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Development of Input Data Layers for the FARSITE Fire Growth Model for the Selway-Bitterroot Wilderness Complex, USA

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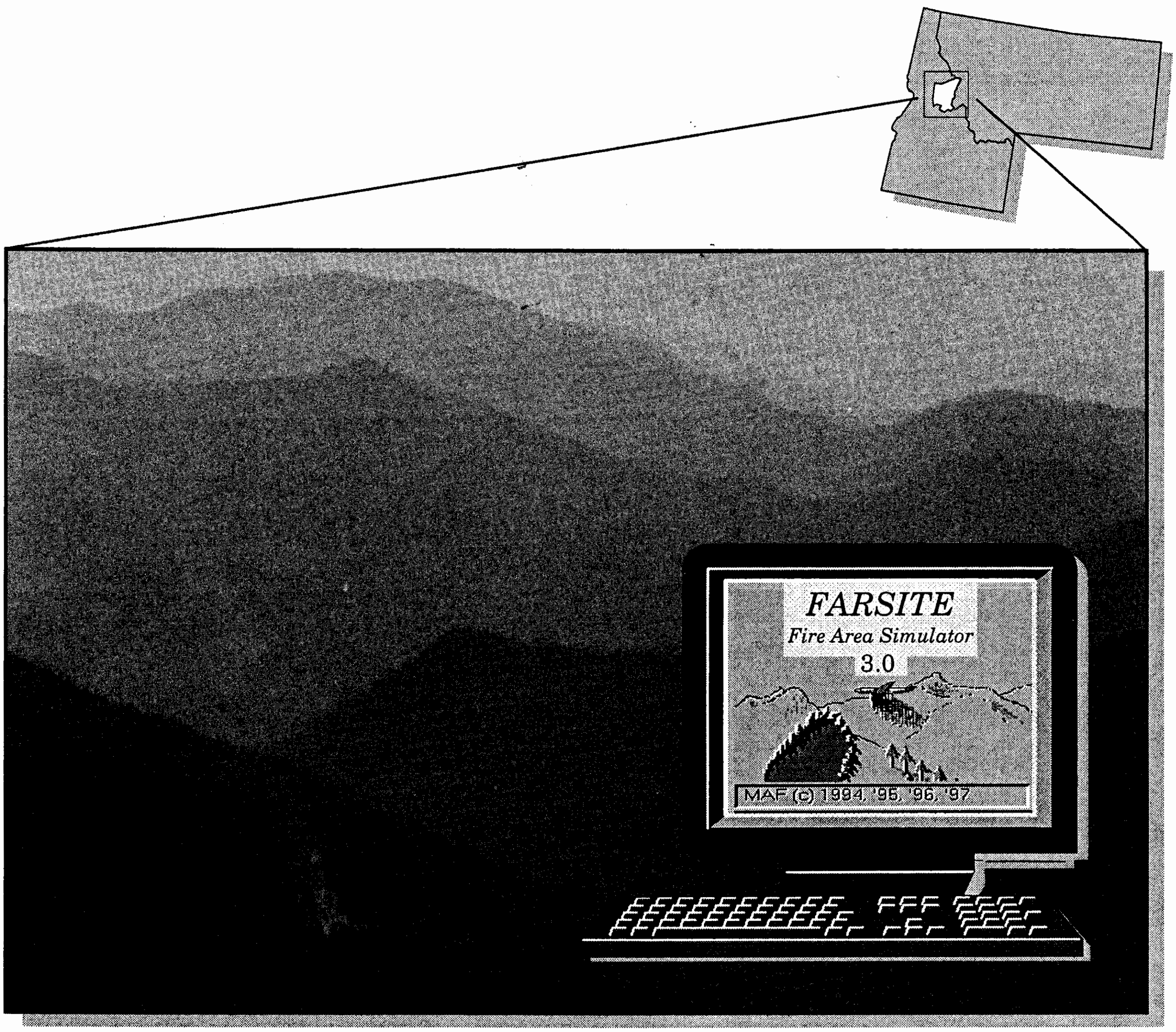

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Research Summary

Fuel and vegetation spatial layers needed for the execution of the FARSITE fire model were created for all lands in and around the Selway-Bitterroot Wilderness Area in Montana and Idaho using satellite imagery and potential vegetation type modeling. FARSITE is a spatially explicit fire growth model used to predict the size, intensity, spread, and rate of wildland fires. FARSITE requires eight data layers as input; fire behavior fuel model, crown closure, crown height, stand height, crown bulk density, elevation, aspect, and slope. These input layers were created from a digital terrain model and the base vegetation layers of potential vegetation type, cover type, and structural stage. This methodology was designed to be easily replicated by others. Potential vegetation types were modeled from topographic and geographic data layers based on criteria developed at modeling workshops. Cover type and structural stage layers were taken from a comprehensive satellite imagery classification of Montana and Idaho lands. Fuel models were assigned to each potential vegetation type, cover type and structural stage combination by area ecologists and fire managers. An accuracy assessment of the layers showed the potential vegetation type layer is 60 percent accurate and the fuel model layer is 59 percent accurate.

Acknowledgments

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Introduction

Fire managers need to quickly evaluate the potential size, rate, and intensity of a wildland fire under current and future conditions to aid in the planning and allocation of resources used to directly or indirectly manage the fire. Recent advances in computer software and hardware technology have allowed the development of several spatially explicit fire behavior simulation models that predict the spread and intensity of fire as it progresses across the landscape (Anderson and others 1982; Andrews 1989; Baker 1992; Ball and Guertin 1992; McAlpine and Wotton 1993; Turner and Dale 1991). Some of these computer programs have the ability to project future fire growth and compute maximum perimeters of wildland fires for planning or for real-time simulations. One of the best spatially explicit fire growth models is Finney's (1994) computer program FARSITE (Fire ARea SImulator) available for most IBM-compatible personal computers. FARSITE is currently being used by many wildland fire mangers in the United States and other countries to predict the characteristics of prescribed natural fires.

FARSITE propagates fire across landscape using the fire behavior routines found in the one-dimensional fire model BEHAVE (Albini 1976; Andrews 1986; Andrews and Chase 1989; Rothermel 1972). FARSITE requires eight spatial data layers for a comprehensive evaluation of surface and crown fire behavior. A spatial data layer, also called a "raster" layer, is defined as a georeferenced grid of squares called pixels that have values that describe certain characteristics of the associated piece of ground. The first raster layer needed by FARSITE is called a Digital Elevation Model (DEM) where each pixel is assigned an elevation. Slope and aspect are also required FARSITE input layers, and they can be derived from the DEM layer using elevation values from surrounding pixels. The fourth layer is a Fire Behavior Fuel Model (FBFM) map. Pixels in this layer are assigned the fire behavior fuel model (Anderson 1982) that best represents the fuel complex that would produce expected fire behavior for the corresponding piece of ground. Average canopy cover, in percent, is needed as a map to compute hourly fuel moistures. FARSITE can compute crown fire behavior if three other data layers are present (Rothermel and others 1986). Average stand height and average crown base height are data layers that FARSITE needs to compute crown fire initiation using the Van Wagner (1977, 1993) model and spread from Rothermel (1991). A crown bulk density raster map is used to compute crown fire spread, along with the previously mentioned crown cover and stand height map.

An important factor in accurately predicting spatial fire behavior using FARSITE is the quality of the input spatial data layers. These data layers must be accurately and consistently derived across all lands and ecosystems in the analysis area, and more important, the layers must agree with all other thematic layers in the Geographic Information System (GIS). Unfortunately, many land management agencies do not have the FARSITE input layers available to compute spatial fire behavior and growth. Moreover, the development of these data layers for large geographic areas with diverse ecosystems requires a high level of expertise, an advanced computer technology, and an abundance of computer resources. An inexpensive and repeatable method of creating these input raster data layers is needed so the layers can be efficiently developed and used by many agencies to spatially model fire behavior and manage wildland fire.

In this paper we describe the development of the suite of data layers needed by FARSITE for the simulation of wildland fires that occur in and around the Selway-Bitterroot Wilderness Complex (SBWC) of Montana and Idaho. We developed these input layers from three base vegetation data layers of potential vegetation type, cover type, and structural stage. A major goal of this effort was to create these layers using a methodology that could be repeated by other land management organizations to create their own FARSITE data layers. This project used a combination of GIS, satellite imagery, ecological and fire management knowledge, and management participation to generate the FARSITE layers. We will detail the generalized methods used to create these maps and then present the results of our fuels mapping effort.

Background

In fall 1995, fire managers from the Nez Perce, Bitterroot, and Clearwater National Forests of Idaho and Montana approached scientists at the Intermountain Fire Sciences Laboratory (IFSL) about developing the set of FARSITE input spatial data layers they would need to simulate prescribed natural fires and wildfires in the Selway-Bitterroot Wilderness Area. The fire managers had tried to create these layers but did not have remote-sensing expertise and adequate computer equipment. Coincidently, many IFSL scientists and support personnel had been intimately involved in the Interior Columbia Basin Ecosystem Management Project (ICBEMP) scientific assessment (Quigley and others 1996) and, as a result, had the needed computer and data resources. These scientists undertook the project under the auspices of a newly formed technology transfer organization called the Fire Modeling Institute managed at the IFSL. The Institute is a new concept for applying technical knowledge and specialized skills to complex issues facing resource managers. Land managers bring potentially complex management analysis projects to the Fire Modeling Institute and participate in the project's successful completion. The IFSL has the latest in computer hardware and software technology, extensive scientific expertise (especially in wildland fire issues), and highly trained personnel available to use on the project.

FARSITE Description

The fire growth model FARSITE (Finney 1995) computes fire intensities and spread rates for numerous points across the landscape using the fire behavior algorithms of Albini (1976), Rothermel (1972), and Rothermel (1991). The fire is then propagated across the landscape from these points using a series of ellipses generated from Huygens' principle, which is a wave-type model. Huygens' principle essentially states that a wave can be propagated from points on its edge that serve as independent sources of smaller waves (Richards 1990). FARSITE then connects all points at the end of the smaller waves to delineate the fire front. The fuels, weather, and topography of areas within the fire line dictate fire intensity and spread rates. A detailed discussion of the FARSITE program is given in a user guide (Finney 1995). FARSITE was developed primarily to be used as a tool in the management of prescribed natural fires, although it could be used in wildfire situations.

The FARSITE model uses spatial data layers of topography, surface fuels, crown fuels, and weather to predict fire behavior. Topography is described as elevation, aspect, and slope from a Digital Elevation Model (DEM) raster layer (USGS 1987). Surface fuels can be input as either a standard FBFM (Anderson 1982) or customized FBFM (Burgan and Rothermel 1984). Crown fuels are described from four stand characteristics. Stand height (m) is the average height of the dominant tree layer. Crown height (m) is the average height of the bottom of the tree crowns in the stand. This parameter is important for predicting the transition of a surface fire to a crown fire. Canopy closure (percent) is the average vertically projected tree crown cover in the stand. Only trees taller than the shrub layer are used to compute this parameter. Last, crown bulk density (kg m^{-3}) is the density of the crown biomass above the shrub layer.

FARSITE weather data are not input as a spatial data layer, but rather as a set of generalized weather text (ASCII) files composed of a stream of hourly or daily temperatures, precipitation, and relative humidities (Finney 1995). Each weather file is assigned to a point on the ground, and FARSITE extrapolates this weather across the landscape using adiabatic lapse rates. Wind is treated differently than other weather parameters in FARSITE. Wind speeds and directions are specified by time of day in a separate set of wind ASCII files. Each wind file is assigned to a portion of the simulation landscape using FARSITE protocols. A complete discussion of input layers and data files is presented in the FARSITE user manual (Finney 1995).

FARSITE creates several raster and vector spatial data layers of computed fire intensity (kW m^{-1}), spread rates, and flame lengths stratified in space and time. Fire growth and intensity patterns are displayed on the computer screen overlaid on topography and fuels layers. All FARSITE output layers can be exported to a GIS for additional analysis and display. Keane and others (1995b) successfully linked FARSITE to a forest succession model to evaluate the effects of fire across a large landscape in Glacier National Park under a climate change scenario.

FARSITE has specific data needs for the simulation of wildland fire. First, spatial fire behavior predictions require a fine spatial resolution of the input data layers to delineate the complexity of the landscape (dissected or flat, for example). Finney (1995) mentions that a 30 m pixel size for all data layers is probably the optimal resolution for accurate assessments of fire spread in heterogeneous conditions considering the slowness of computer simulations with finer grids. Second, all data layers and data files must be congruent. This means that data values assigned to a pixel must agree within and across all data layers. For example, crown height must not exceed stand height for any pixel. Next, FARSITE requires a specific format for all data layers and input files (Finney 1995). These formats are available in many current GIS export programs. Last, the speed of FARSITE displays and simulations can be improved if the simulation landscape is divided into blocks that are approximately 375 by 550 pixels, or roughly the coverage of a standard 7.5 minute U.S. Geological Survey quadrangle map.

Development Tools

Remote sensing is often the primary tool used for development of the FARSITE input layers, especially for large land areas (greater than 100,000 ha). Aerial photo interpretation and classification is a proven technique for spatially defining areas of homogeneous vegetation and fuels (Jensen 1986; Lillesand and Kiefer 1994; Schowengerdt 1983). However, photo delineation is often costly and time-consuming for large geographic areas, and the interpretation of fuels is often limited to the minor textural differences in a photograph and interpreter subjectivity (Jensen 1986). Moreover, describing fuel characteristics from aerial photos is problematic because it is often difficult to see the forest floor through the forest canopy. Most photo interpretation projects assign fuel models to vegetation type or topographic zones (Greer 1994).

Satellite imagery is an inexpensive method to generate fuels and vegetation data layers over large areas (Bain 1990; Greer 1994). Most imagery consists of an assessment of light reflectance measured across various wavelengths in the thermal magnetic spectrum (Jensen 1986; Lillesand and Kiefer 1994; Schowengerdt 1983). An advantage of satellite imagery is that it is frequently, consistently, and comprehensively collected across vast geographical regions. However, many image classifications are often inexact because of confusing spectral signatures, and most classifications only accurately identify broad vegetation communities on the landscape because these types have the greatest difference in light reflectance (Bain 1990; Bolstad and Lillesand 1992; Schowengerdt 1983). Moreover, satellite image classifications are often incompatible with the land classification systems used by land managers. Shadow, atmospheric phenomenon, haze, smoke, topography, and georectification errors can also contribute to potential errors in the final classified image (Foody and Curran 1994; Leprieur and others 1988).

Fuels characteristics are rarely assessed from remotely sensed imagery because forest floor properties are not discriminated well by the satellite sensors because of forest canopy interference (Elvidge 1988). Another problem with using remotely sensed digital imagery to map fuel and vegetation characteristics is the fixed-resolution of the pixels (Jensen 1986). Common satellite imagery products of SPOT, Thematic Mapper (TM), or Multi-Spectral Scanner (MSS) scenes have 10, 30, and 80 m pixel widths, respectively. Unfortunately, many fuel characteristics are not confined to these scales. Surface fuels often have a higher spatial variability than crown fuels. Small pixel sizes usually require more computer resources and result in slower computing and display time depending on the computer system.

Large pixel sizes usually result in loss of spatial information because mapped characteristics must be averaged over large areas. Also, it is difficult to discriminate between woody fuel size classes using current satellite imagery because of the coarse resolution and inadequate wavelengths of available sensors.

Study Approach

All SBWC FARSITE fuels layers were created from three primary vegetation layers—**potential vegetation type, cover type, and structural stage**. This three-tiered classification strategy was successfully used to describe ICBEMP ecosystems and vegetation communities at the coarse and midscale (Quigley and others 1996). We assumed a myriad of ecosystem characteristics could be quantified from this classification triplet based on past succession and ecological research (Arno and others 1985; Kessell and Fischer 1981; Steele and Geier-Hayes 1989). Maps of these ecological characteristics are created by assigning values to classification triplet combinations and then entering these summaries into a data base linked to the three vegetation GIS layers.

The advantages of this approach are many. First, the concept can be used across many spatial scales because the categories in each of the three classifications can be scaled to the appropriate level of application. For instance, a cover type category at a coarse scale may be "needleleaf conifer" whereas the same cover type at a mid or fine scale might be "ponderosa pine." Second, most land management agencies already use these three classifications to some extent in their analyses, and these classifications can be easily developed if they do not exist for some areas. Resource professionals also use some form of these classifications to formally or informally describe stands or watersheds in the field or office. Last, there is a large body of research available on these types of classifications and their mapping (for example, Erye 1980; Shiflet 1994). Many National Forests have existing classifications for these three attributes, but few have accurate maps of these attributes across large land areas.

The first major task was to select the remote sensing medium to create the three base vegetation layers. Our first impulse was to purchase a wide variety of remotely sensed data products, mostly from satellite platforms, and then classify these imagery scenes directly to fuels categories using the latest image processing software. However, it would have been difficult for other land and fire management organizations to repeat the image classification procedure because satellite image processing is as much an art as it is a science, and the final classifications usually have abundant subjective elements. So we decided to use a landscape classification procedure that could be generally applied to any fuels or vegetation mapping project using base vegetation spatial data layers that are commonly available to land management agencies. If these vegetation layers are unavailable, they are probably the layers easiest to create for many geographic areas because they are the ecological attributes most often used in land management planning. We also selected these spatial data layers because they can be used for purposes than other than fuels mapping such as wildlife habitat analysis. Keane and others (1996b) used these same vegetation layers to simulate landscape successional changes across the Interior Columbia River Basin using the model CRBSUM.

The Potential Vegetation Type (PVT) layer, developed specifically for this project, is a spatial map that describes the distribution of "climax" vegetation types across a land area (Kessell 1979; Pfister and others 1977). Climax vegetation types provide an indirect characterization of site type or biophysical setting (Pfister and others 1977). Habitat types and habitat type phases (Pfister and others 1977) are roughly equivalent to PVT's at fine spatial scales, while habitat type groups, fire groups (Fisher and Bradley 1987), or topographic settings (Keane and others 1995b) can be used as PVT's at midscales, which is the scale of reference for this study. The ICBEMP effort used a biophysical model of temperature and moisture to classify and delineate coarse scale PVT's across the Interior Columbia River Basin (Reid and others 1995). The methods used to create the PVT map for this fuels mapping project are discussed in detail in later sections.

The SBWC cover type layer was taken from a comprehensive Satellite Imagery Land Cover (SILC) map developed by the Wildlife Spatial Analysis Laboratory, Montana Cooperative in Wildlife Research Unit at the University of Montana (Redmond and Prather 1996). This project used TM satellite imagery to map vegetation cover types across the entire Northern Region of the USDA Forest Service on both public and private lands. The SILC map is a raster map of polygons with a minimum map size of 2 ha (5 acres). Each polygon is assigned several attributes including cover type, structural stage, and canopy closure. Over 10,000 ground-truth plots were used to validate and refine this extensive map and data base. Several ecological attributes, including structural stage, were assessed at each ground-truth plot, and these data were summarized and assigned to classified polygons. The structural stage layer used in this study was created from the structural stage assignments to SILC polygons that were in turn based on the ground-truth data (Redmond and Prather 1996). This paper does not detail the classification methods needed to create the vegetation cover type and structural stage maps used for fuels mapping because these procedures are quite complex and they have been presented by many other authors (Jensen 1986; Lachowski and others 1995; Redmond and Prather 1996). It is therefore assumed that the vegetation cover type map and structural stage map already exist for any fuels mapping project. These maps can be taken from many sources including timber stand maps, past vegetation mapping projects, and satellite imagery.

Two fire behavior fuel model (FBFM) GIS layers were developed for this project. The SBWC fire managers wanted one FBFM map that would represent fuel characteristics under normal burning conditions and another that would represent severe or extreme burning conditions. Apparently, some plant communities can exhibit drastically different fire behavior after prolonged drought and with high winds. For example, SBWC montane shrub communities are often assigned the Anderson (1982) FBFM 5 (live shrub, low fire intensity fuel model) because of their high summer moisture contents. However, these same communities can exhibit the fire behavior typical of the FBFM 6 (xeric shrub, high fire intensity fuel model) under extreme drought conditions and moderate to high winds because their live fuel moisture contents get quite low. The normal FBFM map will probably be used for many prescribed natural fire plans and real-time simulations. However, the extreme FBFM map is available to simulate wildfires for "worst-case" scenarios. Table 1 presents the fire behavior fuel models used in this study.

Table 1—Fire behavior fuel models (FBFM) used in this project. All fuel models are discussed in detail in Anderson (1982).

Fuel model[a]	Description	Fire behavior[b]	
		Rate of spread	Flame length
		m/sec	*m*
1	Short grass(0.3 m)	0.436	1.22
2	Timber (with grass and understory)	.196	1.83
5	Brush (shrubs and conifer regeneration, 0.8 m)	.10	1.22
6	Dormant brush	.179	1.83
8	Closed timber litter	.0089	.31
9	Ponderosa pine duff	.042	.79
10	Timber (litter and understory)	.044	1.46
98	Water	—	—
99	Nonvegetation (rock, ice, snow)	—	—

[a]From Anderson (1982).
[b]Fire behavior under the following conditions: windspeed 8 km/hr, dead fuel moisture 8 percent, and live fuel moisture 100 percent.

