and condition of vegetation within specified limits of statistical precision.

These three processes and the resulting data models are integrally related, but they are separate. Vegetation classification defines and describes vegetation types and/or structural characteristics (*i.e.,* what is it?). Vegetation mapping spatially depicts the distribution and pattern of vegetation types and/or structural characteristics (*i.e.,* where is it?). Vegetation inventory quantifies the amount, composition, and condition of vegetation (*i.e.,* how much is there?). The conceptual relationships between classification, mapping, and inventory are schematically depicted in figure 3.

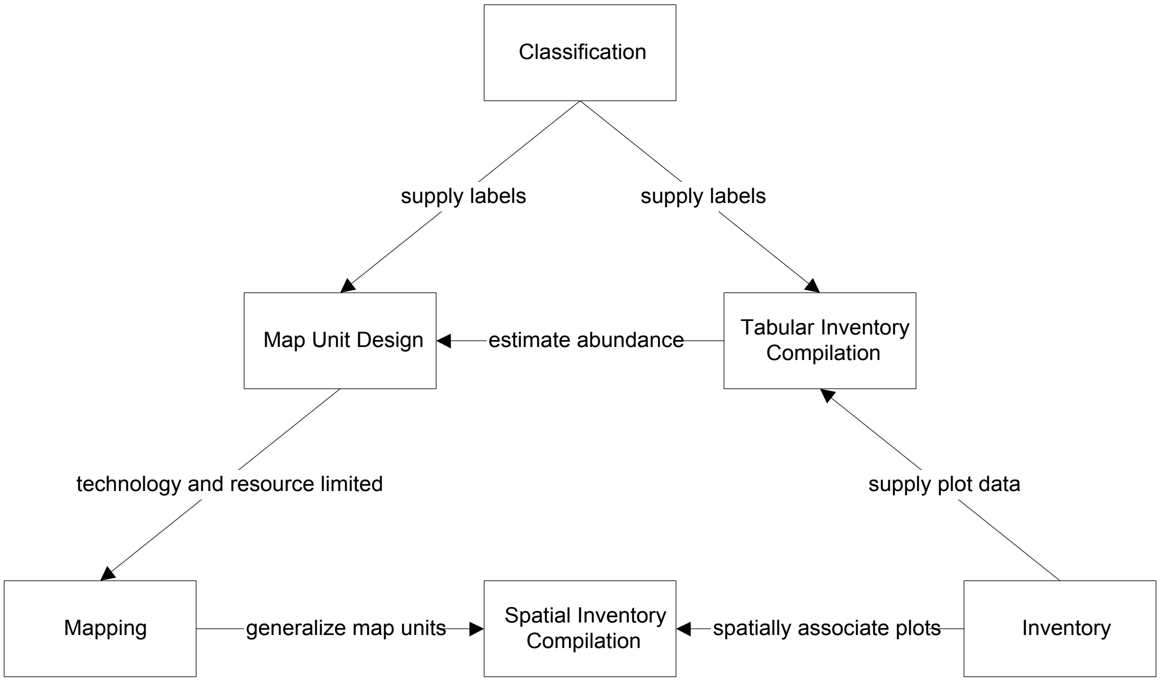


Figure 3. Relationships of vegetation classification, mapping, and inventory.

A one-to-one relationship between vegetation types (from a classification) and vegetation map units is uncommon given the limitations of mapping technology and the level of floristic detail in most classifications. Mapping, therefore, usually entails trade-offs among thematic and spatial resolution and accuracy, as well as cost. The goal is constrained optimization, not perfection. This problem is reduced somewhat when vegetation types, such as dominance types, and structural classifications are designed to be applied to mapping projects. Similarly, there is rarely a sufficient sample size to quantify all vegetation types. Inventory compilation usually involves trade-offs to generalize and aggregate vegetation types and/or structural classes to achieve the sample size needed to provide estimates consistent with the intended analysis applications.

Because these ecosystems are dynamic, evolutionary, and have limited predictability many of the analyses needed for ecosystem management strategies require a variety of simulation models. The majority of these simulation models rely heavily on accurate and relatively detailed vegetation data (*e.g.*, SIMPPLE, WATSED, and FARSITE). These models vary in the specific vegetation data needed as well as the amount of detail needed in those data, but most of them require continuous spatial data with consistently classified attribute data. Classification, mapping, and inventory each contribute data elements used in these simulation models.

The concepts of vegetation classification and mapping as well as the general relationships between them are well described in Existing Vegetation Classification and Mapping Technical Guide (Brohman and Bryant 2003). This project documentation describes the Northern Region procedures used in R1-VMP for classification and mapping of existing vegetation and identifies the mechanism for integrating these classifications and maps with inventory data collected through the Forest Inventory and Analysis (FIA) program. This document also specifically describes the classification logic, mapping methods, and inventory compilation strategies used in R1-VMP.

3.0 Vegetation Classification

A comprehensive discussion of the nature, purposes, and principles of the classification of natural phenomena was included in John Stuart's *A System of Logic* (1st edition, 1846), a treatise on inductive logic as the basis of the scientific method. Classification is a fundamental activity of science and an integral part of human thought and communication (Mill 1846, Buol *et al*. 1980, Gauch 1982). It is how we assimilate and organize information to produce knowledge.

Classification is the process of grouping of similar entities into named types or classes based on selected shared characteristics. Classification is a form of inductive reasoning that "establishes general truths from a myriad of individual instances" (Trewartha 1968). Classification is a fundamental activity of science and an integral part of human thought and communication (Gauch 1982). It is how we assimilate and organize information to produce knowledge. "When we have a definition for anything, when we really have studied its nature to the point where we can say that it is "this" and not "that", we have achieved knowledge" (Gerstner 1980 as cited in Boice 1998). Even if classification categories are conceptual or abstract rather than absolute facts, they still serve to formulate general truths based on numerous observations.

A **class** is "a group of individuals or other units similar in selected properties and distinguished from all other classes of the same population by differences in these properties" (Buol *et al*. 1980). The properties selected as the basis for grouping individuals into classes are called **differentiating characteristics** (Buol *et al*. 1980). There are two fundamental approaches to selecting differentiating characteristics; they produce two different kinds of classes (Mill 1846) and two different kinds of classifications (Buol *et al*. 1980, Pfister and Arno 1980, USDA 1993).

A **natural or scientific classification** is *a* classification in which the differentiating criteria are selected in order to "bring out relationships of the most important properties of the population being classified, without reference to any single specified and applied objective" (Buol *et al*. 1980). In developing a scientific classification, "all the attributes of a population are considered and those which have the greatest number of covariant or associated characteristics are selected as the ones to define and separate the various classes" (Buol *et al*. 1980). A set of classes developed through scientific classification is referred to as **taxonomy** (USDA 1993). A **taxonomic unit** (or **taxon**) is a class developed through the scientific classification process, or a class that is part of taxonomy.

A **technical classification** (or **technical grouping**) is a classification in which the differentiating characteristics are selected "for a specific, applied, practical purpose" (Buol *et al*. 1980, Pfister and Arno 1980). The resulting classes are called **technical groups**. In contrast to natural classifications, technical classifications are based on one or a few properties to meet a specific interpretive need, instead of considering all the properties of the population.

Vegetation classification consists of grouping a potentially infinite number of stands or plots into relatively few vegetation types. A **vegetation type** is a named class of plant community or vegetation defined on the basis of selected shared floristic and/or physiognomic characteristics, which distinguish it from other classes of plant communities or vegetation. Vegetation types are taxonomic units developed through the scientific classification process as described above. Scientific classification makes meaningful generalizations about each vegetation type possible, thus reducing complexity and furthering communication while maintaining meaningful differences among types (Pfister and Arno 1980). Members of a vegetation type (*e.g.,* plots or stands) should be more similar to each other than they are to members of other vegetation types. Structural classifications, such as those based on canopy cover, are technical groups developed through a technical classification process. Technical groups also generalize all possible conditions into classes that are more similar to members of the same class than to members of other classes and provide the basis for analysis applications and interpretations related to the "applied, practical purpose" of the classification.

Following the classification principles described above as well as the mid-level classification standards included in the Existing Vegetation Classification and Mapping Technical Guide (Brohman and Bryant 2003), the Northern Region Vegetation Council developed and adopted the following vegetation and landcover classifications.

3.1 Physiognomic and Floristic Classification

Physiognomic and floristic composition are the most fundamental components of a vegetation map. The National Vegetation Classification (NVC) (FGDC 1997) has defined a hierarchical system for arranging these components into taxonomic units, which is the foundation for the map hierarchy described in the technical guide. When the NVC was adopted as an FGDC standard in 1997 the document provided the description of both the physiognomic and floristic composition components. Two floristic levels, alliances and associations, were defined. Standards were provided for only the physiognomic portion of the hierarchy. To further develop standards for the NVC, the Ecological Society of America (ESA), through a memorandum of understanding with the FGDC, established a vegetation classification panel. In May 2002 the ESA vegetation panel submitted Standards for Associations and Alliances of the U.S. National Vegetation Classification (Jennings *et al.* 2002). The ESA document states as follows: "Consistent with FGDC principles, the standards here for floristic units relate to vegetation classification and are not standards for the identification of mapping units. Nevertheless, types defined using these standards can be mapped and can be used to design useful map units subject to the limitations of scale and mapping technology." The ESA proposed standards for associations and alliances along with the physiognomic standards in the 1997 U.S. National Vegetation Classification form the basis for the mapping standards identified in the technical guide. It is assumed that all map units will fit somewhere within this hierarchy, whether or not they are included in the FGDC classification**.**

Landscape features dominated by land uses (*e.g.*, urban areas) and water bodies are to be mapped as non-vegetative if they are less than the minimum standard for vegetative cover. Mapping continuous areas requires using land use and cover as well as vegetation classification systems. While many areas of the National Forests could be mapped using map units defined by vegetation physiognomic classification only, sparsely vegetated and non-vegetated areas mapped solely as such, give little information to the map user. Water was explicitly included as a lifeform-level land cover class and classes such as snow, clouds, and shadows were replaced using adjacent lifeforms.

