An overview of the Fuel Characteristic Classification System — Quantifying, classifying, and creating fuelbeds for resource planning[1]

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Abstract: We present an overview of the Fuel Characteristic Classification System (FCCS), a tool that enables land managers, regulators, and scientists to create and catalogue fuelbeds and to classify those fuelbeds for their capacity to support fire and consume fuels. The fuelbed characteristics and fire classification from this tool will provide inputs for current and future sophisticated models for the quantification of fire behavior, fire effects, and carbon accounting and enable assessment of fuel treatment effectiveness. The system was designed from requirements provided by land managers, scientists, and policy makers gathered through six regional workshops. The FCCS contains a set of fuelbeds representing the United States, which were compiled from scientific literature, fuels photo series, fuels data sets, and expert opinion. The system enables modification and enhancement of these fuelbeds to represent a particular scale of interest. The FCCS then reports assigned and calculated fuel characteristics for each existing fuelbed stratum including the canopy, shrubs, nonwoody, woody, litter–lichen–moss, and duff. Finally, the system classifies each fuelbed by calculating fire potentials that provide an index of the intrinsic capacity of each fuelbed to support surface fire behavior, support crown fire, and provide fuels for flaming, smoldering, and residual consumption. The FCCS outputs are being used in a national wildland fire emissions inventory and in the development of fuelbed, fire hazard, and treatment effectiveness maps on several national forests. Although the FCCS was built for the United States, the conceptual framework is applicable worldwide.

Résumé : Nous présentons une vue d'ensemble du système de classification des caractéristiques des combustibles (SCCC), un outil qui permet aux aménagistes, aux organismes de régulation et aux scientifiques de créer et de cataloguer les couches de combustibles et de les classer en fonction de leur capacité à supporter un feu et à consumer des combustibles. Les caractéristiques des couches de combustibles et la classification des feux obtenues avec cet outil alimenteront en données les modèles sophistiqués présents et futurs utilisés pour quantifier le comportement et les effets du feu, comptabiliser le carbone ainsi que permettre l'évaluation de l'efficacité du traitement des combustibles. Le système a été conçu à partir des exigences des aménagistes, des scientifiques et des décideurs recueillies lors de six ateliers de travail régionaux. Le SCCC contient un ensemble de couches de combustibles représentatives des États-Unis qui ont été compilées à partir de la littérature scientifique, de séries de photos de combustibles, de bases de données sur les combustibles et de l'opinion d'experts. Le système permet de modifier et d'améliorer ces couches de combustibles pour représenter une échelle d'intérêt particulière. Le SCCC produit ensuite un rapport sur les caractéristiques des combustibles attribuées et calculées pour chaque strate existante de couches de combustibles incluant la canopée, les arbustes, les plantes ligneuses et non ligneuses, le complexe litière–lichens–mousses et l'humus. Finalement, le système classe chaque couche de combustibles en calculant le potentiel d'inflammabilité qui fournit un indice de la capacité intrinsèque de chaque couche de combustibles de supporter un feu de surface, de supporter un feu de cime et de fournir des combustibles pour alimenter des flammes, un feu couvant et l'élimination des résidus. Les résultats du SCCC sont utilisés dans un inventaire national des émissions dues aux incendies de forêt et dans le développement de cartes de couches de combustibles, de risque d'incendie et d'efficacité des traitements dans plusieurs forêts nationales. Bien que le SCCC ait été mis au point pour les États-Unis, le cadre conceptuel est applicable partout.

[Traduit par la Rédaction]

Introduction

Sophisticated and complex models are used for large- and small-scale fire and fuel assessments (Huff et al. 1995; Quigley and Arbelbide 1997; Schaaf et al. 1998; Amiro et al. 2001), prioritization of hazardous fuel projects (USDA Forest Service 2004; Ottmar 2005), wildland fire emissions