Another type of fuel model was also mapped for this project. A Fire **Effects** Fuel Model (FEFM) was assigned to each PVT, cover type, structural stage combination in the SBWC. The FEFM's are different from FBFM fuel models. Whereas FBFM's are used to characterize expected fire **behavior**, FEFM's characterize actual fuel loadings by size class. The FEFM's are primarily used to quantify the amount of fuel present within polygon boundaries so that fire **effects** such as fuel consumption and smoke generation can be predicted using computer models such as FOFEM (Keane and others 1995a; Reinhardt and others 1997). The FEFM's used in this study were taken from the three fuel photo series guides developed by Fischer (1981a,b,c). Each fuel photo within the guides was considered an FEFM, and the fuel loading data describing the photo were used to quantify that fuel model. The page number of the photo series guide served as an identification number. The FEFM's were assigned to each PVT, cover type, structural stage combination based on the ground-truth data collected for this project and on fire manager assessments. Fuel loading data from Brown and Bevins (1986) and Brown and See (1981) were used to adjust some fire effects fuel models to agree with the PVT, cover type, structural stage descriptions.

Study Area

The Selway-Bitterroot Wilderness Complex (SBWC) consists of 1.15 million ha in and around the Selway-Bitterroot Wilderness Area of Montana and Idaho, USA (fig. 1). This rugged country contains great topographic contrasts with elevational relief from valleys to mountain tops often exceeding 1,500 to 1,800 m (Habeck 1972). Geologically, most of the SBWC consists of granites, gneiss, and schists belonging to the Idaho Batholith. The Bitterroot Mountain crest resulted from a great flat fault that was covered with a continuous ice sheet during the Pleistocene. Elevations range from 550 m along the Selway River to over 3,000 m along the Bitterroot Crest. SBWC climate is generally transitional between a north-Pacific coastal type and a continental type (Finklin 1983). The SBWC has a wide variety of potential and existing vegetation types (Cooper and others 1991; Pfister and others 1977).

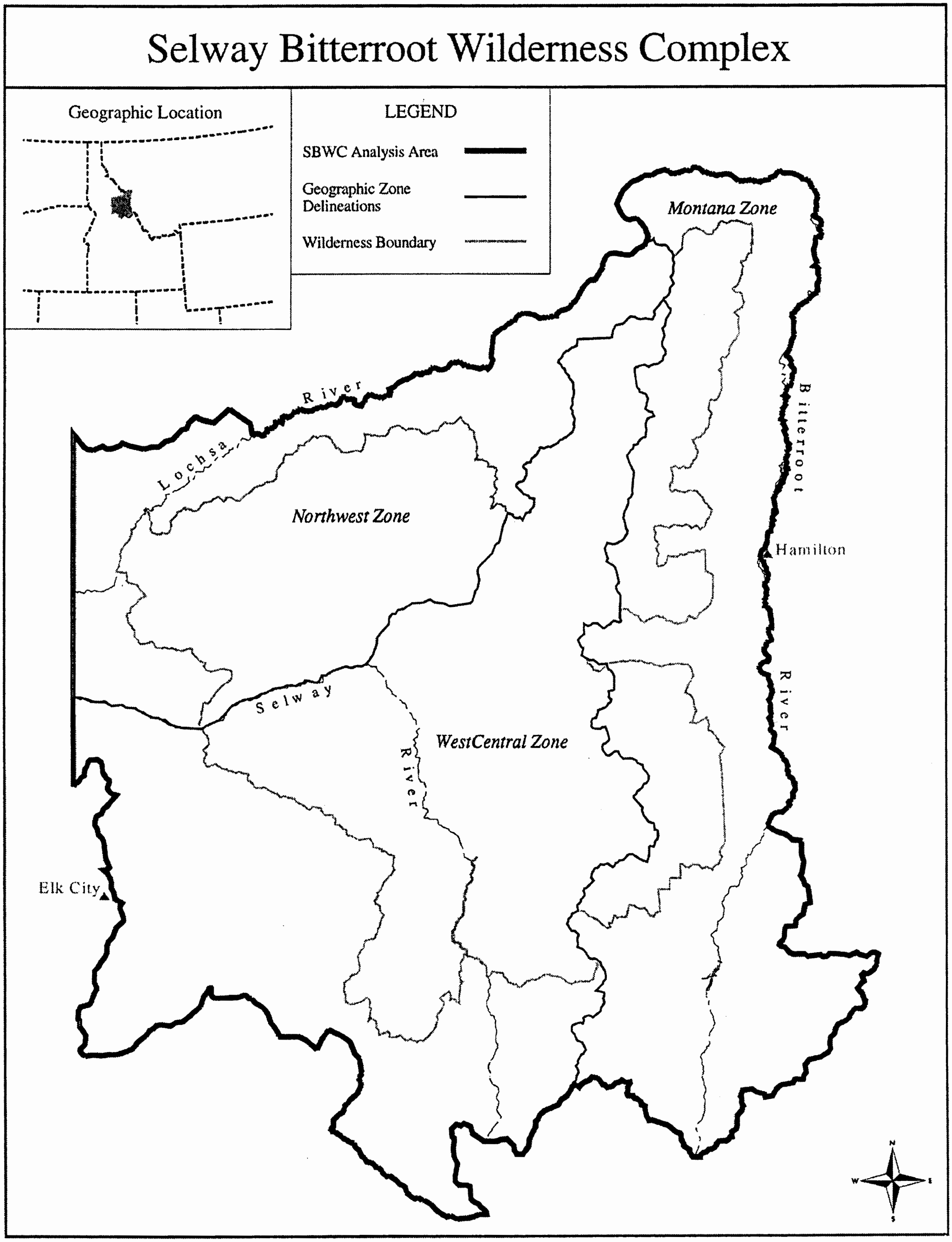

Figure 1—The Selway-Bitterroot Wilderness Complex (SBWC) study area.

The SBWC was divided into three zones because of the great diversity in vegetation, topography, and climate (fig. 1). These zones were delineated based on several coarse scale data layers developed by the ICBEMP scientific assessment (Quigley and others 1996). We used the biophysical settings (Reid and others 1996) and climate maps (Thornton and others 1997) to delineate the broad geographic zones based on similarity in climate, potential vegetation, and topography. The Montana zone (MT) consists of all lands from the crest of the Bitterroot Mountain range down to the Bitterroot River (fig. 1). The North West zone (NW) consists of all lands north of the Selway River to the Lochsa River. The West Central zone (WC) are all remaining lands that are east of Elk City, ID, all the way to the Bitterroot crest.

The MT zone is somewhat drier that the other zones because of the rain-shadow effect of the Bitterroot Mountains. This zone can have grand fir (*Abies grandis*) on north slopes and in valley bottoms below 1,370 m elevation. Douglas-fir (*Pseudotsuga mensiezia*) and ponderosa pine (*Pinus ponderosa*) are usually dominant on the south-facing, lower elevation slopes. Western larch (*Larix occidentalis*) and Douglas-fir grow on the northerly aspects at moderate altitudes. Lodgepole pine (*Pinus contorta*), subalpine fir (*Abies lasiocarpa*), and Engelmann spruce (*Picea engelmannii*) forests are common at the subalpine environments, while upper subalpine and timberline forests consist primarily of subalpine fir, Engelmann spruce, alpine larch (*Larix lyallii*), and whitebark pine (*Pinus albicaulis*). Persistent shrublands are found throughout the MT zone where soils are skeletal, where fire was common, and where climate prevents tree growth mainly above timberline (Habeck 1972).

The NW and WC zones have a more maritime climate with higher rainfall and moderate temperatures (Finklin 1983). Western redcedar (*Thuja plicata*) forests dominate low elevation north slopes and riparian settings, while grand fir and Douglas-fir are the dominant mid-elevation tree species. Subalpine and upper subalpine forests are similar to those in the MT zone. The NW zone has extensive areas that are maintained in shrub dominated communities by repeated fire. There are also extensive alder (*Alnus sinuata*) shrubfields in wet, seep areas (Habeck 1972). Persistent herb lands are also common in these zones.

Methods

The methodology used to develop the FARSITE input layers is based on the premise that most ecological characteristics, including fuels, can be described from three commonly used ecological descriptors—potential vegetation type (PVT), cover type, and structural stage. Keane and others (1996b) used this framework to simulate landscape succession at coarse (for example, ICBEMP), mid- and fine scales. Many hydrologic, wildlife, fire, and fuels characteristics were also mapped for the ICBEMP scientific assessment using this approach (Quigley and others 1996). Shao and others (1996) used potential vegetation types to refine a cover type classification from satellite imagery for a natural reserve in China.

This methods section will detail the data and procedures used to create these three vegetation data layers, and describe how they were then used to develop the fuels layers.

Development of the FARSITE fuels layers was accomplished in two phases (draft and final). In the first phase (started in January 1996), we created a draft version of the FARSITE data layers by June 1996 because fire managers needed them for the 1996 fire season. This meant we could only use historical field data for testing and validation of developed GIS layers. In the second phase, we collected additional field data in summer 1996 to refine and again test the vegetation and fuels maps. The final set of maps were passed to fire managers in spring 1997, with the entire process completed in just over 1 year.

Ground-Truth Data

The extensive field data sets used to modify, test, and refine the developed and acquired SBWC spatial data layers came from both historical plot information and ground-truth plots established specifically for this study (table 2). Ground-truth data are georeferenced plot information used to develop and verify maps and algorithms for this project. These data were essential in the construction and refinement of all FARSITE layers prepared for this study. Additionally, ground-truth data were integral in assessing the accuracy of acquired data layers and the derived heuristic rules bases used to construct PVT and fuel model maps (see later sections). They were also necessary for understanding complexities of the derived classifications as they related to other ecosystem components and processes.

Historical Plots—Three criteria were used to select the historical plots to be included as SBWC ground-truth data. First, each plot needed to be georeferenced to at least a 30 m accuracy and occur in the study area. Second, each plot must have had an estimation of fire behavior fuel model, stand height, and canopy closure. Crown height and crown bulk density were considered optional but desirable measurements. Third, the three base vegetation descriptors (PVT, cover type, structural stage) must have been evaluated for each plot. Only 1,500 plots satisfactorily met these criteria after querying over 100,000 plots from various vegetation data bases including the Northern Region's vegetation data base (Hann and others 1988) (table 2). All selected plots were established and sampled using ECODATA sampling methodologies (Jensen and others 1993, Keane and others 1990).

SBWC Ground-Truth Effort—Ground-truth information collected for this study was obtained using two hierarchically nested sampling

Table 2—Data sources used as ground-truth for all developed spatial data layers.

Name of data set	Reference	Area or zone	Number plots	Purpose
GMRS	Keane and others (1996a)	WC	174	Gradient modeling and remote sensing study
SILC	Redmond and others (1990)	WC, NW	325	Ground-truth of the SILC map
GRIZ	Davis and Butterfield (1991)	NW, WC	974	Grizzly bear habitat study
SBWC	This study	NW, MT	200 plots, 600 validated polygons	Ground-truth SBWC FARSITE maps

methodologies. The less intensive sampling method, called **polygon validation**, was used to quickly assess five major polygon attributes: PVT, cover type, structural stage, normal FBFM, and extreme FBFM. This was accomplished by first printing a set of color maps for the entire SBWC study area at the same size and scale of the U.S.Geological Survey 7.5 minute quadrangle maps using GIS software. These paper maps contained color-coded SILC polygon boundaries, streams, roads, and trails overlaid on 120 m contours. Each polygon was coded as to its PVT, cover type, structural stage, and both types of FBFM's (normal and extreme). We used the maps to navigate to various polygons in the field and then recorded, directly onto the maps, the actual (observed) PVT, cover type, structural stage, and fire behavior fuel models of located polygons. This information was then entered into a data file along with the polygon number for reference in the GIS. We validated only those polygons whose locations were absolutely known because they were adjacent to geographic features that were easily recognizable on the map, such as a stream confluence or road junction.

The second type of ground-truth sampling involved the use of fixed-area (0.04 ha circular) plots to extensively sample ecological attributes of the plant community delineated by the polygon. These data were not only used to validate polygons and quantify stand characteristics, but more important, they were used to understand and interpret ecological relationships that influence fuel models. Plots were established in a representative portion of the polygon, and ecological characteristics were sampled using a modification of the ECODATA methods (Hann and others 1988; Jensen and others 1993; Keane and others 1990). Site information, general vegetation characteristics, fuels descriptions, and ground cover were measured at each plot using the General ECODATA plot form (Mueller-Dombois and Ellensburg 1974). We modified this form to include fields for crown height, crown bulk density, fire effects fuel model (FEFM, page number of fuel photo series; see Fischer 1981a, b, c), extreme fire behavior fuel model, and structural stage, which were not standard ECODATA fields. Species cover, average height, and composition were recorded on the Plant Composition ECODATA form. Appendix A presents the plot forms we used for recording SBWC ground-truth measurements. (We include them in this book in a format in appendix A that we hope might prove useful for the reader.) All plots were georeferenced to UTM coordinates with a Global Positioning System (GPS) receiver and then differentially corrected using base station data from Missoula, MT. These plot locations and their ground-truth attributes (such as cover type, FBFM, PVT) were included in the SBWC GIS as point data.

Spatial Data Layers

Many spatial data layers were either acquired or created for the development of the eight FARSITE input layers. All layers, including the FARSITE input layers, were developed at a 30 m pixel size. A raster layer for the entire analysis area has the dimensions of 5,200 by 4,200 pixels and comprises over 10,000 km^2 (fig. 1). The ARC/INFO and GRASS (USA CERL 1990) GIS software packages were used to perform the majority of spatial analysis on IBM C10 and SUN Sparc 10 UNIX workstations. The SAS and SYSTAT statistical packages were used to perform initial analyses, to compute accuracy assessments, and to construct fuel and vegetation keys. The next sections describe the data layers that were used or created specifically for this project.

Digital Elevation Model (DEM)—The SBWC elevation layer was essential to vegetation mapping, fuel layer development, and FARSITE modeling. It was constructed by edge-matching or tiling 113, 7.5 minute quadrangle (quad) DEM's, each with a 30 m pixel size. A DEM is a raster map with each pixel assigned an elevation value measured above mean sea level. Quadrangle DEM's are distinguished as either Level 1 or Level 2, depending on method of production. Level 1 DEM's sometimes exhibit a horizontal banding pattern, an inherent side-effect of the scanning procedures used in their production (USGS 1987). Level 2 quad DEM's are currently produced from Digital Line Graphs and processed for errors so they do not contain systematic errors that create the banding problem (USGS 1987). Horizontal banding occurred in most Level 1 SBWC DEM quads and needed to be removed because it influenced FARSITE simulations. All Level 2 DEM's currently available, about 67 percent of the total number of SBWC quads, were ordered from Geometronics Service Center in Salt Lake City, UT. The remaining areas were filled using Level 1 quad DEM's obtained from the Northern Region and the Nez Perce National Forest, which contained the banding. The comprehensive SBWC elevation layer was created by merging all DEM quads using a patchwork of Level 1 and Level 2 sources. Merging or splicing quad DEM's sometimes created slivers of missing data along quad edges. These slivers were replaced with the average value of surrounding pixels across DEM quads.

We developed a procedure to correct the horizontal banding in Level 1 DEM's and to maintain the quality and relief of the Level 2 DEM's (see appendix B). The most common method to remove banding is to run a "filter" across the layer (Brown and Bara 1994; Stitt 1990; White and others 1995). A filter is a smoothing tool that adjusts a pixel value based on the surrounding pixels' values using user-specified weights (Jensen 1986; Lachowski and others 1995). We tested several filter sizes and types and concluded an equal-weight, directional filter (1 pixel wide by at least 7 pixels high) removed a majority of banding error. The height of the filter depended mostly on the width of the bands. Since filtering ultimately reduces relief and definition, the directional filter was only applied to Level 1 DEM quads. This was achieved by running the filter twice over the entire tiled layer, then overlaying the original Level 2 DEM's with the final filtered layer, using the filtered tiled layer to fill in areas where no Level 2 DEM's existed. The final steps in DEM processing involved filtering the edges between Level 1 and Level 2 quads, to smooth the transition in elevation from filtered to unfiltered quads (appendix B).

A different problem was encountered in two Level 1 DEM quads along the Bitterroot River. These quads did not exhibit any horizontal banding but rather appeared to have irregular vertical bands. The area is basically flat terrain along the river. The rest of the DEM quads along the Bitterroot River were of Level 2 quality and did not exhibit any vertical banding. In addition, aspect layers derived from these two DEM quads had a scattered, "salt and pepper" appearance caused by small changes in elevation (Stitt 1990). To reduce both effects, these two quads were filtered once with a square (5 x 5 pixel) filter, instead of the directional filter, which would only enhance the vertical banding. Out of several filters tested, the 5 x 5 filter seemed to produce the best visual results, although the vertical banding was still slightly visible. These two DEM's were filtered separately, then merged with the final layer prior to the edge-smoothing process.

Slope and aspect maps were generated from the final SBWC DEM layer using the ***slope*** and ***aspect*** functions in ARC/GRID. We created the same maps using the ***r.slope.aspect*** command in GRASS but found major inconsistencies in the derivation of aspect using this algorithm, so we decided to use the ARC/GRID results. We also developed algorithms to compute slope and aspect, but these were inferior to ARC/GRID results as well. Slope and especially aspect computations are sensitive to minor errors in the DEM layer, so it was essential these layers be validated for accuracy.

SILC Cover Type—The SBWC PVT, cover type, and structural stage data layers were partially or entirely derived from the SILC map developed by Redmond and Prather (1996). Broad cover type classes, structural stage, canopy cover, and other ecological attributes were assigned to mapped polygons by Redmond and Prather (1996) following criteria based on ECODATA sampling methods (Hann and others 1988; Jensen and others 1993; Keane and others 1990). A polygon is a delineation of land area containing pixels that have similar spectral reflectance across several LANDSAT Thematic Mapper (TM) wavelengths (that is, a unique spectral class). The SBWC lies entirely within one TM scene with a 30 m pixel size. Redmond and Prather (1996) processed these polygons in raster format to a minimum polygon size of 2 ha using image processing and GIS software. Initial polygon delineations were validated by ground-truthing field crews from 1994 to 1996 and these data were used to refine the image classification. The field data were also used to assign each polygon over 25 attributes including structural stage, canopy closure, and average spectral reflectance (Redmond and Prather 1996). These attributes assignments were entered into a data base that was linked to the SILC GIS raster layer by polygon identification numbers.

All SILC cover types found in the SBWC study area are presented in appendix C along with the reference to the final SBWC cover type categories. The final set of structural stage categories are shown in table 3 with some size class descriptions. Structural stage categories were created for water, urban,

Table 3—List of structural stages used in the Selway-Bitterroot Wilderness Complex study.

Code	Name	Description
Grasslands		
1	Grasslands	—
Shrub		
2	Low shrub	<2.5 ft
3	Medium shrub	2.5-6.5 ft
4	Tall shrub	>6.5 ft
Tree		
5	Seedling/sapling	<5.0 inch d.b.h.
6	Pole	5.0-8.9 inch d.b.h.
7	Medium	9.0-21.0 inch d.b.h.
8	Large/very large	>21.0 inch d.b.h.
Other		
9	Water	—
10	Urban	—
11	Agriculture	—
12	Rock/alpine/perennial snowfields	—

agriculture, and rock (table 3) to fill in missing values on the map. It is important to note that we did not change any polygon boundary delineated in the SILC map. All polygons in the vegetation maps (PVT, cover type, structural stage) created by this project are the same as the original SILC map polygons. We only changed the vegetation attributes assigned to the SILC map polygons. We found the polygon delineations agreed quite well with community boundaries on the landscape.

SILC cover type codes are stratified as follows: developed lands, grasslands, shrublands, forests, riparian and wetland areas, water, barren lands, alpine meadows, and snow or ice (appendix C). This cover type classification was dependent on canopy cover, both absolute and relative. For instance, to be classified as forested, a polygon must have at least 15 percent total canopy cover of trees. Further, to be classified as a Douglas-fir cover type, the polygon must have at least 66 percent relative cover of Douglas-fir. Details of the SILC classifications are presented in Redmond and Prather (1996). We imported the classified SILC layer into ARC/GRID and then extracted cover types from the comprehensive list of attributes to form a separate layer and clipped the new cover type layer to the analysis area. We maintained the original cover type codes and categories of the SILC map.

Ancillary Vector Layers—Many GIS layers describing SBWC geophysical attributes were available for this area from the Grizzly Bear Evaluation project based out of the Clearwater National Forest (Davis and Butterfield 1991). These vector layers included streams, roads, trails, and the Selway Bitterroot Wilderness Boundary. Streams, roads, and trails were generated at 1:100,000 map scale from USGS digital line graph files. Administrative boundaries were digitized at 1:24,000 map scale from USGS 7.5 minute quads. We also obtained the layers of ownership boundaries, subwatersheds, and biophysical settings from the ICBEMP effort (Quigley and others 1996). A raster map of land type associations was acquired from the Northern Region's Ecology Program. We generated a 100 m vector contour layer from the DEM elevation layer in ARC/INFO. We also created maps that portray soil depth and water-holding capacity for the SBWC using methodologies presented in White (1996).

