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Fuel Characteristic Classification System (FCCS) Field Sampling and Fuelbed Development Guide

Susan J. Prichard, Anne G. Andreu, Roger D. Ottmar, and Ellen Eberhardt

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Authors

Susan J. Prichard and **Anne G. Andreu** are research scientists, University of Washington, College of the Environment, School of Environmental and Forest Sciences, Box 352100, Seattle, WA 98195-2100; **Roger D. Ottmar** is a research forester, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Pacific Wildland Fire Sciences Laboratory, 400 N 34th Street, Suite 201, Seattle, WA 98103; and **Ellen Eberhardt** is a technical information specialist, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Forestry Sciences Laboratory, 3200 SW Jefferson Way, Corvallis, OR 97331.

Cover photos by Roger Ottmar

Abstract

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The Fuel Characteristic Classification System (FCCS) was designed to store and archive wildland fuel characteristics within fuelbeds, defined as the inherent physical characteristics of fuels that contribute to fire behavior and effects. The FCCS represents fuel characteristics in six strata including canopy, shrubs, herbaceous fuels, downed wood, litter-lichen-moss, and ground fuels. Each stratum is further divided into one or more categories and subcategories to represent the complexity of wildland and managed fuels. A variety of techniques to measure and summarize fuelbed data are detailed in this guide. This guide is organized by strata and categories to facilitate data input into FCCS fuelbeds and provides field sampling forms by stratum. The first section provides an overview of how FCCS reference fuelbeds were constructed from databases, literature sources, and expert opinion. The guide next describes how regional pathway fuelbeds can provide a systematic set of management fuelbeds that track vegetation and fuel succession over time as well as management activities such as prescribed burning and mechanical thinning. The final section details common field sampling methodologies for users who wish to use field measurements to construct FCCS fuelbeds.

Keywords: Biomass, fuel characteristics, fuel treatments, field methods, wildland fire.

Contents

Introduction

The Fuel Characteristic Classification System (FCCS) is a comprehensive software system that records wildland fuel characteristics and predicts potential fire hazard and surface fire behavior (Ottmar et al. 2007). With its large fuels dataset and ability to represent a wide variety of fuel conditions, FCCS has many applications, from small-scale fuel reduction projects to large-scale emissions and carbon assessments. Characterizing fuels and assessing their fire hazard has always been important to fire and fuel managers and are becoming increasingly pertinent to other specialists, including ecologists, air quality and smoke managers, land use planners, global change scientists, and carbon modelers (Ottmar et al. 2007).

The FCCS defines a fuelbed as the "inherent physical characteristics of fuels that contribute to fire behavior and effects" (Riccardi et al. 2007). A fuelbed can represent any scale considered to be fairly uniform. For example, a 5000-ha western sagebrush system may be adequately represented by a single fuelbed, whereas a 5-ha tropical rainforest may require several fuelbeds to represent the variability in fuel structure and composition. The FCCS represents wildland fuel characteristics in six strata, including canopy, shrubs, herbaceous fuels, downed wood, litter-lichen-moss, and ground fuels (fig. 1). Each stratum is further divided into one or more categories and subcategories to represent the complexity of wildland and managed fuels.

A variety of techniques to measure and summarize fuelbed data are detailed in this guide. Fuelbeds are the common currency in FCCS and Consume (JFSP 2009), which have recently been integrated into a single user interface called Fuel and Fire Tools (FFT). This guide is organized by strata and categories to simplify data input into FCCS fuelbeds and provides field sampling forms by stratum. Before using the guide, we recommend exploring the fuelbed editor within FFT to become familiar with the fuelbed organization and required inputs. The FCCS calculator, documentation, and tutorials are located online.[1]

This guide is organized into three sections. The first section gives an overview of how FCCS reference fuelbeds were constructed from databases, literature sources, and expert opinion. Users may wish to create generic fuelbeds for their specific purposes and can use this same approach to create customized fuelbeds.

[1] Source information about equations that use FCCS input variables to calculate vegetation biomass, fuel loading, and predicted fire behavior can be found in the FCCS technical documentation (Prichard et al. 2013).

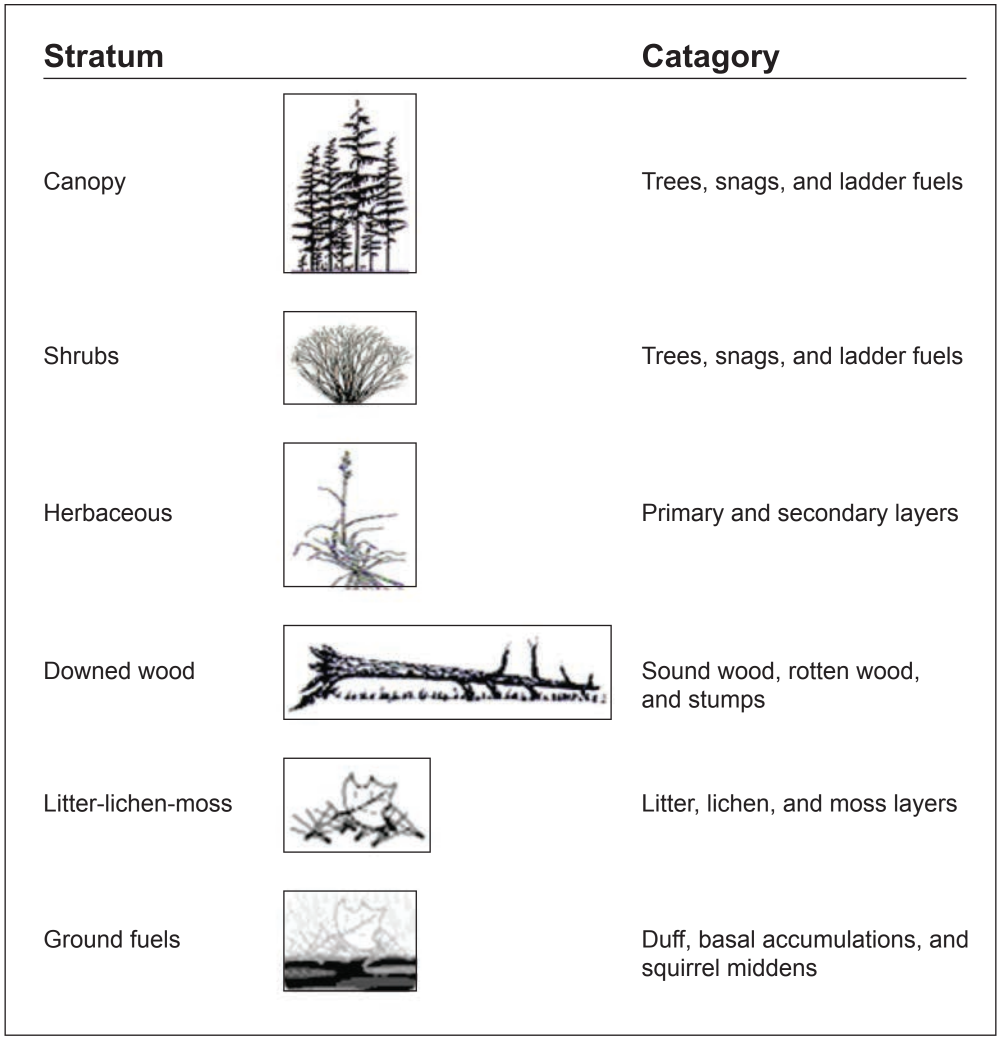

Figure 1—Fuel Characteristic Classification System fuelbed strata and categories (Prichard et al. 2013).

The next section, "Regional Fuelbed Pathway Development," briefly describes how regional pathway fuelbeds can provide a systematic set of management fuelbeds that track forest and fuel succession over time, and also the results of management activities such as prescribed burning and mechanical thinning. Users from land management agencies may wish to construct similar pathways specific to their vegetation types and management activities.

The final section, "Field Protocols for Customizing FCCS Fuelbeds," details common field sampling methodologies for users who wish to use field measurements to construct FCCS fuelbeds to represent wildland fuels.

FCCS Reference Fuelbed Development

Background

In 1999, the Fire and Environmental Research Applications (FERA) team, part of the U.S. Forest Service (USFS), Pacific Northwest (PNW) Research Station, received funding from the Joint Fire Science Program to develop a national system of classifying fuel characteristics (JFSP 2007). Researchers began developing FCCS fuelbeds through a series of regional workshops attended by fire and fuel scientists representing the boreal, tropical and semitropical, dry, western temperate, and eastern temperate regions of the United States. Workshop participants wrote detailed descriptions of vegetation types and fuelbed categories they considered important in their regions. Often, participants also provided fuelbed data based on expert opinion or published literature. These data were incorporated into fuelbeds, and data gaps were filled using images from photo series, literature, and expert opinion (Ottmar et al. 2007, Riccardi et al. 2007).

Members of the FERA team continued to develop fuelbeds that represent the major vegetation types for the United States. Most of these fuelbeds were created from a compilation of data sources including peer-reviewed literature, natural fuels photo series (e.g., logging residue photo series [Ottmar and Hardy 1989, Ottmar et al. 1990]), and government databases and reports (e.g., Forest Service research papers, general technical reports, and research notes). Some Western U.S. fuelbeds were based on datasets from National Park Service (NPS) fire monitoring data. Datasets generally came from sites within narrow geographic areas (usually one park) and did not reflect the complete geographic distribution of the vegetation types. Therefore, these fuelbeds were broadened with available data from pertinent literature or databases to better represent their full geographic range.

Forested fuelbeds were constructed with data derived from the USFS Forest Inventory and Analysis (FIA) national database and natural fuels photo series, where applicable.[2] [3] In many parts of the country, FIA data are limited to canopy and snag data; additional fuelbed data were obtained from relevant scientific literature and reports. In the USFS Pacific Northwest and Pacific Southwest Regions (Washington, Oregon, and California), FIA data included downed wood and understory vegetation information for many plots.

In total, 216 fuelbeds were constructed for use in FCCS version 1.0. Each fuelbed was reviewed for accuracy and consistency by a team of research scientists at the PNW Research Station Pacific Wildland Fire Sciences Laboratory, and by

[2] https://www.fia.fs.fed.us.

[3] https://www.fs.fed.us/pnw/fera/fccs/fuelbed_references.shtml.

regional fire and fuels specialists throughout the United States. A data quality confidence rating was assigned to each fuelbed based on the availability of data sources.[4]

Fuelbeds have been mapped at 30- and 1-km scales across the conterminous United States and Alaska. The 30-m map is available in LANDFIRE (USDI GS 2010), and fuelbed lists developed in LANDFIRE can be used to specify fuelbed lists within the FFT.[5] In advance of the LANDFIRE 2008 refresh (LANDFIRE, n.d.), an additional 93 fuelbeds were constructed to address gaps in national fuels mapping for the conterminous United States and Alaska.

Fuelbed Inputs

Each reference fuelbed was created to broadly represent that fuelbed throughout its geographic distribution. When regional data sources were used for a single fuelbed, the most common (modal) value was used from those sources. The upper and lower limits of the averages, omitting clear outliers, were used for the minimum and maximum entries. Where specific data sources were available, a specific value was used and the range was estimated from general ecological descriptions. The fuelbed editor allows users to view multiple fuelbeds but is not able to accommodate minimum and maximum input values in the user interface. Minimum and maximum values are stored in each reference fuelbed file but are not visible in the fuelbed editor.[6]

Descriptive Data

Fuelbed name—

In general, the name of each FCCS reference fuelbed begins with a list of the most important or diagnostic species in the vegetation type that the fuelbed defines. Species in the same stratum are separated by a hyphen (e.g., red spruce [*Picea rubens* Sargent]–balsam fir [*Abies balsamea* (L.) Mill.] forest), and those in different strata are separated by a slash (e.g., Douglas-fir [*Pseudotsuga* spp.]/oceanspray [*Holodiscu*s sp.] forest). Vegetation type (forest, shrubland, grassland, etc.) is listed after the species names.

Fuelbed description—

Fuelbed descriptions typically contain the geographic extent of a fuelbed, species commonly associated with the fuelbed, a description of applicable change agents, and any other information important to distinguishing that fuelbed from others.

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[4] A list of source references by fuelbed, broken out by strata, is online.

[5] Fuelbed lists developed in LANDFIRE can be used to specify fuelbed lists within the FFT.

[6] Fuelbed files are saved as extensible markup language (.xml) files within the program.

Selection criteria—

Fuelbeds may be selected within the FCCS by any of a set of four criteria:

- Bailey's (1995) ecoregion[7]
- Vegetation form (conifer forest, broadleaf forest, mixed forest, shrubland, or grassland)
- Society of American Foresters cover type (Eyre 1980) or Society for Range Management (SRM) cover type (Shiflet 1994)
- Change agent(s) (includes natural disturbances, silvicultural activities, and other human impacts such as fire exclusion and grazing)

Confidence rating—

The FCCS reference fuelbeds contain an overall rating for the quality of the data used for creating the fuelbed.

- No data (no referenced numbers for any data value)—created from experience, taken from ecological literature, or both
- Partial data—less than 35 percent of data is from literature, photo series, or peer-reviewed data sources
- Partial data—35 to 85 percent of data is from literature, photo series, or peer-reviewed data sources
- Data driven—85 to 100 percent of data is from photo series or peer-reviewed data sources
- Data driven—85 to 100 percent of data, including minimum and maximum values, is from photo series or peer-reviewed data sources

Canopy stratum—

The canopy stratum contains overstory, midstory, and understory tree data, as well as snag data arranged by decay classes (table 1). Canopy inputs represent values for the entire fuelbed as opposed to an individual tree. Most canopy data are from the FIA national database, the NPS database, photo series, literature, and vegetation classifications (Riccardi et al. 2007).[8] [9] Additional data sources for snags were wildlife studies, coarse down wood studies, and old-growth studies.

Ladder fuels data are based on the structure of each particular forest type. For example, if vines, shrubs, or saplings were present in amounts sufficient to create vertical continuity between the canopy layers and lower vegetation strata, an estimate of the maximum and base height is included.

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[7] https://www.fs.fed.us/land/ecosysmgmt/ecoreg1_home.html.

[8] https://www.fia.fs.fed.us/tools-data/.

[9] https://science.nature.nps.gov/im/inventory/veg/.

Table 1—User-input Fuel Characteristic Classification System fuelbed variables used in calculating physical characteristics and properties of wildland fuels

Strata, category, and subcategory	Variable	Field data form
Canopy:		
Total canopy	Percentage cover[a]	2, 3, 4, 5
Trees—	Percentage cover[a c]	
Overstory, midstory, understory	Height (m)	2
	Height to live crown (m)[a]	
	Density (number of stems/ha)[a]	
	Diameter at breast height (cm)	
	Species and relative cover (%)[a]	
Snags—		
Class 1 snags with foliage	Cover (%)[a]	2
	Height (m)[a c]	
	Height to snag crown base (m)[a]	
	Density (number of stems/ha)[a c]	
	Diameter at breast height (cm)[c]	
	Species and relative percentage cover (%)[a c]	
Class 1 (no foliage), class 2, class 3	Height (m)[c]	2
	Diameter (cm)[c]	
	Density (number of stems/ha)[c]	
	Species and relative percentage cover (%)[c]	
Ladder fuels—		2
Type: arboreal lichens and mosses, climbing ferns and other epiphytes, dead branches, leaning snags, stringy or fuzzy bark, tree regeneration, vines-liana	Minimum height (m)	
	Maximum height (m)	
	Is there vertical continuity sufficient to carry fire between the canopy and lower strata?[a]	
Shrubs:		5, 6, 7
Primary layer, secondary layer	Percentage cover (%)[a b]	
	Height (m)[a b c]	
	Percentage live (%)[a b]	
	Loading (Mg ha^{-1})[a b c]—optional	8
	Species and relative cover (%)[a b c]	
Needle drape—	Is needle drape on shrubs sufficient to affect fire behavior?[a]	

Table 1—User-input Fuel Characteristic Classification System fuelbed variables used in calculating physical characteristics and properties of wildland fuels (continued)

Strata, category, and subcategory	Variable	Field data form
Herbs:		
Primary layer, secondary layer	Percentage cover (%)[a b]	5, 6, 7
	Height (m)[a b]	
	Percentage live[a]	
	Loading (Mg ha^{-1})[a b c]	8
	Species and relative cover (%)[a b]	
Woody fuels:		
All woody	Total coverage by fine wood and 1-, 10-, and 100-hr downed wood (percentage)[a b]	
	Depth (m)[a b]	
Sound wood—	Species and relative cover (%)[a b]	
1-hr	Loading (Mg ha^{-1})[a b c]	9
10-hr	Loading (Mg ha^{-1})[a b c]	9
100-hr	Loading (Mg ha^{-1})[a b c]	9
1,000-hr	Loading (Mg ha^{-1})[a b c]	9
10,000-hr	Loading (Mg ha^{-1})[a b c]	9
>10,000-hr	Loading (Mg ha^{-1})[a b c]	9
Rotten wood—	Species and relative cover (%)[a b]	
1,000-hr	Loading (Mg ha^{-1})[a b c]	9
10,000-hr	Loading (Mg ha^{-1})[a b c]	9
>10,000-hr	Loading (Mg ha^{-1})[a b c]	9
Stumps—	Species and relative cover (%)[c]	2
Sound, rotten, lightered/pitchy	Height (m)[c]	2
	Diameter (cm)[c]	2
	Density (number per hectare)[c]	2
Piles—	Type (hand or machine)[c]	10
Number of piles	Piles per hectare[c]	
Pile shape	Half-sphere, paraboloid, half-cylinder, half-frustum of cone, half-cone with rounded ends, half-ellipsoid, and irregular solid[c]	
Pile dimensions	Width, height, and length by pile shape (m)[c]	
Composition (hand piles only)	Conifer or shrub/hardwood[c]	
Soil (machine piles only)	Pile volume that is soil (%)[c]	
Species composition (machine piles only)	Primary and secondary species to assign wood densities[d]	
Litter-lichen-moss:		9
Litter—	Arrangement (fluffy, normal, or perched)[a b c]	

Table 1—User-input Fuel Characteristic Classification System fuelbed variables used in calculating physical characteristics and properties of wildland fuels (continued)

Strata, category, and subcategory	Variable	Field data form
Type: Short needle pine, long needle pine, other conifer, broadleaf deciduous, broadleaf evergreen, palm frond, grass		
	Depth (cm)[a b c]	
	Cover (%)[a b c]	6
	Loading (Mg ha^{-1})[a b c] —optional	
Lichen—	Depth (cm)[a b c]	
	Cover (%)[a b c]	
	Loading (Mg ha^{-1})[a b c] —optional	
Moss—	Depth (cm)[a b c]	
	Cover (%)[a b c]	6
	Loading (Mg ha^{-1})[a b c]—optional	
	Type (sphagnum or other moss)[a b c]	
Ground fuels:		
Upper duff—	Depth (cm)[c]	9
	Total cover (%)[a b c]	
Derivation	Cover of partially decomposed moss and litter (%)	
	Cover of partially decomposed sphagnum moss or peat (%)	
	Cover (%)[c]	
Lower duff—	Depth (cm)[c]	9
	Total coverage (%)[c]	
Derivation	Cover of fully decomposed moss and litter (%)	
	Cover of partially decomposed sphagnum moss or peat (%)	
Basal accumulations—		11
Derivation	Bark slough, branches, broadleaf deciduous, broadleaf evergreen, grass, needle litter, palm fronds	
	Depth (cm)[c]	
	Radius (m)[c]	
	Density (number per ha)[c]	
	Loading (Mg ha^{-1})[c]—optional	
Squirrel middens—	Depth (cm)[c]	11
	Radius (m)[c]	
	Density (number per ha)[c]	
	Loading (Mg ha^{-1})[c]—optional	

[a] Important to crown fire potentials.
[b] Important to surface fire potentials.
[c] Important for biomass and carbon calculations.
[d] If a species is not listed, a proxy species with similar wood density may be used.