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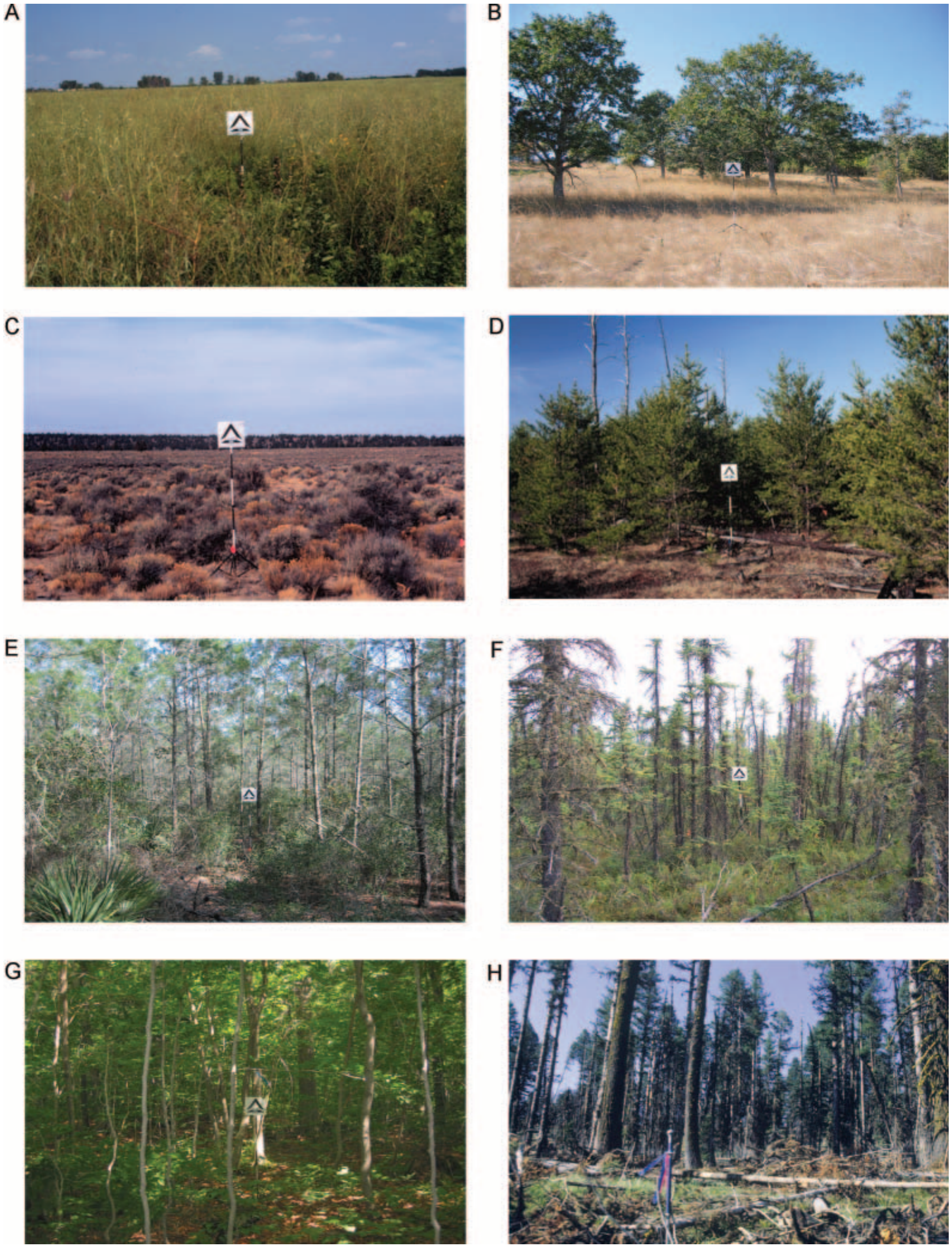
Fig. 1. Fuelbeds of the United States are structurally complex and vary widely in their physical attributes, potential fire behavior, and options presented for fuels treatment, fire control, and use. These grassland, shrubland, woodland, and forest examples illustrate a diversity of vegetation and fuels: (A) Minnesota tallgrass prairie; (B) California oak woodland; (C) Washington sagebrush; (D) Michigan jackpine; (E) Florida sand pine scrub; (F) Alaska black spruce; (G) Northeastern mixed hardwoods; (H) Oregon mixed conifer slash.



inventory (Battye and Battye 2002), and carbon accounting (Johnsen et al. 2001; Banfield et al. 2002; French et al. 2004). These applications require a comprehensive characterization of fuelbeds that captures the structural complexity, geographic diversity, and potential flammability of fuelbed components (Reinhardt et al. 1997; Sandberg et al. 2001; Reinhardt and Crookston 2003; Ottmar 2005) (Fig. 1). Fuelbeds vary widely in their physical attributes, potential fire behavior and effects, and options they present for fuels treatment and fire control. It would be prohibitively difficult to inventory all fuelbed characteristics every time an assessment or management decision was necessary (Sandberg et al. 2001; Ottmar et al. 2004).

A consistent, scientifically based framework for constructing and cataloguing fuelbed descriptions and classifying those fuelbeds based on realistic physical properties derived from direct or indirect observations, inventory, and expert knowledge is needed. Land managers, policy makers, and scientists need this framework to organize some of the complexity of wildland fuelbeds without oversimplifying their description. In this paper, we describe the Fuel Characteristic Classification System, which provides fire managers, scientists, and policy makers with a nationally consistent procedure to characterize and classify all components of both specific and general fuelbeds and provides numerical inputs to fire behavior, fire effects, and dynamic vegetation models.

Early fuel characteristic systems

Attempts have been made during the past 30 years to develop systems to construct and classify fuelbeds for model inputs with various degrees of success (Deeming et al. 1977; Anderson 1982; Hirsch 1996; Cheney and Sullivan 1997; Reinhardt et al. 1997; Ottmar et al. 1998). Because the systems were designed for specific software applications, they included only the portion of the fuelbed components required by the program they were designed to support. Consequently, the systems did not capture certain important fuel characteristics, structural complexities, and geographical diversity required by many fire and fuel models (Sandberg et al. 2001).