Lifeform (order-level of the NVCS physiognomic hierarchy)

Code	**Label**	**Description**
3100	GFB	Grass/Forb dominated lifeform
3300	SHR	Shrub dominated lifeform
4000	TRE	Tree dominated lifeform
5000	WTR	Water landcover
7000	SVG	Sparsely vegetated landcover

Lifeform Key

A. Tree dominated lifeform ≥ 10% canopy cover ……………………..……… **TRE**
A. Tree dominated lifeform < 10% canopy cover……………………..……….Go to B

B. Shrub dominated lifeform ≥ 10% canopy cover ………………….………..**SHR**
B. Shrub dominated lifeform < 10% canopy cover…………………………..…Go to C

C. Grass/Forb dominated lifeform ≥ 10% canopy cover ……………….……. **GFB**
C. Grass/Forb dominated lifeform < 10% canopy cover……………………..…Go to D

D. TRE+SHR+GFB+non-vascular ≥10% canopy cover …………**NDL** [no dominant lifeform]
D. TRE+SHR+GFB+non-vascular <10%…………………………Go to E

E. TRE+SHR+GFB+non-vascular <10% and ≥1% canopy cover…**SVG** [sparsely vegetated]
E. TRE+SHR+GFB+non-vascular <1%……………………………..……**NVG** [non-vegetated]

Floristic map units based on vegetation types from a fully documented and adopted existing vegetation classification system are required by the national standard; however, few vegetation classifications that meet the FGDC exist in the Northern Region. The near term availability of adopted FGDC vegetation classifications prompted the Vegetation Council to develop and adopt a consistent approach to the classification and mapping of dominance types. Dominance types have been widely used in the development of map units where remote sensing imagery is the primary basis for map feature delineation. "Under the dominance approach, vegetation types are classified on the basis of dominant plant species found in the uppermost stratum. Determining dominance is relatively easy, requiring only a modest floristic knowledge. However, because dominant species often have a geographically and ecologically broad range, there can be substantial floristic and ecologic variation within any one dominance type."…" "Dominance types" provide a simple method of classification based on the floristic dominant (or group of closely related dominants) as assessed by some measure of importance such as biomass, density, height, or leaf-area cover (Kimmins 1997). They represent one of the lowest levels in several published classification hierarchies (*e.g.*, Cowardin *et al.* 1979, Brown *et al.* 1980)."

The dominance type classification adopted for R1-VMP is based on relative canopy cover and is exhaustive and mutually exclusive. The basic classification logic is illustrated in the following tree dominance type key:

Tree Dominance Type Key

A. Single most abundant species ≥ **60%** of total canopy cover……… **List single species**
A. Single most abundant species **< 60%** of total canopy cover…..… Go to B

B. 2 most abundant species ≥ **80%** of total canopy cover and each species individually is
≥20% of total canopy cover ………….………………..**List 2 species**, in order of abundance
B. 2 most abundant species **< 80%** of total canopy cover…………..… Go to C

C. 3 most abundant species ≥ **80%** of total canopy cover and each species individually is
≥20% of total canopy cover…………………………**List 3 species**, in order of abundance
C. 3 most abundant species **< 80%** of total canopy cover……………..…. Go to D

D. Shade intolerant species total CC ≥ shade tolerant species total CC…..**IMXS**
D. Shade intolerant species total CC **<** shade tolerant species total CC…..Go to E

E. GF+C+WH canopy cover ≥ AF+S+MH canopy cover ……………………..**TGCH**
E. GF+C+WH canopy cover < AF+S+MH canopy cover ……………………..**TASH**

3.2 Tree Diameter Classification

Tree diameter class (a.k.a. overstory tree diameter class) is defined here as any of the intervals into which a range of tree diameters may be divided for classification (Helms 1998). In this project the mean diameter at breast height (4.5 ft. 1.37 m. above the ground) is calculated for the trees forming the upper or uppermost canopy layer (Helms 1998). Note: this mean is calculated as the basal area weighted mean diameter.

Tree Diameter Class

Code	DBH	Description
1	0-4.9	Seedling/Sapling
2	5-9.9	Small tree
3	10-14.9	Medium tree
4	15-19.9	Large tree
5	20 +	Very Large tree

3.3 Tree Canopy Cover Classification

Tree canopy cover (a.k.a. tree canopy closure) is defined here as the total non-overlapping tree canopy in a delineated area as seen from above. (Note: Tree canopy cover **is not** defined by a hemispherical projection as seen from below.) Tree canopy cover below 10% is considered a non-tree polygon. The tree canopy cover breaks are consistent with the physiognomic class breaks for vegetation.

Tree canopy cover class

Code	Cover %	Description
1	10-24.9%	Low
2	25-59.9%	Moderate
3	60-100%	High

4.0 Map Design

Map design involves two fundamental processes. The first process, map unit design, identifies the vegetation characteristics to be mapped and assembles or develops classification keys for each of the map attributes used to describe those characteristics. This process establishes the relationship between vegetation classification and mapping. The second process, map feature design, identifies the spatial characteristics and structure of the map.

A **vegetation map unit** is a collection of areas defined and named the same in terms of their component taxonomic units and/or technical groups (adapted from USDA, Soil Survey Division Staff 1993). These vegetation map units can be based on the taxonomic units and technical groups of physiognomic, floristic, or structural classifications or on combinations of these. Map units are designed to provide information and interpretations to support resource management decisions and activities. The map unit design process establishes the criteria used to aggregate or differentiate vegetation taxonomic units and technical groups to establish corresponding map units. Therefore, a mapping unit is comprised of one or more taxonomic units and/or technical groups from one or more specific classifications. The criteria used to aggregate or differentiate within physiognomic types, vegetation types, or structural classes to form mapping units will depend on the purpose of, and the resources devoted to, any particular mapping project (Jennings *et al*. 2002). For example, map units designed to provide information on existing forest structure to characterize wildlife habitat or fuel condition would be based on a combination of tree canopy cover technical groups and tree diameter technical groups. The map unit design process is more complex for floristic classifications than for relatively simple structural classifications. The mapping standards for vegetation cover, tree canopy closure, and tree diameter described in this section represent general-purpose map unit designs for each structural classification at all map levels, although local information needs may occasionally require exceeding the standards.

Map units depicted on maps within individual areas or delineations that are non-overlapping and geographically unique are referred to as **map features** (*e.g.,* polygon delineations or region delineations). The map feature delineation process should be based on the map units identified in the map unit design process. Typically, one map unit is repeated across the landscape in many individual map feature delineations.

The map design process for the primary R1-VMP map products is described in the following sections.

4.1 Physiognomic and Floristic Map Design

The dominance type classification described in section 3.1 was aggregated and generalized using the following logic to identify the map units used in R1-VMP. The variable minimum map feature standard used for lifeform applied to dominance types.

DOMINANCE TYPE 1 – ELEMENTAL CLASSIFICATION [DOM1]
Classification Rule Set:

1species >60% tot BA	that species
2species >80% tot BA	those 2-species - listed in order of abundance
3species >80% tot BA	those 3-species - listed in order of abundance
Shade intol > Shade tol	IMXS [intolerant mixed spp]
Shade tol > shade intol	
G, WRC,WH > AF,ES,MH	TGCH
G, WRC,WH < AF,ES,MH	TASH

RESULTS IN OVER 850 DIFFERENT TYPES

DOMINANCE TYPE 4 –SPECIES GROUPS [DOM4]
Classification Rule Set:
1-species: same as DOM1

2-species: All 2-species DOM1-types with the same most abundant species are grouped into SPPP-1MIX [*e.g.,* ABGR-PSME, ABGR-PICO, etc = ABGR-1MIX]

3-species: All 3-species types with the same most abundant species [from DOM1] are grouped into SPPP-2MIX [*e.g*., ABGR-PSME-PICO, ABGR-PICO-LAOC, etc = ABGR-2MIX]

IMXS, TASH, TGCH: same as DOM1

RESULTS IN 42 DIFFERENT TYPES

DOMINANCE TYPE 4M –SPECIES GROUPS MAP UNITS [DOM4M]
Map Unit Design
A frequency distribution of DOM4 types is made from FIA PSU data.

If either the single-species or the single-species-1MIX are less than 1% of the

The dominance type map unit design process described in this section produced slightly different sets of map units for each model reflecting the ecological differences in these models (Appendix A). Combining the map units for each model resulted in 36 unique dominance types. An objective evaluation of the map accuracy of R1-VMP dominance types illustrated the nature and magnitude of map error associated with this large set of map units and suggested logical aggregations of map units to achieve reasonable accuracy for the regional product. It is important to recognize that the structure of the error varied by dominance type and between models. Therefore, forest or planning zones may aggregate dominance types differently depending on the intended analysis application and the geographic extent of the analysis area. This aggregation process is discussed further in section 5.10.

4.2 Tree Diameter Map Design

The tree diameter classification described in section 3.2 was aggregated and generalized to the following three classes for R1-VMP to reduce error to acceptable levels. The variable minimum map feature standard used for lifeform applied to tree diameter classes.

Tree Diameter Map Units

Code	DBH	Description
1	0-4.9	Seedling/Sapling
23	5-14.9	Small/Medium tree
45	15-20 +	Large/Very Large tree

4.3 Tree Canopy Cover Map Design

The tree canopy cover classes described in section 3.3 were adopted and mapped as classified. The variable minimum map feature standard used for lifeform applied to tree canopy cover classes.