Shrub and herbaceous strata—

Shrub and herbaceous strata inputs may be divided into primary and secondary layers. Shrub layers are generally differentiated by height classes. If most shrubs have a similar height, the secondary layer is not populated. In the herbaceous stratum, if both grasses and forbs are present, both primary and secondary layers are populated. Herbaceous stratum fuel loadings were obtained from photo series whenever possible. Other data sources include ecological studies, biomass data and equations, and expert opinion.

Source data for shrub and herbaceous inputs included NPS and FIA databases, vegetation classifications, photo series, and ecological literature. Examples of classifications consulted include the NPS Inventory and Monitoring Program[10] state natural heritage programs such as the Florida Natural Areas Inventory,[11] and the NatureServe vegetation classification.[12]

Reference sources used for determining potential shrub and herbaceous vegetation heights when plot data were not available include the Fire Effects Information System database[13] or PLANTS database[14] and individual plant taxonomic descriptions.

Downed wood stratum—

Total percentage cover and the depth of fine downed wood are not available in most data sources. These were generally estimated from a photo series or with expert opinion (Riccardi et al. 2007). Sound and rotten downed wood loadings were typically derived from photo series. Additional data were available through the FIA and NPS databases and other local studies.

Data on stumps and accumulations of downed wood in natural fuelbeds were generally unavailable. Most data was estimated based on photo series plots, the expert opinions of fuelbed creators or reviewers, or both.

Litter-lichen-moss stratum—

Sources of moss and lichen data were scarce, but it was usually possible to find information about litter depth. Data from databases (e.g., USDI NPS 2016) were used when available. Many vegetation classifications also discuss soils and moss/lichen. Where data were not available, experts assigned values. Litter type and relative percentage cover were estimated from overstory and understory composition.

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[10] https://science.nature.nps.gov/im/networks.cfm.

[11] http://www.fnai.org.

[12] https://www.natureserve.org/biodiversity-science/species-ecosystems/ecosystems.

[13] https://www.feis-crs.org/feis/.

[14] https://plants.usda.gov/java/.

Ground fuels stratum—

Upper and lower duff depths were obtained from literature, soil series descriptions, and fuels and wildlife studies.[15] If only one duff value was available, it was split equally between upper and lower layers. Squirrel midden and basal accumulation inputs were typically based on expert opinion.

Regional Fuelbed Pathway Development

The Fire and Environmental Research Applications Team collaborated with several national forests and with the U.S. Bureau of Land Management (BLM) to create a set of regional fuelbeds that represents major vegetation types, management activities, and fuel succession over time.[16] To date, regional fuelbeds and maps have been developed for:

- Okanogan-Wenatchee National Forest (north-central Washington state)
- Central Oregon (USFS)
- Northeastern Oregon (USFS and BLM)
- Lake Tahoe Basin Management Unit (USFS)
- Southeastern U.S. Army installations

In each case, we worked closely with local land and fire managers to develop fuelbed management pathways. Fuelbeds were customized to represent (1) major vegetation types (mostly forests), (2) common management activities and natural disturbances, and (3) forest and fuel succession over time. Forests that are not actively managed have relatively simple pathways (fig. 2), whereas forests that are actively managed (e.g., precommercial thinning, commercial thinning, and prescribed burning) have complex pathways (fig. 3). Information was synthesized from plant association guides, research studies, vegetation plot data, and expert opinion to develop the pathway fuelbeds. Within similar ecosystems, pathway fuelbeds can be used as templates and customized to represent actual sites. Land managers may also wish to use existing fuelbed pathway handbooks to help design similar pathway fuelbeds that represent major vegetation types and management activities on their management units.

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[15] https://www.fs.fed.us/pnw/fera/fft/maps.shtml.

[16] https://www.frames.gov/partner-sites/ffi/ffi-home/.

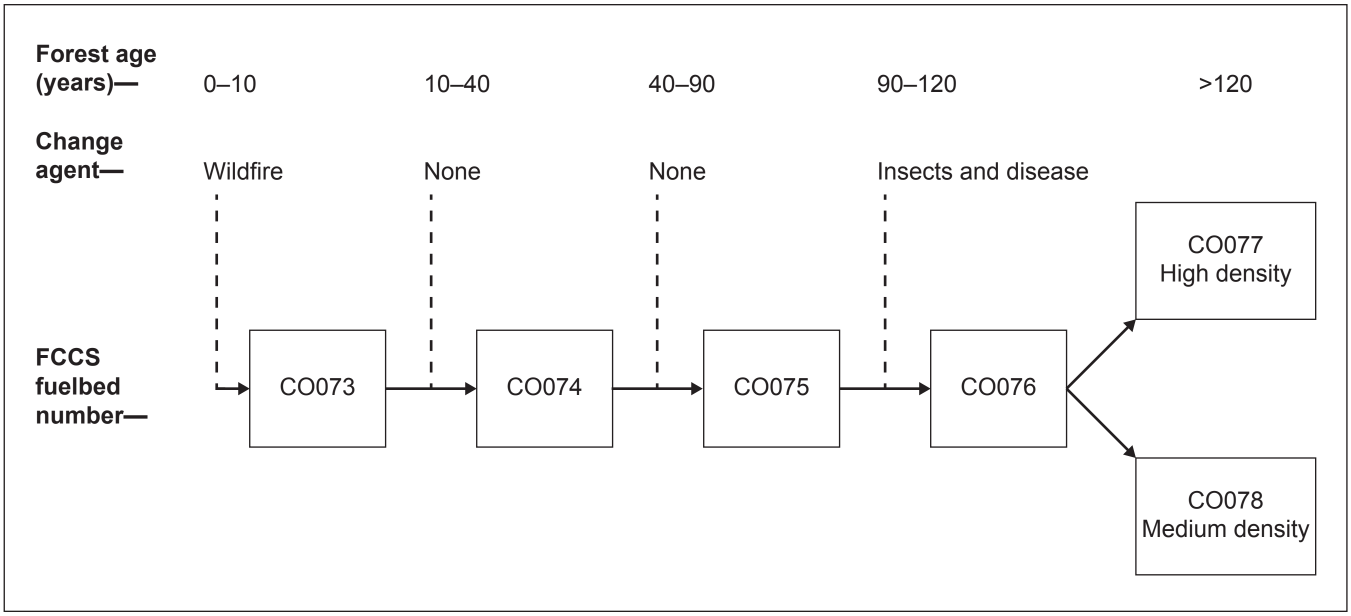

Figure 2—Sample subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.) pathway (central Oregon [CO]), representing forest development over stand ages and insects and diseases. Each box represents a fuelbed, starting with stand initiation following a wildfire (CO073), young subalpine forests (CO074 and CO075), a 90- to 120-year-old subalpine forest with insect and disease (CO076), and two old subalpine forests with either medium- or high-density stocking (CO077 and CO078, respectively). FCCS = Fuel Characteristic Classification System.

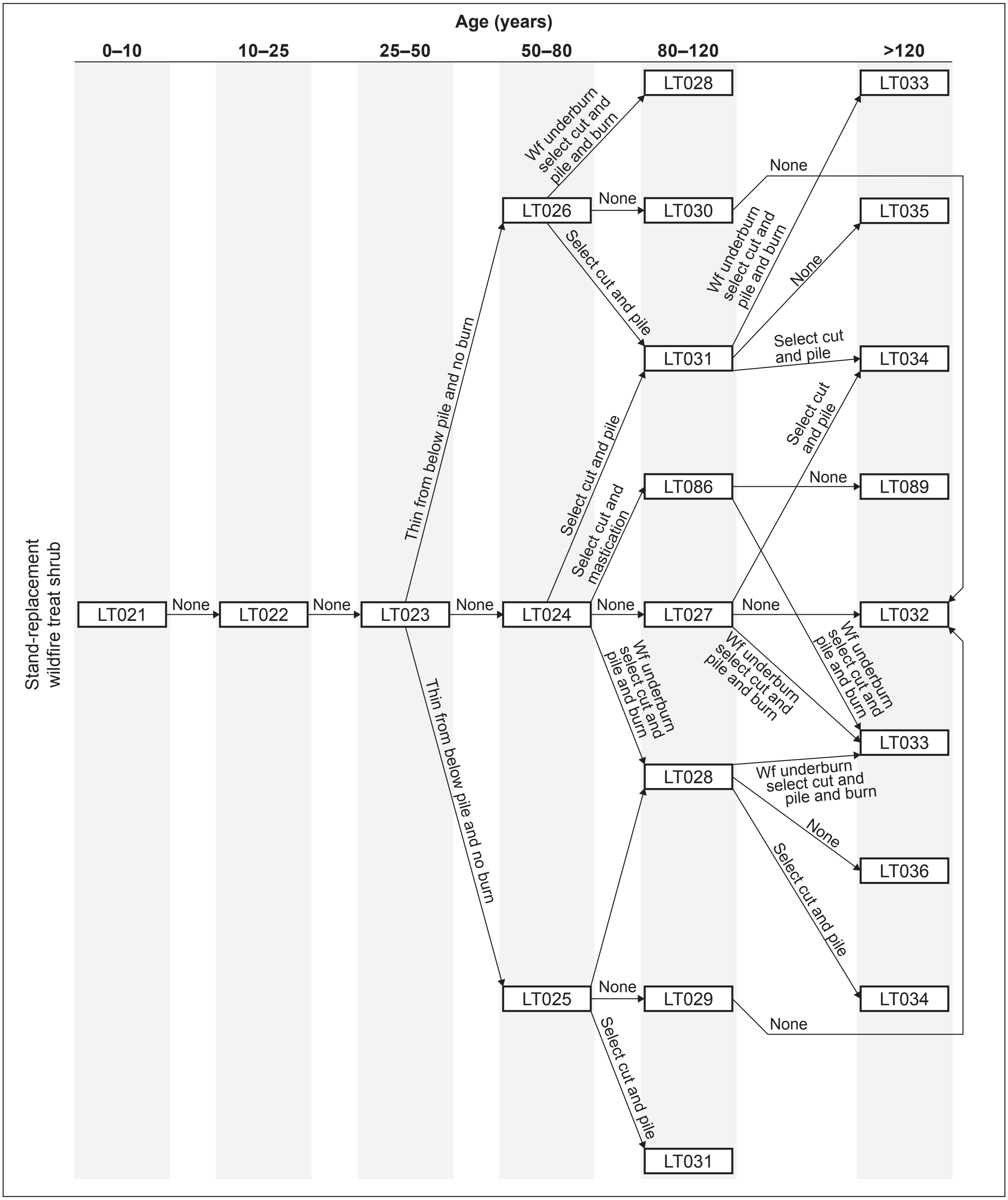

Figure 3—Red fir (*Abies magnifica* [A. Murray bis]) pathway (Lake Tahoe Basin Management Unit [LT]), representing management actions and fuelbed succession over a range of stand ages. Each box represents a fuelbed, beginning with stand initiation following a stand-replacing wildfire, and dividing into many fuelbeds to represent common forest management and fuel reduction treatment activities in young (25 to 30 years) to old (>120 years) red fir forests. Wf = wildfire.

Field Protocols for Customizing FCCS Fuelbeds

The FCCS was designed to represent the geographic and structural complexity of wildland and managed fuels throughout North America. A custom fuelbed may contain only a fraction of the inputs accommodated by FCCS. It is generally most efficient to modify an FCCS fuelbed that closely matches to a specific site and use default data as necessary. For example, a reference fuelbed may have tree and snag data that approximate conditions on the site, but surface fuels (e.g., shrubs, herbs, fine wood, and litter) may need to be adjusted with site-specific data to better inform surface fire behavior predictions, fuel consumption modeling, or both. In addition, some reference fuelbed data may not be needed for a particular fuelbed and can simply be deleted (e.g., secondary shrub and herb layers).

Fuelbeds can be developed for different purposes, and the required inputs differ by application. For surface fire behavior, FCCS needs inputs only in the shrub, herb, wood, and litter-lichen-moss strata (table 1). For crown fire potentials, canopy inputs are also required. Complete fuel loading and carbon assessments can use the full range of fuelbed inputs from canopy to ground fuels.

FCCS and the FIREMON-FEAT Integration Tool

Field sampling methods in this guide closely follow Fire Effects and Monitoring Inventory System (FIREMON) sampling protocols (Lutes et al. 2006), which were developed for use in fire monitoring applications with an emphasis on repeating plot measurements. FIREMON was integrated with the Fire Ecology Assessment Tool (FEAT) (Sexton 2003) to create an online database (FEAT-FIREMON Integrated [FFI]) that can support fire effects monitoring (Lutes et al 2009) (see footnote 15). Where applicable, FIREMON sampling protocols are either duplicated or adapted for use in FCCS.

Before beginning fieldwork, locate a sampling area with relatively uniform fuels. If possible, avoid sampling within a mosaic of different vegetation or fuel types. There are many possible approaches to sampling fuel characteristics, including fixed-area plots, belt transects, prism plots, line transects, and point sampling. In this guide, we recommend that you use fixed, circular plot sampling along a grid with a random start point (fig. 4). This design is consistent with the FIREMON sampling techniques (Lutes et al. 2006) and enables a variety of fuel characteristics to be sampled from each plot location. For further information on sampling design, including determining appropriate plot dimensions and sampling intensity, refer to the FIREMON integrated sampling strategy guide (Lutes et al. 2006).

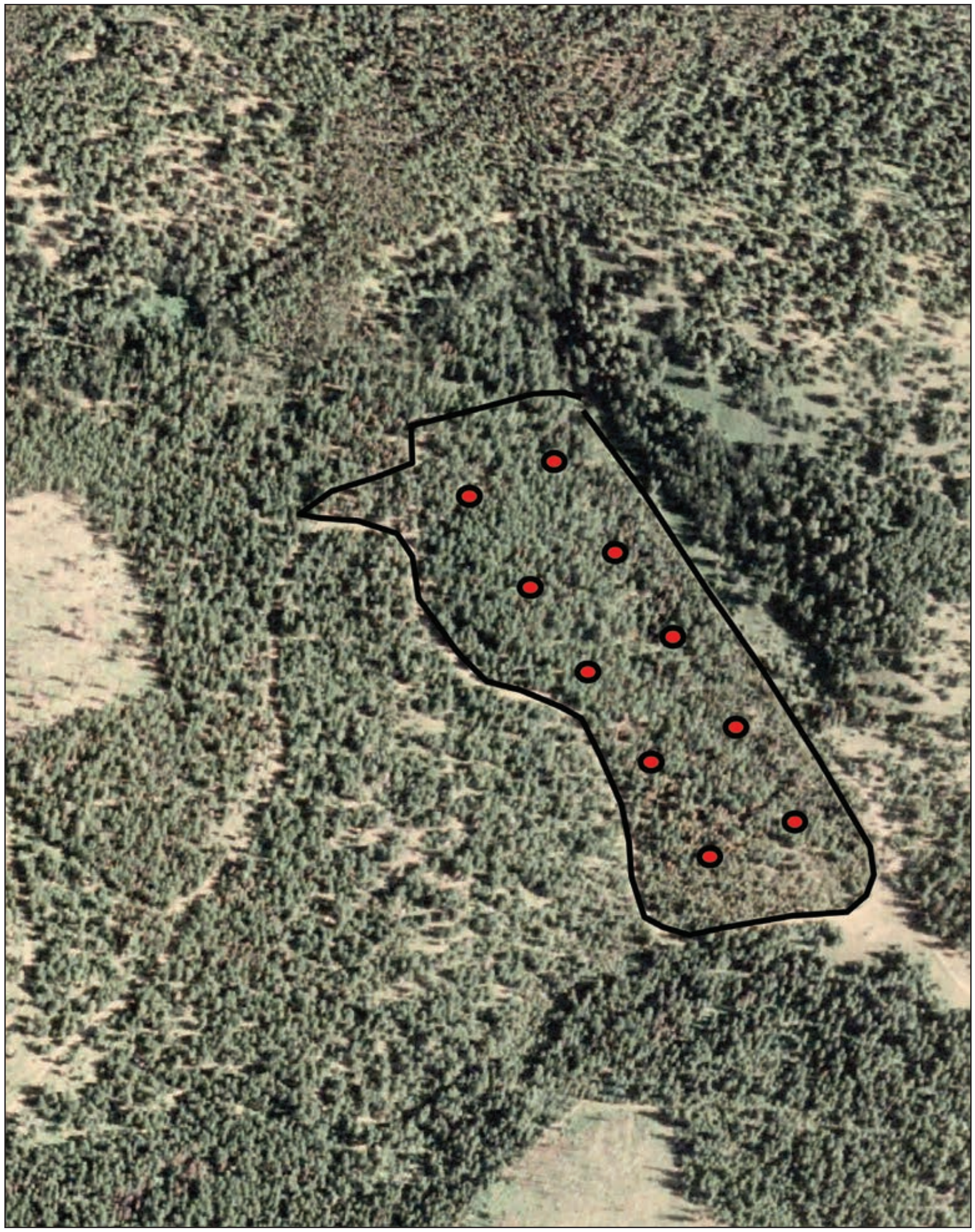

Figure 4—Sample plot layout in a recently thinned unit.

FCCS predicts surface fire behavior and crown fire potentials based on input fuel characteristics (table 1) and environmental variables, including mid-flame windspeed, slope gradient, and fuel moisture scenario (Prichard et al. 2013). Surface fire behavior predictions include reaction intensity (kJ m^{-2}), rate of spread (m min^{-1}), and flame length (m). Because of a limited understanding of crown fire behavior, FCCS calculates crown fire potentials as indexed ranking between 0 and 9.

Fuelbed Description

Each fuelbed is associated with several descriptive fields, including search variables that can be used in FCCS search screen (table 2) and contact information on the fuelbed author or source. Fuelbeds are also associated with a written fuelbed description that generally describes the vegetation type, disturbance history, and geographic extent of each fuelbed.