The limitations of systems for building fuelbeds became evident in the 1990s. The Fire Emissions Tradeoff Model (Schaaf 1996) was developed to demonstrate tradeoffs between wildfire and prescribed fire emissions for three mid- and broad-scale assessment projects including the Eastside Forest Ecosystem Health Assessment (Huff et al. 1995), the Interior Columbia River Basin Ecosystem Management Project (Quigley and Arbelbide 1997; Ottmar et al. 1998), and the Grand Canyon Visibility Transport Commission Assessment (Air Sciences Inc. 2005). These efforts required a more robust way to assign fuel loads across landscapes than could be provided by the 13 fire behavior models used by US federal agencies (Anderson 1982). The Fuel Condition Class (FCC) system (Schaaf 1996; Ottmar et al. 1998) was a precursor to the Fuel Characteristic Classification System (FCCS). It was designed to improve fuel load assignments and account for additional fuelbed characteristics within six fuelbed strata including trees, shrubs, grasses, woody surface fuels, litter (Oi horizon in US soil taxonomy), and duff (Oe and Oa horizons). This system provided a classification framework based on vegetation type (ponderosa pine (*Pinus ponderosa* Dougl. ex P. & C. Laws.), mixed conifer, lodgepole pine (*Pinus contorta* Dougl. ex Loud. var. *latifolia* Englem.), western juniper (*Juniperus occidentalis* Hook.), sagebrush (*Artemesia* spp.), and grass); age category (bare ground, immature, mature, and over mature); load category (low, medium, and high); and activity category (none, precommercial thinning, commercial thinning, pile, lop and scatter, crush, and yard unmerchantable material). The FCC system contained a total of 192 fuelbeds that were populated with fuel input data from scientific literature, large databases, and expert knowledge. The data accompanying each fuelbed included fuel loads by size-class of woody fuels, shrub and grass loads, duff and litter depths, duff and litter loads, tree height, crown base height, tree densities and diameters, and emission factors.

The FCC system had three inherent flaws including (1) a limited number of fuelbeds that generally represented the Pacific Northwest only, (2) a limited list of fuelbed categories representing each fuelbed, and (3) no ability to customize an FCC fuelbed (Ottmar et al. 1998). Although these inadequacies existed within the system, the FCC fuelbeds contained the appropriate fuelbed categories to be implemented in the fuel consumption and emission production software packages Consume 2.1 (Ottmar et al. 2001) and First Order Fire Effects Model (FOFEM; Reinhardt et al. 1997). The FCC system was the forerunner of the Fuel Characteristic Classification System, which improved the system, corrected inherent flaws, and provided a fire hazard rating for the fuelbeds.

FOFEM also contains a set of default fuel load values for land managers and other users of the software based on scientific literature (Reinhardt et al. 1997). The default fuel loads are assigned to Society of American Foresters (Eyre 1980) or Society of Rangeland Management (Shiflet 1994) cover types, and fill the needs of FOFEM, but do not include all fuelbed categories.

Keane (2005) and Lutes et al.[3] are currently developing fuel loading models (FLM) for the LANDFIRE Project, an interagency project for mapping wildland fire, ecosystems, and fuels (LANDFIRE 2005). These FLMs contain representative fuel loads for several fuel components within a fuelbed for a typical stand or rangeland classification. The FLMs are assigned to a vegetative mapping classification to prioritize fuel treatment areas, evaluate fire hazard and potential status, and examine past, present, and future fuel loads. Again, this system provides loads for the key fuelbed components (sound woody fuels, herbaceous and shrub biomass, litter, and duff) that fill the needs of FOFEM (Reinhardt et al. 1997), but do not include all fuelbed categories.

Fire potentials

In this paper, we define FCCS fire potentials as the capacity of a wildland fuelbed to support a surface fire and crown fire, and to consume and smolder fuels at benchmark environmental conditions (Sandberg et al. 2007*a*). Previous classification of fire potential has focused primarily on the capacity of a fuelbed to support rate of spread, resistance to control, and flame length of initiating fires in surface fuels (Sandberg et al. 2001). This approach has been extensively used for fire suppression planning and has become increasingly quantitative as tools for numerical assessment of hazard have become available. Thirteen stylized fire behavior fuel models have simply and adequately filled this need in the United States fire behavior prediction system (Albini 1976). However, this focus has not satisfied the need to predict extreme fire behavior or model fire behavior and effects related to residence time, persistence, or total heat release (biomass consumption) from fires burning throughout all fuel layers. The existing fuel models do not capture actual fuel characteristics and variability found in nature. Scott and Burgan (2005) have recently added 43 models to the 13 original fire behavior fuel models. The original 13 along with the additional 43 models will continue to be useful to fire managers using the current generation of fire behavior models.