4.4 Minimum Map Feature

Minimum map feature is the term used to describe the smallest size polygon required in a map. A homogeneous area must be delineated in a map if it is equal to or greater in areal extent than the minimum map feature standard for each map level. Stated in another way, no differing condition, as defined by the map unit design, greater in area than the minimum map feature can be left as an unmapped inclusion in a larger polygon.

The lifeform and landcover classes described in section 3.1 were adopted and mapped as classified. A variable minimum map feature standard was implemented as follows:

Lifeform Minimum Map Feature

Code	Label	Minimum Map Feature
3100	GFB	2.5 Acres
3300	SHR	2.5 Acres
4000	TRE	5.0 Acres
5000	WTR	1.0 Acres
7000	SVG	5.0 Acres

The dominance type map units, tree canopy cover map units, and tree diameter map units, described in sections 4.1 through 4.3 respectively, nest hierarchically under lifeform and follow the same minimum map feature standard.

5.0 Vegetation Mapping

Vegetation mapping is the process of delineating the geographic distribution, extent, and landscape patterns of vegetation types and/or structural characterisitcs. Satellite-based remote sensing classifications (mainly using LANDSAT-TM data) with their associated GIS coverages or grids and attribute databases have increasingly been used for large area, low-cost vegetation and landcover mapping (Lachowski *et al*. 1996, Redmond *et al*. 1996, Johnston *et al*. 1997, Cohen *et al*. 1998, Mickelson *et al*. 1998, Stoms *et al*. 1998). These satellite-based classifications are gradually replacing aerial photography as the primary image data for vegetation mapping. Wynne and Carter (1997) compare characteristics of satellite remote sensing data and aerial photography relative to these mapping applications:

- Satellite images are digital; they provide direct and cost effective GIS coverages and databases. The spatially accurate conversion of aerial photo delineations to digital coverage is expensive and time consuming.
- Digital images are easy to send over computer networks; they can be delivered within hours of acquisition.
- Given a specified resolution, satellite images typically provide greater coverage than aerial photography.
- Satellite images often have better geometric fidelity than aerial photos because of their altitude and stability of orbits.
- Some spaceborne sensors include wavelengths band, such as mid-infrared, and thermal infrared, that cannot be detected by film.
- Repeat coverage is easily obtained; it is easily co-registered and used for applications such as change detection and monitoring.

The USDA Forest Service national direction contained in the Existing Vegetation Mapping Protocol (Brewer *et al*. In press) within the Existing Vegetation Classification and Mapping Technical Guide (Brohman and Bryant 2003) reflects the trend toward the use of satellite remote sensing classification for vegetation mapping. R1-VMP represents the current implementation of this national direction in the Northern Region. The following sections, exerted and expanded from Brewer and others (2003), describe the analytical logic and general methodology utilized in the mapping process.

5.1 Acquisition and Pre-processing of Image and Ancillary Data

Landsat TM imagery was chosen for this work because the near-infrared and mid-infrared reflectance of vegetation is strongly related to important vegetation canopy characteristics. Additionally, the high spectral resolution of Landsat TM imagery was preferred above the high spatial resolution of other sensors, such as SPOT and Landsat TM data are acquired continuously and archived data could, therefore, be purchased to meet the time and area needs. Landsat TM data can also be purchased as “floating scene” or path-level" data purchasing the equivalent of up to three TM scenes as a single field of view, thereby reducing the image handling and preprocessing requirements as well as costs.

A good seasonal image data acquisition window for forest vegetation opens slightly after the date at which the forest vegetation is fully mature and closes just prior to its senescence. Similarly, a good data acquisition window for exploiting meaningful phenological differences in forest vegetation opens slightly after senescence and ends with snowfall. The consideration of an acquisition window instead of an acquisition date provided greater operational flexibility (to minimize cloud cover or other atmospheric interference), because it permits the actual acquisition date to be chosen from a satellite overpass. In this case, the "peak green" and "fall" image data were obtained from the EROS Data Center with the following acquisition dates and according to the following parameters:

Cell Sizes: 30m reflective, 15m panchromatic, 60m thermal (both high and low)
Orientation: Path
Datum: WGS 84
Projection: Space Oblique Mercator
File Format: FSTL7
Path 41 Image Acquisition Dates: 10 July 2002; 14 October 2002
Path 42 Image Acquisition Dates: 18 August 2002; 6 November 2002
Path 43 Image Acquisition Dates: 6 August 2002; 12 October 2002

All images were ortho-rectified to previously terrain-corrected images for the respective paths using the Geometric Correction Module and the Landsat orbit model in ERDAS IMAGINE (ERDAS 1997) as well as 7.5-minute digital elevation models. Between 200 and 300 ground control points (GCP) throughout each of the unrectified images were used in the ortho-rectification process. The rectification involved the Cubic Convolution algorithm with a resulting Root Mean Square (RMS) error was less than 1/2 of a pixel or 7.5m, 15 m, or 30m depending on the cell size. The R1-VMP image handling steps, ortho-rectification process, and resulting datasets are documented in appendix B. Ancillary topographic data derived from 7.5-minute digital elevation models downloaded from the U.S. Geological Survey were assembled, co-registered, and clipped to the same study area boundary.

5.2 Ecogeographic Stratification

Lillesand and Kiefer (2000) discuss the commonality of using ancillary data to perform geographic stratification of an image dataset prior to classification. They further describe the aim of this process is to "…subdivide an image into a series of relatively homogeneous geographic areas (strata) that are then classified separately." The homogeneity of these geographic areas is largely determined by the composition of biophysical environments included in the stratification. These biophysical environment settings are important for the stratification of this type of project because they facilitate the delineation and description of ecosystems that behave in a similar manner and influence the natural disturbance processes that create finer-scale patterns such as existing vegetation (Jensen *et al*. 1997). The USDA Forest Service National Hierarchical

Framework of Ecological Units (Bailey *et al*. 1994) provided the delineations used for geographic stratification of the R1-VMP project area. As described by ECOMAP the framework "…is a regionalization, classification, and mapping system for stratifying the Earth into progressively smaller areas of increasingly uniform ecological potentials. Ecological types are classified and ecological units are mapped based on associations of those biotic factors and environmental factors that directly affect or indirectly express energy, moisture, and nutrient gradients that regulate the structure and function of ecosystems. These factors include climate, physiography, water, soils, air, hydrology, and potential natural communities." The appropriate level of this hierarchy for ecogeographic stratification in this project is the section-level delineation described by McNab and Avers (1994) and illustrated in figure 4. These delineations were used to stratify Landsat ETM floating scene sets in ERDAS Imagine software (ERDAS 1997). This geographic stratification results in 12 sub-path data models (Figure 5) rather than eight Landsat TM scene models. This stratification improves model performance by limiting the variance associated with vegetation types and increases the utility of reference data.

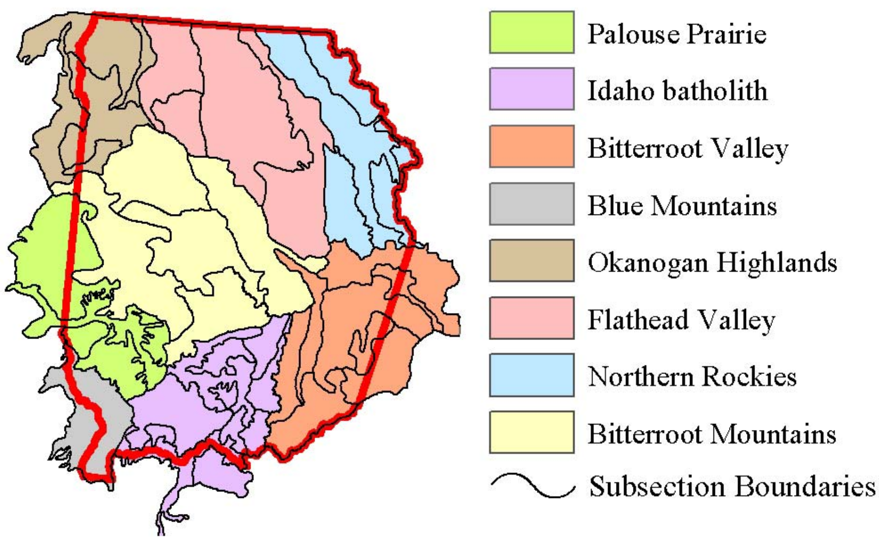


Figure 4. Section- and Subsection-level delineations in the ECOMAP hierarchy.

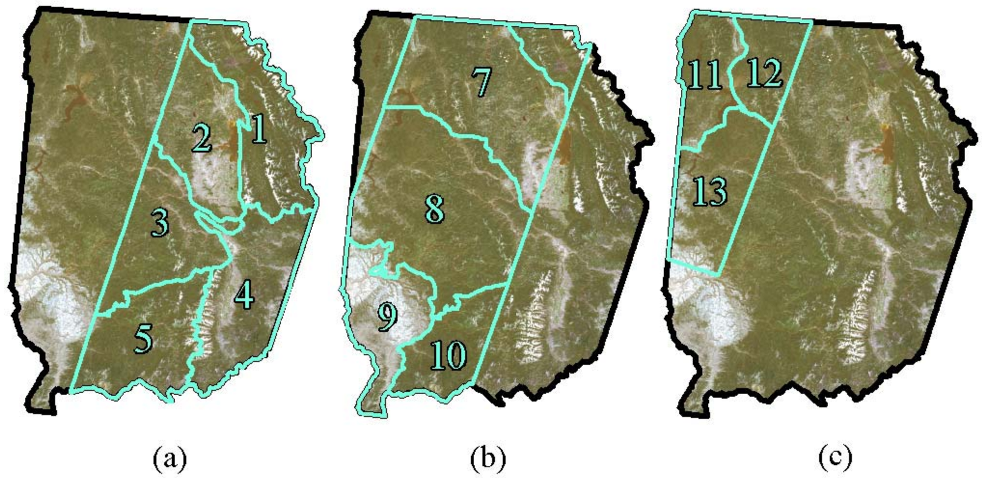


Figure 5. Sub-path data models used for ecogeographic stratification of Landsat ETM floating scenes.