The SBWC analysis area boundary vector layer was created from several of the above coverages (fig. 1). Because wildland fire can burn across wilderness boundaries, we decided to make the study area boundary at least 2 km larger than the boundary of the Selway-Bitterroot Wilderness Area. However, we did not want to impose a standard buffer width on the entire Wilderness Boundary because of the diversity in topography, vegetation, and fuels in the adjacent watersheds. So, we used vectors from an assortment of GIS layers to form the SBWC study area boundaries. The Bitterroot River defines the eastern edge of the analysis area. The western edge was restricted by the limits of our DEM layer. The rest of the boundary is a compilation of vectors from rivers, administrative boundaries, and watersheds. We used three GIS layers in this process to ensure a sufficient buffer around the entire Selway Bitterroot Wilderness Area for fire modeling purposes. Hopefully, we have delineated sufficient land to adequately predict fire growth for any prescribed natural fire in this complex.

Potential Vegetation Type (PVT)—No suitable PVT map was available for this SBWC fuels mapping project. Brown and others (1994) had constructed a fire regimes map for the wilderness area using a topographic rulebase, but these regimes did not adequately stratify the landscape to reflect major changes in biophysical settings, fuel characteristics and distribution. In addition, a large portion of the landscape (40 percent) was classified to only one fire regime type. Reid and others (1995) developed a biophysical settings layer for the ICBEMP effort that was later cross-referenced to a coarse scale PVT layer, but the spatial and organizational scale of this layer was too coarse to spatially predict fuel models for FARSITE. Most other layers that mapped SBWC potential vegetation (for example, habitat type maps) did not cover the entire analysis area, or the PVT classification was not suitable for fuels predictions. Therefore, we decided to create our own PVT map for this FARSITE project.

The SBWC PVT map was created from geographic and topographic settings using a heuristic, rule-based approach. First, a list of midscale PVT's were compiled for the SBWC based on the opinions of local ecologists, research literature, and available field data (table 4) (Habeck 1972; Pfister and others 1977). Four GIS layers were used as primary references in the rule-based

Table 4—List of potential vegetation types (PVT) used in this project.

PVT code	Description	Habitat types[a]	
1	Developed lands (occur only along the Eastern Front of the Bitterroots and the West Fork of the Bitterroot River in Montana)	No reference	
2	THPL — *Thuja plicata* (western redcedar) habitat types	All THPL	
3	ABGR — *Abies grandis* (grand fir) series	ABGR/ASCA ABGR/CLUN ABGR/SETR	ABGR/LIBO ABGR/XETE
4	PSME — *Pseudotsuga menziesii* (Douglas-fir) habitat types, dry ABGR series, and *Pinus ponderosa* (ponderosa pine—PIPO) habitat types	All PSME All PIPO	ABGR/PHMA ABGR/SPBE ABGR/VAGL
5	Lower subalpine-moist — *Abies lasiocarpa* (subalpine fir—ABLA) series	ABLA/ALSI ABLA/CACA ABLA/CLUN ABLA/GATR	ABLA/LIBO ABLA/MEFE ABLA/OPHO ABLA/STAM
6	Lower subalpine-dry — *Abies lasiocarpa* (subalpine fir—ABLA) series	ABLA/CARU ABLA/VACA ABLA/SYAL	ABLA/VAGL ABLA/VASC ABLA/XETE
7	Upper subalpine-moist — *Abies lasiocarpa* (subalpine fir—ABLA) and *Tsuga mertensiana* (mountain hemlock—TSME) series	ABLA/LUHI-MEFE TSME/LUHI	TSME/XETE
8	Upper subalpine-dry — *Abies lasiocarpa* (subalpine fir—ABLA) series, *Larix lyallii* (subalpine larch—LALY) habitat types, and *Pinus albicaulis* (whitebark pine—PIAL) habitat types	ABLA/LUHI-VASC PIAL-ABLA ABLA-PIAL	LALY-ABLA LALY-PIAL
9	Persistent herblands	No reference	
10	Rock/alpine/perennial snowfields	No reference	
11	Water	No reference	

[a]Pfister and others (1977), Cooper and others (1991).

terrain model—geographic zone, elevation, slope, and aspect. Ancillary data layers of average annual precipitation, land type associations (Bailey 1988, 1995), average annual temperature, watercourses, roads, and trails were prepared for the SBWC analysis area but were never used in the PVT terrain modeling because it was difficult to match the PVT list to the map classification categories.

Rules were developed from slope, aspect, and elevation criteria to predict PVT for each zone. These rules were formulated from a March 1996 workshop sponsored by the IFSL and attended by area ecologists and scientists. We refined these rules based on vegetation plot data collected by past research studies and by this project (see "Ground-Truth Data" section). Final sets of PVT rules by geographic zone (appendix D) were a result of three extensive revisions. These rules were mapped onto a PVT raster layer using GIS techniques, and after extensive analysis and revision, a PVT category was assigned to each SILC polygon from this raster layer using methods detailed below.

The first draft PVT map delineated only forest PVT's. It was created by running the GRASS command ***r.infer*** using the rules compiled from the March 1996 workshop. We generated a buffer in ARC/GRID around all major rivers in the SBWC to delineate streamside western redcedar and grand fir PVT's. The width of the buffer was 90 m for narrow stream bottoms and 120 m in wide valleys where slopes were less than 30 percent. Elevation and aspect constraints were also imposed on the streamside buffer. For example, streamside areas with aspects of 315° to 90° (NW to NE), elevations less than 1,463 m, and slopes less than 30 percent were assigned a western redcedar PVT in the northwestern and west-central regions of the SBWC (appendix D).

The SILC cover type map was used to delineate rock, alpine, and barren PVT's because these features could not be predicted from topography and geographic zone. This assumes that the satellite image classification of nonforest cover types is accurate and adequately portrays nonforest site types (Jensen 1986; Redmond and Prather 1996). Persistent herblands on the SILC map also defined associated PVT's using topographical constraints (appendix D). For instance, the persistent herblands PVT was defined as foothill and disturbed grasslands from the SILC map on south aspects (120° to 270° azimuths) at elevations less than 2,256 m and slopes greater than 50 percent in the northwestern zone. Developed and urban lands were considered a separate PVT and were delineated from the ownership layer produced for the ICBEMP (Quigley and others 1996) scientific assessment. We did this because it was difficult to determine habitat type on lands that are intensively managed such as agricultural fields and urban areas.

The PVT map was modified to spatially correspond (overlay) directly with the polygons in the SILC map because all input layers needed to be spatially congruent for FARSITE simulations. We accomplished this by using the zonalmajority function in ARC/GRID, which assigns the modal PVT value to the SILC delineated polygon. We assumed that the delineated SILC polygon boundaries more accurately represented coarse and fine scale changes across the landscape and therefore would be the preferred layer to use as the polygon delineator. However, many SILC polygons exceeded the topographic bounds of some PVT's. We attempted to divide these large polygons along the topographic limits (elevation range, for example) but this created many slivers and small polygons that were well below the 2 ha minimum mapping threshold of the SILC map. As a result, we kept the integrity of the original SILC polygons and allowed large polygons to traverse PVT limits in the final map by assigning the predominant PVT to the polygon attribute data base.

We improved the accuracy of the PVT layer by intensively examining the 1500-plus reference ECODATA plots for topographical characteristics and for PVT and cover type combinations to detect major misclassifications of PVT, cover type, or both. Western redcedar and grand fir PVT's were especially difficult to delineate from topographic criteria because our midscale terrain model often did not detect fine scale PVT boundaries that occur in small microsites often occupied by cedar and grand fir. Based on plot data, 80 percent of observed grand fir cover types occurred within mapped grand fir PVT's, and 57 percent of the observed redcedar cover types occurred within redcedar PVT's. We reclassified areas having grand fir cover types to the grand fir PVT and western redcedar cover types to the western redcedar PVT because we felt the SILC map more accurately represented these types based on ground-truth data. The western redcedar/grand fir cover type (appendix C) was similarly reassigned to its respective PVT and cover type using a cover type-aspect combination, with all but the most northerly and flat aspects being reclassified to grand fir cover type and grand fir PVT.

We created another PVT raster layer independent of the terrain-modeled PVT layer using the statistical analysis techniques of discriminant analysis in the SAS software package. This statistical PVT raster map was created so it could be compared to the terrain-modeled PVT map to evaluate the two methodologies and perhaps fill in some areas that were inappropriately mapped using the terrain modeled approach. This was accomplished by creating a data file from the plot data by extracting field-measured data variables for which we either had a SBWC GIS map or could create a GIS map using modeling techniques. These data included PVT, geographic zone, elevation, aspect, slope, effective soil depth, soil water-holding capacity, slope curvature, topographic slope index, and solar radiation index (based on shading) (Lapen and Martz 1993). The PVT was used as the dependent (predicted) variable and the remaining were considered independent (predictor) variables. Keane and others (1996a) use environmental gradients such as those mentioned here to predict many ecosystem variables including PVT.

Many independent variables included in the discriminant analysis were modeled from the DEM layer and the STATSGO soil layer (SCS 1991) using methods discussed in Thornton and White (1996). Soil depth was taken directly from STATSGO and adjusted using slope and upslope drainage. Water-holding capacity was estimated from the STATSGO layer using soil textures (percent clay, sand, and silt) to compute soil pressure and volume characteristics (Cosby and others 1984) that can then be used to calculate maximum soil water content. Topographic slope index is based on potential saturation deficit, which is computed from upslope drainage to a down slope point and the topographic slope of that point (Thornton and White 1996). Solar radiation index estimates shading potential and is computed using the sun angle from a midsummer's day as a reference point.

SBWC Cover Type—A SBWC cover type map was created from the combination of the SILC cover type map and the PVT map. Many polygons in the SILC map had cover type assignments that did not agree with the classified PVT of that polygon. For instance, there were some polygons in the SILC map that were assigned a cover type of western redcedar but were classified as a Douglas-fir PVT. It is highly unlikely that the mesic western redcedar would flourish on a dry Douglas-fir site because of limited moisture (Pfister and others 1977). All incompatible polygon combinations were reassigned a new cover type on a case-by-case basis. Cover types were changed only if the polygon was assigned a PVT that was mapped with a high degree of confidence, and vice versa. The degree of confidence we had in each layer depended on the zone, PVT, cover type, topographic setting, and ecological knowledge of the SBWC. About 10 percent of the polygons were modified in this phase.

The draft PVT raster layer was compared to the SILC map using the GRASS command ***r.report*** that produces a summary of polygon assignments by zone, cover type and PVT across the two maps. SILC cover types that were not compatible with PVT assignments were reclassified to a cover type more likely to occur in the PVT based on ecological relationships of plant species as defined by the ground-truth data and the habitat type constancy tables in Pfister and others (1977), Cooper and others (1991), and Habeck (1972). An example of such a reclassification would be a mixed high elevation subalpine forest cover type in the low elevation Douglas-fir (*Pseudotsuga menziesii*) PVT. This cover type would be reclassified to the mixed xeric forest cover type (see appendix D) based on an evaluation of the plot data and literature. The SILC map was refined more often than the PVT map because it was developed for the entire Northern Region and its categories were too general for the smaller SBWC geographic region. We copied all other polygon attributes from the SILC map to the SBWC cover type map. The final map created from SILC modifications was called the SBWC cover type map.

The SBWC cover type map was also modified so that polygons assigned a cloud or cloud/shadow cover type were reclassified to the appropriate vegetation cover type. We used the ARC/GRID function nibble (nearest neighbor algorithm) to assign a value to a polygon that has missing or erroneous data based on surrounding polygon values. Many missing data in the SILC map were filled using the nibble command to create the SBWC cover type maps. This command uses Euclidean distance to assign the value of the nearest polygon.

Structural Stage—The structural stage map was created from the SILC map using the structural stage attribute assigned to each polygon by Redmond and Prather (1996). Some structural stage attributes were modified to account for impossible PVT, cover type, structural stage combinations, such as pole size trees occurring on a grassland, but these changes were few (less than 5 percent). We also added structural stage values for grasslands, water, urban, agriculture, rock, and snow because the original SILC map did not have structural stages for these types. The initial SBWC structural stage map was also modified by performing nibble function with the new cover type assignments from the SILC map to fill in cloud and shadow polygons.

Fire Behavior Fuel Models (FBFM)—The three base vegetation layers (PVT, SBWC cover type, and SBWC structural stage) were overlaid to create a worksheet of all possible combinations to assign FBFM's (appendix E). Various ecologists and fire managers assigned the FBFM's to each combination of PVT, cover type, structural stage for normal and severe fire conditions (Anderson 1982). They also estimated the average crown height (height to live crown base) and a fire effects fuel model to each combination. Crown height was estimated by the managers rather than taken from the ground-truth data computations because it is more an index of the transition of surface fires to the crown and may be better characterized by qualitative assessment than a summary of tree structure data. The fire effects model is the page number of the fuel photo series (Fischer 1981a,b,c) that best depicts the fuel loadings of a particular vegetation combination.

We built the fuel model layers by first creating a GIS layer that contained PVT, cover type, and structural stage assignments to each polygon using overlay techniques. We applied a simple map algebra equation in ARC/GRID to accomplish this:

VEGMAP = (PVT * 1,000,000) + (COVER * 100) + (STRUCTURE)

where VEGMAP is the value of a pixel in the final map that portrays all combinations, PVT is the identification number of a pixel in the PVT map (table 4), COVER is the cover type number of a pixel in the cover type map (appendix C), and STRUCTURE is the pixel value of structural stage number assignment (appendix C). This equation resulted in values such as 1420605 (1 = PVT Developed Lands, 4206 = COVER TYPE *Pinus ponderosa*, and 05 = STRUCTURAL STAGE Seedling/Sapling). We then built a reclassification table that cross-references the values in this new map to the fuel model assignment mentioned above. This table was then linked to the VEGMAP layer to produce fuel model layers for normal and severe conditions. For example, the value 1420605 was assigned a normal FBFM 5 based on the worksheet assignments for normal conditions made by the fire managers (appendix F). We changed some FBFM assignments made by fire managers because of discrepancies with field data. A complete list of FBFM assignments to PVT, cover type, structural stage combinations are presented in appendix F.

Canopy Cover—The canopy cover layer was also taken from the original SILC polygon attributes data base, which had a canopy closure code category. Canopy cover or closure is defined as the vertically projected canopy cover (percent) of all tall shrub and tree species. SILC canopy closure (percent) values were categorized, in accordance with ECODATA sampling methods, into the four classes, presented in table 5. However, the SILC maps had assignments of canopy cover to shrub and forested cover types, but the FARSITE program only accepts canopy cover estimates for forested cover types. Therefore, all shrublands were assigned a canopy cover of zero. In addition, the ranges of canopy cover classes in the SILC layer did not conform to those used by FARSITE. Without the actual percent canopy closure, we could not create a perfect fit; therefore, we had to adjust SILC canopy code values to approximate those in FARSITE. Both of the above modifications were done in ARC/GRID by using the combine function on the

Table 5—Canopy cover classes present in the SILC map and used by FARSITE.

Cover class	SILC cover ranges	FARSITE cover ranges
	Percent	
0	0 to 9	1 to 20
1	10 to 39	21 to 50
2	40 to 69	51 to 80
3	70 to 100	81 to 100

cover type and canopy cover layers, and then reassigning new canopy cover estimates based on cover type using the reclass function.

Stand Height—Stand height (ft) was generated using the results of a project conducted by Ottmar and others (1994) as a part of the midscale analysis for the ICBEMP effort (Quigley and others 1996). They compiled data from the Northern Region ECODATA data base (Jensen and others 1993) to compute total crown biomass by cover type and structural stage. In the process, Ottmar and others (1994) generated average values of stand height and other stand characteristics for various cover type and structural stage combinations. These values were entered into a data base structured by ICBEMP cover types and structural stages. We linked our SBWC cover types and structural stages to the most suitable counterpart in the ICBEMP data base on a case-by-case basis, and then we assigned our polygons the corresponding stand height from the linked data base. The layer was then created by building a classification table in ARC/GRID. We adjusted some stand heights based on available field data summaries.

Crown Height—Crown height (ft) was assigned to PVT, cover type, structural stage combinations by the attendees of the April 1996 workshop (appendix E). Crown height is defined as an effective height to live crown base for the stand, and it represents the flame height necessary to enable the transition from surface to crown fire, accounting for the effects of ladder fuels. This layer was created using simple reclassification tables in ARC/GRID, separately assigning the values given to each PVT, cover type, structural stage combination by workshop attendees across each geographic zone.

Crown Bulk Density—Crown bulk density values (kg m^{-3}) were assigned by cover type and structural stage and then reduced by canopy cover class based on the crown bulk density table shown in appendix G. Pole, medium, and large tree stands were assigned a crown bulk density by cover type for high canopy cover values. This value was reduced proportionally for medium and low canopy cover classes (30 and 60 percent, respectively). Seedling/sapling stands were assigned a crown bulk density for the low cover class and increased by 15 percent for the medium cover class. There were no seedling/sapling stands with high canopy cover. The final bulk density assignments were made from polygon attributes using a look-up table that linked the canopy cover, cover type, structural stage values of a polygon to the bulk density values (appendix G). These assignments were multipled by 100 and converted to integers to save computer disk space.

Accuracy Assessment

Testing, validation, and verification of existing and developed data layers involved overlaying the layer in question with the plot layer where each plot was georeferenced as a point. Each point referenced a GIS data base that contained the sampled field values. The point data were compared to the values of the polygon where it resided, and reports were created that compared point values with corresponding map values. We designed several GIS routines to display and report the overlap between the plot layer and the layer in question. These reports were summarized into contingency tables and into data files used by other programs written specifically for this project.

Accuracy assessments procedures differed by the type of map being compared with ground data. Categorical GIS maps are those maps that portray discrete, nominal classification categories such as cover type and structural stage layers. Continuous maps have polygon values that are measured using continuous data scales such as elevation (m) and slope (percent).

We assessed the accuracy of all categorical SBWC maps using the methodologies presented in Congalton (1991) where contingency tables are constructed comparing the reference (ground-truth) data values to the classified (map) values. In addition, we used the same process to compare ground-truth data to the FBFM assignments from workshop participants (appendix E), and to the PVT assignments by local scientists and ecologists (appendix B). Omission and commission errors were computed for each map category, and a final accuracy was estimated using the KHAT statistic (Congalton 1991). The KHAT statistic adjusts overall accuracy to account for the uneven distribution of plot data across classification categories.

The accuracy of continuous SBWC maps such as elevation, aspect, and slope was computed using a regression approach. The observed values at each polygon (plot data) were regressed with the predicted values from the maps using a linear, least-squares regression (Sokal and Rohlf 1969). Three regression statistics were recorded. The coefficient of determination (R^2) provides an index on how tightly correlated the predicted data are to the observed data. Values of R^2 close to 1.0 indicate the data are perfectly correlated (accurate), whereas values near zero mean the data are totally unrelated or inaccurate. The slope of the regression line (alpha) can be used to evaluate trends in the accuracy of predictions. Slopes greater than 1.0 usually indicate map overestimation when observed values (plot data) are high and underestimation when observed values are low. The opposite is true when slopes are less than 1.0 but greater than zero. Ideally, the slope should be 1.0 if the observed values perfectly match the predicted values. Thirdly, the intercept of the regression line (beta) is used to evaluate general overestimation (beta greater than 0.0) or underestimation (beta less than 0.0) of the spatial model (map) predictions to the reference (plot) data. Another statistic called the mean error (ME) was also computed to quantify the error of map predictions. It is defined as:

$$ME = \frac{\sum_{i=1}^{N}(O-P)}{N}$$

where O is the observed (plot) value, P is the predicted (map) value for that plot, and N is the number of plots. This statistic is useful for evaluating the magnitude of accuracy error.

An assessment of aspect accuracy presented some special problems because of its circular scale. Northern aspects are especially difficult to estimate because they traverse the beginning and end of the azimuth scale. A plot with a measured aspect of 10 degrees and a predicted aspect of 350 degrees are only 20 degrees different ecologically but 340 degrees numerically. We used the following transformation to scale aspects along a more ecologically oriented gradient.

$$ASP = 1 + COS\ (ASPECT)$$

Where *ASP* is the ecological representation of aspect (number between 0 and 2), *COS* is the cosine function, and *ASPECT* is the aspect in degrees azimuth (0 to 360). This assumes that equal weight is given to east and west aspects.

Results

Three people completed this project in approximately 1 year. Most of the effort was in the preparation of the GIS data layers used for analysis (30 percent), summarizing workshop results into heuristic rule sets and look-up tables (25 percent), and collecting and analyzing ground-truth information (20 percent). The remaining time was spent creating the FARSITE input maps, checking all data layers for inconsistencies, refining vegetation and fuels maps, and quality control. The entire project cost around $100,000 or about 9 cents per ha (4 cents per acre), which includes software and hardware maintenance, salaries, transportation, and supplies.