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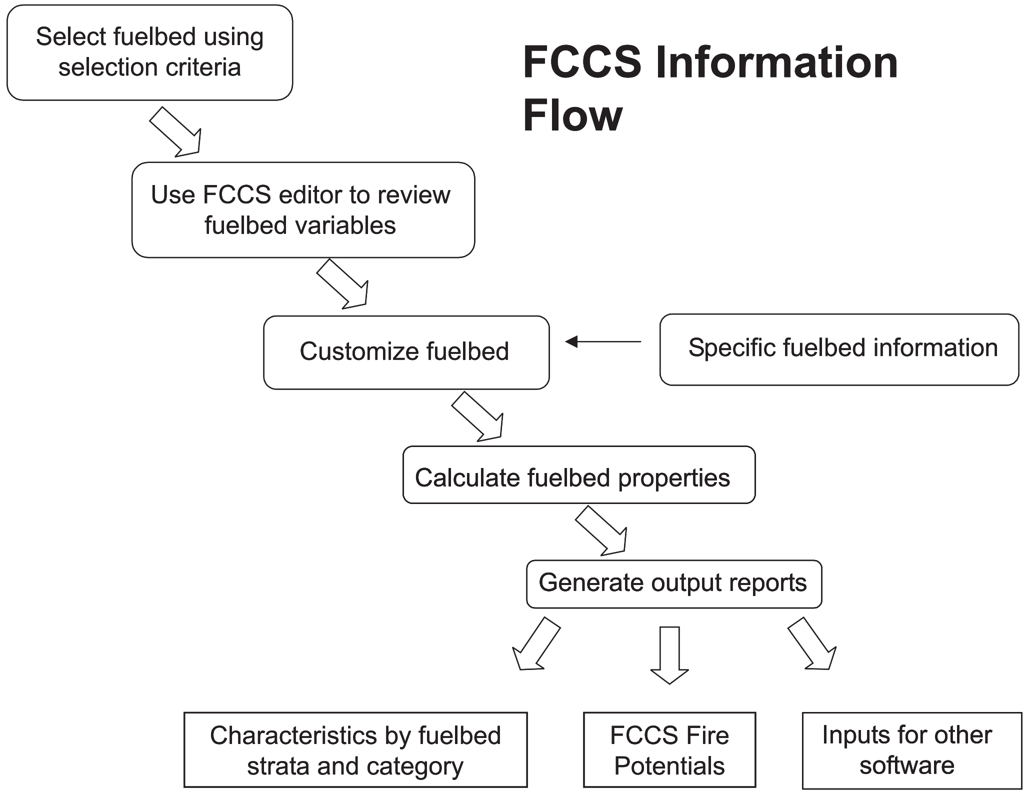
[3] D. Lutes, R.E. Keane, and J. Caratti. Fuel loading models: a statistical classification of wildland fuelbeds for fire effects modeling. In preparation.

Fig. 2. Information flow for the Fuel Characteristic Classification System (FCCS).



Literature on crown fire is limited and does not adequately account for complex fuelbeds, postfrontal torching, or independent crown fires. The limited modeling capability is associated with continued energy input from a spreading fire under a continuous one-story canopy (Van Wagner 1977; Scott and Reinhardt 2001; Cruz et al. 2003). Fahnestock (1970) took a heuristic approach and rated crown fire potential based on crown structure.

There is a significant body of literature on fuel consumption during wildland fires (Byram 1959; Sandberg 1980; Sandberg and Ottmar 1983; Brown et al. 1991; Lawson et al. 1997; Ottmar and Sandberg 2003; Hille and den Ouden 2005) with several models available for managers such as Consume (Ottmar et al. 2005) and FOFEM (Reinhardt et al. 1997). The modeling capability is generally associated with total fuel load and fuel moisture. There is limited research associated with the consumption of biomass in each of the three combustion phases (flaming, smoldering, and residual smoldering).

Fuel Characteristic Classification System

The Fuel Characteristic Classification System (FCCS) is designed to provide quantitative fuelbed information for fire effects models and to assist in building customized fuel models for national application in the United States. The design is based on the needs and requirements gathered from land managers, scientists, and policy makers through a series of six regional workshops (Alaska, Florida, Oregon, Arizona, Georgia, and Nebraska). Workshop participants concluded that the system's architecture will include

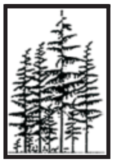
- Application throughout the United States including Alaska and Hawaii.
- Accommodation of a wide range of potential users, operating at different scales, with various levels of detail and quality and quantity of data.
- Data and methods that are scientifically credible.
- Variability found in natural fuelbeds.
- Flexibility with potential for expansion.
- Outputs that are standardized and repeatable.
- User interface that is easily understood and learned.
- Conceptual framework applicable worldwide.

The FCCS (Fig. 2) allows access to an existing database of FCCS fuelbeds through a series of seven selection criteria (see the following). The most appropriate FCCS fuelbed from the list can then be selected and evaluated to determine if it should be customized using site-specific knowledge. When editing of fuelbed data has been completed, the FCCS calculates and generates several reports, quantitative fuel characteristics (physical, chemical, and structural properties), and FCCS fire potentials specific to that fuelbed (Riccardi et al. 2007*a*). The customized fuelbed can be saved and submitted by e-mail to the FCCS support manager for entry into the FCCS as a FCCS fuelbed. Each FCCS or customized fuelbed will be assigned one of the 13 original (Albini 1976; Anderson 1982) or one of the 43 newly created fire behavior fuel models (Scott and Burgan 2005). This will be accomplished by comparing the FCCS surface fire behavior calculations with Rothermel's fire spread model outputs using stylized fuel model inputs. The crosswalk will be provided in a future release of the FCCS (Sandberg et al. 2007*a*).

The fuelbed

The FCCS defines a fuelbed as a relatively homogeneous

Fig. 3. Horizontal stratification of Fuel Characteristic Classification System (FCCS) fuelbeds by stratum and category.

Stratum		Category
CANOPY		Trees, snags, ladder fuels
SHRUBS		Primary and secondary layers
NONWOODY VEGETATION		Primary and secondary layers
WOODY FUELS		All wood, sound wood, rotten wood, stumps, and woody fuel accumulations
LITTER-LICHEN-MOSS		Litter, lichen, and moss layers
GROUND FUELS		Duff, basal accumulations, and squirrel middens

unit on the landscape, representing a unique combustion environment that determines potential fire behavior and effects. A fuelbed can potentially represent any spatial scale. The FCCS stratifies fuelbeds into *six horizontal strata* to represent every fuel element that has the potential to combust, and to better assess potential fire effects from each combustion phase of a fire (Fig. 3). The use of fuelbed strata facilitates the creation of spatial data layers and allows the combination and exclusion of as much detail as is needed to suit a particular use.