The 12 sub-path data models were subsequently modified (Figure 6) to reduce file size and eliminate redundancy. The portion of model 13 not included in model 8 was appended to model 11. Similarly, the portion of model 10 not included in model 5 was appended to model 9. Models 7 and 12 were both carried through the classification process to provide flexibility in eliminating smoke and haze problems present in the image data.

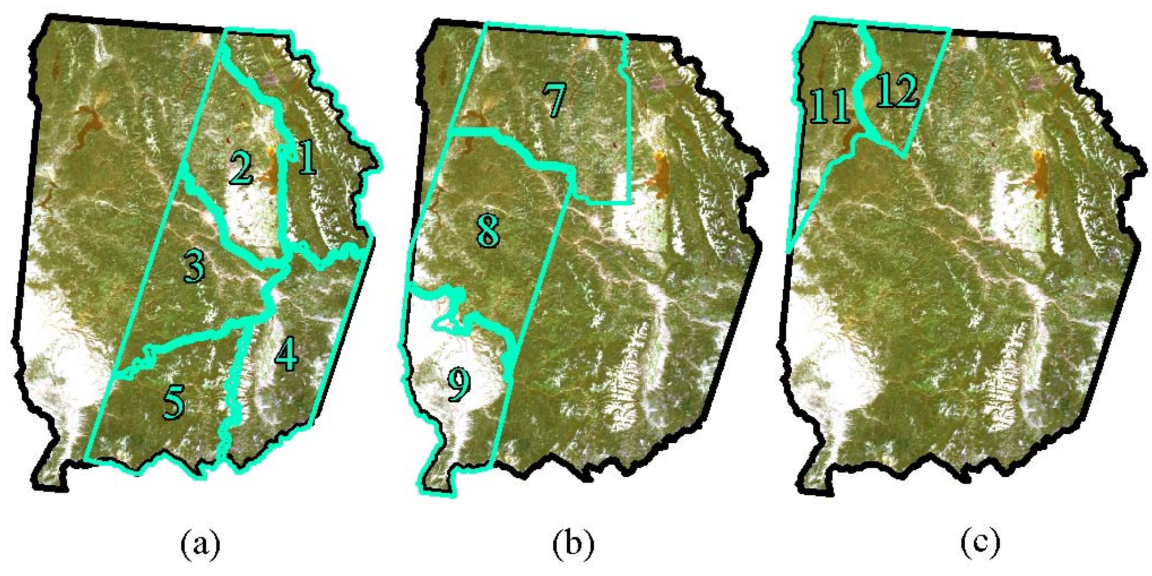


Figure 6. Modified sub-path data models used for ecogeographic stratification of Landsat ETM floating scenes.

5.3 Image Segmentation

As stated in Ryerd and Woodcock (1996), “Image segmentation is the process of dividing digital images into spatially cohesive units, or regions. These regions represent discrete objects or areas in the image”. This segmentation and merging process is influenced by the variance structure of the image data and provides the modeling units that reflect life form composition, stocking, tree crown size differences, and other vegetation and/or landcover characteristics (Haralick and Shapiro 1985, Ryerd and Woodcock 1996). Segmentation and merging of Landsat ETM satellite imagery in R1-VMP utilized the segmentation functionality within the software eCognition (Baatz et al. 2001). The segmentation process in eCognition is based on both the local variance structure within the imagery and shape indices. This segmentation process produces image objects that serve as the base classification units within the object-oriented classification programs. These image objects effectively depict the elements of vegetation and landcover pattern on the landscape (McDonald *et al*. 2002). Figure 7 illustrates the image segmentation-based depiction of landscape pattern displayed over aerial digital imagery. Given the R1-VMP project objective of mapping vegetation and landcover pattern, the criteria for spatially differentiating map features was based on structural, floristic, and physiognomic characteristics of the vegetation to be mapped, as well as non-vegetated landscape elements. Within the context of R1-VMP, the delineation of map features depicting the vegetation configuration across the landscape representing elements of vegetation pattern is synonymous with landscape patch delineation. The term “patch”, as defined in a glossary of common terms included in Land Mosaics: The Ecology of Landscapes and Regions (Forman 1995), is "a relatively homogenous nonlinear area that differs from its surroundings". This definition is consistent with other common reference texts including Picket and White (1985) and Forman and Godron (1986). It is also consistent with the common use of the term in the landscape ecology literature (Hartgerink and Buzzaz 1984, Scheiner 1992). The term patch can specifically describe forested patches, non-forest vegetation patches, rock/barren patches, or water patches. In contrast, the term “stand” has long been used to refer to the basic unit of forest management (Toumey 1937). It also has been used as the basic unit of mapping and inventory (Graves 1913). A “stand” is defined as "a community, particularly of trees, possessing sufficient uniformity as regards composition, age, spatial arrangement, or condition, to be distinguishable from adjacent communities, so forming a silvicultural or management entity". This definition of a stand from the Society of American Forester's Terminology of Forest Science, Technology, Practice, and Products (Ford-Robertson 1971) is consistent with definitions from a variety of reference texts including Toumey (1937), Smith (1986), and Oliver and Larson (1990), as well as A Dictionary of Ecology, Evolution, and Systematics (Lincoln *et al.* 1982) and the definition provided in the USDA Forest Service Timber Management Handbook (FSH 2709). Historically, most vegetation mapping completed by the agency has been conducted through delineation of forest stands. The terms “patch” and “stand” may be synonymous depending on the degree that management considerations are incorporated into stand delineations along with compositional and structural characteristics. It is important to recognize, however, that many past stand delineations contain multiple vegetation conditions and map units and are multiple map features in the R1-VMP mapping effort. The image objects delineated through the R1-VMP image segmentation process and modeled in eCognition readily aggregate thematically and comprise vegetation and landcover patches that represent the various map units in the hierarchy.

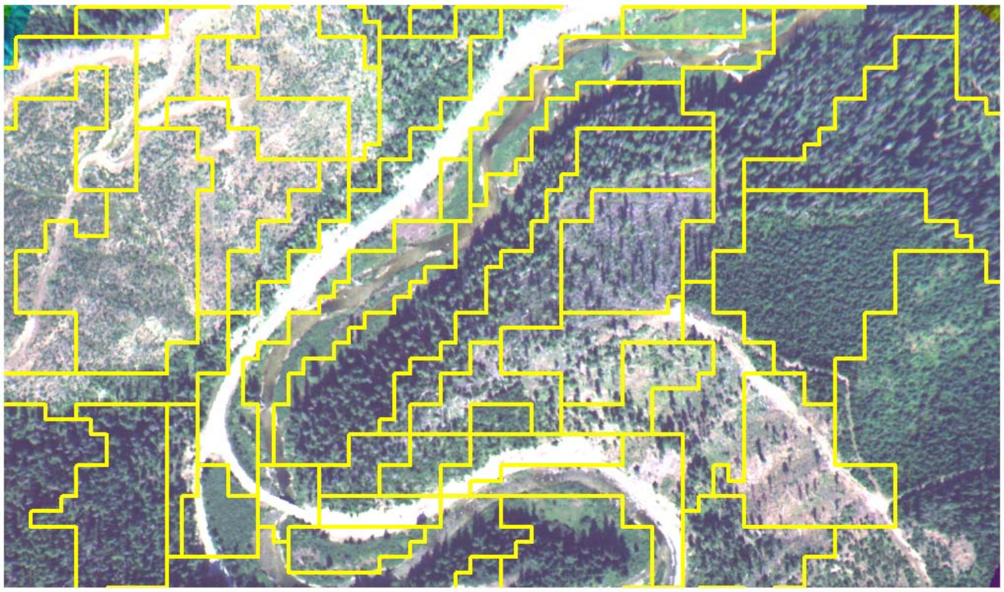


Figure 7. Image segmentation of Landsat ETM data.

5.4 Change Detection

Change detection methodologies using digital data have been used extensively for a wide variety of analysis applications including: fire impact studies (Parra *et al*. 1996), land cover change in wetland areas (Hashem *et al*. 1996), (Mahlke 1996), air pollution damage detection (Hogda *et al*. 1995, Solheim *et al*. 1995), and forest-canopy change (Coppin and Bauer 1994, 1995). Within the context of the vegetation mapping objectives R1-VMP, the change detection method is designed to exploit phenological differences in vegetation types (*i.e*., deciduous tree or shrub species dominance types or senescent grasses and forb species dominance types).

The R1-VMP change detection procedure, like most digital change detection procedures, must assess differences between multi-temporal datasets, and also separate changes of interest from those that are irrelevant to the mapping objectives. The maximization of the signal-to-noise ratio and the extraction of relevant multi-spectral features related to the biophysical characteristics of vegetation canopies are essential to identification of meaningful phenological differences (Ngai and Curlander 1994). Coppin and others (2001) note that preprocessing of satellite images prior to actual change detection is a critical step. They identify the goals of preprocessing as "…the establishment of a more direct linkage between the data and biophysical phenomena (calibration), the removal of data acquisition errors and image noise, and the masking of contaminated and/or irrelevant scene fragments". The synopsis of procedures and their requirements for digital change detection presented by Coppin and Bauer (1996) comprise the basis of R1-VMP preprocessing.