The SBWC study area encompasses over 1.15 million ha across three National Forests and two States (fig. 1). The distribution of area by PVT and cover type is presented in table 6 where the lower subalpine forests of mixed and pure lodgepole pine and subalpine fir compose the majority of the SBWC landscape (over 34 percent). Douglas-fir, shrublands, and mixed mesic forests are next in importance with 10, 11, and 14 percent coverage, respectively. Rockland also is predominantly featured in the SBWC (5 percent) from the SILC polygons. Structurally, the majority of the landscape is in pole and medium tree size classes (20 and 30 percent coverage) while old growth or large tree forests account for only 5 percent of the land area (table 7). Shrubs are tall in lower elevation sites and somewhat low in high elevation stands. Grand fir and western redcedar cover type stands are predominately old growth (table 7).

Timber FBFM's dominate the SBWC landscape under normal conditions (40 percent cover) with closed timber low (FBFM 8) and high (FBFM 10) intensity fuel models the most common (table 8). Low elevation, moist timber sites tended to have FBFM 10, while the high, dry sites often keyed to the low intensity FBFM 8 because of the limited amount of fuels. The closed timber FBFM 8 and shrub FBFM 5 models accounted for over 80 percent of the change from normal to extreme weather conditions (tables 8 and 9). The shrub model (FBFM 5) could shift to all but FBFM 9 depending on the cover type and PVT. All stands classified to the grass FBFM 1 stayed the same from normal to extreme conditions.

Development of a PVT map using discriminant analysis provided a good reference to the terrain-modeled PVT map. We used a stepwise discriminant analysis to create discriminant functions for the entire SBWC and for each zone to produce the final statistically generated PVT map. Many independent variables were evaluated for inclusion in the final discriminant functions (table 10), but only a few seemed to explain the majority of variation. The best statistical PVT map was created using the variables of elevation, aspect, and slope (table 11), which closely matches the variables used to create the terrain PVT map.

We made many refinements to maps and rules after the draft phase of this study because of the additional field data we collected over summer 1996. Based on these data, we merged some SILC cover type categories that were difficult to discriminate on the ground and to map in the GIS. These merged cover types did not seem to have a high fidelity to any one fuel model. Second,

Table 6—Distribution of area (hectares) by potential vegetation type and cover type.

	Potential vegetation type											
Cover type	Developed lands	Western redcedar	Grand fir	Douglas-fir	Lower subalpine moist	Lower subalpine dry	Upper subalpine moist	Upper subalpine dry	Persistent herblands	Rock/ alpine	Water	Totals
Urban	202											202
Agriculture	10,076											10,076
Grasslands	10,451	407	1,857	8,242					7,213			28,170
Montane parkland/ subalpine meadow	7				6,228	25,751	7,524	23,733				63, 243
Warm mesic shrubland	4,487	7,082	20,220	19,284								51,073
Cold mesic shrubland	6				6,677	20,702	1,862	2,780				32,027
Broadleaf forest	9,599	1,046	622		300	502	121					12,190
Englemann spruce					6,766	4,586						11,352
Lodgepole pine	630	736	8,263	11,418	38,838	55,274	9,160	13,187				137,506
Ponderosa pine	9,816		7,046	19,494								36,356
Grand fir	3	4,064	21,109									25,176
Subalpine fir	1				17,690	50,873	18,596	14,336				101,496
Western redcedar		2,557										2,557
Douglas-fir	3,989	5,481	10,156	60,552	21,228	45,769						147,175
Western larch	41		428	432	640	736						2,277
Mixed alpine forest								4,823				4,823
Mixed subalpine forest	24				69,125	103,376	30,531	28,303				231,359
Mixed mesic forest	2,346	6,601	37,655	49,162								95,764
Mixed xeric forest	1,068			13,130								14,198
Douglas-fir/lodgepole pine	357	516	9,336	9,789	5,720	13,722						39,440
Douglas-fir/grand fir		2,808	5,352									8,160
Western redcedar/grand fir		7,105										7,105
Western larch/lodgepole pine	33		601	1,480	4,228	3,937						10,279
Western larch/Douglas-fir	15	2	1,473	2,459	10,279	5,612						19,840
Standing burnt and dead timber			4	295	133	200		171				803
Water											3,181	3,181
Exposed rock										53,958		53,958
Mixed barren land										19		19
Shoreline and stream gravel bars										234		234
Alpine meadow										535		535
Snow or ice										3,493		3,493
Totals	53,151	38,405	124,122	195,737	187,852	331,040	67,794	87,333	7,213	58,239	3,181	1,154,067

Table 7—Distribution of area (hectares) by cover type and size class.

	Size class												
Cover type	Herbland	Low shrub	Medium shrub	Tall shrub	Seedling/ sapling	Pole tree	Medium tree	Large/very large tree	Water	Urban	Agricul- ture	Rock/ alpine	Totals
Urban										202			202
Agriculture											10,076		10,076
Grasslands	28,169												28,169
Montane parkland/ subalpine meadow	63,243												63,243
Warm mesic shrubland		7,044	11,979	32,050									51,073
Cold mesic shrubland		17,474	3,406	11,147									32,027
Broadleaf forest					2,584	6,318	2,839	449					12,190
Englemann spruce					637	317	8,039	2,359					11,352
Lodgepole pine					5,422	30,865	100,164	1,054					137,505
Ponderosa pine					8,645	3,775	23,014	921					36,355
Grand fir					2,653	3,059	4,156	15,309					25,177
Subalpine fir					8,345	15,685	65,564	11,902					101,496
Western redcedar					189	1,186	396	786					2,557
Douglas-fir					18,415	33,104	81,463	14,193					147,175
Western larch					1,206	553	218	301					2,278
Mixed alpine forest					2,791	27	1,987	17					4,822
Mixed subalpine forest					15,252	65,257	147,727	3,124					231,360
Mixed mesic forest					14,957	19,707	36,345	24,755					95,764
Mixed xeric forest					3,797	1,851	8,483	67					14,198
Douglas-fir/lodge pole pine					4,757	4,801	22,425	7,458					39,441
Douglas-fir/grand fir					3,203	2,486	473	1,998					8,160
Western redcedar/grand fir					1,138	351	1,929	3,687					7,105
Western larch/lodgepole pine						185	8,918	1,176					10,279
Western larch/Douglas-fir					15	9,495	10,290	40					19,840
Standing burnt and dead timber	802												802
Water									3,181				3,181
Exposed rock												53,958	53,958
Mixed barren land												19	19
Shoreline and stream gravel bars												234	234
Alpine meadow												535	535
Snow or ice												3,493	3,493
Totals	92,214	24,518	15,385	43,197	94,006	199,022	524,430	89,596	3,181	202	10,076	58,239	1,154,066

Table 8—Spatial distribution (hectares) of potential vegetation type by normal and severe fire behavior fuel model.

Fire Behavior Model	Potential vegetation type: Developed lands	Western redcedar	Grand fir	Douglas-fir	Lower subalpine moist	Lower subalpine dry	Upper subalpine moist	Upper subalpine dry	Persistent herblands	Rock/ alpine	Water
Normal conditions											
1	20,526	407	1,857	8,242	6,174				7,213		
2	6,542		2,826	9,550		25,751	1,950	10,408			
5	8,932	13,434	32,226	38,066	48,167	26,326	9,394	19,990			
8	15,113	9,531	42,271	84,434	54,439	225,259	50,933	54,141			
9			1,167	6,031							
10	1,835	15,033	43,774	49,414	79,072	53,704	5,517	2,794			
98											3,181
99	202									58,239	
Severe conditions											
1	20,533	407	1,857	8,242	6,228		5,574	13,325	7,213		
2	6,542			14,954	3,158	25,751	1,950	10,408			
5	4,231	7,583	15,268	21,857	14,162	31,342	1,680	504			
6	4,695	5,851	19,360	10,658	3,550	20,624	2,140	6,161			
8	12,119	6,606	18,728	67,492	50,264	138,347	11,252	28,885			
9			2,561	6,178	16	10					
10	4,829	17,958	66,348	66,356	110,473	114,965	45,198	28,050			
98											3,181
99	202									58,239	

Table 9—Change in Fire Behavior Model from normal to severe conditions (hectares).

Normal conditions	Severe conditions: 1	2	5	6	8	9	10	98	99
1	44,419								
2		52,465	3,990			147	424		
5	18,961	10,298	66,997	73,038	6,282		20,960		
8			25,640		327,412	1,420	181,651		
9						7,198			
10							251,142		
98								3,181	
99									58,441

Table 10—Variables used to predict potential vegetation type for the discriminant analysis with associated partial correlation coefficient (*R*-square) and the *F* statistics to assess the relative importance of each variable in predicting potential vegetation type.

Variable	Partial *R*-square	*F* statistic	Prob >*F*
Elevation (m)	0.55	163.19	0.0001
Slope (percent)	.09	12.94	.0001
Waterholding capacity[a]	.06	7.86	.0001
Topographic slope index[a]	.05	6.38	.0001
Shading index[a]	.03	4.46	.0020
Soil depth index (m)[a]	.02	2.92	.0079
Aspect (degrees)	.02	2.86	.0092

[a]These indices were created from routines discussed by Thornton and White (1996).

Table 11—Overall and KHAT accuracy (percent correct) of categorical GIS layers used in the Selway-Bitterroot Wilderness Complex fuels mapping study.

Categorical map	Draft version—June1996				Final version—March 1997			
	Historical plots		1996 plots		Historical plots		1996 plots	
	Overall accuracy	KHAT accuracy	Overall accuracy	KHAT accuracy	Overall accuracy	KHAT accuracy	Overall accuracy	KHAT accuracy
PVT[a] - Terrian model rulebase	—	—	—	—	47	37	53	45
PVT[b] - Terrain model raster layer	41	31	47	37	37	25	53	44
PVT[c] - Terrain model polygon layer	40	30	42	31	37	25	60	52
PVT[d] - Terrain model polygons excluding rock	46	35	49	36	42	29	65	57
PVT[e] - Discriminant analysis raster layer	—	—	—	—	41	31	56	48
PVT[f] - Discriminant analysis polygon layer	—	—	—	—	37	27	52	48
SILC cover type	20	14	23	17	—	—	—	—
SILC structural stage	31	10	40	15	—	—	—	—
SBWC cover type	24	19	29	23	17	10	30	24
SBWC structural stage	31[g]	12[g]	40	16	31[g]	12[g]	40	15
Normal FBFM - rulebase	34	4	52	30	36	5	64	44
Normal FBFM layer	34	14	51[h]	36[h]	37	14	59[h]	45[h]
Severe FBFM layer	—	—	42[h]	39[h]	—	—	55[h]	44[h]
Canopy cover[i]	55	27	46	10	55	26	46	9

[a]Validation of the rulesets used to create the PVT raster map.
[b]Accuracy of PVT raster layer created directly from the rulebase and 30 m raster DEM data.
[c]Polygon PVT layer created by assigning PVT to SILC polygons from the PVT raster layer.
[d]Polygon PVT layer with only forested PVT's mapped from terrain model. PVT's mapped from SILC map are excluded.
[e]PVT raster layer created from discriminant analysis.
[f]PVT polygon layer created by assigning PVT to SILC polygons from PVT raster map generated from discriminant analysis.
[g]Includes 1996 ECODATA plot and map validation polygon data.
[h]GRIZ Plots not included in this accuracy because of incompatible structural stages.
[i]Canopy cover was classified into three categories in SILC map — 0 to 30 percent, 30 to 70 percent, 70 to 100 percent.

the topographic criteria designed in the original workshop were revised based on a thorough statistical analysis of the new and historical plot data. We graphed frequency distributions of the topographic variables for each PVT by zone and determined ranges of elevation, aspect, and slope that best fit the data. We also intensively examined the field data to determine if any additional site variables could improve our predictions of PVT, and we found none. Last, some PVT categories were merged because an analysis of the ground-truth data showed there were no significant differences between the categories. For example, the original PVT workshop list included an alder shrub field PVT, but after analyzing the field data, we found no evidence that this type could be successfully mapped in the GIS because our topographical criteria were too coarse for accurate spatial delineation of the alder PVT, and site factors other than topography were more important in alder shrub field development.

Accuracy Assessment

An extensive accuracy assessment was completed for all derived and existing FARSITE data layers using the ground-truth information discussed in the “Methods” section. Most ground-truth plots and polygons were along major travel routes (roads or trails) because of the inaccessibility and remoteness of the SBWC (fig. 2). The SBWC ground-truth data base included over 1,500 historical plots and 767 plots collected from this effort. We stratified our accuracy assessments by four categories—phase of study (draft or final), ground-truth data source (historical or 1996 plots), type of accuracy analysis (categorical or continuous), and accuracy measure (overall and KHAT).

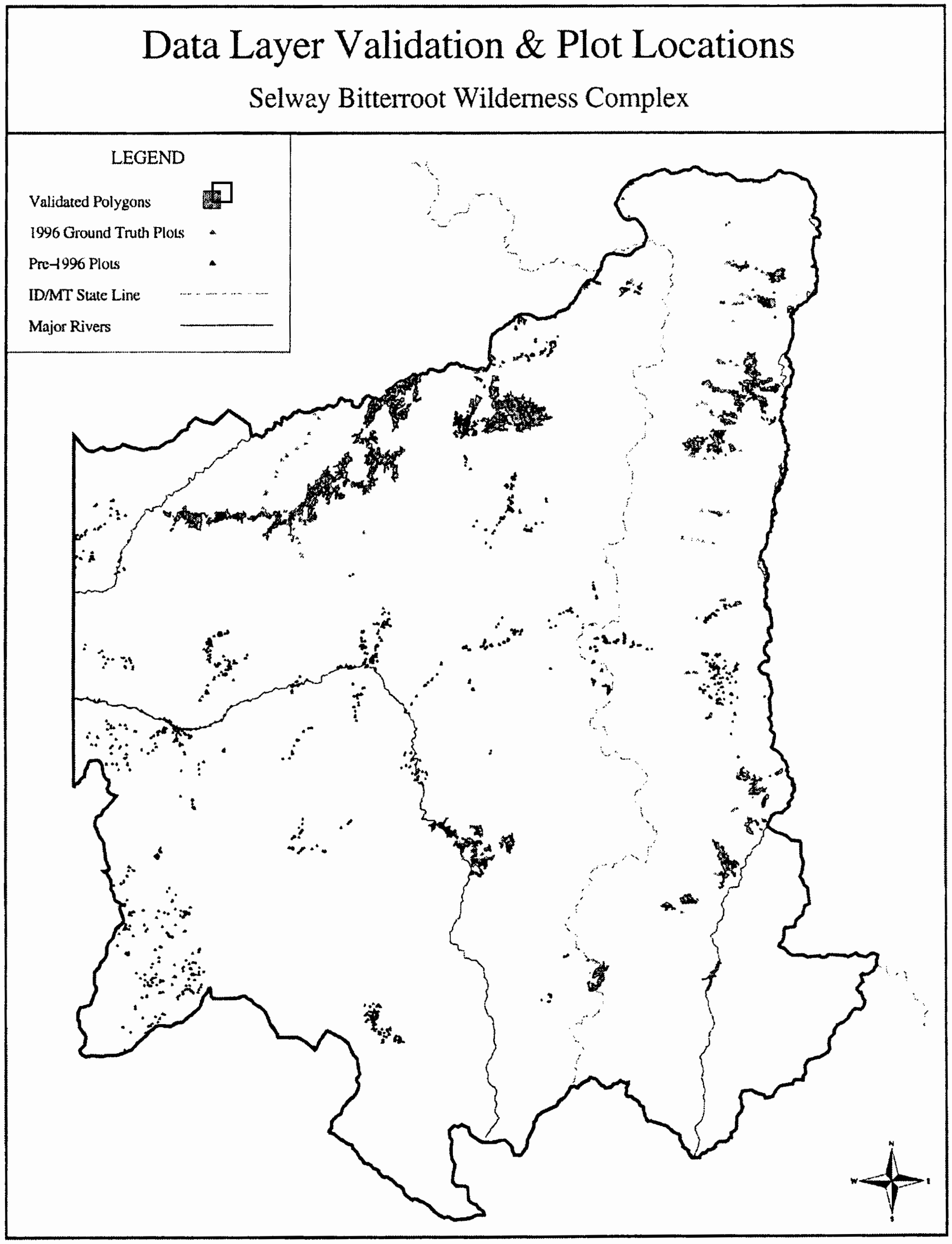

Figure 2—Ground-truthed plots and polygons used in this study. This includes historical plots, plots established during 1996, and validated polygons during this effort.

The first phase of the study released a draft of the fuels data layers in early summer 1996 for immediate use by the National Forest System prescribed fire program. The second and final version of the data layers was released late winter 1997. Accuracies were stratified by data source because we suspected some historical data were inaccurate and probably not appropriate for this study. We extensively used the 1996 SBWC data set to create the final version of fuels and vegetation GIS layers. We also stratified our assessment by two types of accuracies—overall and KHAT. Overall accuracy is simply the percent correct classification of ground-truth data (reference) to predicted polygon attributes (classified). The KHAT accuracy adjusts the overall accuracy to account for the uneven distribution of ground-truth data across map categories (Congalton 1991).

Contingency tables were prepared for every categorical map used in this project to evaluate and refine map components. However, only tables for the final PVT and structural stage maps are presented in appendix H because of space limitations. The cover type contingency table was not included in appendix H because of its large size (over 25 map categories). Once all accuracy assessments were complete, we refined the polygon attributes to reflect actual ground-truth information to create maps that totally agreed with the ground-truth data set. Overall, the ground-truth plots were NOT distributed across most PVT and cover type categories at the same proportion as these attributes are spatially distributed on the landscape (appendix H and table 6). Additionally, we did not have adequate distribution plots across many cover type categories and geographic regions, and many remote portions of the SBWC, such as the west-central zone, were not visited during any of the sampling efforts (fig. 2).

A summary of the overall and KHAT accuracy for all SBWC categorical maps is shown in table 11 for the first (draft) and second (final) project phases. Overall, the revision of the draft layers with the additional plot data increased accuracy over 10 percent. Historical plot data consistently produced approximately 5 to 15 percent lower map accuracies as compared to ground-truth data specifically collected for this project. The modification of SILC cover types based on PVT map values increased SBWC cover type map accuracies by about 10 percent. There was a minor loss of about 10 percent accuracy when PVT and FBFM rulebases were spatially mapped into the associated GIS layers (table 11). Error rates for the PVT map created using discriminant analysis are somewhat higher than the errors in the terrain-based PVT map (52 versus 60 percent accurate). There was generally a loss of 5 percent accuracy when raster maps were converted to polygon maps, except for the 1996 plot data in the final version. Accuracy of the terrain-modeled PVT map increased by 5 percent (60 to 65 percent) when SILC polygons classified as rock were removed from the accuracy assessment (table 11).

Continuous SBWC GIS map accuracies were computed using the regression approach (table 12). All topographic layers had errors inherent in map creation, including the primary layer of elevation (DEM). Layers depicting FARSITE stand and crown characteristics had errors well within the acceptable margin of 20 percent (table 12). Predicted crown height had a poor correlation to plot data because of the way it was assessed. Crown height was estimated by fire managers as an index of crown fire transition potential from PVT, cover type, and structural stage (appendix E). Field

Table 12—Accuracy assessment results for Selway-Bitterroot Wilderness Complex continuous GIS layers using regression analysis.

		Draft revision				Final			
	n	R^2	Slope	Intercept	Mean error	R^2	Slope	Intercept	Mean error
Elevation (m)	1,622	—	—	—	—	0.98	0.99	18.03	4.82
Aspect (degrees)	1,614	—	—	—	—	.54	.68	76.0	–1.35
Slope (percent)	1,600	—	—	—	—	.56	.67	9.58	2.43
Stand height (m)	655	0.21	0.43	7.82	0.59	.21	.43	7.74	.65
Crown height (m)	198	.03	.06	1.37	1.03	.01	.05	1.59	.85
Crown bulk density (kg m^{-3})	198	.30	.55	.063	–.006	.28	.50	.065	–.003

crews estimated crown height directly from stand structure on the plot, not as an index of the vertical fuel ladder. Nearly all errors were positive, and regression slopes were below 1.0, indicating maps were underpredicting crown and stand characteristics. Crown bulk density has a negative error because of the large intercept value (.065 kg m^{-3}). We increased the aspect R^2 by about 0.2 when we performed the accuracy assessment using the aspect transformation mentioned in the "Methods" section rather than using the raw aspect degree values (table 12). The slope of the line also increased by 35 percent with the transformation.