Each fuelbed stratum is separated into *one or more fuelbed categories*, with a further breakdown into *subcategories* where needed (Fig. 3). The fuelbed categories and subcategories contain common combustion characteristics, with a total of 18 fuelbed categories and 20 subcategories (Fig. 3). For example, the woody fuel stratum includes the fuelbed categories of sound and rotten woody material, stumps, and woody fuel accumulations. The sound woody material includes the subcategories of 0–0.6, 0.6–2.5, 2.5–7.6, 7.6–22.9, 22.9–50.8, and >58.8 cm diameter size-classes material, the traditional woody fuel size-classes used in the US National Fire Danger Rating System (Deeming et al. 1977).

Fuelbed category and subcategory are described by *physiognomic and continuous variables*. Physiognomic variables capture qualitative features of a category, including morphological and physical features. For example, the duff category of the ground stratum includes physiognomic variables of the Oe horizon (or fermentation layer) and Oa horizon (or humus layer) as well as the derivation of that material (decayed moss, needle litter, and leaf litter). Continuous variables characterize the quantity of fuel in each stratum or category. The duff category includes mean duff thickness and proportion of rotten material. The system uses these estimates of fuel character (physiognomic variables) and quantity (continuous variables) to calculate or assign total upper and lower duff bulk density and fuel load of the duff category, and other parameters required as inputs by fire models.

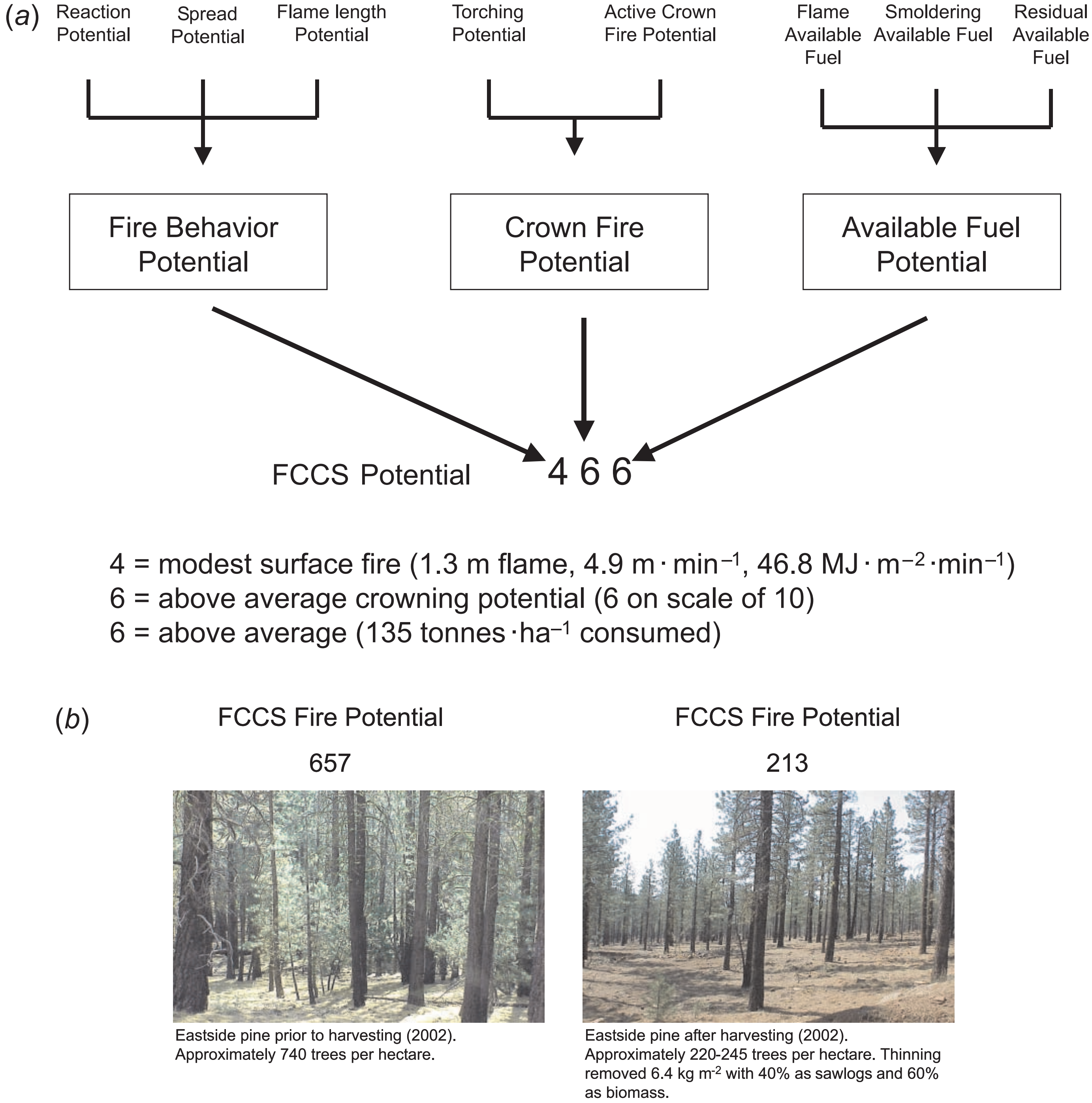
FCCS fuelbeds

The FCCS provides a set of FCCS fuelbeds developed from scientific literature, fuel databases, and in some cases, expert knowledge (Riccardi et al. 2007*a*). Each fuelbed is given a fuelbed name and fuelbed numeric identification. The system has 216 fuelbeds at this time, with new fuelbeds being added periodically. These fuelbeds are designed to include most major fuelbed types throughout the United States and represent a general or site specific focus depending on the data from which the fuelbed was built. General fuelbeds tend to represent the broadest vegetation composition and structure, with data taken from a wide geographic range. Site-specific fuelbeds tend to be based on a single site, management unit, or small geographic area. Data sources for each fuelbed are referenced and documented within the system.