Field sampling forms are provided in appendix 1. There are variables listed in the fuelbed description form (app. 1, form 1) that you may wish to include in your written fuelbed description (table 2). These options include:

- **Fuelbed name**—User-defined name of fuelbed. The FCCS does not require unique names or any particular naming protocol for custom fuelbeds.
- **Description**—User-defined description of the fuelbed. Fuelbed descriptions generally include age, geographic representation, vegetation and disturbance, management history, or a combination of these descriptors.
- **Ecoregion**—Fuelbeds are organized geographically into 13 Bailey ecoregion divisions. Fuelbeds often span multiple ecoregions. A map of these divisions is provided in the fuelbed selection screen.
- **Vegetation form**—Select one of six vegetation forms. Mixed forests are defined as forests in which evergreen and deciduous species each contribute 25 to 75 percent of total tree cover in both overstory and midstory strata.
- **Cover type**—Society of American Foresters and Society for Rangeland Management cover types. More than one cover type may apply to an individual fuelbed.
- **Stand structural class**—Applicable to forested fuelbeds only. Select a structural class that best describes the number of canopy layers, relative size of trees, stage of understory development, and relative degree of stand closure (O'Hara et al. 1996).
- **Change agent(s)**—Select from a list of natural or management activities that have altered your fuelbed. More than one change agent may apply.
- **Plot ID**—Plot identifier (if applicable).
- **Plot dimensions**—Radius (m).
- **Field crew**—Names of field personnel.
- **Description**—Written description of the site.
- **Date**—Sampling date.

Table 2—Fuel Characteristic Classification System fuelbed search variables and options[a]

Search variable	Options	
Ecoregion	120 - Tundra	260 - Mediterranean
	130 - Subarctic	310 - Tropical/subtropical desert
	210 - Warm continental	320 - Tropical/subtropical steppe desert
	220 - Hot continental	330 - Temperate steppe
	230 - Subtropical	340 - Temperate desert
	240 - Marine	410 - Savanna
	250 - Prairie	420 - Rainforest
Vegetation form	Broadleaf forest	Savanna
	Conifer forest	Shrubland
	Grassland	Slash
	Mixed forest	
Cover type	Eyre (1980), Shiflet (1994)	
Structural class	Old-forest multistory	Stem exclusion open canopy
	Old-forest single story	Understory reinitiation
	Stand initiation	Young forest–multistory
	Stem-exclusion closed canopy	
Change agent(s)	Avalanche	Pile burn
	Chipping	Prescribed fire
	Clearcut	Pruning
	Ditching/draining	Residual fertilizer
	Fire exclusion	Restoration work
	Grazing	Salvage logging
	Ice storm	Stumpwooding
	Insects and disease	Thinning (thin from below)
	Introduction of exotic species	Turpentining
	Landslide	Unknown
	Logging methods/equipment damage	Wildfire
	Lop and scatter	Wildfire (crown)
	Mastication	Wildfire (ground)
	None	Windthrow
	Paving	
Natural fire regime	0- to 35-year frequency and low severity	
	0- to 35-year frequency and high severity	
	35 to 200+ year frequency and mixed severity	
	35 to 200+ year frequency and high severity	
	200+ year frequency and high severity	
Fire regime condition class	Class 1: Fire regimes are within the natural (historical) range, and the risk of losing key ecosystem components is low	
	Class 2: Fire regimes have been moderately altered from their natural (historical) range	
	Class 3: Fire regimes have been substantially altered from their natural (historical) range	
Data quality ranking	No data—No data (no hard numbers for any data value)—created from experience or ecological literature.	
	Partial data—Less than 35 percent of mode inputs from literature, photo series, or peer-reviewed data source.	
	Partial data—35 to 85 percent of mode inputs from literature, photo series, or peer-reviewed data source.	
	Data driven—85 to 100 percent of mode inputs from photo series or peer-reviewed data source.	

- **Elevation (m)**—Recorded from a topographic map, calibrated altimeter, or global positioning system (GPS) unit.
- **Slope gradient (percent)**—Recorded from a laser or clinometer.[17]
- **Aspect (°)**—Plot aspect.
- **GPS location**—Coordinate system, latitude, longitude, position error.[18]

The following sections are organized to assist with custom fuelbed creation within the Fuel and Fire Tools (FFT) application. The fuelbed editor within FFT is organized in tabs, starting with fuelbed description. Additional tabs organize inputs by fuel stratum, including the canopy, shrub, herb, wood, litter-lichen-moss, and ground fuels stratum. Many inputs, including vegetation cover, can be sampled by multiple methods, and this guide includes details and suggested forms to support common methodologies. In most cases, field data would need to be collected and summarized prior to creating custom fuelbeds.

Canopy

The canopy stratum is made up of live and dead canopy fuels including live trees (tree category), standing dead trees (snag category), and ladder fuels. Required data and recommended methodologies are detailed by category.

Trees

FCCS divides the tree category into three subcategories. Recently dead trees (termed class 1 snags with foliage) share the same inputs and can be sampled as an additional tree category.

- Overstory trees: dominant trees
- Midstory trees: codominant or intermediate trees
- Understory trees: understory trees, including seedlings and saplings[19]

Trees are defined as tall, perennial woody plants with a central trunk and branches forming distinct elevated crowns. There is no clear distinction between tall shrubs and small trees, and FCCS allows you to define them as either. If you enter a species as a tree in FCCS, it will not contribute to surface fire behavior predictions.

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[17] See Lutes et al. (2006) on how to measure a slope.

[18] See Lutes et al. (2006) on how to record a GPS location.

[19] Surface fire behavior equations in FCCS do not consider understory trees.

With the exception of total percentage cover, the following inputs are required for each tree layer category, and recommended sampling methods are suggested by input variable (table 3). Some forested fuelbeds only have a single layer whereas more structurally complex fuelbeds may have all three layers.

- Percentage cover (m)
- Height (m)
- Height to live crown/height to crown base (m)
- Density (number per hectare)
- Diameter at breast height (cm)
- Species and relative cover (percentage)

Table 3—Input variables for tree and class 1 snag-with-foliage categories

Variable	Definition	Sampling method	Units (hard limits)
Total percentage cover	Total percentage cover, by crown projection, of all trees including overstory, midstory, and understory canopy layers	Moosehorn Spherical densiometer Aerial photography Satellite imagery	Percentage (0–100)
Percentage cover	Percentage cover, by crown projection, of each canopy layer	Plot estimation Line intercept method	Percentage (0–100)
Height	Height of each canopy layer	Laser clinometer	Meters (0–122)
Height to live crown	Height from ground to bottom of live canopy for each canopy layer	Laser clinometer	Meters (0–76.2)
Height to crown base[a]	Height to base of crown for recently dead trees (class 1 snags with foliage)	Laser clinometer	Meters (0–76.2)
Density	Number of trees per unit area for each canopy layer	Fixed plot Prism plot	Number per hectare (0–123 500 ha^{-1})
Diameter at breast height	Diameter at breast height for each canopy layer	Caliper or tape	Centimeters (0–508)
Scientific name	Scientific name of species in each canopy class (overstory, midstory, understory, snag class)	—	—
Relative cover	Relative percentage of each species in each tree canopy class. Must sum to 100 percent.	Plot estimate Inference from tree density	Percentage (0–100)

— = not applicable

[a] Applicable to class 1 snags with foliage.

Sampling design—

Sampling design and plot size will differ greatly depending on forest type. FIREMON recommends a default 0.1-m^2 circular plot (table 4) and, on average, a minimum of 20 trees per plot. Plot radius may need to be expanded in areas with low tree density but should remain consistent throughout your sampling inventory.

Subplots may be required to sample seedlings, saplings, and pole-sized trees in dense stands. Field reconnaissance and preliminary sampling is advisable to determine consistent plot and subplot dimensions and the number of plots to be sampled.

The most efficient strategy for collecting tree data for FCCS is to sample each tree in a given plot, categorize it as a living tree or snag, and record either canopy layer for living trees or snag class for dead trees. Once sampling is complete, you can calculate tree density and relative cover by overstory, midstory, and understory trees. Class 1 snags with foliage may simply be tallied by a live/dead designation of dead trees with foliage.

Table 4—Plot size recommendations based on median tree diameter and height[a]

Median tree diameter	Median tree height	Plot radius	Plot size
Centimeters	- - - - - - - - - - *Meters*	- - - - - - - - -	*Hectares*
<50	<3	11.28	0.04
<100	30–90	12.6	0.05
<200	>90	17.84	0.1

[a] Source: Keane 2006.

Total coverage—

Total percentage cover (percent) is the percentage of the plot covered by crown projection of all live trees, including overstory, midstory, and understory tree canopy layers, and class 1 snags with foliage. Trees are considered to be alive if they have any green foliage in their crowns. For example, deciduous trees generally have no canopy cover when they are dormant (i.e., “leaf off”). When sampling a forest with deciduous tree species, there will likely be a dramatic difference in canopy cover and other fuelbed characteristics between growing and dormant seasons. If you are interested in capturing seasonal differences in fuelbeds, we suggest that you construct at least two different fuelbeds to represent leaf-on and leaf-off conditions.

There are several approaches to estimating total percentage of canopy cover, including:

- Ground estimates using a moosehorn
- Hemispherical camera
- Line-intercept coverage estimate
- Natural fuels photo series
- Remote sensing techniques, including aerial photos and satellite imagery

Ground-based estimates of canopy cover—Sampling time and intensity will depend on the technique you choose. For rapid measurements of total canopy cover, a self-leveling moosehorn is your best option (Fiala et al. 2006). Estimating tree cover along line intercepts is the most time-consuming technique, but where possible, allows for systematic estimates of tree cover by layer (i.e., overstory, midstory, and understory) and by species. Each method is detailed below.

Moosehorn—To adequately measure percentage cover, you will need 30 to 100 samples per forested stand. We recommend that you conduct a preliminary analysis to determine required sample size. A potential option is to establish three slope-corrected transects radiating from each plot center and take self-leveling moosehorn measurements at regular intervals along each transect (after Fiala et al. 2006).

A moosehorn consists of a right-angled PVC tube with a mirror sight. At each measurement site, hold the moosehorn level using the leveling bubble. Using the grid in the sight, at each intersection, determine whether the grid or crosshair crosses tree canopy or sky. These determinations are tallied, and percentage canopy cover is calculated as the percentage of all observations that were recorded as tree (app. 1, form 3).

Line-intercept method—The line-intercept method is time intensive but provides estimates of percentage cover by tree canopy layer and by tree species. A minimum of 51 m of transect is recommended per 0.04-ha plot. Fiala et al. (2006) established three slope-corrected 17-m transects radiating from each 0.25-ha plot center and sampled intersection lengths of canopy cover along each transect.

Canopy cover is recorded for each individual tree and includes the entire length of the vertically projected crown cover along the transect tape (interstitial spaces are included in this estimate) (app. 1, form 4). Tree canopy position (overstory, midstory, and understory) and species are recorded for all trees >1.4 m tall (fig. 5). Shrub and herb cover also can be recorded along transect lines (see next section). Total percentage cover, including class 1 snags with foliage, is calculated as the percentage of total transect length covered by tree crowns, capped at 100 percent. Percentage cover by tree layer and species can be calculated in a similar fashion.

Natural fuels photo series—Depending on the vegetation type and location, your site may be reasonably represented by a photo series. You can access all of the available natural fuel photo series from the digital photo series (University of Washington 2016a). Older photo series on logging residues are sometimes available for locations but have not yet been incorporated in the digital photo series.

Although canopy data differ somewhat by series, they generally contain tree density, diameter at breast height, height, height to live crown, and height to crown base of live and dead trees. Canopy cover is not provided and would need to be estimated separately.

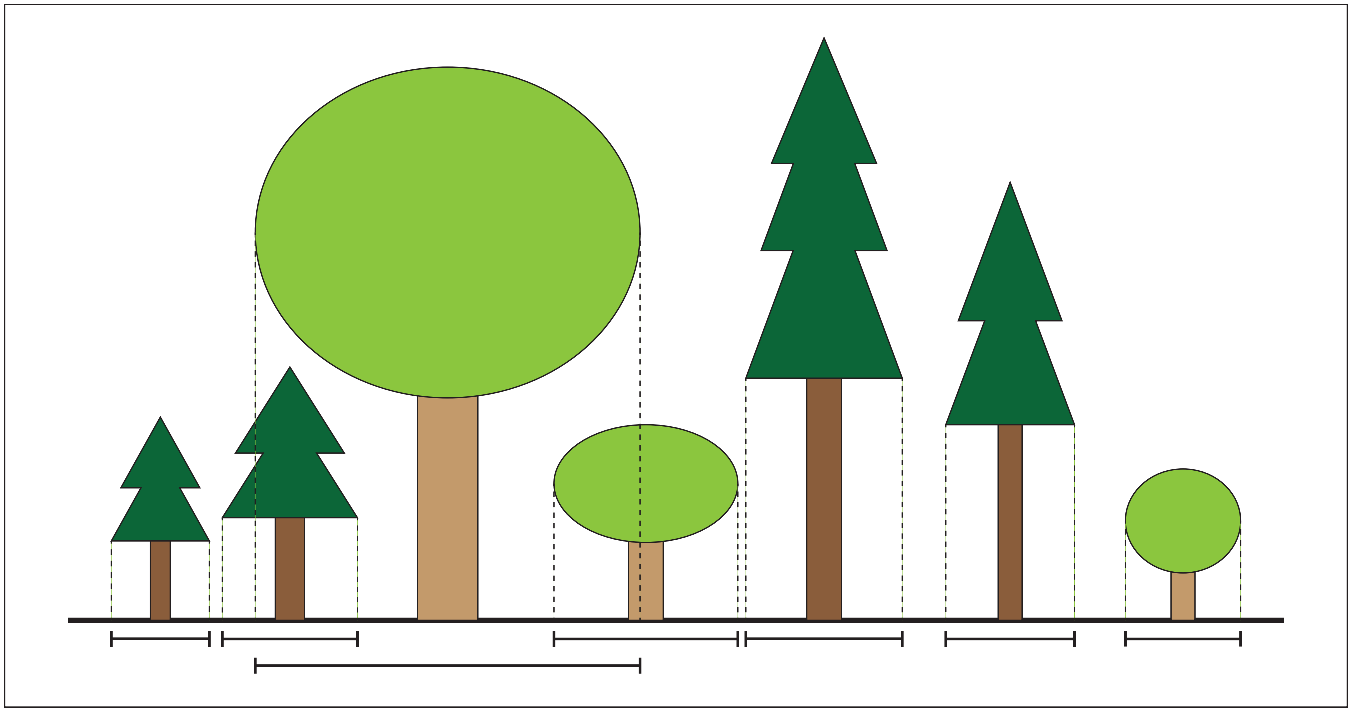

Figure 5—Individual tree crown cover vertically projected on a sampling transect.

Remote sensing techniques and other data sources—

Several LANDFIRE data layers are available that could be used to provide a coarse-scale characterization of forest canopies.[20] The existing vegetation cover layer provides an estimate of the vertically projected, live canopy layer. Similarly, the existing vegetation height layer provides the average height of dominant vegetation cover, interpreted from 30-m Landsat Thematic Mapper images. Given that LANDFIRE is intended for broader scale analyses, we recommend that you visit the site and refine canopy values by visual stand inspection or photo series assessments.

Interpreted LiDAR images can provide highly accurate estimates of canopy cover and other canopy characteristics (Andersen et al. 2005). Aerial photointerpretation is also a good technique for estimating canopy cover and other canopy characteristics (e.g., Hessburg et al. 1999).

If you have stand exam data already entered in the Forest Vegetation Simulator (FVS), you may use the FVS to provide stand summary data (tree density, diameter, height, crown base height, and crown radii) that could be used to populate FCCS canopy characteristics (Fiala et al. 2006).

[20] http://www.landfire.gov.

Percentage cover of each tree layer—

FCCS requires estimates of percentage cover by live tree layer (overstory, midstory, and understory) and class 1 snags with foliage. Because the tree canopy layers may overlap, percentage cover of overstory, midstory, and understory tree layers may sum to greater than 100 percent. However, the total canopy cover input value may not exceed 100 percent. You may want to visually estimate this value for an entire plot. A more empirical approach is to use the line-intercept method and record tree species and tree canopy layer (i.e., overstory, midstory, understory, and class 1 snags with foliage) (app. 1, form 4).

Tree layer definitions—

- Overstory layer—Dominant tree crowns
- Midstory layer—Codominant or intermediate tree crowns
- Understory layer—Understory tree crowns, including seedlings and and saplings that are less than 1.4 m tall
- Class 1 snags with foliage—Recently dead trees (in the overstory, midstory, or understory) that still have foliage

Tree height—

Tree height is summarized by layer in FCCS. For quick estimates of layer height, you can take a single estimate of layer height. A more accurate and repeatable method is to sample height of each tree in your plot and assign each tree to a layer (overstory, midstory, understory, snags). Layer height is calculated as the average height of all trees within each layer.

Tree height is measured from the ground to tree top. For smaller trees such as seedlings and saplings, a height pole should be sufficient. For larger trees, use a clinometer or laser to estimate tree height. If the tree is leaning but with an angle greater than 45° from the ground, measure the length instead of the height of the tree. If you are using a clinometer, record the planar distance to the tree, your height, and angles of elevation (percent) to tree height to live crown, tree height, and tree base (fig. 6). If any angle of elevation exceeds 100 percent, increase your distance from the tree.

Tree height is calculated as:

$$y = \theta_1 (x / 100) - \theta_2 (x / 100) \,, \tag{1}$$

where

y = tree height or height to live crown (m),

x = distance to tree (m),

θ_1 = angle of elevation to tree top (percent), and

θ_2 = angle of elevation to tree base (often a negative number) (percent).

Height to live crown—

Tree height to live crown (and height to crown base for class 1 snags with foliage) is measured as the distance from the ground to crown base (app. 1, form 2). Some trees may have a few live branches below the crown base, which should not be counted in this measure. For smaller trees such as seedlings and saplings, a height pole should be sufficient. For larger trees, use a clinometer or laser to estimate height to live crown (fig. 6).

Density—

Density is measured as the number of trees in each layer. This variable can be summarized once all individual trees in a fixed plot have been sampled and categorized as overstory, midstory, understory, and class 1, 2, and 3 snags.

Tree diameter at breast height is summarized by layer in FCCS. The most repeatable and accurate method for measurement is to survey each tree in each overstory, midstory, and understory layer (app. 1, form 2). Measurements are made to the nearest 0.25 cm at 1.37 m above ground. If the tree is on a slope, remove any basal accumulations and measure on the uphill side of the tree. If the tree is forked below diameter at breast height, record the diameter of each stem. If the tree is forked above diameter at breast height, measure the stem as if it were one tree.