Following preprocessing, single-band radiometric responses are often transformed to strengthen the relationship between spectral data and biophysical characteristics of vegetation canopy. Coppin and others (2001) demonstrated that a solid biophysical link is found between forest canopy features and the Kauth-Thomas transform, a particular case of a principal components analysis. The three main components of Kauth-Thomas variability are termed brightness, greenness and wetness and are the result of a Gram-Schmidt orthogonalization process (Kauth and Thomas 1976). Changes in these three components constitute the basis of the R1-VMP analytical logic to exploit phonological differences in vegetation types (Figure 8).

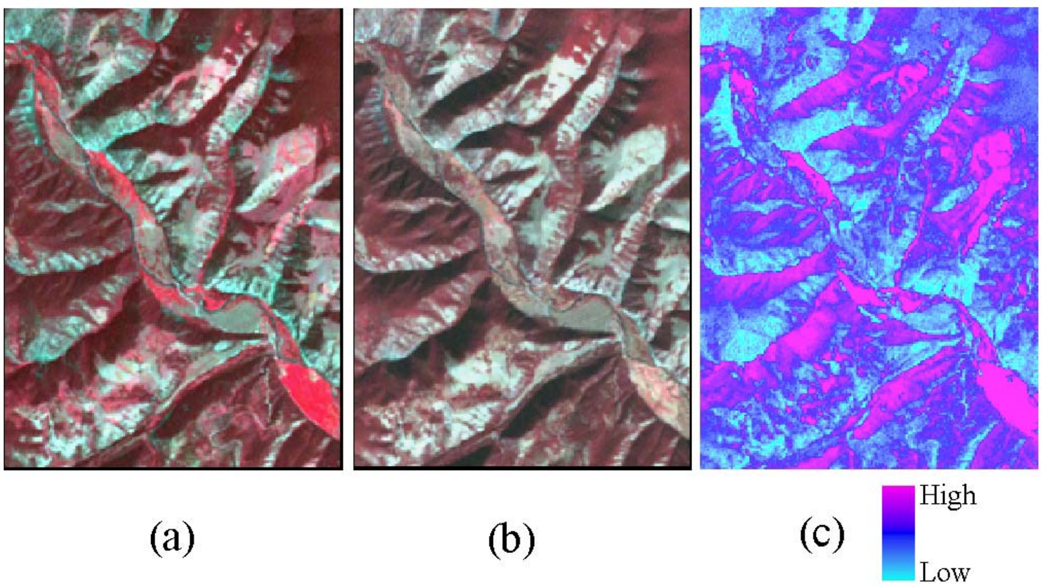


Figure 8. Changes in K-T greenness from multi-date imagery. (a) July date. (b) October date. (c) Degree of change between dates.

5.5 Ecological Modeling and Other Ancillary Data

Ecological modeling and other ancillary data are used extensively by R1-VMP to improve classification results. These ecological modeling approaches are incorporated into the multi-source system through knowledge-based classification and reference data stratification within the object-oriented image analysis software, eCognition (Baatz et al. 2001). This process facilitates the use of additional data such as potential vegetation settings, subsection level ecological units, topography, and image illumination strata for grouping or splitting classes to improve classification accuracy (Cibula and Nyquist 1987, Bolstad and Lillesand 1992, Cohen and Spies 1992, Brown *et al.* 1993, Coppin and Bauer 1994, Goodchild 1994).

One of the primary ecological modeling approaches used in R1-VMP incorporates data on Potential Natural Vegetation (PNV). PNV is "the vegetation…that would become established if all successional sequences were completed without interference by man under the present climatic and edaphic conditions…." (adapted from Tuxen 1956 as cited in Mueller-Dombois and Ellenberg 1974). PNV classifications are based on existing vegetation, successional relationships, and environmental factors (*e.g*., climate, geology, soil, etc.) considered together. The PNV classifications within the R1-VMP project area include: Forest Habitat Types of Montana (Pfister *et al*. 1977), Forest Habitat Types of Northern Idaho: A Second Approximation (Cooper *et al*. 1991), and Grassland and Shrubland Habitat Types of Western Montana (Mueggler and Stewart 1980). The PNV types and their associated biophysical settings have strong relationships with existing vegetation and, therefore, provide useful information in the image classification process. The habitat types from these classifications were aggregated to 38 types and mapped by Jones and others (1998, 2002). R1-VMP further aggregated the 38 types to 10 types to facilitate the classification process.

In addition to PNV, R1-VMP incorporated two other biophysical variables: 1) two indices of insolation derived from combinations of slope and aspect generated from 30 meter DEM data, and 2) subsection level delineations further subdividing the ecogeographic stratification described above and illustrated in figure 4 (McNab and Avers 1994).

R1-VMP also stratified the image data by the illumination at the time of image acquisition. This process results in three strata: 1) illuminated in both the "summer" and "fall" images, 2) non-illuminated in both the "summer" and "fall" images, and 3) illuminated in "summer" but non-illuminated in "fall". These strata improve the spectral relationships between vegetation types and reflectance values (Figure 9).

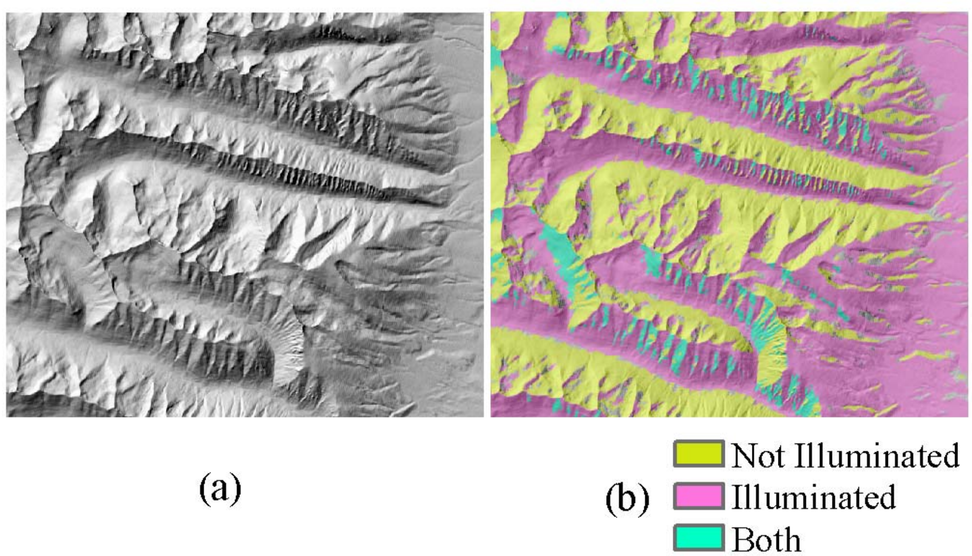


Figure 9. Illumination strata. (a) Hillshade created from digital elevation model. (b) Illumination classes of surface for both dates of imagery.

Additional ancillary data are provided by fire severity data classifying recently burned areas (Figure 10). These fire severity data were operationally produced by the USDA Forest Service (Gmelin and Brewer 2002) following major fire events in 2000 and 2001 and are used to characterize first order fire effects on vegetation. These data are generated from a Normalized Difference Burn Ratio (NBR) analytical approach, following Key and Benson (1999) as adapted by Brewer and others (In review).

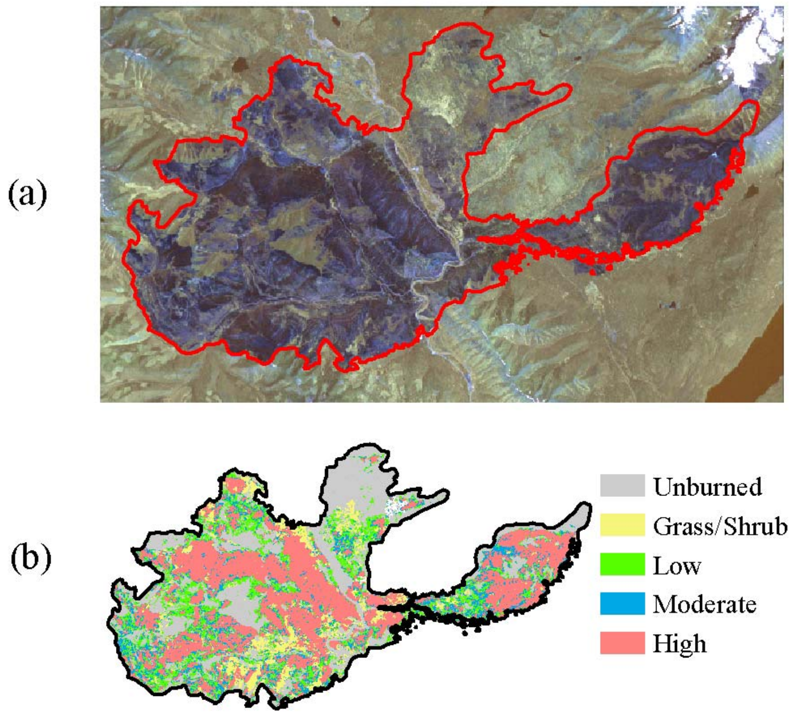


Figure 10. Fire severity data. (a) Post-fire image with fire scar and burn perimeter. (b) Fire severity classes generated through a change detection process.

5.6 Reference Data

In remote sensing projects, reference data serve two main purposes. First, reference data establish a link between variation on the ground and in the image. This link is necessary for assigning image-modeling units (pixels or regions) to discrete land cover classes in the image classification process. Secondly, reference data help assess the accuracy of a map.