Final GIS and FARSITE Input Layers

The final FARSITE input layers were exported from the SBWC GIS into FARSITE landscape format files by individual USGS quads and then written onto a compact disk (CD). This disk was formatted using a directory structure recommended by Finney (1995) where input data layers were stored by 7.5 minute quad to improve FARSITE simulation and display time. Included on the disk were the eight FARSITE input layers (DEM, slope, aspect, normal FBFM, stand height, crown height, crown cover, and crown bulk density) and several ancillary data layers including extreme FBFM, streams, roads, trails, elevation contours, and wilderness boundary. Copies of the final revision were sent to all the SBWC fire managers for use on laptop personal computers. An electronic version of this document and a file containing data storage details were also included on the CD.

The entire SBWC GIS (all spatial data layers) created for this project was also made available to the personnel at each National Forest within the study area on the CD and on the computer network. This spatial data base contains all vegetation layers (PVT, cover type, structural stage) and the FARSITE layers mentioned above in ARC/INFO format. Also included in the GIS are the cartographic features of ownership boundaries, transportation routes, streams, rivers, soils, and weather. In addition, the GIS data base that links ecological data to mapped polygons contained the assignments of FEFM's to polygons so that fire effects can be calculated.

Discussion

Data Layer Development

The primary limitation of this project was using cover type and structural stage maps that were inaccurate and not developed in concert with the PVT map. This resulted in many inconsistencies among the three maps. The assignment of PVT to the SILC polygon attributes from the terrain-modeled PVT raster layer proved problematic. Many polygons (about 15 percent) traversed the topographic criteria used to create the raster PVT layer, and when these polygons were split along the topographic limits, over 500,000 small slivers (smaller than the minimum mapping specification) were created. This compromised map integrity. We tried to merge the slivers in the surrounding larger polygons, but this required over 4 weeks of computer time and abundant computer resources. Conversely, we accepted a great deal of error in the final PVT map when we allowed original polygon boundaries to remain intact and cross the topographic thresholds. In fact, the overall accuracy of the PVT rulebase was 47 percent, while the accuracy of the draft PVT map created from polygons was less than 42 percent (table 11). This problem can be easily be remedied if the PVT and cover type maps are developed together to ensure polygons remain above minimum map sizes and do not cross topographic limits. In fact, a list of possible cover types should be specified for each PVT to avoid ecologically impossible combinations such as western redcedar occurring on a Douglas-fir PVT. Polygon boundaries should not exceed PVT topographic constraints, and polygon cover types should be constrained by modeled PVT.

The most important GIS layer used in this project was the SBWC cover type map. Unfortunately, this layer was the most inaccurate for several reasons (table 11). First, there were many instances of confusing spectral signatures in the classified imagery of the base SILC map. For instance, the SILC map classified many spruce communities in the Montana zone to Douglas-fir cover types, probably because the two cover types have similar spectral reflectances. As a result, the fire behavior fuel models were often inaccurate because the cover type, structural stage, or both were wrong. Second, over 25 cover type categories described vegetation dominance on the SILC map. When classification units increase, the accuracy of spatial data layers constructed from imagery classifications often decreases because of inadequate ground sampling. Third, the SILC cover type map was developed for use at a slightly coarser scale than the scale required by the FARSITE model. The SILC map was intended to depict midscale differences in vegetation across large land areas that are sometimes in excess of 2 million ha. As a result, the cover type classification categories were sometimes difficult to identify on the plot because the sampling was done at a stand level.

PVT Map—The terrain-modeling approach for producing a midscale PVT data layer proved somewhat successful for this project. The PVT topographic criteria were composed quickly (less than 6 hours) with an acceptable accuracy (60 to 65 percent) (table 11). The topographic rulebase was easily coded into the GIS to create the final PVT raster layer. Terrain modeling is recommended when ground-truth data are scarce and there is a reliable source of expert knowledge for the land area in question. The design of PVT categories is perhaps the most important part of PVT terrain modeling. These categories must effectively discriminate a set of ecosystem properties and site conditions for a specific objective (fuel mapping, for example). They must also have characteristics that can be quantitatively described from existing GIS data layers and from field data. Category design must also match the scale of application and the resolution of associated GIS layers.

There was no significant advantage in developing the PVT layer using a statistical approach rather than a terrain-modeling approach for this project. The PVT map created using discriminant analysis was marginally less accurate (about 5 percent) than the terrain-based PVT map, mainly because of the limited and incomplete ground-truth data base (table 11). Data used to create the discriminant functions were not evenly distributed across all PVT categories, and the data set did not include process-based variables that directly influence site conditions such as weather (radiation, temperature, precipitation), soils (texture, nutrient availability), and productivity. A discriminant PVT mapping approach is recommended when the ground-truth data set is extensive and comprehensive, and when there are accurate GIS data layers that match the independent variables in the data set. The PVT map created from discriminant analysis did have some unexpected and beneficial characteristics. First, fine-scale PVT delineations along riparian corridors and other linear features were mapped successfully using this statistical procedure. Also, the discriminant functions predicted PVT values for every map pixel with no "holes" in the data layer. However, the discriminant model did not accurately predict the distribution of the upland PVT's, which composed a majority of the SBWC landscape. Interestingly, both PVT polygon maps looked quite similar after their raster originals were merged with the SILC polygon layer.

Fuels Maps—Overall, the workshop approach for assigning fire behavior fuel models to vegetation attributes was successful. Many models assigned by the workshop participants tended to be representative of the FBFM sampled in the field with an overall accuracy of 64 percent (table 11). In several instances, workshop FBFM assignments needed additional explanations before we went to the field to verify them. This was especially true for stands of ponderosa pine that had dense understories of Douglas-fir. The workshop participants assigned FBFM 10 to many of these cover types because of the high amount of conifer regeneration, while field crews were assessing FBFM 8 at the stands because of the sparce woody fuel on the ground. Determination of the FBFM by fire managers on the ground is subjective because it relies on a comprehensive knowledge of expected fire behavior across a wide range of weather and fuel conditions. Therefore, a great deal of discrepancy in FBFM estimates often emerges between fire personnel. However, the fire managers involved with this project seemed to agree on most fuel model assignments for each PVT, cover type, structural stage combination. This was also true for the ecologist's and scientist's design of PVT topographic criteria (table 11) although that rulebase had a substantially lower accuracy (53 percent). It was apparent that many of these resource specialists knew a great deal about fuel and ecological relationships in this area at a meso-scale level and their knowledge could be somewhat captured in a GIS layer using this approach.

Map Accuracy

Of the many sources of error in map design and development, probably the most important were spatial and organizational scale inconsistencies. Base vegetation maps used to create the FARSITE input maps were developed for midscale applications, whereas the FARSITE simulation model must have data that accurately characterize fine scale spatial fuel distribution and dynamics. This factor was probably most important during the construction of PVT and fuel model rulebases. Midscale classification categories for the vegetation maps (PVT, cover type, structural stage) were sometimes too broad to uniquely identify an appropriate FBFM. For instance, three FBFM fuel models (5, 8, and 10) were sampled for the grand-fir PVT, Douglas-fir cover type, and medium tree structural stage combination in the field. Finer delineations of structural stages in this PVT could have reduced the number of possible fuel models. The differentiation of structural stage in the field was often subjective, inexact, and difficult because many managed forest stands have a diverse distribution of tree diameter classes. Last, some cover type categories did not mesh well with our PVT classification. For example, it was difficult to decide if mixed xeric forest as defined by Redmond and Prather (1996) was restricted to the Douglas-fir PVT.

Probably the next important factor contributing to low map accuracies is inadequate and incomplete ground-truth information. The historical field data used in this project were not an ideal ground-truthing source because these data were collected for diverse studies with specific objectives. Keane and others (1996a) gradient modeling data set (table 2) was accurate and extensive, but many of their plots were established in stands that were smaller than the SILC minimum mapping size because their primary objective was to sample environmental gradients rather than to map vegetation attributes. As a result, many small stands (less than 2 ha) sampled by Keane and others (1996a) were not represented on the original SILC map because they had been "smoothed" into larger polygons. The FBFM's and PVT estimates sampled by Davis and Butterfield (1991) did not correspond well to our PVT, cover type, structural stage assignments. This is probably because of inadequate habitat type and fire behavior fuel model training for their ground crews, inaccurate plot locations, and limited spatial coverage. However, the accuracy of some maps increased only marginally when the historical plot data were removed from the accuracy assessment (table 11).

The clumpy spatial distribution of ground-truth information did not provide an adequate representation of all topographic and vegetation settings in the SBWC (fig. 2). Most ground-truth plots were established along roads or trails because of the logistical problems sampling inaccessible areas. This lack of sampling was especially true in the remote interior and west-central portions of the SBWC. We did not extensively sample some cover types on the SBWC landscape because they either were rare or confined to the remote, untrailed portions of the wilderness. A large number of ground-truth samples is usually recommended for comprehensive satellite imagery analyses and accuracy assessments (sometimes over 100 plots per category depending on size of land area) to ensure statistical validity (Congalton 1991; Mowrer and others 1996). However, sampling intensities of remote wilderness settings must reflect a compromise between logistics, costs, statistical significance, and desired map accuracies.

The initial topographically based PVT rules and FBFM assignments contained errors that lowered map accuracy. Fire managers were unfamiliar with some PVT, cover type, structural stage combinations because they are either rare or in less frequented areas (timberline and upper subalpine, for example) in the SBWC, and therefore the assignment of FBFM was difficult. Some areas had cover types or PVT's that were not represented in the SBWC cover type or PVT list. For example, bogs, seeps, fens, and marshes were not represented in the SBWC PVT list, but they were present on the SBWC landscape (2 percent of total). Ceanothus shrubfields are common on the SBWC landscape and have distinctive fuel characteristics (FBFM 6) compared with other upland shrubs, but this cover type is lumped into the SILC "mesic shrub" cover type (appendix C). Refinements to the PVT rule set based on the plot data may have improved the classification across the entire landscape, but this was difficult to assess because less than 1 percent of the polygons were ground-truthed. Changes in the PVT or FBFM rules resulted in major changes across the SBWC, but often these changes did not affect sampled polygons. Often our refinements would improve one PVT category but weaken the predictive value of several others. Moreover, it was difficult to assess the value of a PVT or FBFM refinement because of the limited ground-truth information for that category. The only solution is to increase the ground-truth sample to represent at least 5 percent of the area, and this may be logistically and financially impossible for some projects.

The FBFM layers had a low accuracy (approximately 59 percent) for a number of reasons. First, this accuracy was difficult to evaluate because fuel models on many of the historical plots were wrong or they were evaluated at the wrong scale. FBFM's were assigned to PVT, cover type, structural stage combinations, and because the cover type and structural stage layers were imprecise, the FBFM layer was also inaccurate (Baker 1989). In addition, FBFM's can be variable within the minimum 2 ha mapping limit used in the SILC effort. As a result, the FBFM was often wrong when the cover type was wrong. Accuracies of the historical data were low (under 37 percent) primarily because they were wrongly assessed at the sample site. However, it is interesting that the fuels maps had higher accuracies than cover type or structural stage maps. This is probably because of the close relationship of fuels to site (PVT) and the small number of fuel categories.

We were surprised at the low accuracy of the acquired continuous SBWC GIS layers (table 12). Over 10 percent of the DEM pixels had elevation errors in excess of 50 m based on a comparison with elevations measured at the plots with a GPS receiver (table 13). Minimum and maximum DEM errors were quite large with a range that sometimes exceeded 2,200 m (table 13a). Slope and aspect errors (table 13b,c) were high because their field measurement has a high degree of variability across a polygon, and the DEM layer had elevational errors. The distribution of errors across all sampled SBWC pixels for elevation, aspect, and slope are shown in figure 3. A majority of validated DEM pixels (83 percent) were within 30 m (about 100 ft) of the observed value. This error was acceptable for PVT elevation constraints but unsatisfactory for slope and aspect computation. The wide spread of errors for aspect and slope is probably a result of the errors in the DEM compounded with errors generated by the ARC/INFO GIS commands used to create these layers and also errors and limitations in field measurement (table 14).

The crown-based fuel layers of stand height, crown height, and crown bulk density also had low accuracies, which is probably an artifact of the mapping procedure rather than the assignments by PVT, cover type, and structural stage. We assessed the accuracy of these assignment keys using the ground-truth data and found substantially higher percent accuracies and higher correlations to observed data (table 15). These assignments were entered into the GIS data base as a reference or "look-up" table that attributes each polygon

Table 13a—Percentage of plots where field-measured elevation deviates from the DEM by more than 30, 50, and 100 m.

	>30 m error	>50 m error	>100 m error
Percent of all plots n = 1,622	17.6	10.3	3.9
Percent of 1996 plots n = 141	13.5	1.4	1.4

Table 13b—Percentage of plots where field-measured slope deviates from DEM-derived slope by more than 10 and 20 percent.

	>10 percent error	>20 percent error
Percent of all plots n = 1,600	35.7	14.2
Percent of 1996 plots n = 140	35.7	11.4

Table 13c—Percentage of plots where field-measured aspect deviates from DEM-derived aspect by more than 45 and 90 degrees.

	>45 degree error	>90 degree error
Percent of all plots n = 1,614	30.7	13.3
Percent of 1996 plots n = 141	24.8	11.3

with the crown characteristic based on PVT, cover type, and structural stage. The accuracy of some crown characteristics (such as crown height in table 15) varied greatly by geographic zone. Most of the error in the assignments is due to the inherent ambiguity in the broad PVT, cover type, and structural stage categories. Any fine-scale stand characteristic such as stand height can have a high variation across the mapped midscale polygons. These assignments can be improved by using finer scale PVT, cover type, and structural stage classifications, or by not using a plot-level approach but rather a sampling methodology that assesses vegetation characteristics across the entire polygon.

Recommendations

Development of the FARSITE fuels data layers should be considered a process and not a product by many land management agencies. These maps should be constantly updated and improved as more ground-truth data are gathered and as better vegetation maps are created. It is a costly and time-consuming task to gather the vast amounts of data needed to adequately validate an image classification from remote sensing, especially if the mapping project only lasts 1 or 2 years. So fire managers shouldn't expect high FARSITE input map accuracies at first, given most land management

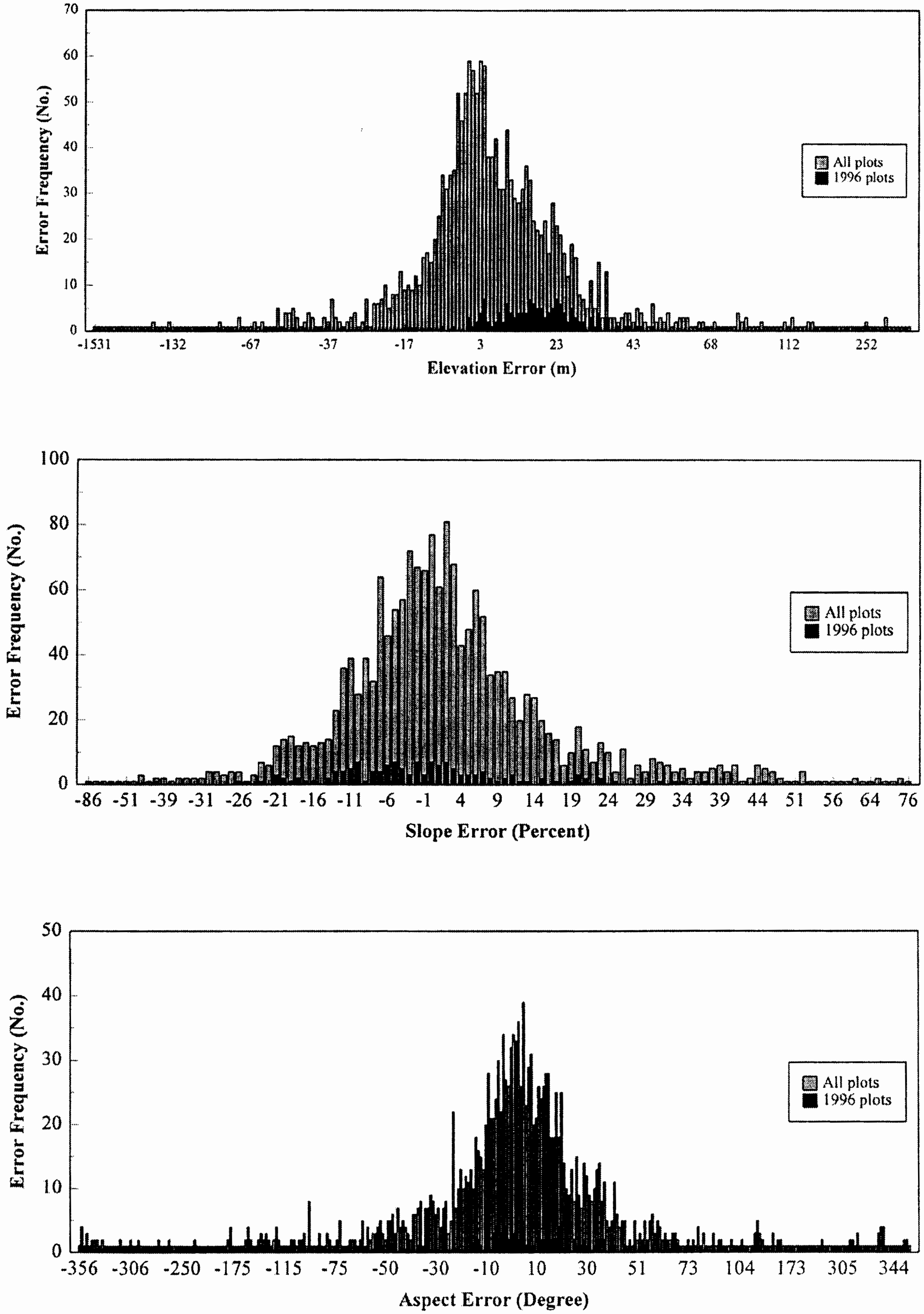

Figure 3—Distribution of error for the continuous GIS layers of elevation, aspect, and slope.

Table 14—Error statistics for elevation, slope, and aspect (all plots).

	Mean signed error	Mean unsigned error	Minimum error	Maximum error	Standard error
Elevation (m) n = 1,622	4.816	25.227	–1,531.730	763.850	1.647
Slope (percent) n = 1,600	2.425	10.945	–86.0	76.0	.298
Aspect (degrees) n = 1,614	–1.349	49.485	–356.0	358.0	1.994

Table 15—Accuracy analysis of the assignment keys of the vegetation-based fuels characteristics of stand height, crown height, and crown bulk density from PVT, cover type, and structural stage. Predicted value obtained from look-up tables; only forested cover types included.

Key	n	R^2	Slope	Intercept	Mean error
Stand height	60	0.65	0.89	2.05	–0.14
Crown height-Montana	37	.08	.23	2.28	–.17
Crown height-northwest/west-central	45	.44	.21	1.04	3.59
Crown bulk density	63	.60	.88	.037	–1.78

agencies do not have and probably will never be able to collect the amount of georeferenced field data required for high accuracy map development. However, map accuracy can be improved over time as additional field data are gathered and as remote sensing platforms and data analysis techniques improve in technology resolution, and quality. The methodology presented in this paper allows for future revisions as new vegetation layers and FBFM keys are created.

The importance of the ground-truth data to map development cannot be overemphasized. These data provide the reference for classification and mapping, and the limitations of these data will surface in the resultant maps. Inadequate plot coverage for important cover types or PVT's will result in an inadequate spatial representation of that type on developed maps. Because of the high cost of georeferenced ground-based information, it is often necessary to evaluate other sources of existing ground-truth data. Stand maps delineated from aerial photos can be used for ground-truth and may be available for some portions of a project area. Although stand maps have some inaccuracies (70 to 90 percent accurate), they can be used to assess the success of developed classifications and mapping algorithms. Other sources of ground-truth data are continuous forest inventory plots, stand examination plots, and other research and management ground-truth efforts. Current university, government, and private research and management projects within the study area may also be potential field data sources. However, it is important that the objectives and methodologies used to collect historical data be consistent with objectives of fuel mapping. For instance, data collected from plots that represent stands that are smaller than the minimum mapping size may not be appropriate for midscale mapping.

Sampling efforts concerned with quantifying fine-scale characteristics such as fuel loading or tree densities may not produce data that are compatible with coarser scale characterizations. It is critical to address the problem of scale in any sampling effort.

It is important that any ground-truth sampling effort require the sampling of more than just the map categories in the field. A complete site and vegetation description is often necessary to understand the processes that created the designed map classification or why a sampled stand keys to a particular map category. Moreover, maps are more useful if they can be expanded for resource applications other than fire. Additional ecosystem characteristics sampled at each plot can be summarized and linked to the vegetation maps for use in other management projects such as the FEFM data base we linked to the vegetation maps. The Northern Region's ECODATA sampling package (Jensen and others 1993; Keane and others 1990) provides the methodology, plot forms, and data base needed for most ground-truthing efforts. This system can be modified in various ways to include new fields or improve existing fields. In addition, it contains standardized methods to extensively describe site characteristics so that other data can be augmented with data collected for a specific ground-truthing effort.