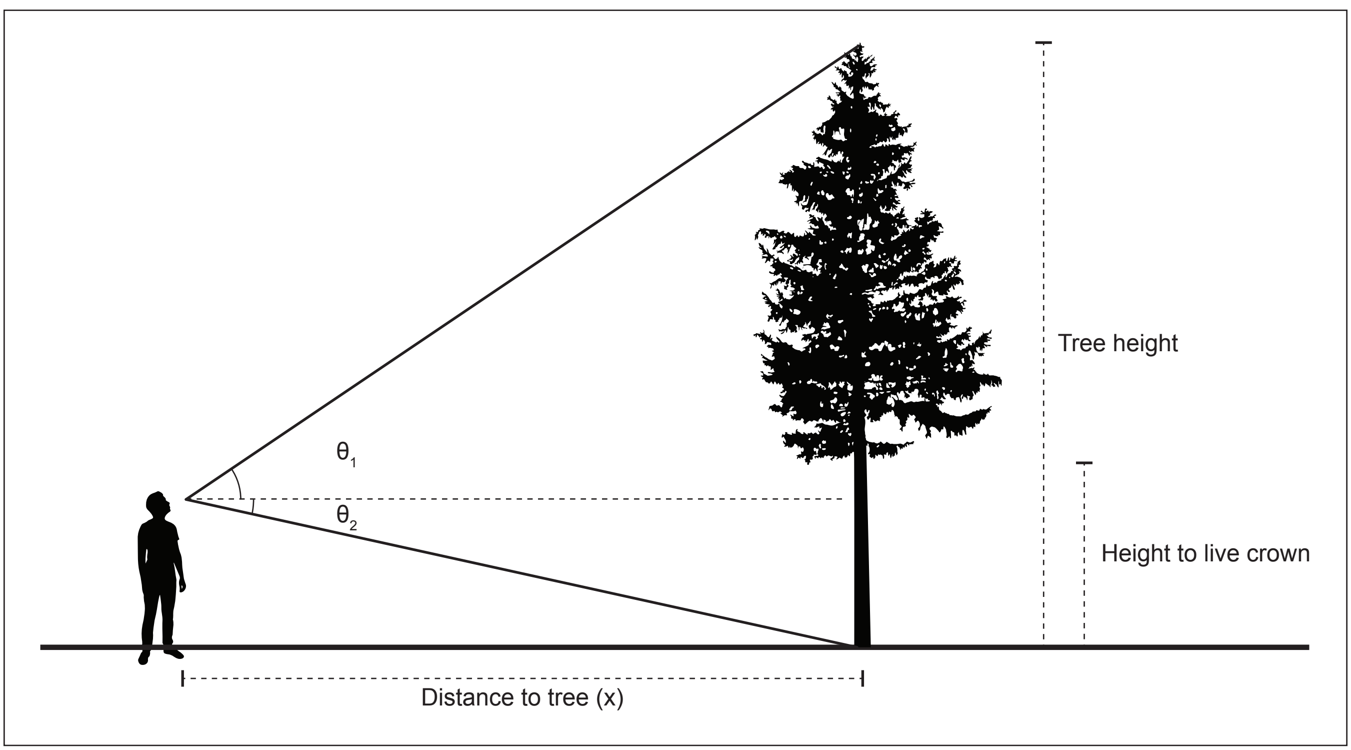

Figure 6—Tree height and height-to-live-crown can be sampled with a laser or a clinometer. Clinometer measurements should be taken as a percentage. Refer to equation 1.

Species and relative cover—

Species and relative cover (the percentage of each species cover in overstory, midstory, and understory tree layers) can be visually estimated over an entire plot or surveyed. Measuring the relative cover of each species for each layer may be difficult and time consuming. In stands where each species has a similar crown shape and projection, you may be able to calculate the relative density of each species and use that value to represent relative cover. However, for more accurate estimates and in more diverse forest types (i.e., mixed conifer–hardwood forests), we recommend that you use the line-intercept method (see "Total Canopy Cover" above) and calculate relative cover as:

$$100\left(\frac{\%\text{Cover}_i}{\sum_i \%\text{Cover}_i}\right) \quad (2)$$

where

Relative cover = the percentage of total canopy cover comprised by each tree species,

i = tree species, and

%Cover = percentage of canopy cover by ground projection by tree species.

Snags

The snag category represents standing dead trees in the following four categories.

- Class 1 snags with foliage: recently dead trees that still have dead foliage intact.
- Class 1 snags without foliage: recently dead trees that have lost their foliage. Bark and branches are intact and wood is sound.
- Class 2 snags: older dead trees. Coarse branches and bark are present. Wood is partially decayed.
- Class 3 snags: older dead trees. Branches and bark not present.

Input variables are defined in table 5. Field sampling techniques are the same as trees (detailed above). It will be most efficient to sample snags within tree plots and simply note if each tree is alive or dead. Dead trees would then be classified into one of the four FCCS snag categories.

Table 5—Snag input variables

Variable	Definition	Sampling protocol	Units (hard limits)
Density	Number of snags per hectare for each class	Fixed plot	Area (0–24 700 ha)
Diameter	Diameter at breast height, or highest point if broken below breast height, of snags for each class	Measuring tape	Diameter (0–508 cm)
Height	Height of snags for each class	Laser clinometer	Height (0–122 m)
Scientific name	Scientific name of species in each snag class	—	—
Relative cover	Relative percentage of each species in each snag class. Must sum to 100 percent.	Percentage of total snag density	Percentage (0–100)

— = not applicable

Ladder Fuels

Ladder fuels have the potential to spread a surface fire into tree canopies (fig. 7). Currently, the variables minimum and maximum height are placeholders in FCCS and are not used in fire behavior calculations. Vertical continuity and ladder fuel type are used in the calculation of crown fire potential.

Minimum height—

Minimum height is the base height of ladder fuels. This variable can be measured directly by a height pole, clinometer, or laser (see "Tree" section).

Maximum height—

Maximum height from ground to top of ladder fuels. This variable can be measured directly by a height pole, clinometer, laser, or a combination of those tools (see "Tree" section).

Nichole Noyer

Figure 7—Dead branches acting as ladder fuels.

Is vertically contiguous?—

If ladder fuels are sufficiently abundant and continuous to provide vertical continuity between surface and canopy fuels, crown fire initiation potential increases. This answer is subjectively determined from field observations.

Type—

Although multiple ladder fuels may exist for your fuelbed, select the most dominant ladder fuel type for inclusion in FCCS. Input variables are listed in table 6. Ladder types include:

- Arboreal lichen and moss (e.g., bearded lichen [*Usnea* spp.)
- Climbing ferns and other epiphytes (e.g., climbing fern or Spanish moss (*Tillandsia usneoides*)
- Dead branches (retained on trees)
- Leaning snags
- Profuse epicormic sprouting (e.g., side branching in recently thinned Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco])
- Stringy or fuzzy bark (e.g., eucalyptus bark)
- Tree regeneration
- Vines/lianas (e.g., kudzu (*Pueraria lobate* [Wild.] Ohwi) or clematis)

Table 6—Ladder fuel input variables

Variable	Definition	Sampling protocol	Units (hard limits)
Minimum height	Height from ground to base of ladder fuels	Laser clinometer	Meters (0–23)
Maximum height	Height from ground to top of ladder fuels	Laser clinometer	Meters (0–91)
Is vertically contiguous	Do surface and canopy provide vertical continuity between tree crowns and lower strata?	Field observation	—
Type	Type of ladder fuel[a]	Field observation	—

— = not applicable.
[a] Arboreal lichen and moss (e.g., beard lichen [*Usnea* spp.]), climbing ferns, and other epiphytes (e.g., climbing fern or Spanish moss), dead branches (retained on tree), leaning snags, profuse epicormics sprouting (e.g., side branching in recently thinned Douglas-fir), stringy or fuzzy bark (e.g., eucalyptus bark [*Eucalyptus* spp.]), tree regeneration, or vines/lianas (e.g., kudzu [*Pueraria* spp.] or clematis [*Clematis* spp.]).

Shrubs

Shrubs are low woody plants, generally with multiple stems. There is no clear distinction between tall shrubs and short broadleaf deciduous or evergreen trees, and FCCS allows you to define them as either. If you enter a species as a shrub in FCCS, it will contribute to surface fire behavior predictions. In contrast, if you enter the same species as a tree in FCCS, it will not contribute to predicted surface fire behavior.

The primary shrub layer is the main layer of shrubs. Primary and secondary layer shrubs can be delineated by height, shrub species groupings, or any other classification you choose (app. 1, form 5).

The secondary shrub layer is an optional layer with a different species composition, height, biomass, or other distinguishing factor from the primary shrub layer. Surface fire behavior calculations treat the shrub stratum as a single layer and combine primary and secondary shrub layers (Prichard et al. 2013).

Shrub input variables in FCCS (table 7) include:

- Is needle drape sufficient to affect fire behavior?
- Percentage cover (percent) of primary and secondary shrub layers (if present), and of relative cover by shrub species
- Height (m)
- Percentage live (percent)
- Loading (Mg ha^{-1})

Table 7—Shrub stratum input variables by primary and secondary layer

Variable	Definition	Sampling protocol	Units (hard limits)
Percentage cover	Percentage cover by crown projection	Line intercept, quadrant plots, photo series	Percentage (0–100)
Height	Average height from ground to top of shrub layer	Meter stick, clinometer, photo series	Meters (0–22.9)
Percentage live	Percentage of shrub biomass that is living[a]	Clip plots, field observation	Percentage (0–100)
Needle drape	Is the needle drape sufficient to affect surface fire behavior?	Field observation	Yes or no
Loading (optional)	Loading of the shrub layer[b]	Clip plots, allometric equations, photo series	Megagrams per hectare (0–336)
Scientific name	Scientific name of shrub species	—	Centimeters (0–508)
Relative cover	Relative percentage of each species. Must sum to 100 pecent.	Clip plots, field observation	Percentage (0–100)

— = not applicable
[a] This input can differ markedly between growing and dormant seasons.
[b] Fuels Characteristic Classification System will calculate shrub loading if this value is left as zero in the fuelbed editor.

Sampling Design

Sampling strategy and plot size will vary widely depending on vegetation type. If you are sampling a shrub stratum under a forest canopy, use the same sample plot for canopy sampling to sample shrubs. To estimate shrub percentage cover and height, the FIREMON sampling guide recommends a default 0.04-ha circular plot with a minimum of five transects containing five sample point quadrats (fig. 8). If you are working in a shrub-dominated vegetation type, consult appendix C of the FIREMON sampling guide for specific sampling recommendations.

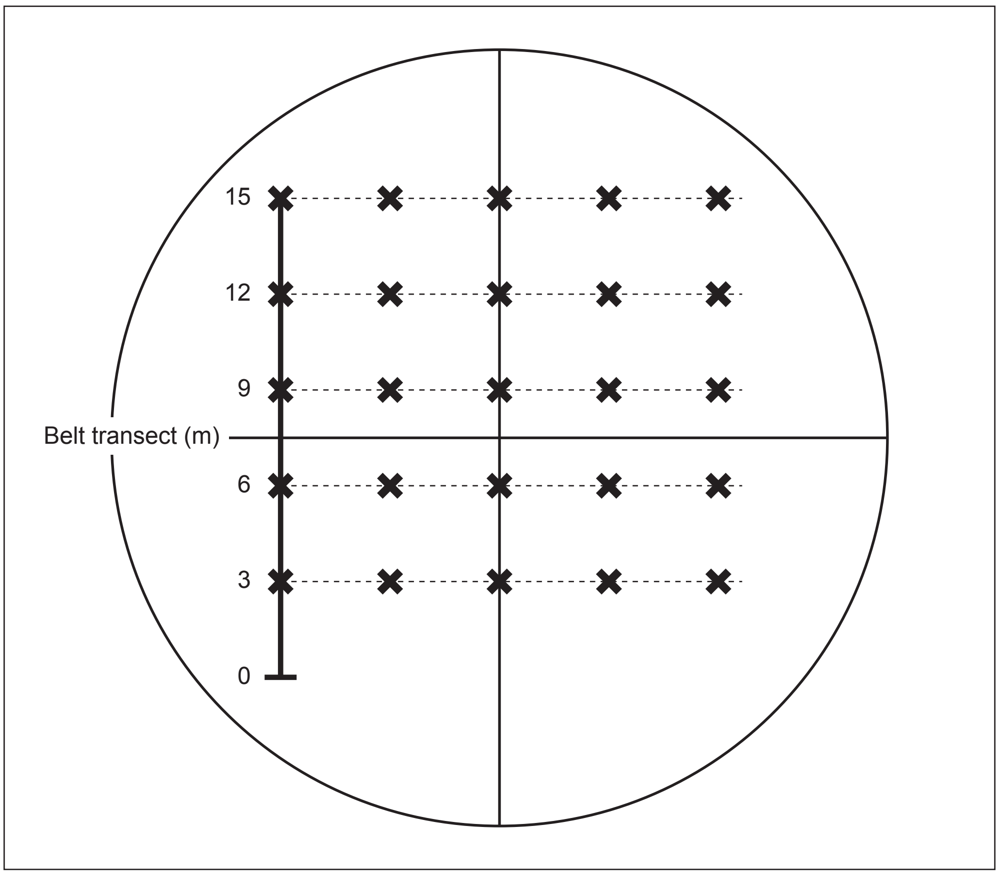

Figure 8—Sample layout of quadrats. In this example, a 15.25-m baseline is established in the bottom left corner of the macroplot. Transects are positioned at 3.05-m intervals along the baseline and run perpendicular to the baseline.

Needle Drape

Suspended needles on a shrub understory can substantially increase fire hazard in some fuelbeds. For example, pine forests in the Southeastern United States with a shrub understory often have needle drape that is sufficient to affect fire behavior (fig. 9).[21] This variable is recorded as either present or absent in FCCS.

[21] This variable is not used in the FCCS crown fire potential algorithms.

Susan Prichard

Figure 9—Needle drape/suspended long needles on shrubs, Southeastern United States.

Percentage Cover

Percentage cover is input in primary and optional secondary shrub layers in FCCS and is the vertical projection of each layer over the ground surface. In deciduous shrub types, percentage cover estimates will vary markedly between leaf-on growing season conditions and leaf-off dormant season conditions; it may be useful to create separate fuelbeds to represent both vegetation states. Because shrub layers may overlap, percentage cover of the two layers may sum to greater than 100 percent.

There are a variety of techniques to estimate percentage cover. This guide covers three main techniques:

- Estimation of percentage cover in quadrats
- Line-intercept method
- Photo series guides

Visual estimation of percentage cover by quadrat—

Estimating percentage cover in quadrats along lines is a more accurate method than estimating cover over entire plots or subplots (Lutes et al. 2006). For most vegetation types, FIREMON recommends sampling five quadrats along five transects per macroplot. A baseline is established, and transects are run perpendicular to the baseline at regular intervals. If the plot is on a slope gradient, the slope-corrected baseline runs upslope, and transects run across slope.

Standard quadrat size is 0.5 by 0.5 m but will depend on your vegetation type. You may wish to mark the quadrat frame to delineate subplots with known percentages. You can then mentally group plant species within subplots (fig. 10). For larger shrubs, and if you are working in a shrub-dominated ecosystem, consult appendix C of the FIREMON sampling guide (Lutes et al. 2006).

Depending on the complexity of the shrub stratum, visual estimations of percentage cover can be difficult, and estimates can differ between observers. Cover guides (app. 4) can be helpful to calibrate your eye, and careful calibration between field observers is strongly recommended. Using cover classes may also provide more consistency between observers (table 8). Plants are still counted if they are not rooted within the quadrat frame but have measureable cover.

If a fuelbed has two distinct shrub layers composed of different species, you can record percentage cover and height by species and summarize inputs by primary and secondary species groupings. However, if the shrub stratum is divided into a primary and secondary layer based on height alone, it will probably be necessary to estimate percentage cover by species for each individual layer. Grouping all shrubs into a single layer or dividing them into two layers is completely optional and has no consequence on surface fire behavior calculations or total shrub stratum fuel loading.

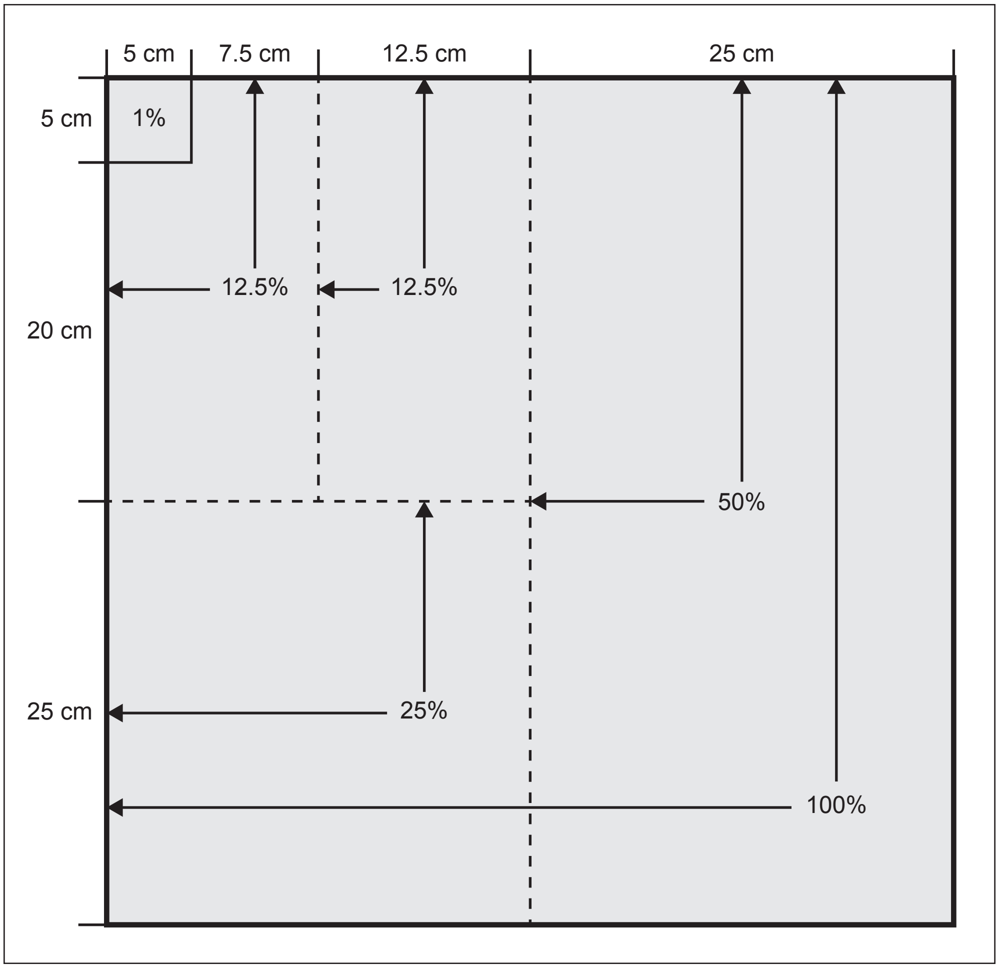

Figure 10—Sample quadrat with sample subplots and corresponding percentages (Lutes et al. 2006).