The most common sources of reference data for remote sensing projects are aerial photo interpretation and field data collection. It is quite common for remote sensing projects to use photo interpretation as a primary source of reference data or to combine these two sources. Numerous references illustrate the development and use of reference data (Strahler 1980, Shasby and Carneggie 1986, Cibula and Nyquist 1987, Fung and LeDrew 1987, Chuvieco and Congalton 1988, Leprieur and Durand 1988, Franklin and Peddle

1990, Janssen *et al.* 1990, Marceau *et al.* 1990, Cetin and Levandowski 1991, Loveland *et al.* 1991, Peddle and Franklin 1991, Bolstad and Lillesand 1992, Foody *et al.* 1992, Gong and Howarth 1992, Gong *et al.* 1992, Bauer *et al.* 1994, Coppin and Bauer 1994, Green *et al.* 1994, Woodcock *et al.* 1994, Cohen *et al.* 1995, Dikshit and Roy 1996, Shandley *et al.* 1996, Jakubauskas 1997, Johnston *et al.* 1997, Cross *et al.* 1988, Deppe 1998, and Lo and Watson 1998). Many of these studies used photo interpretation in conjunction with field sampling, while many relied exclusively on the photo interpretation to provide these reference data. Independent of the source of reference data, it is important to promote consistency between the training and accuracy assessment data. It should be of similar type and follow the taxonomic logic and data standards. For most projects, the same type of data is collected for training and accuracy assessment applications.

In R1-VMP, training and accuracy assessment data are generated through a structured aerial photo interpretation process (Appendix C) that integrates a variety of field sampled inventory datasets (Appendix D). Our experience suggests that an aerial perspective is often useful for remote sensing training data acquisition and that skilled interpreters can add local knowledge and experience to the classification process. Additionally, resource aerial photography remains the most commonly available remote sensing data source; however, we integrate high-resolution, multi-spectral data, with resource photography where available.

This structured photo interpretation process provides an explicit mechanism to integrate existing field sample data from a variety of sources, both within the USDA Forest Service and from cooperating entities. Existing field data is screened to insure data quality and currency using a standardized process. This provides the opportunity to benefit from the agency's substantial investment in field data while screening out data rendered unusable by management activities, disturbance agents, and/or time since collection. Through this process the image interpreter is able to "fit" field data and other ancillary data to the segmented imagery. This process accomplishes the same objective described by Robinson and Tilton (1991), but fits the training data to the segmentation rather than fitting the segmentation to the training data.

Common image interpretation techniques are used to characterize elements of vegetation pattern that comprise lifeform, dominance type, tree size class, and tree canopy cover (Avery 1977, Campbell 1987, Lillesand and Kiefer 1987, Lachowski *et al.* 1996). The variables collected include: lifeform/landuse class cover percent and connectivity, dominance type cover percent and connectivity, tree size class cover percent, tree canopy cover percent, and connectivity, and total vegetation canopy cover percent (Figure 11).

Field-sampled tree, vegetation composition and ground-cover composition data were collected on a subset of a randomly-selected set of region-polygons as a means to validate the photo interpretation reference data collection. Data were collected following Forest Service common stand exam (CSE) protocols and data was loaded into Field Sampled Vegetation (FSVeg) database. A comparison of the field-sampled data and the photo-interpreted data for tree dominance type, tree sizeclass and tree canopy cover is found in appendix E.

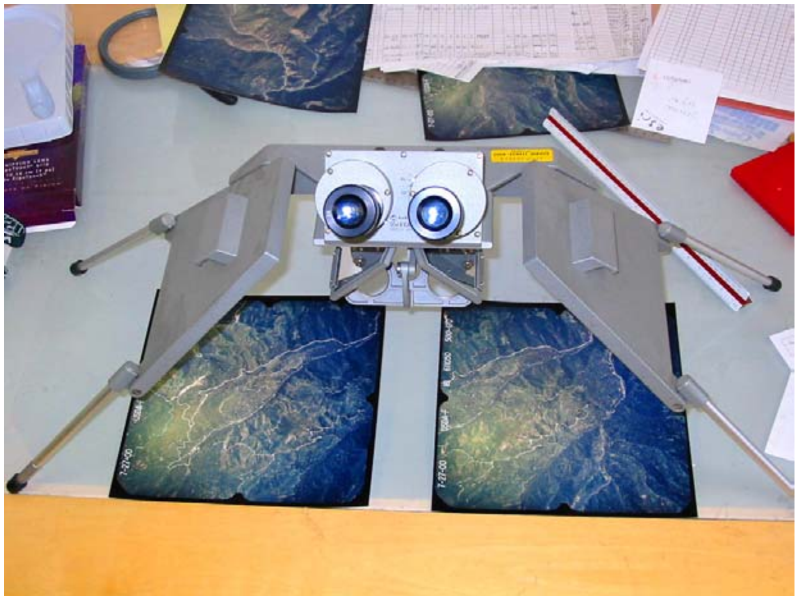


Figure 11. Stereoscope used in the reference data collection process.

5.7 Hierarchical Classification

The Federal Geographic Data Committee (FGDC) Vegetation Classification Standards (FGDC 1997) establishes a hierarchical existing vegetation classification with nine levels. The top seven levels are primarily based on physiognomy. The two lowest levels, alliance and association, are based on floristic attributes. The USDA Forest Service recently released the national direction for classification and mapping of existing vegetation to implement the FGDC standards and to provide direction for classifying and mapping structural characteristics (Brohman and Bryant 2003). This direction applies to a variety of geographic extents and thematic resolutions characterized as map levels. The Northern Region Vegetation Mapping Project is specifically designed to meet this national program direction at the mid-level.

Through the classification functionality of eCognition, a nested hierarchical classification scheme is applied that uses membership functions derived from knowledge bases for the physiognomic and structural classifications and fuzzy-set classifiers based on reference data and nearest neighbor algorithms for the floristic (dominance type) classification. This design provides a consistent linkage between the floristic and structural classifications commonly used by the agency at the mid-level and the physiognomic classifications used at the broad-level and national-level and required by the FGDC vegetation classification standards (Brohman and Bryant 2003).

Implementation of this classification hierarchy produces separate GIS coverages, grids and associated geospatial databases for four primary attributes. These attributes include:

lifeform, dominance type, tree canopy cover, and tree size class. The hypothetical dominance type, tree size class, and tree canopy cover map products included in figure 12 illustrate the relationships of these attributes to the original image objects. These original image objects were merged following the minimum map feature standards from section 4.4. The merged image objects were then used to produce the GIS coverages and grids for the four primary map products. The original image objects with the four primary attributes could be obtained for analysis applications requiring different minimum map feature standards and/or different attribute combinations than those available from the R1-VMP deliverable map products. For information and assistance contact Northern Region, Engineering Staff; Geospatial Group. No coverage and grid combining the four attributes was produced through R1-VMP. The analytical logic used to combine these attributes should be based on intended analysis objectives. Any combination of these four primary map products could be produced to meet specific analysis objectives, with the logic of the combination defined by the end user. It is expected that a combined coverage and grid will be required to meet a variety of general analysis objectives and business needs. The specific process and logic used to produce this combined product will be defined by the Northern Region Vegetation Council and released as a map product following its completion.

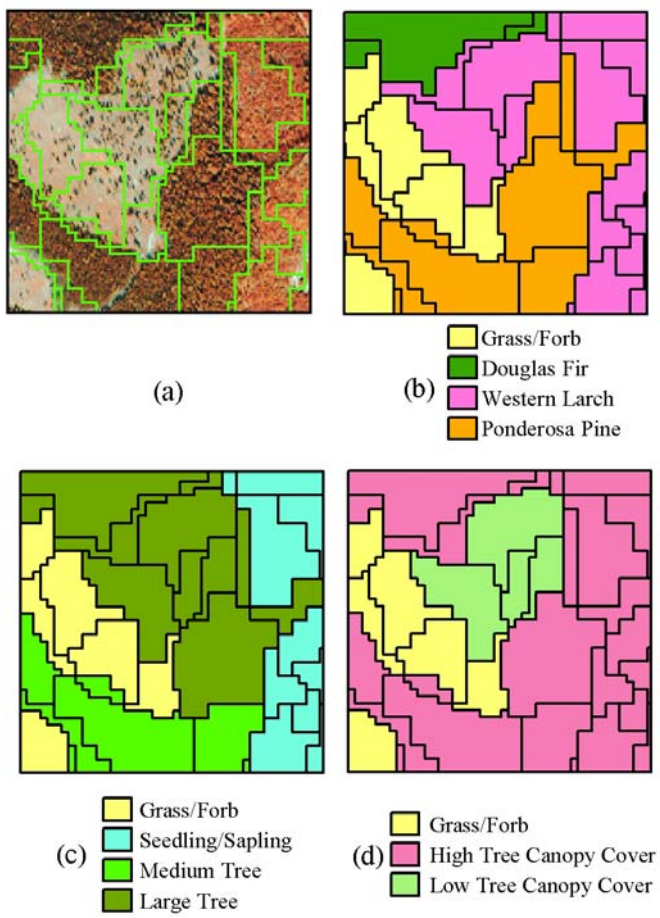


Figure 12. Hypothetical classification attributes (map units) and image objects.

5.8 Mosaic Sub-path Data Models

The sub-path data models described in section 5.2 and processed as described in sections 5.3 through 5.7 were clipped and merged to create continuous GIS coverages and grids for the four primary map products. The clip and merge process created non-overlapping model boundaries (Figure 13) within the overlap zones form the original sub-path data models.

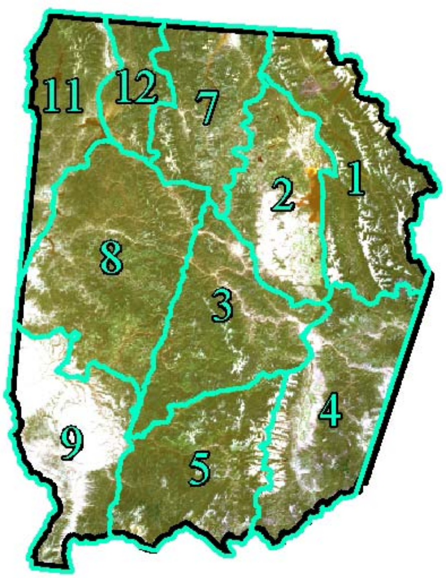


Figure 13. Sub-path data model mosaic used for primary map products.