The general information used to organize the FCCS fuelbeds includes

- Ecoregion division (Bailey 1997): FCCS fuelbeds are organized geographically to improve prototype selection when only general information such as vegetation form is available.
- Vegetation form (adapted from Küchler (1964) and Küchler and McCormick (1965)): Vegetation form describes the gross physiognomic structure of a landscape unit. Options include conifer forest, hardwood forest, mixed forest, shrubland, grassland, savanna, and slash. Coupled

Fig. 4. (*a*) Fuel Characteristic Classification System (FCCS) fire potentials are a set of relative index values (0–9) that rate the intrinsic physical capacity of a fuelbed to support surface and crown fire and to consume and smolder fuels. (*b*) The forested area on the Eagle Creek Ranger District of the Lassen National Forest has been thinned and the fuels treated, resulting in reduced FCCS surface, crown, and available fuel potentials. (Reproduced with permission of the Eagle Lake Ranger District, Lassen National Forest, Susanville, California).



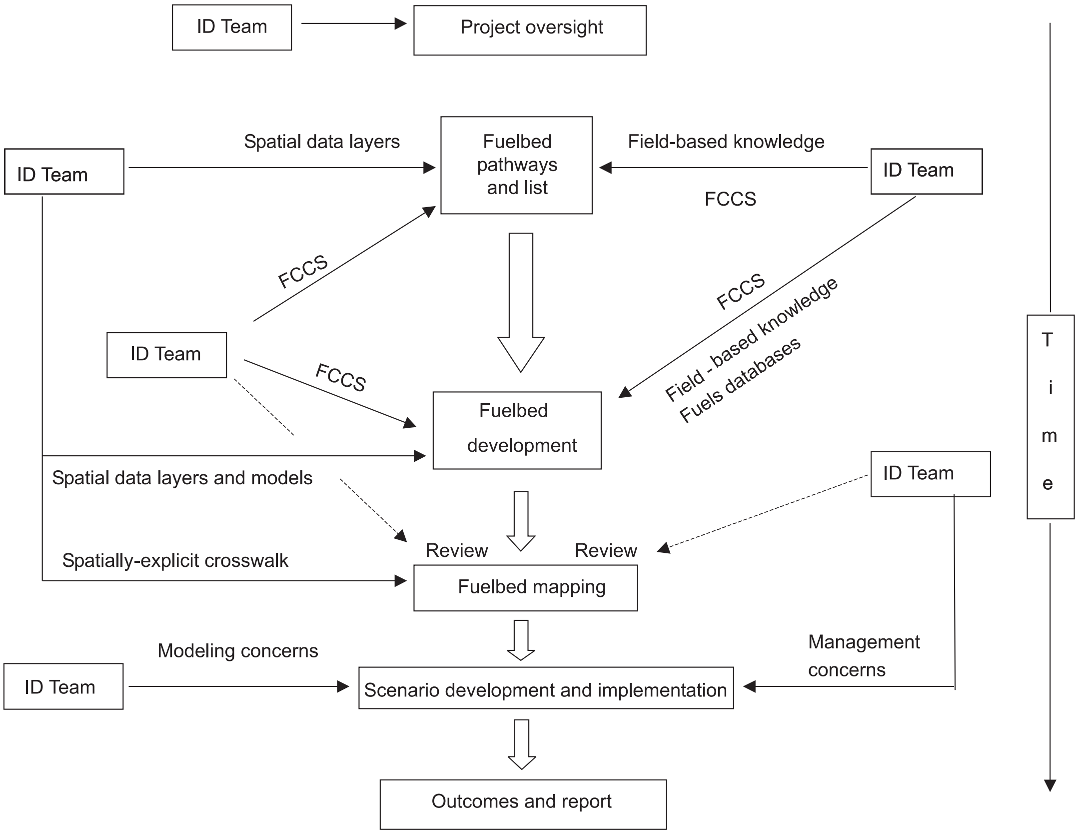
Eastside pine prior to harvesting (2002). Approximately 740 trees per hectare.

Eastside pine after harvesting (2002). Approximately 220-245 trees per hectare. Thinning removed 6.4 kg m^{-2} with 40% as sawlogs and 60% as biomass.

with a choice of Bailey's ecoregion division and a vegetation form of conifer forest, the system provides a pull-down menu of all conifer forest forms available for a certain division. Vegetation form can also be used with remote sensing data where only general information about vegetation is available.