Table 8—Fire effects and monitoring system cover class codes

Code	Cover class	Code	Cover class
	Percentage		*Percentage*
0	No cover	50	45–55
0.5	0–1	60	55–65
3	1–5	70	65–75
10	5–15	80	75–80
20	15–25	90	85–95
30	25–35	98	95–100
40	35–45	—	—

— = not applicable.
Source: Adapted from Lutes et al. 2006.

Estimating percentage cover by line intercept—
Percentage cover of shrubs (and other understory plants) also can be measured along line intercept transects (app. 1, form 6). Each line defines the imaginary vertical plane to be measured. For each line, the total length of shrub cover that crosses the plane is counted and summed. Overlap of plant cover is common, and any given line can total more than 100 percent cover. The total number and length of transect lines will depend on the variability of shrub layers. If you are planning to estimate tree cover using the line-intercept method, it may be most efficient to sample shrubs and herbs along the same transect lines (see “Canopy: Total coverage” section above under “Canopy”).

Using a photo series guide to estimate percentage cover—
For rapid assessments of shrub stratum characteristics, a photo series guide may be used. Some photo series guides provide data on shrub cover (app. 1, form 7). Because photographs offer an oblique view of fuel properties rather than a vertical view, cover may be difficult to discern from photographs. For instructions on using the Natural Fuels Photo Series, refer to the shrub “Loading” section below.

Height

Average shrub height is recorded for each shrub layer. Shrub height may be measured along with percentage cover and percentage live estimates in quadrats (app. 1, form 5) or the line-intercept method (app.1, form 6). A tree pole or measuring rod or tape will be sufficient for most shrub heights. For taller shrub layers, you may need to use a laser or clinometer (see “Canopy: Tree height” section above under “Canopy”).

Primary and secondary shrub layer heights may be calculated as the mean height of individual shrubs in each layer. For fairly uniform shrub layers, height may be estimated for the entire layer rather than by individual shrubs. Shrub layer height should be recorded as the average height of that layer rather than the maximum height of any specific shrubs within that layer.

Percentage Live

Percentage live is a measure of live biomass in each shrub layer. This variable takes into account that for most living plants, a portion of the biomass is dead. Percentage live can vary markedly by season. For example, for deciduous plants that retain their dead leaves, it may be necessary to construct different fuelbeds that represent standing live and dead shrub biomass during dormant and growing seasons. The most accurate method for estimating percentage live is through direct biomass sampling in clip plots and sorting live and dead vegetation. A less accurate but more expedient approach is to visually estimate this input while estimating percentage cover using either quadrats (app. 1, form 5) or the line-intercept method (app. 1, form 6).

Loading

Shrub loading is an optional input in FCCS fuelbeds. The FCCS supports 29 allometric equations assigned by shrub species to estimate shrub biomass by input percentage cover. Using sampled fuel loading or estimates using local biomass equations will likely offer better estimates of shrub loading and will override FCCS calculations (table 9).

There are a number of techniques for which to estimate shrub loading (or "biomass"):

- Direct biomass sampling the most accurate technique
- Allometric equations can be used to estimate biomass from measured shrub height, percentage cover, or basal diameter
- The natural fuels photo series may be used to visually estimate shrub biomass

Table 9—Sample calculation of loading of manzanita (*Arctostaphylos columbiana* Piper)[a]

Cover	Loading[a b]	Cover	Loading[a b]
Percent	*Grams* m^{-2}	*Percent*	*Grams* m^{-2}
0	0.07	30	71.46
1	1.77	40	96.07
2	3.96	50	120.76
5	10.87	60	145.51
10	22.75	80	195.14
20	46.98	100	244.89

[a] Loading values in g m^{-2} are converted to either tons ac^{-1} or Mg ha^{-1} for entry into the Fuel Characteristics Classification System.
[b] Loading (g m^{-2}) = 0.0681 + (2.5312COV) – (0.8305COV0.5).
Source: Martin et al. 1981.

Direct biomass sampling—

Clip plots are the most accurate way to determine the loading of vegetation on a specific site (app. 1, form 8). However, they require considerable field time and a drying oven. The number of plots and sampling locations depends on the heterogeneity of the shrub stratum you are measuring. Clip plot locations should be evenly spaced along a grid across the vegetation type to be assessed (fig. 4). Lay the plot frame on the ground at each grid intersection (fig. 11). Place the same corner of the biomass square at each intersect. (e.g., top left hand corner in the southeast quadrat of the intersect).

Sparse vegetation should be measured in 1- by 1-m plots. More consistent vegetation should be measured in 0.5- by 0.5-m plots. A minimum of 10 plots per sampling location is recommended. At ground level, clip all rooted vegetation within the plot frame. Dead shrubs that are no longer rooted in the soil are counted as downed wood. Separate vegetation into the following live and dead categories: grasses, forbs/herbs, and shrubs; and collect into labeled bags.

Susan Prichard

Figure 11—Clip plot biomass sampling.

When clip plots yield large quantities of vegetation, it may be more efficient to record the gross weight of each sample in the field and collect subsamples to estimate moisture content. Place each sample into a pre-weighed drying tin and dry in a drying oven at 21 °C for at least 48 hours. Record the dry weight. Calculate the percentage fuel moisture (eqs. 3 and 4) and use this to estimate the dry weight of your field sample, such that

$$\text{Fuel moisture (percent)} = (\text{gross weight} - \text{dry weight}) / \text{gross weight} \quad (3)$$

$$\text{Dry weight (kg)} = \text{gross weight} - (\text{gross weight} \times \text{fuel moisture}) \quad (4)$$

Allometric equations—

Allometric equations can be used to estimate shrub loading from commonly collected field measurements. Allometric equations are regression models developed from sampled biomass and its correlation with other measured variables such as percentage cover, height, and basal diameter. Regression models are appropriate only for data that fall within the variable ranges for which they were developed. For example, if an equation is based on sampled shrub heights of 1.5 to 3.0 m, it will not necessarily be reliable for shrubs shorter or taller than this. Allometric equations are also more generally reliable in the bioregion they represent. An equation for sagebrush created in central Arizona, for instance, may not correctly estimate biomass of sagebrush in eastern Oregon.

The FCCS contains 31 standard biomass equations that can be used to estimate shrub loading based on input shrub percentage cover and height (table 9). Depending on available time and resources, you may opt to simply collect shrub percentage cover and height and rely on the general shrub equations that FCCS provides. If local allometric equations are available to you, they will likely be more reliable. Methods to estimate shrub percentage cover and height are detailed in previous sections. The FCCS shrub loading equations only require percentage cover and height, but many regional shrub biomass equations require basal diameter as well. Basal diameter is the stem diameter of an individual shrub, measured at ground level.

Natural fuels photo series—

Shrub biomass can also be estimated using a photo series.[22] All photo series volumes include shrub loadings, where present (app. 1, form 7). Photo series are land management tools that can be used to assess fuels through appraisal of living and dead woody material, vegetation, and stand characteristics.

The natural fuels photo series, created by the FERA team, is a collection of volumes for quantifying unmanaged fuels, each representing a region of the United States. Photo series are also available for central Brazil and montane ecosystems of Mexico. A list of available photo series, ordering information, and a tutorial on how to use the photo series are available (FERA 2016).

The Digital Photo Series is a Web-based application to the Natural Fuels Photo Series[23] (also see footnote 22). It takes advantage of data collected for the published photo series, and the technology to create a software application that includes a fuels database—allowing users to search, browse, compare, and format output for other fire science software. However, because it does not support stereoscopic viewing of fuelbeds, it complements but does not replace the printed versions. The following sections detail how to use the photo series and are applicable to other sections in this guide (see footnote 23).

Getting started. Select an area in the landscape that is representative of the site you are interested in categorizing. To best match the conditions of your site, consider using more than one site and possibly more than one photo series to estimate various fuel characteristics.

[22] https://depts.washington.edu/nwfire/dps/.

[23] Before you begin to use the photo series, read the "Note to users" section of each photo series. In this section, you will find important information for that specific photo series (e.g., calculations, loading specifics, and series limitations).

Framing fuels. Frame your site into fuel categories. You may need to use multiple sites within a photo series or sites from other photo series to estimate the values you require for the various fuels within your site.

Making a visual inventory—Make a visual inventory by observing fuel and stand conditions within your site and compare them to the photographs. Observe the following:

- Characteristics of each fuel category.
- Select a photo series, or multiple photo series, that closely matches or encompasses observed characteristics.
- Using the data summary tables, look up the value(s) for the characteristics being estimated or interpolate a value between multiple photo series. Repeat steps for each characteristic inventoried. For more complex sites or larger areas, you may need to take multiple inventories.

Using stereo photos—You may get an additional perspective on fuel arrangement by viewing the stereo photos with a stereoscope. The three-dimensional view can aid in the separation of fuel components and more accurately estimate characteristics.

Limitations—The photo series alone may not be sufficient for estimating a reliable estimate. In these cases, you will need to take actual field measurements. The following examples highlight some limitations of the photo series:

- Some fuel characteristics may not be distinguishable in a photograph. If you need these values for your inventory, you should measure or estimate them using a different tool or reference.
- Fuels or vegetation may not be visible from a single vantage point at your field site or be obscured by other fuels. Make sure you make a thorough reconnaissance of the site before making your estimations.
- If your site has seasonal variation in fuel conditions (e.g., a deciduous forest in leaf-on or leaf-off condition), be aware of what the photo series data actually represent relative to the current condition of your site.
- The Natural Fuels Photo Series was developed over many years, and earlier volumes do not contain all of the variables collected in later volumes. In addition, data collected in an individual photo series are somewhat dependent on the ecosystem type.

Scientific names—Scientific names are used throughout the photo series. You will find the species list with common names in the introductory section of each photo series.

Fuel categories crosswalk to FCCS—A crosswalk was created to help users enter photo series data into FCCS. Table 10 provides translation between FCCS inputs and data available in the Natural Fuels Photo Series. Not all categories will pertain to your fuelbed.

Table 10—Crosswalk from the natural fuels photo series to Fuel Characteristic Classification categories

		Fuel Characteristic Classification System	
Natural fuels photo series fuel category		**Stratum**	**Category**
Saplings and trees	↔	Canopy	Trees, snags
Shrubs (understory vegetation)	↔	Shrub	Primary and secondary layers
Graminoids and forbs (understory vegetation)	↔	Herbaceous vegetation	Primary and secondary layers
Woody materials	↔	Woody fuels	Sound and rotten wood
Forest floor—litter or surface material	↔	Litter-lichen-moss	Litter
Forest floor—lichen	↔	Litter-lichen-moss	Lichen
Forest floor—cryptogams	↔	Litter-lichen-moss	Moss
Forest floor—duff	↔	Ground fuels	Duff

Herbs

The herbaceous (herb) stratum includes grasses, sedges, and other herbaceous fuels.

The primary herb layer is the main layer of vegetation within the herb stratum. Users can determine the primary layer based on a number of selection criteria including species, height, mass, etc. The secondary herb layer is an optional herb layer with a different species composition or height than the primary herb layer.

FCCS input variables for herbs (table 11) are very similar to those required for the shrub stratum and include:

- Percentage cover (percent) of primary and secondary herbaceous layers (if present) and relative percentage cover (percent) by species
- Height (m)
- Percentage live (percent)
- Loading (Mg ha^{-1})

With the exception of shrub needle drape, all methods detailed in the shrub stratum section are applicable to the herbaceous stratum (app. 1, forms 5 and 6).

Table 11—Herb stratum input variables

Variable	Definition	Sampling protocols	Units
			Input limits
Percentage cover	Percentage cover by crown projection of the herb layer (primary or secondary)	Line intercept, quadrant plots, photo series	Percentage (0–100)
Height	Average height from ground to top of herb layer (primary and secondary	Meter stick, clinometer, photo series	Meters (0–22.9)
Loading	Loading of herb layer (primary or secondary)	Clip plot, photo series	Percentage (0–100)
Scientific name	Scientific name of species in the primary or secondary herb layer	—	—
Relative cover	Relative percentage of each species in the primary or secondary herb layer. Must sum to 100 percent.	Clip plot, visual estimate	Percentage (0–100)

— = not applicable.

Downed Wood

Downed wood represents all downed and dead woody material in a fuelbed. Dead trees that are still standing are input in the snags category of the canopy stratum. Similarly, dead shrubs that are still rooted are input in the shrub stratum.

The downed wood stratum is divided into four categories:

- Sound wood: downed and dead sound wood
- Rotten wood: downed and dead rotten wood (coarse wood only)
- Stumps: remaining sawn or broken stems up to 1.4 m
- Piles: naturally occurring or human-made piles or accumulate downed wood

Brown's planar intersect method (Brown 1974) is a standard approach for sampling downed wood. This technique involves counting intersections of wood particles with a vertical sampling plane (app. 1, form 9). All material less than 7.6 cm in diameter is considered sound. Downed wood greater than 7.6 cm in diameter are separated into sound and rotten wood categories by time-lag class (table 12).

To survey downed wood using Brown's method, locate a plot center within a designated fuelbed and mark the sampling point with a chaining pin or center stake, avoiding disturbance of the plot. To avoid sampling bias, it is recommended that you run planar intercept transects at randomly selected angles from plot center. The length and number of lines run can vary depending on the density of downed wood. Suggested length of transect lines is 20.1 m, and three to five lines are typically surveyed from each plot center. Fuel loadings can be underrepresented if the planar intersect lines have little to no intersects with downed wood. It is important to achieve an accurate loading; multiple lines and lengths can be run to achieve this goal (table 13).

Table 12—Downed wood input variables

Variable	Definition	Units
		Input limits
Percentage cover	Percentage cover of fine downed wood (1-hr, 10-hr, and 100-hr time-lag classes)	Percentage (0–100)
Depth	Average depth of fine wood (1-hr, 10-hr, and 100-hr time-lag classes)	Centimeters (0–304.8)
Sound 1-hr	1-hr time-lag class sound downed wood (≤0.6 cm diameter)	Megagrams per hectare (0–112)
Sound 10-hr	10-hr time-lag class sound downed wood (0.6–2.5 cm diameter)	Megagrams per hectare (0–112)
Sound 100-hr	100-hr time-lag class sound downed wood (2.5–7.6 cm diameter)	Megagrams per hectare (0–448)
Sound 1,000-hr	1,000-hr time-lag sound downed wood (7.6–22.9 cm diameter)	Megagrams per hectare (0–1121)
Sound 10,000-hr	10,000-hr time-lag sound downed wood (22.9–50.8 cm diameter)	Megagrams per hectare (0–2242)
Sound >10,000-hr	>10,000-hr time-lag sound downed wood (>50.8 cm diameter)	Megagrams per hectare (0–2242)
Rotten 1,000-hr	1,000-hr time-lag rotten downed wood (7.6–22.9 cm diameter)	Megagrams per hectare (0–1121)
Rotten 10,000-hr	10,000-hr time-lag rotten downed wood (22.9–50.8 cm diameter)	Megagrams per hectare (0–2242)
Rotten >10,000-hr	>10,000-hr time-lag rotten downed wood (>50.8 cm diameter)	Megagrams per hectare (0–2242)

Table 13—Transect length by size class

Time lag class	Diameter	Transect length
	Centimeters	*Meters*
1-hr	0–0.64	1.8
10-hr	0.064–2.54	3.0
100-hr	2.54–7.62	20.1

Source: Adapted from Brown 1974.

Starting from the outer edge of the transect line and working in toward plot center, tally the number of wood particles (generic term for sticks or logs) that intersect the sampling plane by each size class (fig. 12). The actual diameter of the particle at the point of intersection determines the size class. For example, if a wood particle lies across the transect line, the correct measure is the actual diameter, not the horizontal length it spans across the intersection. A go-no-go gauge is helpful to accurately measure fine fuel diameter classes (fig. 13). For 1,000-hr fuels, species, width, length, and decay class are also recorded.

Fine Downed and Dead Wood

This category records the overall depth and percentage cover of fine (<7.6 cm) downed wood and is an important variable in surface fire behavior modeling. Because large-diameter fuels (>7.6 cm diameter) do not contribute to surface fire behavior, they are not included in the depth or percentage cover measurements.

Depth—

Downed wood depth represents the average depth of small-diameter downed wood (<7.6 cm) and is analogous to "fuelbed depth" in surface fire behavior modeling (Rothermel 1972). The Brown (1974) line intercept method for sampling downed wood has a technique for estimating downed wood depth along planar transect lines, and it has been adapted for use in FCCS. Fine wood depth is estimated as the highest particle height within a vertical partition of the planar intercept (fig. 14). If there is more than a 0.9-m gap between particles (e.g., a dead branch hangs over the intercept but is more than 0.9 m higher than the other downed wood within the partition), it is tallied but not factored into the depth measurement at that point. Because depth can vary considerably between sampling points, we recommend sampling at regular intervals along transect lines. A suggested sampling intensity is to measure depth within 0.3-m segments every 1.5 m until reaching 15 m along your transect line.

Total percentage cover—

Total percentage cover of fine downed wood represents the portion of ground area covered by <7.6 cm diameter downed wood. Because downed wood coverage is heterogeneous and sometimes obscured by live vegetation and litter, it is not easy to visually estimate. However, there is no good alternative, and use of cover guides (app. 4) may be the best option.

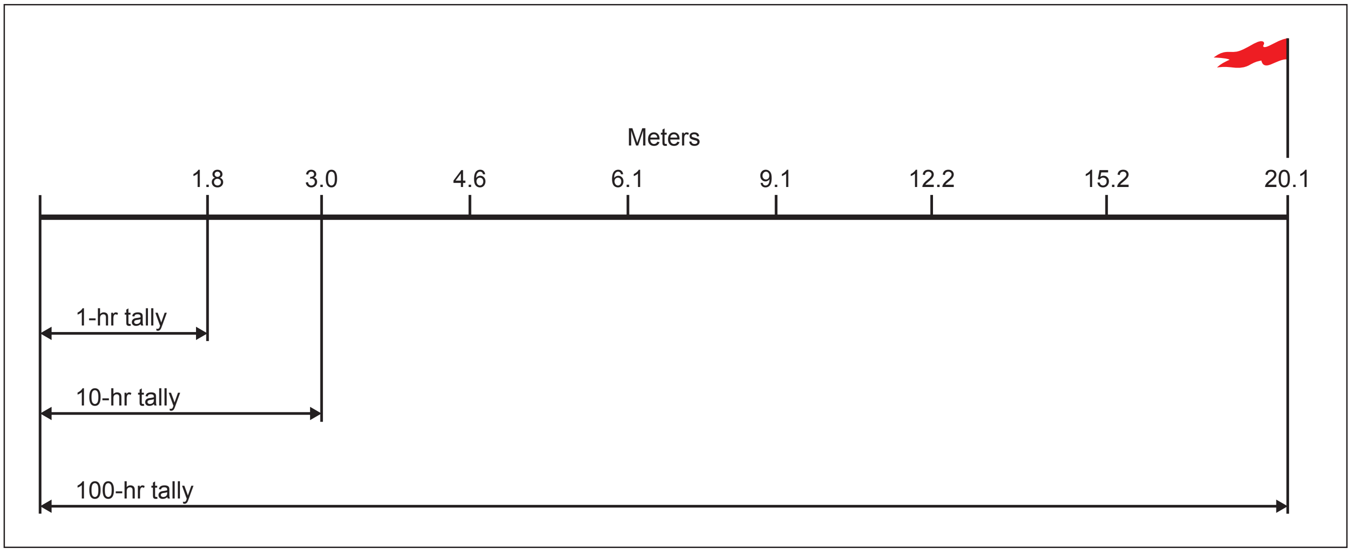

Figure 12—Suggested sampling intervals for downed wood by size class. Starting from the outer edge of the transect and working back to plot center, 1-hr fuels are sampled to 1.82 m; 10-hr fuels to 3.05 m); and 100-hr fuels and greater are sampled along the entire transect.