5.9 Accuracy Assessment

Accuracy assessments are essential parts of all remote sensing projects. First, they provide the basis to compare different methods and/or sensors. Secondly, they provide information regarding the reliability and usefulness of remote sensing techniques for a particular application. Finally, and most importantly, accuracy assessments support the spatial data used in decision-making processes. Too often vegetation and other maps are used without a clear understanding of their reliability. A false sense of security about the accuracy of the map may result in an inappropriate use of the map and important management decisions may be made on data with unknown and/or unreliable accuracy. Although quantitative accuracy assessment can be time-consuming and expensive, it must be an integral part of any vegetation-mapping project.

Accuracy, however, is not a state variable. It is very important to evaluate the results of any accuracy assessment in the context of the intended analysis application and the management decision the data and analyses are intended to support. This evaluation needs to balance the desired level of precision (i.e., the level of thematic detail) with the desired level of accuracy. For many analyses, detailed thematic classes are aggregated to produce fewer, less detailed and more accurate classes. It is appropriate in these instances to assess the accuracy of the aggregated classes rather than characterize the aggregations with the detailed assessment. It may even be appropriate to aggregate some classes based on the structure of the error, provided that the aggregations meet the analysis objectives. It is also important to determine the level of uncertainty that is acceptable to support a particular management decision. Many management decisions are based on the relative ranking of alternatives rather than the absolute differences. Conversely, some simulation modeling applications are better served by more precise (thematically detailed) data than by more accurate generalized data. These modeling applications are often used to establish long-term vegetation pattern and process relationships. These models generally perform better with a more detailed representation of vegetation patterns.

The dominance type map unit design process described in section 4.1 produced slightly different sets of map units for each model reflecting the ecological differences in these models. Combining the map units for each model resulted in 36 unique dominance types. An objective evaluation of the map accuracy of R1-VMP dominance types illustrated the nature and magnitude of map error associated with this large set of map units and suggested logical aggregations of map units to achieve reasonable accuracy for the regional product. The R1-VMP dominance type map product represents a general-purpose aggregation from 36 to 16 types that are suitable for most analysis applications. It is important to recognize, however, that the structure of the error varied by dominance type and between models. Therefore, forests and/or planning zones may aggregate dominance types differently depending on the intended analysis application and the geographic extent of the analysis area. The hierarchical classification logic used in R1-VMP allows for a relatively simple aggregation of types and recalculation of accuracy for analysis objectives that are not well served by the general-purpose product provided. The accuracy assessment documentation for the R1-VMP dominance type map product is included in appendix E.

Quantitative accuracy assessment depends on the collection of reference data. Reference data is known information of high accuracy (theoretically 100% accuracy) about a specific area on the ground (the accuracy assessment site). The assumed-true reference data can be obtained from ground visits, photo interpretations, video interpretations, or some combination of these methods. R1-VMP used the reference data process described in section 5.6 with a random sample design following Czaplewski (1999). R1-VMP training and accuracy assessment data are generated through a structured aerial photo interpretation process that integrates a variety of field sampled inventory datasets. Our experience suggests that an aerial perspective is often useful for remote sensing training data acquisition and that skilled interpreters can add local knowledge and experience to the accuracy assessment process. Additionally, collecting enough field observations is so prohibitively expensive that valid map evaluation cannot be conducted. R1-VMP followed a random selection process for accuracy assessment regions. However, the photo interpretation process was limited to areas with resource aerial photography coverage. The accuracy assessment locations are illustrated in figure 14.

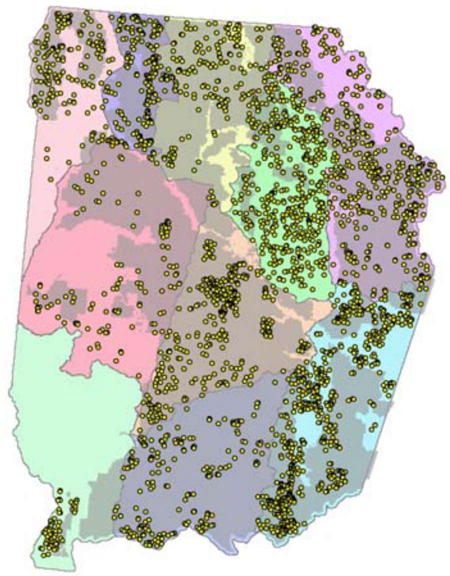


Figure 14. Accuracy assessment region locations used for primary map products.

In a map accuracy assessment sites are generally the same type of modeling unit used to create the map (image objects as well as image objects merged to a specified minimum map feature in R1-VMP map products). Accuracy assessment involves the comparison of the categorized data for these sites (*i.e.*, image objects and merged objects) to the reference data for the same sites. The error matrix is the standard way of presenting results of an accuracy assessment (Story and Congalton 1986). It is a square array in which accuracy assessment sites are tallied by both their classified category in the image and their actual category according to the reference data. The following table provides a hypothetical example error matrix to illustrate accuracy assessment concepts and relationships (actual R1-VMP error matrices are provided in Appendix E). Typically, the rows in the matrix represent the classified image data, while the columns represent the reference data. The major diagonal, highlighted in the following table, contains those sites where the classified data agree with the reference data.

		Tree Dominated	Shrub Dominated	Herbaceous/Non-vascular Dominated	Sparsely Vegetated	Row Total
Classified Data	Tree Dominated	65	4	22	24	115
	Shrub Dominated	6	81	5	8	100
	Herbaceous/ Non-vascular Dominated	0	11	85	19	115
	Sparsely Vegetated	4	7	3	90	104
	Column Total	75	103	115	141	**434**

Overall Accuracy = 321/434 = 74%

Producer's Accuracy
Tree Dominated = 65/75 = 87%
Shrub Dominated = 81/103 = 79%
Herb/Non-vasc. Dominated = 85/115 = 74%
Sparsely Vegetated = 90/141 = 64%

User's Accuracy
Tree Dominated = 65/115 = 57%
Shrub Dominated = 81/100 = 81%
Herb/Non-vasc. Dominated = 85/115 = 74%
Sparsely Vegetated = 90/115 = 87%

The nature of errors in the classified map can also be derived from the error matrix. In the matrix, errors (the off-diagonal elements) are shown to be either errors of inclusion (commission errors) or errors of exclusion (omission errors). Commission errors are shown in the off-diagonal matrix cells that form the horizontal row for a particular class. Omission error is represented in the off-diagonal vertical row cells. High errors of omission/commission between two or more classes indicate confusion between these classes (Story and Congalton 1986).

Useful measures of accuracy are easily derived from the error matrix.

- Overall accuracy, a common measure of accuracy, is computed by dividing the total correct samples (the diagonal elements) by the total number of assessment sites found in the bottom right cell of the matrix.

- Producer's accuracy, which is based on omission error, is the probability of a reference site being correctly classified. It is calculated by dividing the total number of correct accuracy sites for a class (diagonal elements) by the total number of reference sites for that class found in the bottom cell in each column.

- User's accuracy, which is based on commission error, is the probability that a map feature on the map actually represents that category on the ground. User's accuracy is calculated by dividing the number of correct accuracy sites for a category by the total number of accuracy assessment sites, found in the right-hand cell of each row, that were classified in that category.

Confidence intervals are a commonly reported component of statistical estimates. They provide the user additional information regarding the reliability of the map product. Confidence intervals are included for each of the R1-VMP accuracy assessments.

It is often useful to evaluate these measures of accuracy relative to the aerial extent of each class. For example, when a particularly common class (e.g., 50 - 75% of the map area) has either a very high or a very low accuracy it has a disproportionate effect on the utility of the map for general analysis applications without a corresponding effect on the accuracy assessment. Conversely, a relatively rare type (e.g., 1 - 2% of the map area) regardless of its accuracy has relatively little effect on the utility of the map for general analysis applications but has the same effect on the accuracy assessment as the common type. For this reason, the R1-VMP accuracy assessment error matrices include proportions of area represented by each class.

A relatively recent innovation in accuracy assessment is the use of fuzzy sets for accuracy assessments. Traditional accuracy assessment, as described above, suffers from certain limitations. First, it assumes that each accuracy site can be unambiguously assigned to a single map category (Gopal and Woodcock 1994); when in truth it may be part of a continuum between map categories. Secondly, the traditional error matrix makes no distinction between magnitudes of error. For example, in a traditional error matrix, misclassifying "Ponderosa pine dominance type" as "Intolerant mixed conifer dominance type" carries the same weight as the error of misclassifying it as "water." Fuzzy logic is designed to handle ambiguity and, therefore, constitutes the basis for part of the R1-VMP accuracy assessment. Instead of assessing a site as correct/incorrect as in a traditional assessment, an assessment using fuzzy sets can rate a site as absolutely wrong, understandable but wrong, reasonable or acceptable match, good match, or absolutely right (Gopal and Woodcock 1994). The resulting accuracy assessment can then rate the seriousness of errors as well as absolute correctness/incorrectness. For these reasons, the R1-VMP accuracy assessments for life form and dominance type include fuzzy set-based error matrices as well as the "fuzzy weights" used to convert the "straight up" error matrix.

6.0 Vegetation Inventory

The vegetation inventory data for most land management agencies and private companies only partially covers their ownership, are often out of date, and are rarely compatible with adjacent landowners. This is particularly true for federal land management agencies such as the USDA Forest Service, Northern Region, that manage large geographic areas for a variety of management objectives. Historically, most ground-based inventory data have been collected using standard plot and quick plot stand exams, as defined by the Timber Management Control Handbook (USDA Forest Service, FSH 2709). Using the USDA

Forest Service, Northern Region, as an example, Brewer and others (2002) observed that most of these data apply almost exclusively to the suitable timber base, as defined by the National Forest Management Act of 1976 (US Public Law 94-588 1976). The remaining areas outside the suitable base have few stand exam data even though many of the resource questions and issues apply to all lands. The collection of stand-based data on part of the land base introduces an unknown bias when these data are used to represent the whole land base. In addition, there are no specific design considerations for the collection and storage of these data to facilitate their use by other land management agencies or private landowners.

