The fuelbed: a key element of the Fuel Characteristic Classification System[1]

Cynthia L. Riccardi, Roger D. Ottmar, David V. Sandberg, Anne Andreu, Ella Elman, Karen Kopper, and Jennifer Long

Abstract: Wildland fuelbed characteristics are temporally and spatially complex and can vary widely across regions. To capture this variability, we designed the Fuel Characteristic Classification System (FCCS), a national system to create fuelbeds and classify those fuelbeds for their capacity to support fire and consume fuels. This paper describes the structure of the fuelbeds internal to FCCS. Fuelbeds are considered relatively homogeneous units on the landscape, representing distinct combustion environments that determine potential fire behaviour and effects. The FCCS fuelbeds are organized into six strata: canopy, shrubs, nonwoody fuels, woody fuels, litter–lichen–moss, and ground fuels. Fuelbeds are described by several qualitative and quantitative physical and biological variables with emphasis on characteristics useful for fuels management and fire behaviour planning. The FCCS includes 216 fuelbeds that represent the major vegetation types of the United States. The FCCS fuelbeds can be used as presented or modified to create customized fuelbeds with general or site-specific data to address fire science management or research questions. This system allows resource managers to evaluate wildland fuels operations and management activities, fire hazard, and ecological and air quality impacts at small and large spatial scales. The FCCS fuelbeds represent the United States, although the system has the potential for building fuelbeds for international application.

Résumé : Les caractéristiques des couches de combustibles en milieu naturel sont complexes dans le temps et l'espace et peuvent varier énormément d'une région à l'autre. Dans le but de saisir cette variabilité, nous avons élaboré le système de classification des caractéristiques des combustibles (SCCC), un système national pour créer et classer ces couches de combustibles selon leur capacité à supporter un feu et à consumer des combustibles. Cet article décrit la structure des couches de combustibles intrinsèques au SCCC. Les couches de combustibles sont considérées comme des unités relativement homogènes dans le paysage et représentent des milieux de combustion distincts qui déterminent les effets et le comportement potentiel du feu. Les couches de combustibles du SCCC sont organisées en six strates : canopée, arbustes, combustibles non ligneux, combustibles ligneux, litière-lichens-mousses et combustibles au sol. Les couches de combustibles sont caractérisées par plusieurs variables physiques et biologiques qualitatives et quantitatives en mettant l'accent sur les caractéristiques utiles pour la gestion des combustibles et la planification du comportement du feu. Le SCCC inclut 216 couches de combustibles qui représentent les principaux types de végétation des États-Unis. Les couches de combustibles du SCCC peuvent être utilisées telles quelles ou modifiées pour créer des couches de combustibles sur mesure à partir de données générales ou spécifiques à une station pour s'attaquer à des problèmes de recherche ou de gestion en pyrologie forestière. Ce système permet aux gestionnaires d'évaluer les activités de gestion et les interventions visant les combustibles en milieu naturel, le risque d'incendie ainsi que les impacts écologiques et sur la qualité de l'air à petite ou grande échelle. Les couches de combustibles du SCCC sont représentatives des États-Unis mais le système offre la possibilité d'élaborer des couches de combustibles pour une application internationale.

[Traduit par la Rédaction]

Introduction

Fuels are often defined as the physical characteristics (e.g., loading, depth, height, and bulk density) of live and dead biomass that contribute to wildland fire (Davis 1959). Because these characteristics affect the character, size, intensity, and duration of a fire, identifying and quantifying fuels are important in understanding fire behaviour and ef-

Received 1 September 2006. Accepted 24 July 2007. Published on the NRC Research Press Web site at cjfr.nrc.ca on 26 December 2007.

C.L. Riccardi. USDA Forest Service, 400 N. 34th Street, Suite 201, Seattle, WA 98103, USA.
R.D. Ottmar.[2] Pacific Wildland Fire Sciences Laboratory, US Forest Service, Pacific Northwest Research Station, 400 N. 34th Street, Suite 201, Seattle, WA 98103-8600, USA.
D.V. Sandberg. US Forest Service, Pacific Northwest Research Station, 3200 Jefferson Way, Corvallis, OR 97331, USA.
A. Andreu. University of Washington, College of Forest Resources, Box 352100, Seattle, WA 98195-2100, USA.
E. Elman. College of Forest Resources, University of Washington, Box 352100, Seattle, WA 98103, USA.
K. Kopper. North Cascades National Park Service Complex, Marblemount, WA 98267, USA.
J. Long. USDA Forest Service, 5775 US W Highway 10, Missoula, MT 59808, USA.