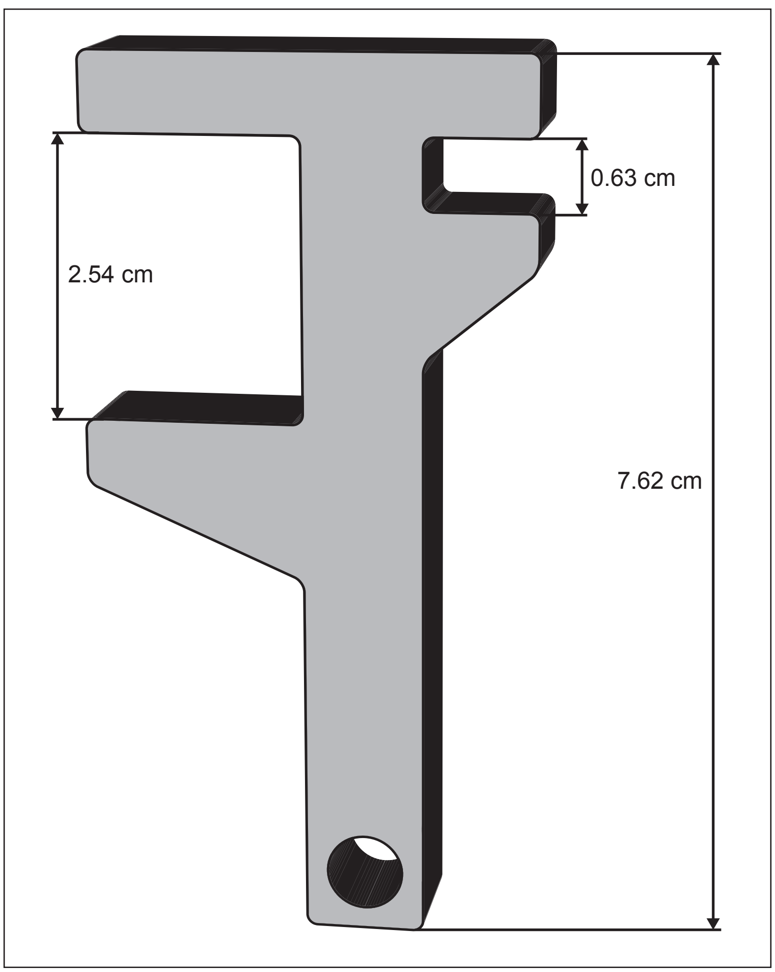

Figure 13—A wildland fire fuel sizing gauge (i.e., go/no-go gauge) can be used to quickly and accurately determine the size class of fine downed wood (Brown et al. 1974). Wood diameters are sampled as the actual diameter of the downed wood.

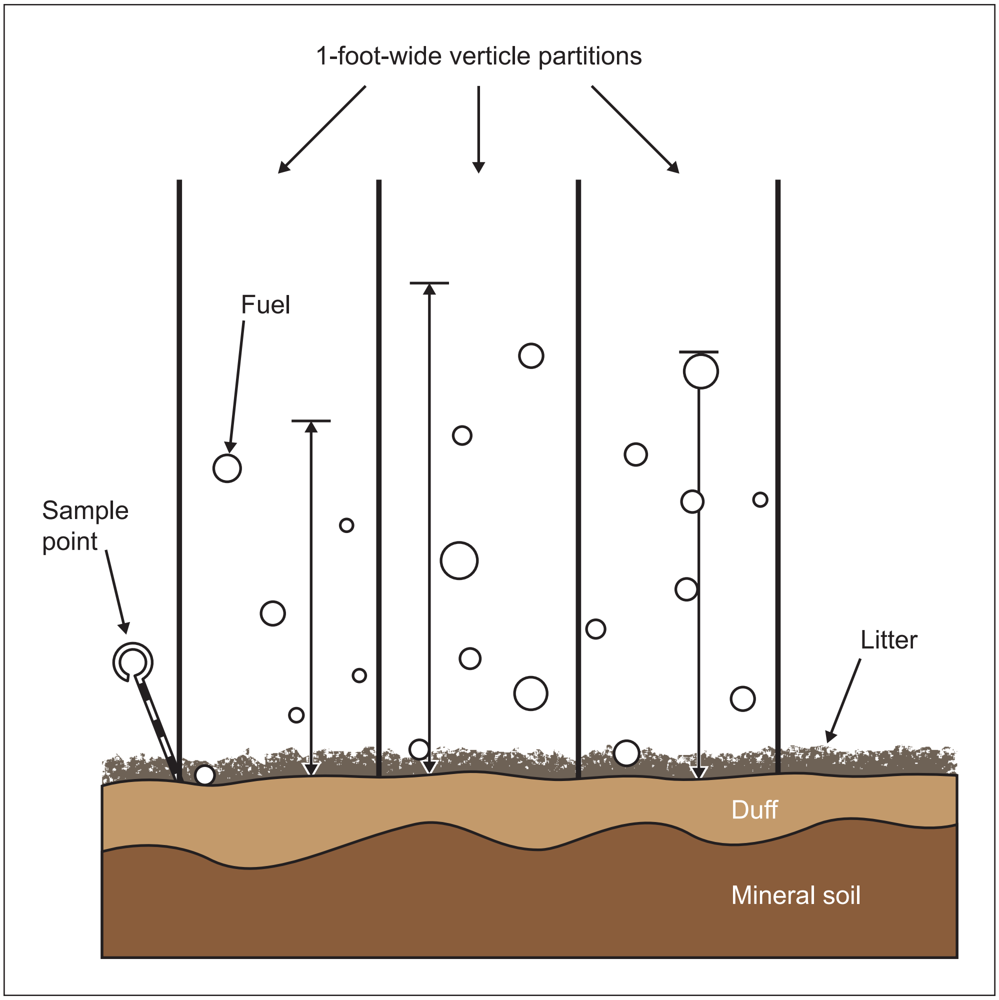

Figure 14—Fine downed wood depth is sampled at regular intervals along the transect lines (e.g., 1.5 to 1.9 m, 3.0 to 3.4 m, 4.5 to 4.9 m). Downed wood depth is recorded as the highest particle height in each 30-cm vertical partition, excluding fuels that are suspended more than 0.91 m above the other downed wood in the 91-cm vertical partition (Brown 1974).

Sound Wood

Sound wood is downed wood that has minimal decay. The FCCS inputs for sound wood include loadings by size class of small downed wood (<7.6 cm diameter) and large downed wood (>7.6 cm diameter). The two most common species and relative covers are assigned to small and large downed wood groups separately. If you cannot identify downed wood to species, you might consider using the two dominant species in the forest or shrubland you are sampling.

The standard method for sampling downed wood is to use the Brown (1974) planar intercept method (see above). Photo series can provide a faster but less accurate estimate of downed wood biomass.

Rotten Wood

The rotten wood category enters fuel loading for less than 7.6 cm downed wood size classes. Rotten wood is defined as partially decomposed wood debris with obvious signs of decay, such that the material falls apart when kicked. The three rotten wood time lag classes are 1,000-hr, 10,000-hr, and >10,000 hr. Smaller rotten wood is generally too decayed to accurately sample. Species designations and relative cover apply to all rotten wood size classes.

Rotten wood loadings are estimated along with sound wood. The standard method is the Brown (1974) planar intercept sampling protocol. Photo series can provide a faster but less accurate estimate of downed wood biomass.

Stumps

Stumps are defined as the remaining portion of a tree stem after it has been sawn or broken (fig. 15). Broken-top, dead trees that are greater than breast height (1.4 m) are generally considered to be snags and are recorded in the canopy stratum. The three stump categories are:

Sound stumps—Bark intact; hard when kicked

Rotten stumps—Bark may or may not be intact; represents decay classes 3, 4, and 5; feels soft or punky when kicked

Lightered stumps—Rotten with resin-soaked heartwood; particularly common in Southeastern pine stands

Susan Prichard

Figure 15—Stumps can contribute to long-term smoldering emissions.

The most efficient way to sample stumps is to include them in tree measurement plots (app. 1, form 2). For each stump, collect the following information (table 14):

- Category (sound, rotten, or lightered)
- Diameter
- Height
- Species
- Density

Table 14—Stump input variables applicable to sound, rotten, and lightered-pitchy categories

Variable	Definition	Sampling protocol	Units (input limits)
Density	Number of stumps per area	Plot tally	Number per hectare (0–123,500)
Diameter	Average depth of fine wood (1-hr, 10-hr and 100-hr time-lag classes)	Measuring tape/stick	Centimeters (0–508)
Height	Stump height, measured from the ground to top of the stump	Measuring tape/stick	Meters (0–1.5)
Scientific name	Dominant woody plant species	—	—
Relative cover	Relative percentage of each species. Must sum to 100 percent.	—	Percentage (0–100)

— = not applicable

1. **Density.** Density refers to the number of stumps per hectare. Number of stumps can be sampled along with trees and snags (see "Canopy stratum" above). Stumps can be tallied by category to calculate sound, rotten, and lightered-stump densities.
2. **Diameter.** For all stumps less than breast height, diameter should be measured at the top of each stump using a standard measuring tape or caliper. For sawn stumps greater than breast height, diameter should be measured at breast height using a diameter tape.
3. **Height.** Height of each stump should be sampled from the ground to the top of each stump. Each stump should include a decay class category.
4. **Species and relative cover.** Species of each stump should be recorded. Once you have sampled all stumps, you can calculate the "relative cover" of each species for each stump category. For example, in the sound stump category, 70 percent of the stumps may have been loblolly pine [*Pinus taeda* L.] and 30 percent may have been slash pine [*Pinus elliottii* L.]. For consistency between canopy, shrub, herb fuel, and downed wood input screens, FCCS refers to the percentage each species by stump category as "relative cover."

Piles

Piles are defined as accumulations of downed wood, including natural fuel accumulations ("jackpots"), hand piles, and machine piles. Pile inputs can be collected for use in the online pile calculator (University of Washington 2016b) or FFT fuelbed editor to calculate pile volume and biomass within an FCCS fuelbed. Piles of the same dimensions can be compiled into groups (app. 1, form 10). More than one pile group can be specified to represent the piles in a fuelbed (e.g., 100 hand piles and 2 machine piles).

Required measurements differ between hand piles (piles that were not created by machines), and machine piles (material was piled using equipment) (table 15).

Hand-pile variables—

- Number of piles or number of piles per unit area
- Pile shape
- Pile dimensions
- Pile composition (hardwood/shrub or conifer)

Table 15—Machine and hand-pile inputs

Variable	Definition	Sampling protocol	Units
Pile type	Hand or machine	Number per pile group	Number of piles per hectare
Number of piles	Number of piles per unit area[a]	Field observations	—
Pile shape	Geometric shape of pile[b]	Measuring tape, laser[c]	Meters
Pile dimensions	Necessary dimensions vary by pile shape[d]	Field observation	—
Pile composition	Conifer, or shrub/hardwood[e]	Field estimate	—
Percentage soil	Percentage of soil by volume[f g]	Field observation	Percent
Packing ratio	Pile packing ratio[g h]	Field observation	—
Pile species composition	Primary and optional secondary species to specify a wood density[g]	Field observation	—
Pile quality	Rating of pile cleanliness including clean (hand piles), dirty, and really dirty[i]	Field observation	—

— = not applicable.
[a] Data can be organized into pile groups (of similar type and dimensions).
[b] Half sphere, parabola, half cylinder, half frustum, half cone with rounded ends, half ellipsoid, or irregular solid.
[c] Groups can be formed by piles of similar size and shape.
[d] Width, height, and length.
[e] Applicable only to hand piles.
[f] This measure accounts for soil that may be mounded below a pile and should be subtracted by the actual pile volume.
[g] Applicable only to machine piles.
[h] Piles with a lot of air space (10 percent), densely packed piles (20 percent), or very densely packed piles with large logs (25 percent).
[i] Pile quality refers to how coated pile particles are with dirt, and can affect pile emission calculations.

Machine pile variables—

- Number of piles
- Pile shape
- Pile dimensions
- Pile composition
- Percentage soil
- Packing ratio
- Species composition
- Pile quality

Number of piles—

Count the number of piles per area or across a burn unit.

Shape and dimensions—

Pile shape and dimensions (m) inform which geometric equation will be used to estimate pile volume (fig. 16).

Composition—

Hand piles—Record whether the pile group is dominated by broadleaf hardwood and shrub or by conifers.

Machine piles—Select up to two dominant tree species and their relative composition. In cases where species are not listed, proxy species with similar wood densities can be used.

Percentage soil—Estimate the percentage of pile, by volume, which is soil. This generally pertains to landing piles that may have mounds of soil under them.

Packing ratio— For machine piles only, select one of three options to best represent how densely packed the fuel particles are in a pile group:

1. ***Ten percent (10 percent)***—Piles dominated by long-needled pines or broadleaf deciduous litter. Mean diameter of large downed wood is less than 25 cm.
2. ***Twenty percent (20 percent)***—Pile dominated by short-needled conifers. Mean diameter of large downed wood is less than 25 cm.
3. ***Twenty-five percent (25 percent)***—Very compacted and clean piles generally constructed by a crane or loader. Mean diameter of logs is greater than 25 cm.

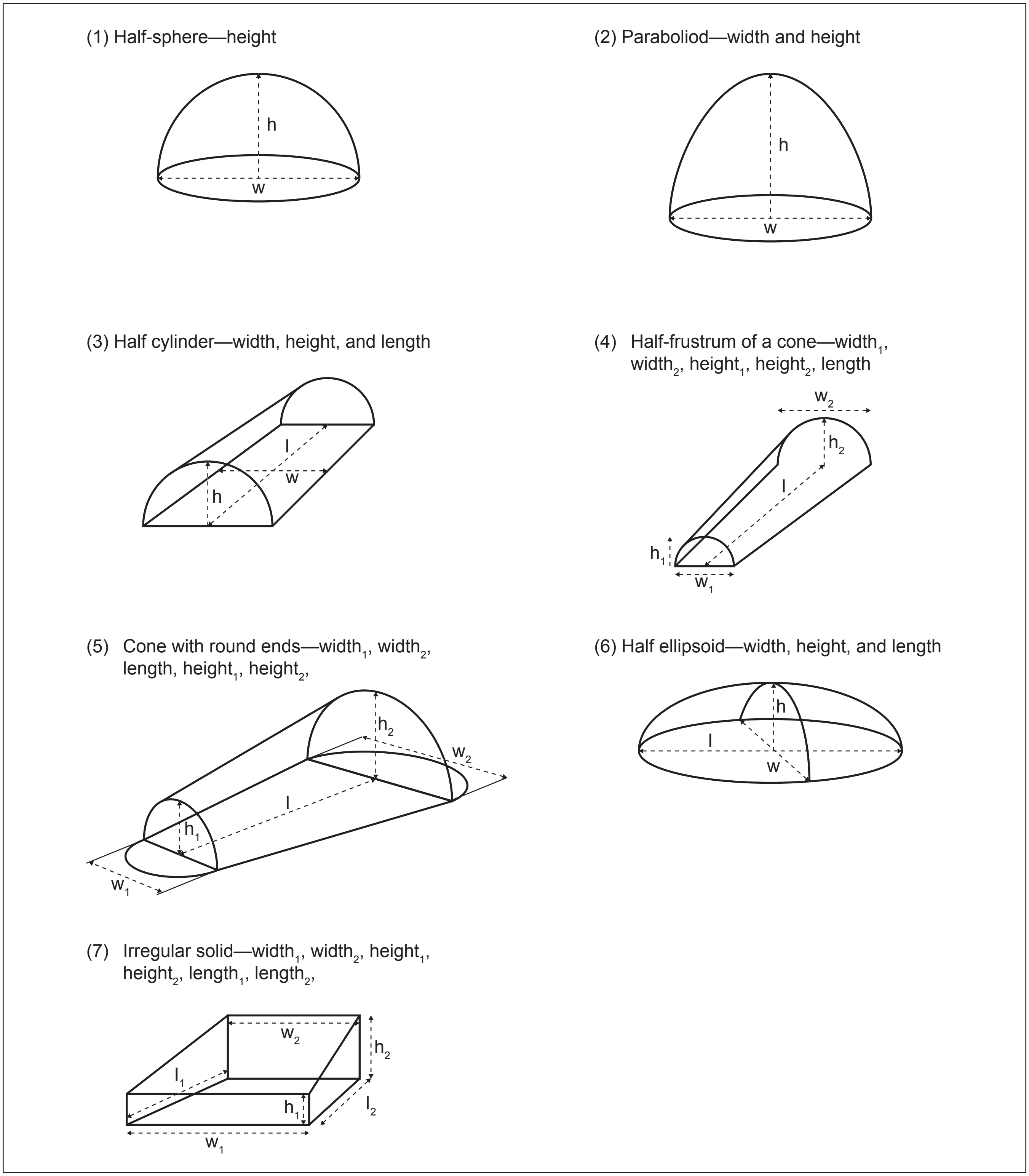

Figure 16—Various pile shapes and their dimensions.

Pile quality—

Machine piles can either be clean or mixed with soil, depending on how they were constructed (e.g., crane or bulldozer). Clean piles burn more efficiently than dirty piles. Record three levels of pile cleanliness for each pile group:

- Clean (no soil)
- Dirty (up to 10 percent soil)
- Very dirty (more than 10 percent soil)

Litter-Lichen-Moss

Litter, ground lichen, and moss (LLM) are treated as a single stratum in FCCS.

Litter is the top layer of the forest floor (also called the O1 or Oi organic soil horizon) and is composed of loose debris of dead sticks, branches, twigs, and recently fallen leaves or needles; little altered in structure by decomposition.

Lichen grows on forest, shrubland, and grassland floors. The FCCS does not inventory arboreal lichen; they are included as a type of ladder fuels in the canopy stratum.

Moss grows on forest, shrub, and grassland floors, particularly in moist habitats.

Inputs are similar between LLM layers (table 16) and include depth, percentage of cover, type (for moss and litter), and litter arrangement. The LLM measurements are most efficiently sampled along downed wood planar intercept transects (refer to downed wood stratum) (app. 1, form 9).