We received some positive feedback from fire managers during summer and fall 1996 concerning the accuracies and value of the SBWC FARSITE fuels maps. Most people were pleased with the maps, but they have not yet identified areas of possible improvement. Most comments submitted by fire mangers concerned the operation and application of the FARSITE program rather than the quality of the fuels maps. Comments submitted by fire managers will be integrated into the next version of the fuels maps.

We are currently refining and modifying the methods used in this study to map fuels and vegetation on the Gila National Forest in New Mexico. A gradient modeling technique is being used to predict PVT's, cover types, and fuel models on this southwestern United States landscape (Keane and others 1996b; Kessell 1979). We use expressions of primary ecological process mapped across the landscape to drive the development of vegetation layers. For example, PVT's are being predicted from maps of average annual precipitation, net primary productivity, solar radiation, and temperature.

Conclusions

This project successfully created the FARSITE fuels input maps from three vegetation layers of potential vegetation type, cover type, and structural stage. These vegetation layers provide the context in which to understand fire behavior fuel model distributions across the landscape. Moreover, the intermediate products used to create the fuels maps can be easily revised and refined to create better fuel maps or to extend fuel mapping to other areas. However, the quality of these maps could be improved if several items are accomplished. First, the three vegetation layers must be developed together to ensure consistency and quality. Second, an extensive and comprehensive ground-truth data base is essential for map development and accuracy assessment. This data base should contain plot data that are evenly distributed across all geographic regions, map categories, and fuel attributes. Third, the input maps should be continually revised and modified as new data are collected and better base vegetation maps become available.

Development of the PVT map can be accomplished using either of the two approaches discussed here. The terrain-modeling, rule-base approach is best when little ground-truth data are available for extensive statistical analysis and there are resource personnel that know and understand the area's ecological relationships. The statistical approach is best when abundant data are available to derive accurate predictive models for PVT assignments. Perhaps a third approach is to meld the two approaches so that a rule-based model can confine the discriminant analysis to only those areas where substantial data have been gathered or only those areas where a particular PVT can occur.

The inherent errors in all GIS layers can be propagated as new maps are created from base data layers. We found error in the DEM base layer, and this error was compounded in the secondary slope and aspect layers and in the tertiary PVT and fuels layers. The SILC cover type map had low accuracies because spectral reflectance did not adequately discriminate many forest cover types and structural stages. The PVT map was inaccurate because of scale discrepancies in the heuristic rulebase. The only way to improve map accuracies is to refine map categories, gather additional ground-truth information, and use better GIS base layers.

References

Albini, Frank A. 1976. Computer-based models of wildland fire behavior: a user's manual. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 68 p.

Anderson, Hal E. 1982. Aids to determining fuel models for estimating fire behavior. Gen. Tech. Rep. INT-122. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 22 p.

Anderson, D. G.; Catchpole, E. A.; DeMestre, N. J.; Parkes, T. 1982. Modeling the spread of grass fires. Journal Australian Mathematical Society (Ser. B). 23: 451-466.

Andrews, Patrica L. 1989. Application of fire growth simulation models in fire management. In: Maciver, D. C.; Auld, H.; Whitewood, D. 10th Conference on Fire and Forest Meteorology; October 26-28; Ottawa, Canada: 317-321.

Andrews, Patrica L. 1986. BEHAVE: Fire behavior prediction and fuel modeling system—BURN subsystem, part 1. Gen. Tech. Rep. INT-194. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 130 p.

Andrews, Patrica L.; Chase, Carolyn H. 1989. BEHAVE: Fire behavior prediction and fuel modeling system—BURN subsystem, part 2. Gen. Tech. Rep. INT-260. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 93 p.

Arno, S. F.; Simmerman, D. G.; Keane, R. E. 1985. Characterizing succession within a forest habitat type—an approach designed for resource managers. Res. Note INT-357. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 8 p.

Bailey, R. G. 1988. Ecogeographic analysis: a guide to the ecological division of land for resource management. Misc. Publ. 1465. Washington, DC: U.S. Department of Agriculture, Forest Service. 16 p.

Bailey, R. G. 1995. Description of the ecoregions of the United States. Misc. Publ. 1391. Washington, DC: U.S. Department of Agriculture, Forest Service. 108 p.

Bain, S. 1989. LANDSAT classification and field correlation methods for vegetation classification used at the Flathead National Forest. In: Ferguson, Dennis E.; Morgan, Penelope; Johnson, Frederic D., comps. Proceedings—land classification based on vegetation: applications for resource management; 1987 November 17-19; Moscow, ID. Gen. Tech. Rep. INT-257. Ogden, UT: U.S. Department of Agriculture, Forest Service. Intermountain Research Station: 255-258.

Baker, William L. 1989. Effect of scale and spatial heterogeneity on fire-interval distributions. Canadian Journal of Forest Research. 19: 700-706.

Baker, William L. 1992. Effects of settlement and fire suppression on landscape structure. Ecology. 73(5): 1879-1887.

Ball, George L.; Guertin, Phillip D. 1992. Advances in fire spread simulation. In: Proceedings on the third Forest Service Remote Sensing applications conference—protecting natural resources with remote sensing; 1992 April 9-13; Tucson, AZ. American Society of Photogrammetry and Remote Sensing: 241-249.

Bolstad, P. V.; Lillesand, T. M. 1992. Improved classification of forest vegetation in northern Wisconsin through a rule-based combination of soils terrain, and LANDSAT Thematic Mapper data. Forest Science. 38(1): 5-20.

Brown, D. G.; Bara, T. J. 1994. Recognition and reduction of systematic error in elevation and derivative surfaces from 7½-minute DEM's. Photogrammetric Engineering and Remote Sensing. 60(2): 189-194.

Brown, J. K.; Arno, S. F.; Barrett, S. W.; Menakis, J. P. 1994. Comparing the prescribed natural fire program with presettlement fires in the Selway-Bitterroot Wilderness. International Journal of Wildland Fire. 4(3): 157-168.

Brown, James K.; Bevins, Collin D. 1986. Surface fuel loadings and predicted fire behavior for vegetation types in the Northern Rocky Mountains. Res. Note INT-358. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 9 p.

Brown, James K.; See, Thomas E. 1981. Downed dead woody fuel and biomass in the Northern Rocky Mountains. Gen. Tech. Rep. INT-117. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 48 p.

Burgan, Robert E.; Rothermel, Richard C. 1984. BEHAVE: fire behavior prediction and fuel modeling system—FUEL subsystem. Gen. Tech. Rep. INT-167. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 126 p.

Cooper, Stephen V.; Neiman, Kenneth E.; Roberts, David W. 1991. Forest habitat types of northern Idaho: a second approximation. Gen. Tech. Rep. INT-236. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 143 p.

Congalton, R. G. 1991. A review of assessing the accuracy of classifications of remotely sensed data. Remote Sensing of the Environment. 37: 35-46.

Cosby, B. J.; Hornberger, G. M.; Clapp, R. B.; Ginn, T. R. 1984. A statistical exploration of the relationships of soil moisture characteristics to the physical properties of soils. Water Resources Research. 20: 682-690.

Davis, D.; Butterfield, B. 1991. The Bitterroot grizzly bear evaluation area: a report to the Bitterroot Technical Review Team. U.S. Department of Agriculture, Forest Service. 56 p.

Elvidge, C. D. 1988. Thermal infrared reflectance of dry plant materials: 2.5-20.0 micrometers. Remote Sensing of Environment. 26: 265-285.

Eyre, F. H., ed. 1980. Forest cover types of the United States and Canada. Washington, DC: Society of American Foresters. 147 p.

Finklin, Arnold I. 1983. Weather and climate of the Selway-Bitterroot Wilderness. Moscow, ID: University Press of Idaho. 144 p.

Finney, Mark A. 1994. Modeling the spread and behavior of prescribed natural fires. In: 12th Conference on Fire and Forest Meteorology; 1993 October 26-28; Jekyll Island, GA. Washington DC: Society of American Foresters. 796 p.

Finney, Mark A. 1995. FARSITE Fire Area Simulator Version 1.0 user guide and technical documentation. Systems for Environmental Management Report. Missoula, MT: Systems for Environmental Management. 76 p.

Fischer, W. C. 1981a. Photo guide for appraising downed woody fuels in Montana forests: grand fir-larch-Douglas-fir, western hemlock, western hemlock-western redcedar, and western redcedar cover types. Gen. Tech. Rep. INT-96. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 53 p.

Fischer, W. C. 1981b. Photo guide for appraising downed woody fuels in Montana forests: interior ponderosa pine, ponderosa pine-larch-Douglas-fir, larch-Douglas-fir, and interior Douglas-fir cover types. Gen. Tech. Rep. INT-97. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 133 p.

Fischer, W. C. 1981c. Photo guide for appraising downed woody fuels in Montana forests: lodgepole pine, and Engelmann spruce-subalpine fir cover types. Gen. Tech. Rep. INT-98. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 143 p.

Fischer, W. C.; Bradley, A. F. 1987. Fire ecology of western Montana forest habitat types. Gen. Tech. Rep. INT-223. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 95 p.

Foody, Giles; Curran, Paul. 1994. Environmental remote sensing from regional to global scales. New York: John Wiley and Sons. 238 p.

Greer, Jerry D., ed. 1994. Remote sensing and ecosystem management. Proceedings of the 5th Forest Service remote sensing applications conference. Bethesda, MD: American Society of Photogrammetry and Remote Sensing. 377 p.

Habeck, James R. 1972. Fire ecology investigations in Selway-Bitterroot Wilderness—historical considerations and current observations. Publ. No. R1-72-001. Missoula, MT: University of Montana.

Hann, W. J.; Jensen, M. E.; Keane, R. E. 1988. Chapter 4: Ecosystem management handbook—ECODATA methods and field forms. Northern Region Handbook. Missoula, MT: U.S. Department of Agriculture, Forest Service. On file at Northern Region.

Jensen, J. R. 1986. Introductory digital image processing. Englewood Cliffs, NJ: Prentiss-Hall. 379 p.

Jensen, M. E.; Hann, W.; Keane, R. E.; Caratti, J.; Bourgeron, P. S. 1993. ECODATA—a multiresource data base and analysis system for ecosystem description and evaluation. In: Jensen, M. E.; Bourgeron, P. S., eds. Eastside forest ecosystem health assessment, volume II, ecosystem management: principles and applications. Washington, DC: National Forest System Information Report. U.S. Department of Agriculture, Forest Service: 249-265.

Keane, R. E.; Reinhardt, E. D.; Brown, J. K. 1995a. FOFEM—a first order fire effects model. In: Brown, J. K.; Mutch, R. W.; Spoon, C. W.; Wakimoto, R. H., tech. coords. Proceedings: symposium on fire in wilderness and park management; 1995 March 30-April 1; Missoula, MT. Gen. Tech. Rep. INT-GTR-320. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 214-215.

Keane, Robert E.; McNicoll, Cecilia H.; Schmidt, Kirsten M.; Garner, Janice L. 1996a. Spatially explicit ecological inventories for ecosystem management planning using gradient modeling and remote sensing. In: Proceedings of the sixth Forest Service remote sensing applications conference—remote sensing; people in partnership with technology. Bethesda, MD: American Society of Photogrammetry and Remote Sensing: 135-146.

Keane, R. E.; Jensen, M. E.; Hann, W. J. 1990. ECODATA and ECOPAC—analytical tools for integrated resource management. The Compiler. 23: 11-24.

Keane, R. E.; Ryan, K.; Running, S. W. 1995b. Simulating the effect of fire on Northern Rocky Mountain landscapes using the ecological process model Fire-BGC. Tree Physiology. 16: 319-331.

Keane, R. E.; Menakis, J. P.; Long, D.; Hann, W. J.; Bevins, C. 1996b. Simulating coarse scale vegetation dynamics with the Columbia River Basin succession model—CRBSUM. Gen. Tech. Rep. INT-340. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 50 p.

Kessell, Stephen R. 1979. Gradient modeling: resource and fire management. New York: Springer-Verlag. 432 p.

Kessell, Stephen R.; Fischer, William C. 1981. Predicting postfire plant succession for fire management planning. Gen. Tech. Rep. INT-94. Ogden, UT: U.S. Department of Agriculture, Forest Service, Forest and Range Experiment Station. 19 p.

Lachowski, Henry; Maus, Paul; Golden, Mike; Johnson, Jan; [and others]. 1995. Guidelines for the use of digital imagery for vegetation mapping. EM-7140-25. Washington, DC: U.S. Department of Agriculture, Forest Service Engineering Staff. 168 p.

Lapen, David R.; Martz, Lawrence W. 1993. The measurement of two simple topographic indices of wind sheltering-exposure from raster digital elevation models. Computers and Geosciences. 19(6): 769-779.

Leprieur, C. E.; Durand, J. M.; Peyron, J. L. 1988. Influence of topography on forest reflectance using LANDSAT thematic mapper and digital terrain data. Photogrammetric Engineering and Remote Sensing. 54(4): 491-496.

Lillesand, T. M.; Kiefer, R. W. 1994. Remote sensing and image interpretation. 3d ed. New York: John Wiley and Sons. 333 p.

McAlpine, R. S.; Wotton, B. M. 1993. The use of fractal dimension to improve wildland fire predictions. Canadian Journal of Forest Research. 23: 1073-1077.

Mowrer, Todd H.; Czaplewski, Raymond L.; Hamre, R. H., tech. coords. 1996. Spatial accuracy assessment in natural resources and environmental sciences: second international symposium; 1996 May 21-23; Fort Collins, CO. Gen. Tech. Rep. RM-GTR-277. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 728 p.

Mueller-Dombois, D.; Ellenburg, H. 1974. Aims and methods of vegetation ecology. New York: John Wiley and Sons. 547 p.

Ottmar, Roger D.; Vihnanek, Robert; Alvarado, Ernesto. 1994. Forest health assessment: air quality tradeoffs. In: Proceedings of the 12th international conference on fire and forest meterology; 1993 October 26-28; Jekyll Island, GA. Bethesda, MD: Society of American Foresters: 47-62.

Pfister, Robert D.; Kovalchik, Bernard L.; Arno, Stephen F.; Presby, Richard C. 1977. Forest habitat types of Montana. Gen. Tech. Rep. INT-34. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 174 p.

Quigley, Thomas M.; Graham, Russell T.; Haynes, Richard W. 1996. An integrated scientific assessment for ecosystem management in the Interior Columbia River Basin and portions of the Klamath and Great Basins. Gen. Tech. Rep. PNW-GTR-382. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 303 p.

Redmond, Roland L.; Prather, Martin L. 1996. Mapping existing vegetation and land cover across western Montana and north Idaho. Report on file at: U.S. Department of Agriculture, Forest Service, Northern Region, Ecosystem Management. P.O. Box 7669, Missoula, MT. Contract 53-0343-4-000012. 211 p.

Reid, Marion; Bourgeron, Patrick; Humphries, Hope; Jensen, Mark. 1995. Documentation of the modeling of potential vegetation at three spatial scales using biophysical settings in the Columbia River Basin. Report on file at: U.S. Department of Agriculture, Forest Service, Northern Region, Ecosystem Management. P.O. Box 7669, Missoula, MT. Contract 53-04H1-6890.

Reinhardt, Elizabeth; Keane, Robert E.; Brown, James K. 1997. FOFEM user's guide. Gen. Tech. Rep. INT-344. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 65 p.

Richards, G. D. 1990. An elliptical growth model of forest fire fronts and its numerical solution. International Journal Numerical Methods Engineering. 30: 1163-1179.

Rothermel, Richard C. 1972. A mathematical model for predicting fire spread in wildland fuels. Res. Pap. INT-115. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 40 p.

Rothermel, Richard C. 1991. Predicting behavior and size of crown fires in the Northern Rocky Mountains. Res. Pap. INT-438. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 46 p.

Rothermel, Richard C.; Wilson, Ralph A.; Morris, Glen A.; Sackett, Stephen S. 1986. Modeling moisture content of fine dead wildland fuels: Input to the BEHAVE fire prediction system. Res. Pap. INT-359. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 62 p.

Schowengerdt, R. A. 1983. Techniques for image processing and classification in remote sensing. New York: Academic Press. 289 p.

Shao, Guofan; Zhao, Guang; Zhao, Shidong; Shugart, Herman H.; [and others]. 1996. Forest cover types derived from Landsat Thematic Mapper imagery for Changbai Mountain area of China. Canadian Journal of Forest Research. 26: 206-216.

Shiflet, T.N., ed. 1994. Rangeland cover types of the United States. Denver, CO: Society of Range Management. 151 p.

Soil Conservation Service (SCS). 1991. State soil geographic data base (STATSGO): data user's guide. Misc. Publ. 1492. Washington, DC: U.S. Department of Agriculture, Soil Conservation Service. 123 p.

Sokal, Robert R.; Rohlf, F. James. 1969. Biometry. San Francisco, CA: W. H. Freeman and Company. 776 p.

Steele, Robert; Geier-Hayes, Kathleen. 1989. The Douglas-fir/ninebark habitat type in central Idaho: succession and management. Gen. Tech. Rep. INT-252. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 65 p.

Stitt, S. 1990. Processing DEM data. Grassclippings. 4(1): 1-8.

Thornton, Peter E.; White, Joseph D. 1996. Biogeochemical characterization of the Columbia River Basin using the BGC model: model description, ecophysiological inputs and landscape description. Final report on file at: U.S. Department of Agriculture, Forest Service, Intermountain Fire Sciences Laboratory, Missoula, MT. 61 p.

Thornton, Peter, E.; Running, S. W.; White, M. A. [In press]. Generating surfaces of daily meteorological variables over large regions of complex terrain. Journal of Hydrology.

Turner, Monica G.; Dale, Virginia H. 1991. Modeling landscape disturbance. In: Turner, Monica; Gardner, Robert, eds. Quantitative methods in landscape ecology. New York: Springer-Verlag: 323-351.

USA CERL. 1990. GRASS 4.0 reference manual. Champaign, IL: United States Army Corps of Engineers, Construction Engineering Research Laboratory. 208 p.

U.S. Geological Survey. 1987. Digital elevation models data users guide. Washington, DC: Department of the Interior. 38 p.

Van Wagner, C. E. 1977. Conditions for the start and spread of crown fire. Canadian Journal of Forest Research. 7: 23-24.

Van Wagner, C. E. 1993. Prediction of crown fire behavior in two stands of jack pine. Canadian Journal of Forest Research. 23: 442-449.

White, Joseph D. 1996. Spatial and temporal scale effects on assessment of a regional ecosystem model: modeling climate change in Glacier National Park, USA. Missoula, MT: University of Montana. 191 p. Dissertation.

White, J. D.; Kroh, G. C.;. Pinder, J. E., III. 1995. Forest mapping at Lassen Volcanic National Park, California, using Landsat TM data and a Geographical Information System. Photogrammetric Engineering and Remote Sensing. 61(3): 299-305.

Appendix A: SBWC ECODATA Ground-Truth Plot Forms

The following four pages contain the forms we used in gathering the field data for this study. We hope the forms, as presented here, might prove useful for the reader in similar data-gathering ventures. See Methods section for further explanation.