Declining budgets for public land management agencies have resulted in dramatic reductions in the amount and geographic extent of current, detailed inventory data. The precipitous decline in standard plot and quick plot stand exams reflects budget trends for inventory programs throughout the USDA Forest Service. Brewer and others (2002) describe the effects of these reductions on current data and graphically depict the status of stand exam based inventory data for the USDA Forest Service, Northern Region (Figure 13). This graph illustrates the decline in acreage of stand exams, by year, from 1980 to 2001.

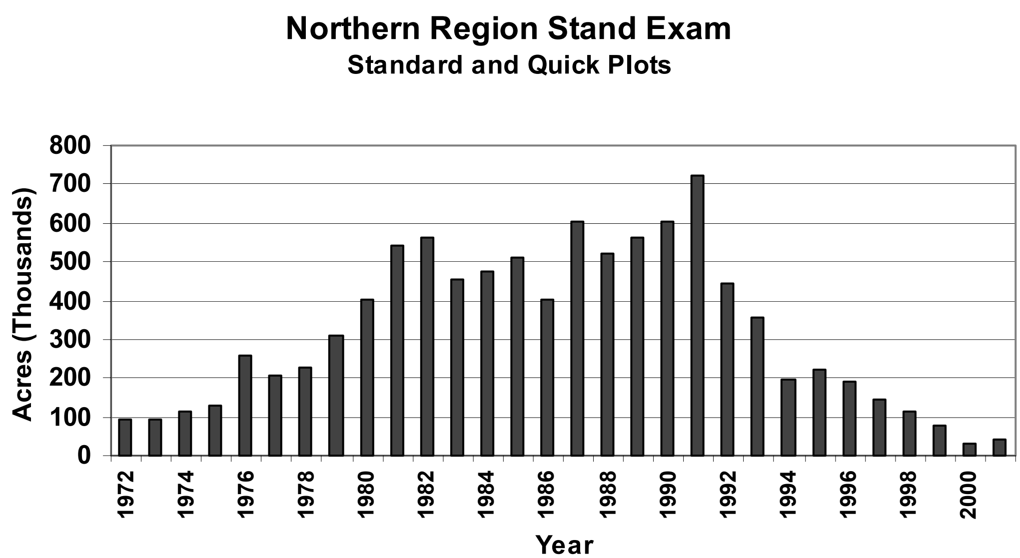


Figure 15. USDA Forest Service, Northern Region, stand exam program status summary for 1980-2001.

Reductions in timber sale programs on public lands, particularly National Forests, have had effects on the management (*i.e.*, harvest schedules) of both industrial and non-industrial private forests (Flowers *et al.* 1993). This change in harvest schedules has affected the currency and completeness of inventory data from private forests; proprietary data private forest landowners are reluctant to share.

Given the discontinuous and incomplete nature of most forest inventory data, as well as the difficulty in maintaining currency and sharing with other landowners, data generated by the Forest Inventory and Analysis (FIA) program of the USDA Forest Service provides a viable alternative. FIA utilizes a systematic random grid of plot clusters, remeasured periodically, to monitor the extent, condition, uses, impacts of management, and health of forest ecosystems across all ownerships in the United States. These data provide an unbiased sample for many inventory related questions. The Society of American Foresters (2000) state that "FIA is the only program that monitors the extent, condition, uses, impacts of management, and health of forest ecosystems across the United States." They further state… "FIA data serve as the foundation of large-scale policy studies and perform a pivotal role in public and private forest planning." They cite examples of regional and sub-regional analyses that influence major economic and ecological management decisions including:

- Strategic planning efforts by wood-using industries routinely incorporate FIA data into timber supply and timber product outputs.
- Development of criteria and indicators of forest sustainability depend on the growth removals, and inventory data compiled by FIA (Reams *et al*. 1999).
- National forest carbon budgets for reporting under international agreements are dependent on FIA data (Heath and Birdsey 1997).
- Assessment of ecological change and economic damage resulting from disasters such as hurricanes or widespread wildfires.

Van Deusen and others (1999) suggest a current and accurate forest ecosystem inventory is prerequisite to substantive discussion of issues like sustainability, national forest policy, carbon sequestration, changes in growth and productivity, changes in landuse and demographics, ecosystem health, and economic opportunities in the forest sector.

Over the past decade concerns have been raised regarding the currency of FIA data, historically remeasured every 6 to 18 years (Gillespie 1999). These concerns prompted the American Forest and Paper Association (AF&PA) to convene two Blue Ribbon Panels on FIA (AF&PA 1992, 1998). The high level of user community support and concerns regarding currency of FIA data surfaced by these panels and subsequent Congressional hearings resulted in legislation to implement an annualized forest inventory and monitoring program to reduce the remeasurement interval (Czaplewski 1999). It is expected that the annualized inventory design will result in substantial improvements in the currency of FIA data.

Historically, the FIA program produced area estimates of forest types in two phases following a double sampling design (Reams and VanDeusen 1999). Phase one placed a systematic random grid on aerial photography (normally 1:40,000 scale National Aerial Photography Program NAPP). These points (with a minimum area of at least 1 acre or a strip at least 250 feet wide) were then classified as forest or non-forest based on the FIA definition of at least 10% tree canopy cover. The second phase subsampled the first phase points in the field to confirm the classification. This process provided the forest area estimation for the application of the field sampling of the permanent plot clusters in the third phase. Reams and VanDeusen (1999) suggest the following three problems associated with this historical method:

- No forest non-forest map is produced
- The photo interpretation process is time-consuming and labor intensive
- Current aerial photography is not always available

These issues become increasingly problematic with the shift to an annualized inventory program. R1-VMP utilizes FIA data for two important processes. In the map unit design process FIA data are classified and utilized to estimate abundance of dominance types. These estimates are used to define the dominance types with sufficient aerial extent to include as a map unit and to identify logical aggregation strategies for dominance types with insufficient extents. The FIA data are also used for the development of sample-based Map Unit Descriptions (MUDs). In this process the FIA data are spatially associated to the R1-VMP map products and are then compiled to quantify various vegetation characteristics for each of the thematic classes in the map product (*e.g.*, dominance types or tree diameter classes). The map unit descriptions for the primary map products from R1-VMP are included in appendix F. Similar MUDs could be developed for any map products derived from R1-VMP data.

7.0 Maintaining Existing Vegetation Maps and Associated FIA Data

One key element to planning, inventory and monitoring success is the establishment of consistent vegetation baseline information. Once established, changes to vegetation can be determined along with cause of change. This information provides monitoring data to analyze the effects of change in condition of wildlife habitats, late successional old growth, forest health, mortality, growth, and standing forest volumes. Vegetation maps, when combined with ground-based inventories information, are fundamental to meet the needs of Forest and Rangeland Resources Planning Act (RPA), Forest Land and Resource Management Plans, bioregional assessments, and more localized watershed and project planning efforts. To understand vegetation changes on the landscape and its affect on related natural resources, it is necessary to track changes as well as cause of change for comparing to baseline inventories. Tracking imagery source and dates of baseline maps as well as update imagery source and date are necessary metadata. Cause of change is also important to know and aids in analysis of affected resources, such as wildlife habitat or cumulative watershed impacts.

The goal for vegetation resource information, stated in the Existing Vegetation Classification and Mapping Technical Guide (Brohman and Bryant 2003), is to have vegetation maps no older than 5 years. Map areas require updates where changes to vegetation have occurred from various causes, such as wildfire, harvest, insect and disease damage, vegetation treatments, re-growth, agriculture or other type conversions. Activity databases, aerial detection surveys, and fire severity mapping, along with digital change detection methods are useful in identifying where updates need to occur, as well as determining causes of changes in vegetation cover.

This maintenance and update strategy is designed to work with the Forests and other cooperating entities to annually identify areas of changed conditions for systematic updates of the R1-VMP data. The coordination work will occur near the end of each field season (late-September/early-October) to facilitate both a field and office review. These reviews, along with other feedback throughout the year, will serve to identify the priority areas for the next fiscal year program of work. Once the identified areas of changed condition are updated (within the limits of budget and resources) the R1-VMP data will be re-released annually on April 1st of each year.

It is expected that the Remote Sensing Applications Center (RSAC) will continue its support of the Burned Area Emergency Recovery (BAER) teams with the production of Burned Area Reflectance Classifications (BARC). The BARC data, with local interpretation and correction, will provide part of the basis for large fire activity updates. It is also expected that the Cooperative Forestry and Forest Health Protection staff will continue to provide Aerial Detection Survey (ADS) data for areas included in the current year's program of work. The ADS data, with local interpretation and correction, will provide part of the basis for insect, pathogen, and climate disturbance activity updates. Systematic digital change detection (following Coppin *et al*. 2001) coupled with activity records for National Forest System lands can provide part of the basis for silvicultural activity updates. Areas identified through theses processes can be spatially associated with the FIA plot locations and provide information for the following year's annualized inventory program of work.

By design, R1-VMP had extensive local involvement and review by the Forests as well as other cooperators. However, there will be systematic and non-systematic errors identified once these data are used operationally. This maintenance strategy also includes a "correction" component for addressing errors that were not identified during production and reviews. Additionally, this process could provide a mechanism for adding data elements to R1-VMP that were not in the original design or deliverable products. These additional data elements could result in adaptations of base products for specific analysis objectives or new specifically designed map products.

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