Table 16—Litter-lichen-moss stratum inputs

Variable	Definition	Sampling protocol	Units (input limits)
Depth	Total depth of litter, lichen, or moss layer	Ruler	Centimeters (0−76)
Percentage cover	Percentage cover of litter, lichen, or moss layer based on linear or subplot coverage	—	Percentage (0−100)
Litter arrangement	Dominant of three arrangements: normal, fluffy, or perched (on grass or forb)	Field observation	—
Litter type	Composition of litter type including short needle pine, long needle pine, other conifer, broadleaf deciduous, broadleaf evergreen, palm fronds, and grass	Clip plots, field observation	—
Relative percentage cover	Relative cover of each litter type. Must sum to 100 percent	Clip plots, field observations	Percentage (0−100)
Moss type	Dominant of two types including sphagnum moss or other moss (e.g., feathermoss)	Clip plots, field observations	—

— = not applicable.

Depth

Depth refers to the thickness of each LLM layer. LLM depth is most efficiently sampled at regular intervals along downed wood transect lines (e.g., 1.5 to 1.8 m, 3.1 to 3.4 m, 4.6 to 4.9 m) and is recorded as the vertical distance between the bottom and top of each layer (app. 1, form 9). For example, litter depth is measured as the top of the litter layer to the bottom, defined as the boundary between distinguishable litter and decomposed material (duff) (fig. 17). Depth of LLM is generally measured along an exposed vertical profile of the upper soil. Forest soils are variable, and frequent depth measurements will be required to obtain a reliable fuelbed estimate.

Roger Ottmar

Figure 17—Litter and duff layers above mineral soil.

Percentage Cover

Percentage cover refers to the percentage of the ground covered by each LLM layer. The most efficient way to estimate percentage litter, moss, and ground lichen is to add these as categories in your shrub and herb surveys. If you use the quadrat method (app. 1, form 5) or the line-intercept method (app. 1, form 6) to estimate plant cover, simply record percentage cover of each litter type, each moss type, and ground lichen as additional plant species.

Additional descriptors are required for moss and litter:

Moss Type

Record the dominant moss type for your fuelbed.

- Sphagnum moss
- Other moss

Litter Arrangement

Record the dominant litter arrangement for your fuelbed. The selected litter arrangement determines which inferred bulk density value FCCS uses in its loading calculations.

- Fluffy (freshly fallen). The most common occurrence of a "fluffy" litter arrangement is broadleaf deciduous litter in the autumn. Long-needled pine litter may also be considered fluffy. Other needle litter may also be relatively uncompact after a windstorm or other disturbance.
- Normal. A normal litter arrangement includes most conifer-dominated litter types and broadleaf deciduous litter after compaction by rain and snow.
- Perched (on grass or forb). In fuelbeds with abundant herbaceous or downed wood, recently fallen litter may be perched on surface fuels.

Litter Type

Many fuelbeds will contain a mix of litter types. Assign a relative cover for each litter type that applies to your fuelbed.

- Short needle pine (i.e., lodgepole pine [*Pinus contorta* Dougl.])
- Long needle pine (i.e., ponderosa pine [*P. ponderosa* Dougl. ex Laws], loblolly pine, longleaf pine [*P. palustris* Mill.])
- Other conifer (i.e., Douglas-fir, larch [*Larix* spp.], hemlock, cedar)
- Broadleaf deciduous (i.e., maple [*Acer* spp.])
- Broadleaf evergreen (i.e., madrone [*Arbutus* spp.])
- Palm fronds
- Grass

Ground Fuels

The **ground fuels** stratum has three categories:

- **Duff** is organic soil between the LLM stratum and mineral soil. Duff is recorded in two layers: an upper layer representing the Oe soil horizon and a lower layer representing the Oa soil horizon. These layers are also called fermentation and humic layers, respectively. Many fuelbeds have only a single, upper duff layer, but boreal and high-elevation forests often have two duff layers. The upper duff layer contains partially decomposed organic matter in which tree needles, leaves, and other material are identifiable. The lower duff layer, where it exists, contains mostly decomposed organic matter and is much denser than the upper duff layer.
- **Basal accumulations** are accumulations of bark, downed wood, and forest floor surrounding tree trunks.
- **Squirrel middens** are mounds of litter, tree cones, and other plant material accumulated by squirrels; these are generally limited to boreal-spruce-dominated forest fuelbeds in Alaska.

Duff

Depth—

Depth refers to the thickness of each duff layer (table 17). Upper duff depth is the average depth from the base of the litter layer to the top of the lower duff layer. Lower duff depth is the average depth from the base of the upper duff layer to the start of mineral soil. Forest soils are generally variable, and multiple depth measurements will be necessary to obtain a reliable estimate (see LLM "Depth" section on page 49).

Table 17—Upper and lower duff layer input variables

Variable	Definition	Sampling protocol	Units (input limits)
Depth	Total depth of upper of lower duff layer	Ruler	Centimeters (0–508)
Percentage cover	Percentage cover of the upper or lower duff layers based on linear or subplot coverage	Ocular	Percentage (0–100)
Derivation	Derivation of upper duff layer or lower duff layers (2 options each)	Clip plots, field observation	—
Loading	Optional loading by layer[a]	Clip plot	Megagrams per hectare (0–448)

— = not applicable.
[a] If left at zero, Fuels Characteristic Classification System will calculate loading.

Percentage cover—

Percentage cover is estimated as the percentage of the ground area covered by each duff layer (see LLM "Depth" section).

Derivation—

Derivation is recorded for each duff layer. There are two derivation types per layer:

Upper duff—

- Partially decomposed moss and litter.
- Partially decomposed sphagnum moss or sedge, generally found in bogs and boreal tussocks.

Lower duff—

- Fully decomposed moss and litter.
- Fully decomposed sphagnum moss or sedge, generally found in bogs and boreal tussocks.

Loading—

Upper and lower duff loading values are optional inputs and can be estimated by multiplying measured depth by measured bulk density and proportional cover (percentage divided by 100). Inferred bulk density values within FCCS are listed in table 18.

Table 18—Inferred bulk density values by duff type and derivation

Duff type	Bulk density
	Mg ha^{-1} cm^{-1}
Partially decomposed moss and litter	1
Partially decomposed sphagnum moss or peat	1
Fully decomposed moss and litter	7
Fully decomposed sphagnum moss or peat	16

Basal Accumulations

Basal accumulations are twigs, bark pieces, litter, and duff that accumulate and form a deep organic layer surrounding the base of trees (fig. 18). Inputs are defined in table 19.

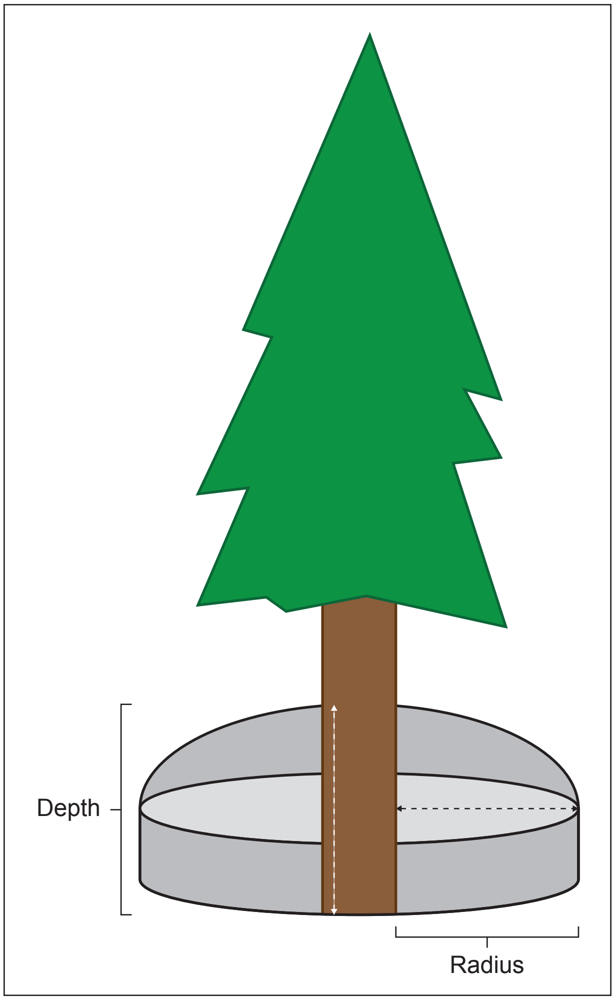

Figure 18—Diagram of a basal accumulation.

Table 19—Basal accumulation input variables

Variable	Definition	Sampling protocol	Units (input limits)
Depth	Depth of basal accumulation of ground fuels around tree trunks	Ruler	Centimeters (0–127)
Radius	Radius of basal accumulation of ground fuels around tree trunks	Ruler, laser	Meters (0–6)
Density	Density of trees with basal accumulations	Tally	Number per hectare (0–127,000)
Type	Type of basal accumulation[a]	—	—
Loading	Optional loading[b]	Clip plot	Megagrams per hectare (0–336)

— = not applicable.
[a] Bark slough, branches, broadleaf deciduous litter, broadleaf evergreen litter, grass, palm fronds, needle litter.
[b] If left at zero, Fuels Characteristic Classification System will calculate loading.

Depth—

Depth is generally measured in several median locations within the sloped ring of tree basal accumulations and averaged for a single depth (app. 1, form 11).

Radius—

Radius is measured from the outer edge of the tree trunk to the outer edge of the basal accumulation. Because basal accumulations may be irregular in shape and differ between trees, you may wish to take multiple depth and radius measurements and report modal (i.e., the most commonly occurring) values.

Density—

Density is the number of trees with basal accumulation per unit area.

Type—

Note the dominant basal accumulation type of your fuelbed. Options include:

- Bark slough: accumulated pieces of old bark
- Branches: dead tree and shrub branches
- Broadleaf evergreen: dead leaves of broadleaf evergreen trees and shrubs
- Broadleaf deciduous: dead leaves of broadleaf deciduous trees and shrubs
- Grass: grass litter
- Needle litter: dead conifer needles
- Palm fronds: dead palm fronds

Loading—

Basal accumulation loading is an optional input and can be estimated by first calculating the volume of a representative basal accumulation and then calculating loading based on measured bulk density. Because basal accumulations form around tree stems, the volume of the trees stems in the center of the basal accumulation must be subtracted from an estimated gross volume. Table 19 lists inferred bulk densities by derivation type.

$$\text{Loading (Mg ha}^{-1}\text{)} = \text{volume (m}^3\text{)} \times \text{density (number per ha}^{-1}\text{)} \times \text{bulk density (kg m}^{-3}\text{)} \times 0.001 \text{ (Mg kg}^{-1}\text{)} \qquad (5)$$

Where

volume (m^3) = gross volume – tree stem volume,

density (ha^{-1}) = number of basal accumulations per hectare,

bulk density ($kg\ m^{-3}$) = bulk density of basal accumulation type (table 20), and

conversion kilograms to megagrams ($Mg\ kg^{-1}$) = 0.001,

and where

gross volume (m^3) = π × depth (m) × radius (m^2), and

tree stem volume (m^3) = π × depth (m) × overstory tree radius (m^2) / 8.

Table 20—Inferred bulk density values by basal accumulation type

Type	Bulk density
	Mg m^{-3}
Bark slough	98.67
Branches	98.67
Broadleaf deciduous	61.36
Broadleaf evergreen	61.36
Grass	45.57
Needle litter	59.20
Palm fronds	45.57

Squirrel Middens

Squirrel middens are mounds of cone scales and other cone debris accumulated over time from generations of squirrels extracting seeds from cones. The mounds are composed exclusively of organic matter that can burn for extended periods of time. They are generally found in boreal forests and are uncommon in the contiguous United States.

Depth—
Depth is generally measured in several median locations within squirrel middens (app. 1, form 12) and averaged for a single depth input (table 21).

Radius—
Radius is measured from the center of the squirrel midden to the outer edge of the accumulation (fig. 19). Because squirrel middens may be irregular in shape and differ between trees, you may wish to take multiple depth and radius measurements and report modal (i.e., the most commonly occurring) values.

Table 21—Squirrel midden input variables

Variable	Definition	Sampling protocol	Units (input limits)
Depth	Average depth of squirrel middens	Ruler	Centimeters (0–508)
Radius	Average radius of squirrel middens	Ruler, laser	Meters (0–15.2)
Density	Number per unit area of squirrel middens	Tally	Number per hectare (0–101)
Loading	Optional loading[a]	Clip plot	Megagrams per hectare (0–560)

[a] If left at zero, Fuels Characteristic Classification System will calculate duff loading.

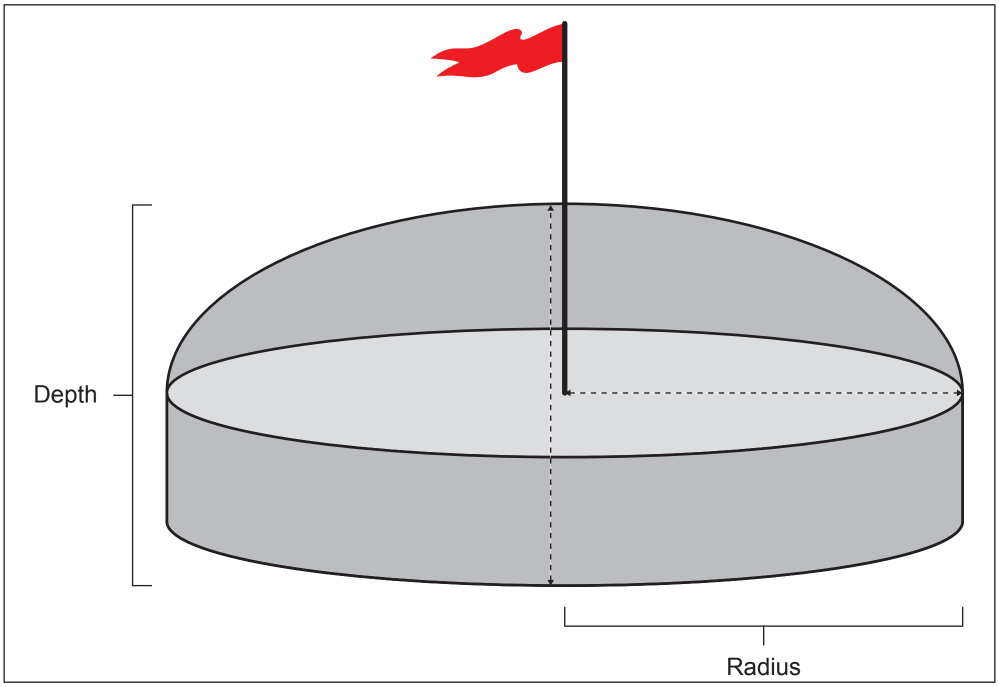

Figure 19—Diagram of a squirrel midden.

Loading—

Squirrel midden loading is an optional FCCS input that can be estimated by first calculating the volume of the midden and then calculating loading based on measured bulk density (g m^{-3}) of the squirrel midden material. The FCCS inferred bulk density value for squirrel middens is 97.12 g m^{-3}.

$$\text{Volume } (m^3) = [\pi \text{ Depth } (m) \times \text{Radius } (m)^2] / 8$$
$$\text{Loading (tons } m^{-2}) = \text{Volume } (m^3) \times \text{Density } (\# \, m^{-2}) \times$$
$$\text{Bulk density } (kg \, m^{-3}) \times 410.95 \text{ kg } kg^{-1}$$

Density—

Density is the number per unit area of squirrel middens.

Conclusions

Methods presented in this guide are intended to provide guidelines for measurement of input variables and development of FCCS fuelbeds. The FCCS was designed to represent the spatial and temporal variability of wildland fuels. Fuelbeds can be constructed to characterize fuels in six strata including canopy, shrubs, herbaceous fuels, downed wood, litter–lichen–moss, and ground fuels. Each stratum is further divided into one or more categories and subcategories. A fuelbed can represent any scale that is relatively uniform on the landscape that represents a distinct fire environment. A planned prescribed burn unit, for example, may contain many stand types that can be represented by individual fuelbeds. Alternatively, fuelbeds can be constructed to represent growing season versus dormant season conditions to reflect temporal changes in available fuels throughout the year.

Although there are over 300 possible fuelbed inputs, constructing fuelbeds to represent a specific site does not have to be an exhaustive process. Because FCCS was designed to accommodate wildland fuel characteristics across a range of geographic locations and ecosystems, many fuelbed inputs may not apply to regionally- or site-specific fuelbeds.

The amount of field sampling required for fuelbed customization depends on the intended application. For prescribed burning with a low probability of affecting tree crowns, customizing the fuelbed could focus on surface and ground fuel characteristics, including shrubs, grasses, downed wood, litter, and duff. In contrast, fuelbeds may also be constructed to represent total carbon stores of a particular site. In that case, careful accounting of fuel characteristics from ground to canopy fuels may be required.

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U.S. Equivalents

When you know:	Multiply by:	To find:
Inches	2.54	Centimeters
Feet	.305	Meters
Acres	.405	Hectares
Square feet	.0929	Square meters
Cubic feet	.0283	Cubic meters
Pounds	.454	Kilograms
Pounds per square foot	4.88	Kilograms per square meter
Pounds per cubic foot	16.0185	Kilograms per hectare
Number per acre	2.471	Number per hectare
Degrees Celsius (°C)	1.8 °C +32	Degrees Fahrenheit

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Appendix 1: Fuel Characteristic Classification System Field Sampling Forms

Form 1—Fuelbed description and search variables

Fuelbed name ____________ Date ____________ Coordinate system[a] ____________

Plot ID ____________ Elevation ____________ Latitude ____________

Plot dimensions ____________ Slope gradient (%) ____________ Longitude ____________

Field crew ____________ Aspect (°) ____________ GPS location ____________

____________ GPS error ____________

Description[b] ____

____

____

____

Ecoregion (select all that apply)

- ☐ 120: Tundra
- ☐ 130: Subarctic
- ☐ 210: Warrn continental
- ☐ 220: Hot continental
- ☐ 230: Subtropical
- ☐ 240: Marine
- ☐ 250: Prairie
- ☐ 310: Tropical/subtropical desert
- ☐ 320: Tropical/subtropical steppe

Desert

- ☐ 340: Temperate desert
- ☐ 410: Savanna
- ☐ 420: Rainforest

Vegetation form (select one)

- ☐ Broadleaf forest
- ☐ Conifer forest
- ☐ Grassland mixed forest
- ☐ Savanna
- ☐ Shrubland
- ☐ Slash

Stand structural class (select one)

- ☐ Old-forest multistory
- ☐ Old-forest single story
- ☐ Stand initiation
- ☐ Stem-exclusion closed canopy
- ☐ Stem-exclusion open canopy
- ☐ Understory reinitiation
- ☐ Young forest-multistory

SAF or SRM cover type (list all that apply)[c d]

____

____

____

____

____

Change agent (select all that apply)

Change over time

- ☐ Fire exclusion
- ☐ Introduction of exotic spp.
- ☐ Stand development

Fuel treatments

- ☐ Chipping
- ☐ Lop and scatter
- ☐ Mastication
- ☐ Pile and burn
- ☐ Prescribed fire

Timber harvest

- ☐ Pruning
- ☐ Clearcut
- ☐ Logging methods/equipment
- ☐ Salvage logging
- ☐ Stumpwooding
- ☐ Thinning (thin from below)

Land use change

- ☐ Ditching/draining
- ☐ Paving

Natural event

- ☐ Avalanche
- ☐ Flood
- ☐ Ice damage
- ☐ Insects and disease
- ☐ Landslide
- ☐ Windthrow

Vegetation

- ☐ Grazing
- ☐ Residual fertilization
- ☐ Tree planting
- ☐ Restoration work
- ☐ Tree planting
- ☐ Turpentining

Wildfire

- ☐ Wildfire
- ☐ Wildfire (ground)
- ☐ Wildfire (crown)

[a] Latitude and longitude, Universal Transverse Mercator (UTM), or Albers equal area conic projection (Albers).
[b] For example, geographic location, major vegetation, disturbance, and management history.
[c] Eyre 1980.
[d] Shiflet 1994.