GENERAL FIELD DATA FORM (GF)

Key Id (Ag R/S NF RD Yr Ex Plt) *F1-7*: __ __ __ __ __ __ ___   Name *F8*: ________________   Mo *F9*: __   Day *F10*: __

F11-30: Sample Forms __ __ __ __ __ __   *F31*: Unit E   *F32* Plot Radius (ft): __ . _   *F33*: PW 0 0 0

Potential Vegetation

PVT: __   *F37-41*: Form: __   Author: ____   Yr: __   Ind Spp 1: ________   Ind Spp 2: ________   Ind Spp 3: ________

Existing Vegetation

F43-46: Lifeform: __   LSC: __   DSC: __   CC: _   ICRB Stand Structure: __   GAP Stand Structure: __

Vegetation Layers *F47-52*: UL Dom Spp1: ________   UL Dom Spp2: ________   Cover Type: ____

ML Dom Spp1: ________   ML Dom Spp2: ________

LL Dom Spp1: ________   LL Dom Spp2: ________

Live Tree
F86-89: BAF: __ BAN: __ BA: __ DBH: __ Ht: ___

Dead Tree
F90-92: BAF: __ BAN: __ BA: __ DBH: __ Ht: __

Tree Cover (%) *F93-99*: Tot: __ Se: __ Sa: __ PT: __ MT: __ LT: __ VL: __

Shrub Cover (%)
F100-103: Tot: __ LS: __ MS: __ TS: __

Herb Cover (%)
F104-107: Gram: __ Forb: __ Fern: __ Moss: __

Site Data

Spec Ftr *F53*: __   Landform *F54-56*: __ __ __   Par Mat *F57-59*: __ __ __   Position *F60-61*: __ __   Vert Pos *F62*: _   Hor Pos *F63*: _

Map Elev(ft) *F64*: _____   Aspect (deg) *F65*: ___   Slope (%) *F66*: ___   Horizons (%) *F67-69*: East: ___ South: ___ West: ___

Ground Cover (%)
F72-79: BS: __ Gr: __ Ro: __ LD: __ Wo: __ ML: __ BV: __ Wa: __

Fuels Data

Fire Behavior Model Normal(*F80*): __   Fire Behavior Model Severe: __   Fuel Depth (ft) *F81*: _._   DLDepth (in) *F82*: __._   DWCover (%) *F83*: __

Down Log Diam (in) *F84*: __   Dom Layer Ht (ft) *F85*: ___   Ht to Crown (ft): __._   Crown Bulk Density: _.__

Fischer Photo Series:
GTR No: __   Page No: __

Form LL: Location/Linkage Data

Key ID: F1-7: | Ag FS | R/S 01 | NF | RD | Yr | Ex | Plt |

Stand ID: F8-11: | D/Co 0 | Sc | St | SE* |

F12*-TGrp | |

F13* | TID | PID |

F14-18*: Watershed | HUC5 | HUC6 | HUC7 | HUC8 | HUC9 |

F19-23*: Rip Reach ID | 1 | 2 | 3 | 4 | 5 |

F24*- ECOCLASS ID | |

Quad ID: F25-26: | ID | Quad Name* |

Photo ID: F27-28*: | Date | ID* |

Spectral Info: F29-33*: | Date | ID* | Class 1 | Class 2 | Class 3 |

F34-35: Plt Loc | Meth | Accuracy |

F36-39: Lat (N) | Deg | Min | Sec | HSec |

F40-43: Long (W) | Deg | Min | Sec | HSec |

F44-47: UTM | Yr | N | E | Z |

F48-53*: Legal ID | T | R | S | QS | QQS | PM |

F54: Purp | | F55*-Project | | F56*-Picture | | F57*-Pic ID | | F58: Stand/Reach Data | |

GPS File   Elev

F59: State | | F60: County | | F61: Range | Allot | Pas | F62* FCA | | F63-FMA | |

F64: SUK | | F65*-SU ID | | F66*-VegType1 | | F67*-VegType1ID | |

F68*-VegType2 | | F69*-VegType2ID | | F70*-OtherType1 | | F71*-OtherType1ID | |

F72*-OtherType2 | | F73*-OtherType2ID | |

F74-79*-LSI Info:

Subsection	LT Association	Landtype	LTPhase	VBLT	LT Group

F80*-Weather ID | | F81*-Century | | F82*-Avg Precip | | F83*-Avg Snowpack | |

*Optional Fields

Plant Composition Data Form (PC)

Key Id:	Ag	R/S	NF	RD	Yr	Ex	Plt
F1-7:	__	__	__	__	__	__	___

F8: Plant IDL 0 3

	F9 LF	F10 Plant Code	F11 CC (%)	F12 Mht (ft)	F13: Size Classes (%) 1	2	3	4	5	6	Notes
1											
2											
3											
4											
5											
6											
7											
8											
9											
10											
11											
12											
13											
14											
15											
16											
17											
18											
19											
20											
21											
22											
23											
24											
25											
26											
27											
28											
29											
30											
31											
32											
33											
34											
35											
36											
37											
38											
39											

Comments Data Form (CD)

Key Id:	Ag	R/S	NF	RD	Yr	Ex	Plt
F1-7:	_ _	_ _	_ _	_ _	_ _	_ _	_ _

ID: *F8*: Comments: (Always enter your sampling method ID in the first 2 characters, i.e., PC for Plant Composition.)

1. ____________________

2. ____________________

3. ____________________

4. ____________________

5. ____________________

6. ____________________

7. ____________________

8. ____________________

Appendix B: DEM Filtering Procedure

I. The following procedure was used to remove horizontal banding in the Level 1 DEMs yet retain the quality of the Level 2 DEMs

1. DEM files converted to lattices using the ARC commands

   DEMREAD and DEMLATTICE.

2. All Level 1 DEMs were merged using LATTICEMERGE in ARC.
3. All Level 2 DEMs were merged with LATTICEMERGE.
4. Both the Level 1 and Level 2 layers were converted to integers in GRID:

   GRID: lev1dem_int = int(lev1_lattice)

5. The Level 1 layer and Level 2 layer were merged in GRID:

   GRID: DEMsbw_1st = merge(lev2dem_int,lev1dem_int)

6. Remove NODATA slivers resulting from the merge:

   GRID: DEMsbw_sliv = con(isnull(DEMsbw_1st),int(focalmean(DEMsbw_1st)),DEMsbw_1st)

7. The above grid was filtered twice with a vertical filter (1 cell wide x 7 cells high):

   GRID: DEMsbw_filt1 = int(focalmean(DEMsbw_sliv,rectangle,1,7))
   GRID: DEMsbw_filt2 = int(focalmean(DEMsbw_filt1,rectangle,1,7))

8. The Level 2 dem layer was merged with the filtered layer, giving preference to the Level 2 DEMs:

   GRID: dem_2-filtmrg = merge(lev2dem_int,DEMsbw_filt2)

9. Two quads along the Bitterroot River did not have horizontal banding, but rather seemed to have irregular vertical banding. In addition, aspect grids derived from these two DEMs had a scattered "salt and pepper" appearance caused by small changes in elevation (see Stitt, 1990). To reduce both effects, these two DEMs were filtered differently, with one pass of a square 5 cell x 5 cell filter, then merged with the above grid (dem_2-filtmrg).

   GRID: btr_filt5x5 = int(focalmean(lev1_btrflats,rectangle,5,5))
   GRID: btr_2-filtmrg = merge(btr_filt5x5,dem_2-filtmrg)

II. Edge smoothing process: the final "merged" layer from the above steps did not appear to have smooth elevational transitions between Level 2 and filtered DEMs. Several edges were apparent in shaded relief and aspect grids as single horizontal or vertical bands. The following procedure was used to smooth these edges.

1. Create a line coverage with arcs only where edges between Level 2 and Level 1 DEMs occur. This was created in Arcedit from a $7^1/_2$ minute quad coverage by selecting and deleting arcs. Separate coverages were made for horizontal edges and vertical edges. Resulting coverages: hzedge_line and vredge_line
2. Create 30 m grids from the above line coverages:

   GRID: setwindow btr_2-filtmrg
   GRID: setcell 30
   GRID: edgegrd_hz = linegrid(hzedge_line)
   GRID: edgegrd_vr = linegrid(vredge_line)

3. Create mask grids:

   GRID: edgemsk_hz = edgegrd_hz / edgegrd_hz
   GRID: edgemsk_vr = edgegrd_vr / edgegrd_vr

4. Increase the width of the mask grids from 1 cell to 11 cells:

   GRID: hz_11cell = int(focalmax(edgemsk_hz,rectangle,1,11,data))
   GRID: vr_11cell = int(focalmax(edgemsk_vr,rectangle,11,1,data))

5. Using hz_11cell and vr_11cell as masks, filter the edges with a 7 cell directional filter:

   GRID: setmask hz_11cell
   GRID: dem_hzedge = int(focalmean(btr_2-filtmrg,rectangle,1,7,NODATA**))
   GRID: setmask vr_11cell
   GRID: dem_vredge = int(focalmean(btr_2-filtmrg,rectangle,7,1,NODATA**))

** The NODATA option ensures that if any cell in the neighborhood (in this case a 7 cell strip) has a value of nodata, then the output for the processing cell will be nodata. Therefore, of the 11 cell wide mask, only the 5 central cells will receive a value.

6. Merge the filtered edges with the DEM layer

   GRID: dem_final = merge(dem_hzedge,dem_vredge,btr_2-filtmrg)

** MOST of the edges were smoothed nicely with this process. However, because the mask grids were derived from a line coverage not related to the dem layer, some areas of the mask grid did not precisely overlay the edges in the dem layer.

Appendix C: Cover Type Cross Reference Table

SILC code[a]	SILC cover type	PVT[b]	SBWC code	SBWC cover type
1000	Urban or developed land	1	1000	Urban or developed land
2000	Agricultural	1	2000	Agricultural
3101	Foothills grasslands	1-4	3100	Grasslands
		5,6	3104	Montane parklands and subalpine meadows
3102	Disturbed grasslands	1-4	3100	Grasslands
		5-8	3104	Montane parklands and subalpine meadows
3104	Montane parklands and subalpine meadows	1-4	3100	Grasslands
		5-8	3104	Montane parklands and subalpine meadows
3202	Warm mesic shrubland	1-4	3202	Warm mesic shrubland
		5,6	3203	Cold mesic shrubland
3203	Cold mesic shrubland	1-4	3202	Warm mesic shrubland
		5-8	3203	Cold mesic shrubland
3301	Curlleaf mountain mahogany	1-4	3202	Warm mesic shrubland
		5-8	3203	Cold mesic shrubland
3304	Bitterbrush	1-4	3202	Warm mesic shrubland
		5-8	3203	Cold mesic shrubland
3305	Mountain big sagebrush	1-4	3202	Warm mesic shrubland
		5-8	3203	Cold mesic shrubland
3306	Wyoming big sagebrush steppe	1-4	3202	Warm mesic shrubland
		5-8	3203	Cold mesic shrubland
3308	Black sagebrush steppe	1-4	3202	Warm mesic shrubland
		5-8	3203	Cold mesic shrubland
4102	Broadleaf forest	1-3, 5-7	3202	Broadleaf forest
		4	3202	Warm mesic shrubland
4201	Engelmann spruce	3	4207	Grand fir
		4	4212	Douglas-fir
		5-7	4201	Engelmann spruce
4203	Lodgepole pine	All	4203	Lodgepole pine
4206	Ponderosa pine	1,3,4	4206	Ponderosa pine
		2, 5-7	4203	Lodgepole pine
4207	Grand fir	1-3	4207	Grand fir
		4-7	4212	Douglas-fir
4208	Subalpine fir	4	4212	Douglas-fir
		5-8	4208	Subalpine fir
4210	Western redcedar	2	4210	Western redcedar
		1,3	4207	Grand fir
		4	4212	Douglas-fir

(con.)

Appendix C (Con.)

SILC code[a]	SILC cover type	PVT[b]	SBWC code	SBWC cover type
4212	Douglas-fir	1-6	4212	Douglas-fir
		7,8	4208	Subalpine fir
4215	Western larch	1-6	4215	Western larch
		7	4220	Mixed subalpine forest
4219	Mixed alpine forest	4	4222	Mixed xeric forest
		5-7	4220	Mixed subalpine forest
		8	4219	Mixed timberline forest
4220	Mixed subalpine forest	1,3,4	4221	Mixed mesic forest
		5-8	4220	Mixed subalpine forest
4221	Mixed mesic forest	1-4	4221	Mixed mesic forest
		5-8	4220	Mixed subalpine forest
4222	Mixed xeric forest	1,2	4222	Mixed xeric forest
		2,3	4221	Mixed mesic forest
		5-7	4220	Mixed subalpine forest
4223	Douglas-fir/ lodgepole pine	1-6	4223	Douglas-fir/lodgepole pine
		7,8	4220	Mixed subalpine forest
4224	Standing burnt and dead timber	All	4224	Standing burnt and dead timber
4225	Douglas-fir/grand fir	2,3	4225	Douglas-fir/grand fir
		4,5	4212	Douglas-fir
		6,7	4220	Mixed subalpine forest
4226	Western redcedar/grand fir	2	4226	Western redcedar/grand fir
		3	4207	Grand fir
		1,4	4221	Mixed mesic forest
		5	4220	Mixed subalpine forest
4228	Western larch/lodgepole pine	All	4228	Western larch/lodgepole pine
4229	Western larch/Douglas-fir	All	4229	Western larch/Douglas-fir
4301	Mixed needleleaf/broadleaf forest	All	4102	Broadleaf forest
5000	Water	11	5000	Water
7300	Exposed rock	10	7300	Exposed rock
7800	Mixed barren land	1	2000	Agriculture
		2-4	3100	Grasslands
		5-8	3104	Montane parklands and subalpine meadows
7900	Shorleline and stream gravel bars	10	7900	Shorleline and stream gravel bars
8100	Alpine meadow	10	8100	Alpine meadow
9100	Perennial snowfields	10	9100	Perennial snowfields

[a]See Redmond and others (1996) for detail description of SILC cover types.
[b]This number references the PVT in which the cover type occurs. See table 3 for PVT description.

Appendix D: Terrain Models

Terrain models of potential vegetation in three zones in the Selway-Bitterroot Wilderness of Idaho and Montana, USA.

Number	PVT group	Series and habitat types	Aspects	Elevation range	Slope	Comments[a]
West-Central Zone						
			Azimuths	*Meters (ft)*	*Percent*	
1	Developed/ agricultural/ urban lands					Not in WC
2	THPL		315-90	1<1,463 (4,800)	<30	Streamside buffer
			90-315	<1,067 (3,500)		
3	ABGR		315-90	THPL buffer- 1,524 (5,000)		Not THPL Not PSME
			90-315	THPL buffer- 1,524 (5,000)	<30	
4	PSME	Dry and moist PSME, PIPO, dry ABGR	90-315	<1,585 (<5,200)	>30	
			315-90	<1,280 (<4,200)	>20	
5	Lower subalpine-moist	ABLA/CLUN, LIBO, ALSI, MEFE, CACA	315-90	1,525-2,134 (5,000-7,000)		
6	Lower subalpine-dry	ABLA/XETE	90-315	1,586-2,195 (5,200-7,200)		
7	Upper subalpine-moist	ABLA/LUHI-MEFE	315-90	2,135-2,286 (7,000-7,500)		
8	Upper subalpine-dry	ABLA/LUHI-VASC, PIAL-ABLA, LALY-ABLA	All	2,196+ (7,200+)		Not rock or alpine
9	Persistent herblands		90-315		>50	From SILC map
10	Rock/alpine/ perennial snowfields					From SILC map
11	Water					From SILC map

(con.)

Appendix D (Con.)

Number	PVT group	Series and habitat types	Aspects	Elevation range	Slope	Comments[a]
		Northwest Zone				
			Azimuths	*Meters (ft)*	*Percent*	
1	Developed/ agricultural/ urban lands					None in NW
2	THPL	THPL/CLUN	280-120	<1,219 (4,000)		
			120-280	<1,280 (4,200)	<40	
3	ABGR	ABGR/CLUN, LIBO, XETE	280-120	1,219-1,524 (4,000-5,000)		Not PSME
			120-280	1,280-1,585 (4,200-5,200)		
4	PSME	Dry and moist PSME, dry ABGR	120-280	<1,463 (4,800)	>40	
5	Lower subalpine-moist	ABLA/CLUN, LIBO, ALSI, MEFE, CACA	280-120	1,525-2,012 (5,000-6,600)		
			120-280	1,586-1,829 (5,200-6,000)	<15	
6	Lower subalpine-dry	ABLA/XETE	120-280	1,586-2,073 (5,200-6,800)	>15	
7	Upper subalpine-moist	ABLA/LUHI-VAGL	280-120	1,890-2,134 (6,200-7,000)	<30	
			120-280	1,830-2,073 (6,000-6,800)	<15	
8	Upper subalpine-dry	ABLA/LUHI-VASC, PIAL-ABLA, LALY-ABLA	280-120	2,013+ (6,600+)		Not rock or alpine
			120-280	2,074+ (6,800+)		
9	Persistent herblands		120-270	<2,256 (<7,400)	>50	From SILC map
10	Rock/alpine/ perennial snowfields					From SILC map
11	Water					From SILC map

(con.)

Montana Zone						
Number	**PVT group**	**Series and habitat types**	**Aspects**	**Elevation range**	**Slope**	**Comments**[a]
			Azimuths	*Meters (ft)*	*Percent*	
1	Developed/ agricultural/ urban lands		All			From ICB ownership map
2	THPL	THPL/CLUN				Not in MT
3	ABGR	ABGR/CLUN, LIBO, XETE	All	<1,372 (4,500)	<30	Streamside buffer
			120-280	1,219-1,677 (4,000-5,500)	<15	Not lower, subalpine-moist
			330-70	1,219-1,677 (4,000-5,500)		
4	PSME	Dry and moist PSME, PIPO, dry ABGR	280-120	915-1,829 (3,000-6,000)		Not ABGR not lower subalpine-moist
			120-280	915-1,829 (3,000-6,000)		
5	Lower subalpine-moist	ABLA/CLUN, LIBO, ALSI, MEFE, GATR, CACA	330-70	1,524-1,829 (5,000-6,000)	<25	
6	Lower subalpine-dry	ABLA/XETE	90-315	1,646-2,256 (5,400-7,400)		
7	Upper subalpine-moist	ABLA/LUHI-MEFE	315-90	1,830-2,317 (6,000-7,600)		
8	Upper subalpine-dry	ABLA/LUHI-VASC, PIAL-ABLA, LALY-ABLA	90-315	2,257+ (7,400+)		Not rock or alpine
			315-90	2,318+ (7,600+)		
9	Persistent herblands					Not in MT
10	Rock/alpine/ perennial snowfields					From SILC map
11	Water					From SILC map

[a]SBWC = Selway-Bitterroot Wilderness Complex Assessment Area; NW = Northwest section of SBWC; WC = West-central section of SBWC; MT = Montana section of SBWC; SILC Map is the Satellite Imagery Land Cover spatial classification developed by the Wildlife Spatial Analysis Laboratory, University of Montana, Missoula.

Appendix E: Fuels Mapping Worksheet Example

Worksheet directions: Fill in FBFM Normal[a], FBFM Severe[b], HLCB[c], and FEFM[d].

PVT[e], COVER TYPE, STRUCTURAL STAGE	FBFM Normal	FBFM Severe	HLCB	FEFM
PVT CODE, NAME				
Cover Type Code, Cover Type Name				
Structural Stage Code, Structural Stage Description	1-10 (11-13)	1-10 (11-13)	To nearest foot	Book No. Page No.

Example:

PVT, COVER TYPE, STRUCTURAL STAGE	FBFM Normal	FBFM Severe	HLCB	FEFM
1 Grand Fir, *Abies grandis*				
4212 Douglas-fir				
5 Seedling/Sapling <5.0" d.b.h.[f]	5	5	3	NA
6 Pole Tree 5.0-8.9" d.b.h.	8	8	4	98, 14
7 Medium Tree 9.0-21.0" d.b.h.	8	10	6	98, 18
8 Large/Very Large Tree >21.0" d.b.h.	10	10	4	98, 38

[a] FBFM Normal = Fire Behavior Fuel Model under normal conditions, Anderson (1982): Number 1-10 (11-13 are slash fuels)
[b] FBFM Severe = Fire Behavior Fuel Model under severe conditions, Anderson (1982): Number 1-10 (11-13 are slash fuels)
[c] HLCB = Height to live crown base
[d] FEFM = Fire Effects Model (Fischer Photo Series, 1981a-c), only natural fuels
[e] PVT = Potential Vegetation Type
[f] d.b.h. = Diameter at breast height

Appendix F: Fire Behavior Fuel Model Assignments

Fire behavior fuel model assignments to PVT, cover type, structural stage combinations.

Montana					West-Central and Northwest				
PVT	Cover	Stg	FBFM Norm	FBFM Sev	PVT	Cover	Str	FBFM Norm	FBFM Sev
1	1000	10	99	99	2	3100	01	1	1
1	2000	11	1	1	2	3202	02	5	5
1	3100	01	1	1	2	3202	03	5	5
1	3104	01	1	1	2	3202	04	5	6
1	3202	02	5	5	2	4102	05	8	8
1	3202	03	5	6	2	4102	06	8	8
1	3202	04	5	6	2	4102	07	8	8
1	3203	02	5	5	2	4102	08	10	10
1	3203	03	5	6	2	4201	06	8	8
1	3301	02	5	5	2	4201	07	10	10
1	3301	03	5	6	2	4201	08	10	10
1	3301	04	5	6	2	4203	05	8	8
1	3304	02	5	5	2	4203	06	8	8
1	3304	03	5	5	2	4203	07	10	10
1	4102	05	5	5	2	4203	08	10	10
1	4102	06	5	5	2	4206	05	5	5
1	4102	07	5	5	2	4206	06	8	9
1	4102	08	10	10	2	4206	07	9	9
1	4201	07	8	10	2	4206	08	2	10
1	4201	08	10	10	2	4207	05	5	5
1	4203	05	5	5	2	4207	06	8	8
1	4203	06	8	8	2	4207	07	8	10
1	4203	07	10	10	2	4207	08	10	10
1	4203	08	10	10	2	4208	06	8	8
1	4206	05	5	6	2	4210	05	8	8
1	4206	06	8	8	2	4210	06	8	8
1	4206	07	8	8	2	4210	07	8	8
1	4206	08	10	10	2	4210	08	8	10
1	4207	05	5	6	2	4212	05	5	5
1	4207	06	8	8	2	4212	06	8	8
1	4207	07	10	10	2	4212	07	8	10
1	4207	08	10	10	2	4212	08	10	10
1	4212	05	5	6	2	4221	05	5	5
1	4212	06	8	8	2	4221	06	8	8
1	4212	07	8	10	2	4221	07	10	10
1	4212	08	10	10	2	4221	08	10	10
1	4215	05	5	6	2	4223	05	5	5
1	4215	06	8	8	2	4223	06	8	8
1	4220	05	5	6	2	4223	07	10	10
1	4220	06	8	8	2	4223	08	10	10
1	4220	07	10	10	2	4225	05	5	5
1	4220	08	10	10	2	4225	06	8	8
1	4221	05	5	6	2	4225	07	8	10
1	4221	06	8	8	2	4225	08	10	10
1	4221	07	8	8	2	4226	05	5	5
1	4221	08	10	10	2	4226	06	8	8
1	4222	05	5	6	2	4226	07	10	10
1	4222	06	8	8	2	4226	08	10	10
1	4222	07	8	8	2	4229	06	8	8
1	4222	08	10	10	2	4301	05	8	8
1	4223	06	8	8	2	4301	06	8	8
1	4223	07	8	10	2	4301	07	8	9
1	4223	08	10	10	2	4301	08	8	9
1	4225	05	5	6	3	3100	01	1	1
1	4225	06	8	8	3	3104	01	2	2

(con.)