- Structural class: Structural class applies mainly to forests and captures the number of canopy layers, relative size of trees, stage of understory, and relative degree of stand closure (Oliver and Larson 1996). Descriptions of forest structure are used to fine tune the categories present and the partitioning of fuels in canopy layers.
- Cover type: FCCS fuelbeds are assigned a cover type based on dominant vegetation using forest cover types of the United States (Eyre 1980) and rangeland cover types of the United States (Shiflet 1994).

Fig. 5. Flow diagram of how the Fuel Characteristic Classification System (FCCS) will be used to list, build, and characterize fuelbeds on the Okanogan and Wenatchee National Forests for assessing fuel hazard.



- Change agent: Change agent refers to activities such as fire suppression, insect and disease mortality, wind, timber harvest, and prescribed fire that significantly alter fuelbeds. FCCS fuelbeds reflect a range of possibilities.
- Natural fire regime: General classification of the role fire would play across a landscape in the absence of postsettlement human intervention, but including the influence of aboriginal burning. The FCCS uses six fire regimes based on the historic characteristics of disturbance defined by Agee (1993) and Heinselmann (1981), and outlined in the Interagency Fire Regime Condition Class Guidebook (Hann et al. 2004). These include (1) 0–35 year fire frequency and low severity, (2) 0–35 year fire frequency and high severity, (3) 35–200+ year frequency and mixed severity, (4) 35–200+ year fire frequency and high severity, (5) 200+ year fire frequency and high severity, and (6) unknown.
- Fire regime condition class (FRCC): A qualitative measure describing the degree of departure from historical fire regimes. There are three condition classes including Class 1, fire frequencies have departed from historical frequencies by no more than one return interval and fire regimes are moderately altered; Class 2, fire frequencies have departed from historical frequencies by more than one return interval and fire regimes are significantly altered; and Class 3, fire frequencies have departed from historical frequencies by multiple return intervals with changes to fire regimes (Hann and Bunnell 2001).

Although the FCCS fuelbeds are classified by seven qualitative criteria, only ecoregion and vegetation form are required for the fuelbed query.

Each FCCS fuelbed is rated for quality of the information used for creating the fuelbed: (1) no data, data created from experience and (or) reading the literature; (2) partial data, <35% of data from the literature, photo series, or good data source; (3) partial data, 35%–85% of data from the literature, photo series, or good data source; (4) data driven, 85%–100% of data from the literature, photo series, or good data source; (5) data driven, all data from the literature, photo series, or good data source.

Fuelbed characteristics

The FCCS has the ability to provide continuous fuel characteristics based on FCCS fuelbed input, user input, and calculated outputs (Riccardi et al. 2007*b*). The characteristics include percent cover, depth, height, height to live crown, percent live foliar moisture content, density, diameter at breast height (DBH), loading live, loading dead, fuel area index (dimensionless index of fuel surface area, analogous to the leaf area index), packing ratio, and optimum packing ratio. The FCCS calculates and reports these characteristics for each fuelbed stratum, category, and subcategory where applicable and displays them in the report feature of the FCCS.

Fuel characteristics are calculated or inferred using the best available scientific information including biomass equations, photo series, and other published fuels data, and relationships between physiognomic features and physical parameters such as surface-area-to-volume ratio, bulk density, and flammability. This information is stored in an internal FCCS file that links information to the appropriate fuelbed stratum, categories, and subcategories.

FCCS fire potentials

Fire potentials are a set of relative values that rate the intrinsic physical capacity of a wildland fuelbed to support a surface fire at benchmark conditions (Sandberg et al. 2007*a*, 2007*b*), support a crown fire (Schaaf et al. 2007), and to provide fuels for flaming, smoldering, and residual consumption (Sandberg et al. 2007*a*). The benchmark conditions used for the surface fire behavior are 6.4 km/h for midflame wind speed, and 0%, 30%, and 60% moisture content for the dead, herbaceous, and live moisture contents (Sandberg et al. 2007*a*, 2007*b*). At these benchmark environment conditions the FCCS fire potential calculations are not dependent upon Rothermel's (1972) specific equations of response to wind and fuel moistures. Fire potentials enable the system to provide data to (1) map fire hazard, (2) compare and communicate the degree of fire hazard, and (3) measure the change in fire hazard caused by fuel management, natural events, or the passage of time. The fire potentials can also be used to approximate fire behavior and effects when used in conjunction with knowledge of environmental conditions. FCCS fire potentials include indexed values for surface fire behavior potential, crown fire potential, and fuel consumption potential.

The FCCS calculates each of the fire potentials on a scale of one to nine in a three-digit integrated fire potential. The first digit represents relative potential surface fire behavior, the second digit represents relative crowning potential, and the third digit represents the fuels available for consumption.

Surface fire potential consists of a combination of three component potentials, all patterned after the fire spread model by Rothermel (1972):

- Reaction potential: This potential is the approximate reaction intensity (energy release per unit area per unit time) at benchmark environmental conditions. It is a function of the volume of fuels per unit ground surface, depth of the surface fuelbed strata, heat of combustion, damping coefficients due to moisture and mineral content, and a scaling factor.
- Spread potential: This component is proportional to the rate of spread (distance per unit time at benchmark environmental conditions) in surface fuels, and is a function of reaction intensity, propagating energy flux, and the heat sink provided by unburned fuels in advance of the spreading flame.
- Flame length potential: A measure of predicted flame length (at benchmark environmental conditions). It is proportional to fireline intensity or flame length and has been derived from the product of reaction intensity.