Form 2—Total canopy cover sampling form (general)

Canopy

	Percentage cover
Total canopy	______
Overstory	______
Midstory	______
Understory	______

Ladder fuels

Characteristics	
Minimum height (m)	______
Maximum height (m)	______
Vertical continuity?	______

Ladder fuels—select one type

- ☐ Arboral lichens and moss
- ☐ Climbing ferns and other epiphytes
- ☐ Dead branches
- ☐ Leaning snags
- ☐ Profuse epicormic sprouting
- ☐ Stringy or fuzzy bark
- ☐ Tree regeneration
- ☐ Vines/lianas

Live tree ID number	Species code	Layer	Alive or dead	Snag decay class	Stump decay class DBH[a]	Height	Height to live crown	Basal accum?	Notes
		O, M, U[b]	L, D[c]	1F, 1, 2, 3[d]	S, R, L[e]	*Centimeters*	*Meters*	Yes/No	
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
18									
19									
20									

[a] Diameter at breast height.
[b] O = overstory, M = midstory, U = understory.
[c] L = alive, D = dead.
[d] 1F = class 1 snag with foliage, 1 = class 1 snag, 2 = class 2 snag, 3 = class 3 snag.
[e] S = sound, R = rotten, L = lightered.

Form 3—Total canopy cover sampling form (moosehorn method)

Fuelbed name ______________________ Date ______________________

Plot ID ______________________ Field crew ______________________

Description ____

____

____

____

Point No.	Transect 1a	Transect 2a	Transect 3a

Point No.	Transect 1a	Transect 2a	Transect 3a

Form 4—Total canopy cover sampling form (intercept method)

Fuelbed name ________________________ Date ________________________

Plot ID ________________________ Field crew ________________________

Description ____

Transect ID	Tree number	Species	Status	Tree layer	Start	Stop	Distance
			L/D[a]	(O, M, U)[b]		- - - - - *Meters* - - - - -	

[a] L = alive, D = dead.
[b] O = overstory, M = midstory, U = understory.

Form 5—Shrub and herb sampling form (quadrant method)

Fuelbed name ________________________ Date ________________________

Plot ID ________________________ Field crew ________________________

Description ____

Transect	Quadrant	Species	Percentage live	Layer	Cover code[a]	height
ID Number		—	*Percent*	*Primary or secondary*	—	*Meters*

[a] Cover code:
0 = no cover; 0.5 = >0–1%; 3 = >1–5%; 10 = >5-15%; 20 = >15–25%; 30 = >25–35%; 40 = >35–45%;
50 = >45–55%; 60 = >55–65%; 70 = >65–75%; 80 = >75–85%; 90 = >85–95%; 98 = >95–100%

Form 6a—Shrub and herb sampling form (intercept method)

Fuelbed name ____________________ Date ____________________
Plot ID ____________________ Field crew ____________________

Transect length ____
Sampling notes ____
____
____

Shrub and herb cover by line intercept method—

Transect ID	Species	Layer	Percentage live	Height	Start	Stop	Distance
Number	—	1, 2[a]	*Percent*	- - - - - - - *Meters* - - - - - - -			

[a] 1 = primary layer, 2 = secondary layer.

Transect summary by primary or secondary shrub/herb vegetation layer—

Transect ID	Total Distance	Transect length	Percentage cover
Number	- - - - - - - - - - - - - - *Meters* - - - - - - - - - - - - - -		*Percent*
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

Plot cover (%) ____________________

Form 6b—

Transect	**Point**	**Litter**				**Lichen**		**Moss**			**Duff**			
											Upper		Lower	
		Cover	Depth	Arrangement	Type[1]	Cover	Depth	Cover	Depth	Type	Cover	Depth	Cover	Depth
		Percent	*cm*	*F, N, P2*		*Percent*	*cm*	*Percent*	*cm*	*S, O3*	*Percent*	*cm*	*Percent*	*cm*
1	1													
1	2													
1	3													
1	4													
1	5													
2	1													
2	2													
2	3													
2	4													
2	5													
3	1													
3	2													
3	3													
3	4													
3	5													
4	1													
4	2													
4	3													
4	4													
4	5													

Form 7—Shrub and herb characteristics (photo series method)

Fuelbed name ________________________ Date ___________________
Plot ID ________________________ Field crew ___________________
Plot dimensions ________________________ Subplot dimensions ___________________

Plot notes ____

Is needle drape sufficient to affect fire behavior? Yes No

Primary shrub layer—	Primary herb layer—
Photo series volume and ID ______________	Photo series volume and ID ______________
Percentage cover (%) ______________	Percentage cover (%) ______________
Layer height (m) ______________	Layer height (m) ______________
Loading (Mg ha^{-1}) ______________	Loading (Mg ha^{-1}) ______________
Species list—	Species list—

Secondary shrub layer—	Secondary herb layer—
Photo series volume and ID ______________	Photo series volume and ID ______________
Percentage cover (%) ______________	Percentage cover (%) ______________
Layer height (m) ______________	Layer height (m) ______________
Loading (Mg ha^{-1}) ______________	Loading (Mg ha^{-1}) ______________
Species list—	Species list—

Form 8—Clip plot sampling form

Fuelbed name ________________________ Date ________________________

Plot ID ________________________ Field crew ________________________

Clip plot dimensions ____

Notes ____

____

____

Plot ID	Material type	Bags per sample	Bag weight	Net dry weight	Notes
	Shrub, shrub, LLM[a]*, or ground fuel*	*Number*	*Grams*	*Grams*	

[a] Litter, lichen, and moss

Form 9—Downed wood, litter-lichen-moss, and duff sampling form

Fuelbed name ______________ Date ______________
Plot ID ______________ Field crew ______________
Plot dimensions ______________ Duff derivation ______________
Plot description ____

Transect direction	
Transect	Azimuth
	Degrees
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	

Fine wood tally			
	Diameter		
Transect	<0.64 cm	0.64–2.54 cm	2.54–7.62 cm
	Number of pieces of wood		
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			

Course wood measurements			
Transect	Diameter	Species	Decay class
	centimeters	—	*1, 2, or 3*[a]
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			

Form 10—Pile group sampling form

Fuelbed name ______________________ Date ______________________

Sampling area (ha) ______________________ Field crew ______________________

Site notes ____

____

____

		All piles							Hand piles only	Machine piles only				
										Relative cover				
Pile group	**Type**[a]	**Shape**[b]	**W1**[c]	**W2**	**H1**	**H2**	**L1**	**L2**	**Composition**[d]	**Species 1**	**Species 2**	**Soil**	**Packing ratio**	**Pile quality**
ID number	—	—	- - - - - - - - - *Meters* - - - - - - - - -						—	- - - - - - *Percentage* - - - - - -			10, 20, or 25%	*Clean, dirty, really dirty*

[a] M = machine, H = hand.

[b] 0 = half sphere, 1 = paraboloid, 2 = half cylinder, 3 = half fulstrum of cone, 4 = half fulstrum of cone with rounded ends, 5 = half ellipsoid, 6 = irregular solid.

[c] W = width, H = height, L = length.

[d] c = conifer, h = hardwood.

Form 11—Forest floor sampling form

		Litter				Lichen		Moss			Upper duff		Lower duff	
		Cover	Depth	Arrangement[a]	Type[b]	Cover	Depth	Cover	Depth	Type[c]	Cover	Depth	Cover	Depth
Transect	Point	*Percent*	*cm*	*F, N, P*	—	*Percent*	*cm*	*Percent*	*cm*	*S, O*	*Percent*	*cm*	*Percent*	*cm*
1	5													
1	10													
1	15													
1	20													
1	25													
1	30													
1	35													
1	40													
1	45													
1	50													
2	5													
2	10													
2	15													
2	20													
2	25													
2	35													
2	40													
2	45													
2	50													
3	5													
3	10													
3	15													
3	20													
3	25													
3	30													
3	35													
3	40													
3	45													
3	50													

[a] Litter arrangement (F = fluffy; N = normal, P = perched).
[b] Litter type (SP = short-needled pine, LP = long-needled pine, OC = other conifer, BD = broadleaf deciduous, BE = broadleaf evergreen, PF = palm frond, GR = grass).
[c] Moss type (S = sphagnum, O = other).

Form 12—Basal accumulation and squirrel midden sampling form

Fuelbed name ____________________ Date ____________________

Plot ID ____________________

Site notes ____

____

Basal accumulation measurements—

Group	**Depth**	**Radius**	**Density**	**Type**[a]
	Centimeters	*Meters*	*No. per hectare*	
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Squirrel midden measeurements—

Group	**Depth**	**Radius**	**Density**	**Type**[a]
	Centimeters	*Meters*	*No. per hectare*	
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

[a] BD (broadleaf deciduous); BE (broadleaf evergreen [e.g., madrone (*Arbutus* spp.)]); BR (branches); BS bark slough); G (grass); NL (needle litter); P (palm fronds).

Appendix 2: Slope Correction Table

		Plot size in hectares						
		0.05	0.1	0.5	1.0	2.5	5.0	10.0
Slope	Correction factor[a]	Plot radius[b]						
Percent		*- - - - - - - - - - - - - - - - - - - Meters - - - - - - - - - - - - - - - - - - -*						
5	1.000	12.6	17.8	39.9	56.4	89.2	126.2	178.4
10	1.005	12.7	17.9	40.1	56.7	89.7	126.8	179.3
15	1.010	12.7	18.0	40.3	57.0	90.1	127.4	180.2
20	1.020	12.9	18.2	40.7	57.5	91.0	128.7	182.0
25	1.031	13.0	18.4	41.1	58.2	92.0	130.1	183.9
30	1.044	13.2	18.6	41.6	58.9	93.1	131.7	186.3
35	1.060	13.4	18.9	42.3	59.8	94.6	133.7	189.1
40	1.077	13.6	19.2	43.0	60.8	96.1	135.9	192.2
45	1.097	13.8	19.6	43.8	61.9	97.9	138.4	195.7
50	1.118	14.1	19.9	44.6	63.1	99.7	141.0	199.5
55	1.141	14.4	20.4	45.5	64.4	101.8	143.9	203.6
60	1.166	14.7	20.8	46.5	65.8	104.0	147.1	208.0
65	1.194	15.1	21.3	47.6	67.4	106.5	150.6	213.0
70	1.221	15.4	21.8	48.7	68.9	108.9	154.0	217.8

[a] Corrections are provided for circular plots.
[b] For each incremental step in slope gradient, plot radius (m) is listed.

Appendix 3: Random Number Table

86	85	19	85	71	95	31	6	2	4	60
17	48	32	58	98	12	58	85	89	72	82
55	69	44	46	76	64	23	93	38	37	39
60	31	66	11	80	80	62	74	9	96	79
84	56	99	1	25	46	32	24	35	85	18
72	74	51	78	66	61	17	17	84	72	16
46	78	47	93	82	35	8	52	39	17	100
90	68	38	99	56	89	93	85	5	2	88
68	59	38	82	87	20	62	93	95	35	69
8	29	79	45	8	19	95	49	53	97	80
95	8	27	28	51	83	72	66	47	50	23
95	13	13	93	26	22	1	97	99	24	51
7	82	21	40	16	53	22	74	75	61	74
1	17	6	13	0	23	72	83	12	31	40
30	82	41	55	92	35	28	83	39	57	2
66	17	13	25	36	69	96	41	44	74	87
6	55	22	67	89	89	15	33	38	69	96
84	63	100	100	21	95	79	75	8	83	42
59	85	69	14	92	69	24	72	71	89	57
5	33	22	38	55	47	57	24	39	5	14
50	39	11	88	79	47	26	49	68	27	42
78	95	54	86	16	89	57	93	68	9	49
62	20	75	58	16	18	5	16	52	79	1
8	32	82	77	37	60	76	49	90	52	9
59	27	38	39	72	58	96	25	93	45	22
64	58	14	67	61	79	18	55	98	7	43
6	3	55	96	37	92	8	85	73	43	81
89	95	89	7	10	4	93	98	44	66	30
90	52	29	99	39	11	29	38	16	31	20
54	47	69	15	4	60	17	31	14	10	27

Appendix 4: Percentages of Cover of Vegetation

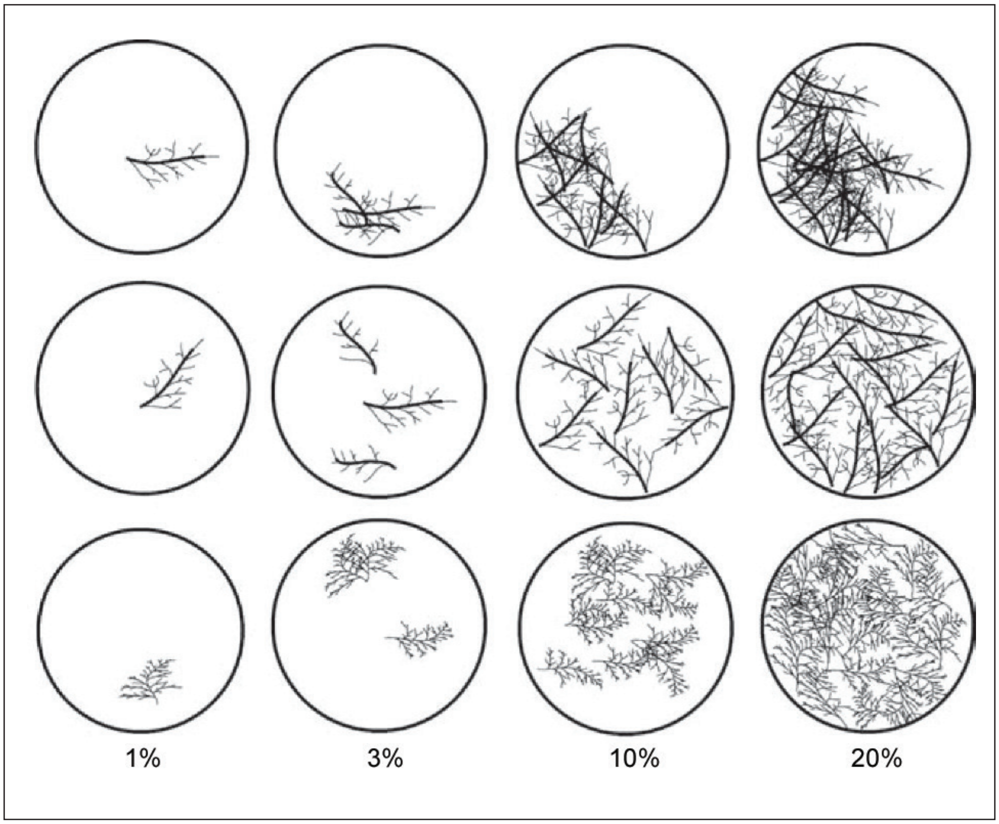

Figure A4-1—Percentage cover of live vegetation (illustration from Lutes et al. 2006).

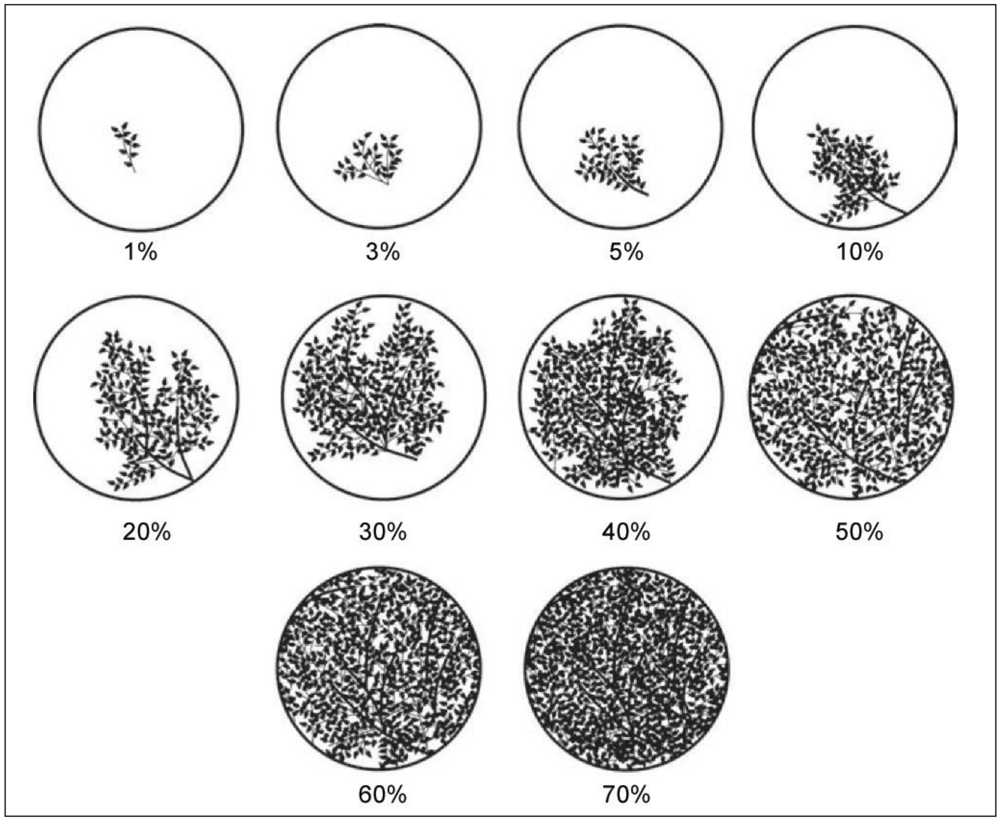

Figure A4-2—Percentage cover of live vegetation on a 6-cm diameter sampling area (Lutes et al. 2006).

Pacific Northwest Research Station

Website	http://www.fs.fed.us/pnw/
Telephone	(503) 808–2100
Publication requests	(503) 808–2138
FAX	(503) 808–2130
E-mail	pnw_pnwpubs@fs.fed.us
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Pacific Northwest Research Station
1220 SW 3rd Ave., Suite 1400
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Portland, OR 97208–3890