Appendix F (Con.)

Montana

PVT	Cover	Stg	FBFM Norm	FBFM Sev
1	4225	07	10	10
1	4225	08	10	10
1	4228	07	8	8
1	4228	08	10	10
1	4229	06	8	8
1	4301	05	5	6
1	4301	06	8	8
1	4301	07	8	10
1	4301	08	10	10
1	7300	12	99	99
1	7800	12	99	99
1	7900	12	99	99
3	1000	10	99	99
3	2000	11	1	1
3	3100	01	1	1
3	3104	01	5	1
3	3202	02	5	5
3	3202	03	5	6
3	3202	04	5	6
3	4102	05	8	8
3	4102	06	8	8
3	4102	07	8	10
3	4102	08	8	10
3	4201	05	5	6
3	4201	06	8	8
3	4201	07	8	8
3	4201	08	10	10
3	4203	05	5	6
3	4203	06	8	8
3	4203	07	10	10
3	4203	08	10	10
3	4206	05	5	6
3	4206	06	8	8
3	4206	07	8	10
3	4206	08	10	10
3	4207	05	5	6
3	4207	06	8	10
3	4207	07	10	10
3	4207	08	10	10
3	4212	05	5	6
3	4212	06	8	8
3	4212	07	10	10
3	4212	08	10	10
3	4215	05	5	6
3	4215	06	8	8
3	4215	07	8	10
3	4215	08	10	10
3	4221	05	5	6
3	4221	06	8	10
3	4221	07	8	10
3	4221	08	10	10
3	4222	05	5	6
3	4222	06	8	8
3	4222	07	8	10
3	4222	08	10	10
3	4223	05	5	6

West-Central and Northwest

PVT	Cover	Str	FBFM Norm	FBFM Sev
3	3202	02	5	6
3	3202	03	5	5
3	3202	04	5	6
3	4102	05	8	8
3	4102	06	8	9
3	4102	07	8	9
3	4201	05	5	5
3	4201	06	8	8
3	4201	07	8	10
3	4201	08	10	10
3	4203	05	8	8
3	4203	06	8	8
3	4203	07	10	10
3	4203	08	10	10
3	4206	05	2	5
3	4206	06	8	9
3	4206	07	9	9
3	4206	08	2	10
3	4207	05	5	5
3	4207	06	8	8
3	4207	07	10	10
3	4207	08	10	10
3	4212	05	5	5
3	4212	06	8	8
3	4212	07	8	8
3	4212	08	10	10
3	4215	05	5	5
3	4215	06	8	8
3	4215	07	8	10
3	4215	08	10	10
3	4221	05	5	5
3	4221	06	8	8
3	4221	07	8	10
3	4221	08	10	10
3	4222	05	8	8
3	4222	06	8	8
3	4222	07	8	10
3	4222	08	10	10
3	4223	05	5	5
3	4223	06	8	8
3	4223	07	10	10
3	4223	08	10	10
3	4225	05	5	5
3	4225	06	8	8
3	4225	07	10	10
3	4225	08	10	10
3	4228	05	5	5
3	4228	06	8	8
3	4228	07	10	10
3	4228	08	10	10
3	4229	05	5	5
3	4229	06	8	8
3	4229	07	8	10
3	4229	08	10	10
3	4301	05	8	8
3	4301	06	8	8

(con.)

Appendix F (Con.)

Montana

PVT	Cover	Stg	FBFM Norm	FBFM Sev
3	4223	06	8	8
3	4223	07	8	10
3	4223	08	10	10
3	4224	01	10	10
3	4225	05	5	6
3	4225	06	8	8
3	4225	07	10	10
3	4225	08	10	10
3	4226	05	5	6
3	4226	06	8	8
3	4226	07	10	10
3	4226	08	10	10
3	4228	05	5	6
3	4228	06	8	8
3	4228	07	8	10
3	4228	08	10	10
3	4229	05	5	6
3	4229	06	8	8
3	4229	07	8	10
3	4229	08	10	10
3	4301	05	5	6
3	4301	06	8	8
3	4301	08	8	10
3	7701	12	99	99
4	1000	10	99	99
4	2000	11	1	1
4	3100	01	1	1
4	3104	01	2	2
4	3202	02	5	5
4	3202	03	5	6
4	3202	04	5	6
4	4102	05	5	5
4	4102	06	8	8
4	4102	07	8	8
4	4102	08	8	10
4	4203	05	5	6
4	4203	06	8	8
4	4203	07	8	10
4	4203	08	10	10
4	4206	05	5	5
4	4206	06	8	8
4	4206	07	2	2
4	4206	08	10	10
4	4212	05	5	6
4	4212	06	8	8
4	4212	07	8	8
4	4212	08	10	10
4	4215	05	5	5
4	4215	06	8	8
4	4215	07	8	8
4	4215	08	10	10
4	4221	05	5	6
4	4221	06	8	8
4	4221	07	8	10
4	4221	08	10	10
4	4222	05	5	6
4	4222	06	8	8

West-Central and Northwest

PVT	Cover	Str	FBFM Norm	FBFM Sev
3	4301	08	8	8
3	7701	12	99	99
4	3100	01	1	1
4	3104	01	2	2
4	3202	02	5	6
4	3202	03	5	5
4	3202	04	5	2
4	4203	05	8	8
4	4203	06	8	8
4	4203	07	10	10
4	4203	08	10	10
4	4206	05	2	5
4	4206	06	9	9
4	4206	07	9	9
4	4206	08	2	9
4	4212	05	5	5
4	4212	06	8	8
4	4212	07	8	8
4	4212	08	10	10
4	4215	05	5	5
4	4215	06	8	8
4	4215	07	10	10
4	4215	08	10	10
4	4221	05	5	5
4	4221	06	8	8
4	4221	07	10	10
4	4221	08	10	10
4	4222	05	8	8
4	4222	06	8	8
4	4222	07	8	10
4	4222	08	10	10
4	4223	05	5	5
4	4223	06	8	8
4	4223	07	10	10
4	4223	08	10	10
4	4224	01	10	10
4	4228	05	5	5
4	4228	06	8	8
4	4228	07	10	10
4	4228	08	10	10
4	4229	05	5	5
4	4229	06	8	8
4	4229	07	8	10
4	4229	08	10	10
4	7300	12	99	99
4	7701	12	99	99
4	7800	12	99	99
5	3103	01	5	2
5	3104	01	1	1
5	3202	02	5	6
5	3202	03	5	6
5	3202	04	5	6
5	3203	02	5	6
5	3203	03	5	6
5	3203	04	5	2
5	4102	05	8	8
5	4102	06	8	9

(con.)

Appendix F (Con.)

Montana

PVT	Cover	Stg	FBFM Norm	FBFM Sev
4	4222	07	8	8
4	4222	08	10	10
4	4223	05	5	6
4	4223	06	8	8
4	4223	07	8	10
4	4223	08	10	10
4	4224	01	10	10
4	4228	05	5	6
4	4228	06	8	8
4	4228	07	8	10
4	4228	08	10	10
4	4229	05	5	6
4	4229	06	8	8
4	4229	07	8	10
4	4229	08	10	10
4	4301	05	5	6
4	4301	06	8	8
4	4301	07	8	10
4	4301	08	10	10
4	7300	12	99	99
4	7701	12	99	99
4	7800	12	99	99
5	3104	01	5	1
5	3202	02	5	5
5	3202	03	5	6
5	3202	04	5	6
5	3203	02	5	5
5	3203	03	5	6
5	3203	04	5	6
5	4102	05	5	5
5	4102	06	8	8
5	4102	07	8	8
5	4102	08	8	10
5	4201	05	5	6
5	4201	06	8	8
5	4201	07	10	10
5	4201	08	10	10
5	4203	05	5	6
5	4203	06	8	8
5	4203	07	8	10
5	4203	08	10	10
5	4208	05	5	6
5	4208	06	8	8
5	4208	07	10	10
5	4208	08	10	10
5	4212	05	5	6
5	4212	06	8	8
5	4212	07	8	10
5	4212	08	10	10
5	4215	05	5	5
5	4215	06	8	8
5	4215	07	8	10
5	4215	08	10	10
5	4220	05	5	6
5	4220	06	8	8
5	4220	07	8	10
5	4220	08	10	10
5	4223	05	5	6
5	4223	06	8	8
5	4223	07	8	10

West-Central and Northwest

PVT	Cover	Str	FBFM Norm	FBFM Sev
5	4102	07	8	9
5	4102	08	8	9
5	4201	05	5	5
5	4201	06	8	8
5	4201	07	8	10
5	4201	08	10	10
5	4203	05	8	8
5	4203	06	8	8
5	4203	07	10	10
5	4203	08	10	10
5	4208	05	5	5
5	4208	06	5	5
5	4208	07	5	10
5	4208	08	10	10
5	4212	05	5	5
5	4212	06	5	5
5	4212	07	5	10
5	4212	08	10	10
5	4215	05	5	5
5	4215	06	8	8
5	4215	07	10	10
5	4215	08	10	10
5	4220	05	5	8
5	4220	06	8	8
5	4220	07	10	10
5	4220	08	10	10
5	4223	05	5	5
5	4223	06	8	8
5	4223	07	10	10
5	4223	08	10	10
5	4224	01	10	10
5	4228	05	5	5
5	4228	06	8	8
5	4228	07	10	10
5	4228	08	10	10
5	4229	05	5	5
5	4229	06	8	8
5	4229	07	8	10
5	4229	08	10	10
5	7701	12	99	99
6	3104	01	2	2
6	3202	02	5	6
6	3202	03	5	6
6	3202	04	5	6
6	3203	02	5	6
6	3203	03	5	6
6	3203	04	5	6
6	4102	05	8	8
6	4102	06	8	9
6	4102	07	8	9
6	4201	05	5	5
6	4201	06	8	8
6	4201	07	8	10
6	4201	08	10	10
6	4203	05	8	8
6	4203	06	8	8
6	4203	07	8	8
6	4203	08	10	10
6	4208	05	8	5
6	4208	06	8	5

(con.)

Appendix F (Con.)

Montana				
PVT	Cover	Stg	FBFM Norm	FBFM Sev
5	4223	08	10	10
5	4224	01	10	10
5	4228	05	5	6
5	4228	06	8	8
5	4228	07	8	10
5	4228	08	10	10
5	4229	05	5	6
5	4229	06	8	8
5	4229	07	8	10
5	4229	08	10	10
5	4301	05	5	6
5	7701	12	99	99
6	3104	01	2	2
6	3202	02	5	5
6	3202	03	5	6
6	3202	04	5	6
6	3203	02	5	5
6	3203	03	5	6
6	3203	04	5	6
6	4102	05	5	5
6	4102	06	8	8
6	4102	07	8	10
6	4201	05	5	6
6	4201	06	8	8
6	4201	07	10	10
6	4201	08	10	10
6	4203	05	5	6
6	4203	06	8	8
6	4203	07	8	10
6	4203	08	10	10
6	4208	05	5	6
6	4208	06	8	8
6	4208	07	10	10
6	4208	08	10	10
6	4212	05	5	6
6	4212	06	8	8
6	4212	07	8	10
6	4212	08	8	10
6	4215	05	5	5
6	4215	06	8	8
6	4215	07	8	10
6	4215	08	10	10
6	4220	05	5	6
6	4220	06	8	8
6	4220	07	8	10
6	4220	08	10	10
6	4223	05	5	6
6	4223	06	8	8
6	4223	07	8	8
6	4223	08	10	10
6	4224	01	10	10
6	4225	05	5	6
6	4225	06	8	8
6	4225	07	10	10
6	4228	06	8	8
6	4228	07	8	10
6	4228	08	10	10
6	4229	05	5	6
6	4229	06	8	8
6	4229	07	8	10

West-Central and Northwest				
PVT	Cover	Str	FBFM Norm	FBFM Sev
6	4208	07	10	10
6	4208	08	10	10
6	4212	05	8	5
6	4212	06	8	5
6	4212	07	8	10
6	4212	08	10	10
6	4215	05	5	5
6	4215	06	8	8
6	4215	07	10	10
6	4215	08	10	10
6	4220	05	8	5
6	4220	06	8	8
6	4220	07	8	8
6	4220	08	10	10
6	4223	05	5	5
6	4223	06	8	8
6	4223	07	10	10
6	4223	08	10	10
6	4224	01	10	10
6	4228	06	8	8
6	4228	07	10	10
6	4228	08	10	10
6	4229	05	5	5
6	4229	06	8	8
6	4229	07	8	10
7	3104	01	2	2
7	3203	02	5	6
7	3203	03	5	6
7	3203	04	5	6
7	4102	05	8	8
7	4102	07	8	8
7	4201	05	5	5
7	4203	05	8	8
7	4203	06	8	8
7	4203	07	10	10
7	4203	08	10	10
7	4208	05	5	5
7	4208	06	5	5
7	4208	07	10	10
7	4208	08	10	10
7	4219	05	5	5
7	4219	06	5	5
7	4219	07	10	10
7	4219	08	10	10
7	4220	05	8	8
7	4220	06	8	10
7	4220	07	8	10
7	4220	08	10	10
7	4224	01	10	10
7	7300	12	99	99
7	9100	12	99	99
8	3104	01	2	2
8	3203	02	5	6
8	3203	03	5	6
8	3203	04	5	6
8	4201	05	5	5
8	4203	05	8	8
8	4203	06	8	8
8	4203	07	8	8
8	4208	05	8	8

(con.)

Appendix F (Con.)

Montana				
PVT	Cover	Stg	FBFM Norm	FBFM Sev
6	7300	12	99	99
6	7701	12	99	99
6	9100	12	99	99
7	3104	01	5	1
7	3203	02	5	5
7	3203	03	5	6
7	3203	04	5	6
7	4102	05	5	5
7	4102	07	8	8
7	4201	05	5	6
7	4201	07	10	10
7	4203	05	5	6
7	4203	06	8	8
7	4203	07	8	10
7	4203	08	10	10
7	4208	05	5	6
7	4208	06	8	8
7	4208	07	8	10
7	4208	08	10	10
7	4219	05	5	6
7	4219	06	8	8
7	4219	07	8	10
7	4219	08	10	10
7	4220	05	5	6
7	4220	06	8	8
7	4220	07	8	10
7	4220	08	10	10
7	4224	07	10	10
7	7300	12	99	99
7	9100	12	99	99
8	3102	01	1	1
8	3104	01	5	1
8	3203	02	5	5
8	3203	03	5	6
8	3203	04	5	6
8	4201	05	5	6
8	4203	05	5	6
8	4203	06	8	8
8	4203	07	8	10
8	4208	05	5	6
8	4208	06	8	8
8	4208	07	10	10
8	4208	08	10	10
8	4219	05	5	6
8	4219	06	8	8
8	4219	07	8	8
8	4219	08	10	10
8	4220	05	5	6
8	4220	06	8	8
8	4220	07	8	10
8	4220	08	10	10
8	4224	01	10	10
8	9100	12	99	99
9	3100	01	1	1
10	7300	12	99	99
10	7800	12	99	99
10	7900	12	99	99
10	8100	12	99	99
10	9100	12	99	99
11	5000	09	98	98

West-Central and Northwest				
PVT	Cover	Str	FBFM Norm	FBFM Sev
8	4208	06	8	8
8	4208	07	8	10
8	4208	08	10	10
8	4219	05	8	8
8	4219	06	8	8
8	4219	07	8	10
8	4219	08	8	10
8	4220	05	8	8
8	4220	06	8	8
8	4220	07	8	8
8	4220	08	10	10
8	4224	01	10	10
8	9100	12	99	99
9	3100	01	1	1
9	3104	01	1	1
10	7300	12	99	99
10	7800	12	99	99
10	7900	12	99	99
10	8100	12	99	99
10	9100	12	99	99
11	5000	09	98	98

Appendix G: Crown Bulk Density Reference Data

Species	Canopy cover: Low cover	Medium cover	High cover
Ponderosa pine			
Seedling/sapling	0.10	0.12	—
Pole/medium/large	.09	.14	0.20
Douglas-fir			
Seedling/sapling	.10	.12	—
Pole/medium/large	.10	.18	.25
Lodgepole pine			
Seedling/sapling	.10	.12	—
Pole/medium/large	.09	.15	.22
Western larch			
Seedling/sapling	.10	.12	—
Pole/medium/large	.09	.14	.20
Western redcedar			
Seedling/sapling	.15	.17	—
Pole/medium/large	.12	.21	.30
Englemann spruce			
Seedling/sapling	.10	.12	—
Pole/medium/large	.10	.18	.25
Grand fir			
Seedling/sapling	.15	.17	—
Pole/medium/large	.12	.21	.30
Subalpine fir			
Seedling/sapling	.15	.17	—
Pole/medium/large	.12	.21	.30
Whitebark pine			
Seedling/sapling	.10	.12	—
Pole/medium/large	.09	.14	.20

Appendix H: Accuracy Assessment Matrices of PVT and Structural Stage

PVT Categories — REFERENCE PVTs Plot Data

		2	3	4	5	6	7	8	9	10	11	TOTAL	COMMISSION ERROR (%)
	2	13	9	24	0	0	0	0	0	1	1	48	73
	3	30	84	49	17	9	1	0	13	0	2	205	59
	4	47	53	139	28	15	0	0	0	7	6	295	53
	5	4	23	1	55	62	1	12	8	4	0	170	68
CLASSIFIED PVTs	6	2	56	22	42	123	10	10	7	8	0	280	56
From Terrain Model	7	0	0	0	11	24	1	2	0	2	0	40	98
	8	0	0	0	9	72	4	57	3	13	0	158	64
	9	1	0	22	0	0	0	0	0	4	2	29	100
	10	0	2	20	5	11	3	18	6	14	1	8	83
	11	0	0	1	1	0	0	0	0	0	7	9	22
	TOTAL	97	227	278	168	316	20	99	37	53	19	1314	
	OMISSION ERROR (%)	87	63	50	67	61	95	42	100	74	63		

OVERALL ACCURACY = 37%
KHAT ACCURACY = 25%

(con.)

Appendix H (Con.)

STRUCTURAL STAGE

CLASSIFIED STAGES from SBWC polygons	REFERENCE STAGE (Plot data) 1	2	3	4	5	6	7	8	11	12	TOTAL	COMMISSION ERROR (%)
1	15	3	1	1	8	6	14	3	1	0	52	71
2	2	4	1	1	4	1	6	1	0	0	20	80
3	1	0	3	4	1	2	1	2	0	0	14	79
4	0	0	0	6	2	0	6	4	0	2	20	70
5	2	1	0	2	3	12	32	2	0	0	54	94
6	5	0	1	1	7	9	25	10	0	0	58	84
7	3	1	3	1	11	35	76	21	0	0	151	50
8	0	0	0	1	1	6	25	15	0	0	48	69
11	0	0	0	0	0	0	0	0	1	0	1	100
12	1	0	0	0	1	2	0	1	0	0	5	100
TOTAL	29	9	9	17	38	73	185	59	2	2	423	
OMISSION ERROR (%)	48	56	67	65	92	88	59	75	100	100		

OVERALL ACCURACY = 31%
KHAT ACCURACY = 12%

Keane, Robert E.; Garner, Janice L.; Schmidt, Kirsten M.; Long, Donald G.; Menakis, James P.; Finney, Mark A. 1998. Development of input data layers for the FARSITE fire growth model for the Selway-Bitterroot Wilderness Complex, USA. Gen. Tech. Rep. RMRS-GTR-3. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 66 p.

Fuel and vegetation spatial data layers required by the spatially explicit fire growth model FARSITE were developed for all lands in and around the Selway-Bitterroot Wilderness Area in Idaho and Montana. Satellite imagery and terrain modeling were used to create the three base vegetation spatial data layers of potential vegetation, cover type, and structural stage. Fire behavior fuel models and crown characteristics were assigned to combinations of base layer categories on these maps by local fire managers, ecologists, and existing data. FARSITE fuels maps are used to simulate growth of prescribed natural fires in the wilderness area, aiding managers in the planning and allocation of resources. An extensive accuracy assessment of all maps indicated fuels layers are about 60 percent accurate. This methodology was designed to be replicated for other areas.

Keywords: fuels mapping, fire behavior fuel model, GIS, terrain modeling, satellite imagery

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