FCCS crown fire potential is a semiempirical model that describes crown fire initiation and propagation in vegetative canopies. It is based on whether the energy supplied by a surface fuelbed layer is sufficient to ignite and sustain fire spread in the canopy and uses an updated model based on the work by Van Wagner (1977) and Rothermel (1991), with some new concepts for modeling crown fire behavior derived from the reformulated Rothermel (1972) surface fire modeling proposed by Sandberg et al. (2007*b*). Its use is currently limited to assessing the crown fire potential of FCCS fuelbeds.

The general forms for each component of the FCCS crowning potentials are

- Torching potential: This component is a dimensionless measure of the potential for a surface fire to spread into the canopy as single- or group-tree torching.
- Active crown fire potential: This component is a dimensionless measure of the potential for a surface fire to spread into and actively propagate through the canopy

Available fuel is the fuel load of all fuel elements within a set depth from the surface of the fuel component, intended to approximate the combustible biomass under oven-dry moisture conditions in each of three stages of combustion — flaming, smoldering, and residual. The general form for each available fuel component is

- Flame-available surface available fuel: The mass of fuel consumed within 1.2 cm of the surface of the fuel element (e.g., fuel consumed during the flaming front of a spreading surface fire).
- Smoldering available fuel: The mass of fuel consumed between 1.2 and 5.1 cm of a surface (e.g., fuel consumed during the smoldering combustion phase).
- Residual available fuel: The mass of fuel consumed between 5.1 and 10.2 cm of a surface (e.g., fuel consumed during the residual combustion phase).

The FCCS number assigned to each fuelbed indicates the level of each index (Fig. 4).

An FCCS fuelbed with a fire potential of 466 will have a surface fire behavior potential index of 4 (modest reaction potential, surface spread, and flame height), a crown fire potential index of 6 (above average crowning potential representing 6 on a scale of 10), and an available fuel potential index of 6 (above average available fuel representing 135 tonnes·ha^{-1} consumed). Additional fire potentials such as smoke production and tree mortality may be added in the future to represent other measures of potential fire effects.

Implementation and application

The FCCS can create, catalogue, and analyze fuelbeds at any spatial scale of interest because the fuelbed is defined as "a relatively uniform unit on the landscape that represents a unique combustion environment and that determines potential fire behavior and effects." Fuelbeds and characteristics can be used to map fuels across small or large landscapes and administrative units, thereby facilitating assessment of fire hazard and various ecological characteristics (McKenzie et al. 2007). The FCCS has a well-documented scientific foundation, represents diverse conditions within and between fuelbeds, and readily accepts new and customized fuelbeds. Quantitative information from FCCS fuelbeds can be used in nearly any fire effects model and to assist in building customized fuel models.

Perhaps the greatest value of the FCCS is that it provides realistic physical properties of a fuelbed in a consistent and searchable framework for a range of applications in fire, fuel, smoke, and carbon assessment. In addition, users can assess the effects of human (e.g., logging slash) and natural (e.g., insect attack and fungal pathogens) disturbances on a range of fuel characteristics and fire hazard. All of these applications lead to a rigorous national framework for planning, decision making, and policy analysis. We anticipate that the FCCS will be especially useful for planning fuel treatments and measuring the effectiveness of those fuel treatments through space and time.

The FCCS is currently being used to prioritize fuel treatments on the Okanogan and Wenatchee National Forests (Washington) and on the Deschutes National Forest (Oregon) (Fig. 5) (Ottmar 2005; McKenzie et al. 2007). Fuelbed and fuel load maps have been completed for a national wildland fire emissions inventory for the US Environmental Protection Agency, which is being used to track wildland smoke emissions (McKenzie et al. 2007; see figure 6 in their manuscript). Efforts are also underway to ensure that the FCCS will link with existing fire and landscape assessment models. A variety of linkages exist or are in progress for (1) the fire and fuels extension to the forest vegetation simulator (FFE-FVS, a model that simulates fuel dynamics and potential fire behavior over time, in the context of stand development and management; Reinhardt and Crookston 2003), (2) CONSUME 3.0 (a model that predicts fuel consumption and emissions; Ottmar et al. 2005), (3) fire effects tradeoff model (a model that evaluates tradeoffs between wildfires and prescribed fires; Schaaf et al. 2004), (4) SMOKETRACS (a database model designed to compile fuels information; Sanford 2005), and (5) BlueSky (a compilation of tools that determine wildland fire emission concentrations; Pouliot et al. 2005). Linkages to other fire tools will include (1) BEHAVE (a model that predicts fire behavior; Andrews and Chase 1989), (2) FARSITE (a model that calculates fire spread; Finney 1998), (3) first-order fire effects model (FOFEM, a model that estimates fuel consumption, emissions, and fire effects from wildland fires; Reinhardt et al. 1997), and (4) LANDFIRE (a project to map fuels across the United States; LANDFIRE 2005).

The FCCS architecture is amenable to international application because the dynamic nature of the system allows users to create and map fuelbeds for any scale desired and for any vegetative environment. The system will be continually updated and improved as more information is added to the database, new equations are added to the calculator, and feedback from users is accommodated. An online tutorial learning tool has been developed that will assist instructors demonstrating the system. At the present time, the fire potentials are in an index form. However, conversion to actual values for surface fire, crown fire, and available fuel potentials is being planned with the addition of weather, fuel moisture, and slope variables.

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