[1]This article is one of a selection of papers published in the Special Forum on the Fuel Characteristic Classification System.
[2]Corresponding author (e-mail: rottmar@fs.fed.us).

 doi:10.1139/X07-143 © 2007 NRC Canada

fects, as well as in providing information for activities such as prescribed fire, fire suppression, and fuel treatments. Furthermore, fuelbed characteristics are important aspects to consider when assessing wildlife habitat and carbon stores.

Fuel characteristics often vary widely across regions (Ottmar et al. 2007). For instance, fuel loads can range from (1) <0.6 t·ha^{-1} for a perennial grassland in the central part of the United States with no rotten woody material or duff (organic material that includes Oe horizon and Oa horizon), to (2) 35 t·ha^{-1} in a woodland in California with a grass and shrub understory and a litter layer, to (3) 195 t·ha^{-1} in a mixed conifer forest with insect and disease mortality in the US Rocky Mountains with dead and down sound and rotten woody material, snags, litter and duff, and to (4) 381 t·ha^{-1} in a black spruce (*Picea mariana* (Mill.) BSP) forest of Alaska with a deep moss and organic forest floor layer (Ottmar and Vihnanek 1998, 1999; Ottmar et al. 1998*a*, 2007; Hardy et al. 2001).

It would be prohibitively difficult to inventory all fuelbed characteristics every time a fire behaviour or effects assessment is required (Sandberg et al. 2001; Ottmar et al. 2004). Attempts have been made during the past 30 years to develop systems to construct and classify fuelbeds for loading and other characteristics with various degrees of success. These include the original and standard fire behavior fuel models (Anderson 1982; Andrews and Chase 1989; Scott and Burgan 2005), National Fire Danger Rating System fuel models (Deeming et al. 1977), Fuel Condition Class System fuelbeds (Schaaf 1996; Ottmar et al. 1998*b*), First Order Fire Effects Model fuelbeds (Reinhardt et al. 1997; Reinhardt and Crookston 2003); Canadian Forest Fire Danger Rating System (Hirsch 1996); Australian Fire Danger Rating System fuel models (Cheney and Sullivan 1997; Cheney et al. 1990); Photo Series (Ottmar et al. 2004); and Fuel Load Models (Keane 2005; Rollins and Frame 2006). Many of these models were designed for specific software applications or as inputs to predict specific fire behaviour and effects. Therefore, they include the fuelbed components or characteristics required by the program or model they were designed to support. Consequently, these models do not capture all fuel components required to estimate fire behaviour and fire effects (Sandberg et al. 2001; Ottmar et al. 2007).

In this paper, we describe the structure of the FCCS fuelbeds that captures the complexity and diversity of wildland fuelbeds in the United States. The fuelbed design and classification discussed here is the basis for calculation of a common set of fuel characteristics (Riccardi et al. 2007) that are used as inputs into FCCS fire potentials and fire behaviour calculations (Sandberg et al. 2007*a*, 2007*b*; Schaaf et al. 2007) and that have a variety of applications in fire and fuels management and in ecological analysis.

FCCS fuelbeds

Definition of a fuelbed

An FCCS fuelbed is defined as the measured or averaged physical characteristics of a relatively uniform unit on the landscape that represents a distinct fire environment. (Sandberg et al. 2001, 2007*b*). The fuelbed can represent any scale or precision of interest and can be used to manage, predict, assess, or differentiate fire behaviour and effects.

Design of FCCS fuelbeds

The FCCS fuelbeds were initially designed by scientists, researchers, land managers, and other experts who participated in a series of FCCS fuelbed workshops for the boreal (Fairbanks, Alaska), tropical (Palm Coast, Florida), subtropical, dry (Phoenix, Arizona), western temperate (Welches, Oregon), subtropical (Atlanta, Georgia), and eastern temperate (Nebraska City, Nebraska) regions of the United States. The design of the fuelbed was required to account for all categories of biomass that had the potential to consume and affect fire behaviour and effects. To do this, an FCCS fuelbed is classified into six horizontal fuelbed strata that represent unique combustion environments: canopy, shrubs, nonwoody fuels, woody fuels, litter–lichen–moss, and ground fuels (Table 1 and Fig. 1). Strata are further divided into 18 fuelbed categories and 20 fuelbed subcategories. Any one or combination of these levels may or may not be present in a fuelbed (i.e., the canopy stratum may not be present in a grassland fuelbed). Similarly, variables differ among strata and categories because of differences in vegetation form. Reported values include the mode, minimum, and maximum values. The mode is the most frequently occurring value, while the minimum and maximum are the recommended limits based on the data from which the fuelbed is built. Statistical resolution of the data was necessary because it was decided that minimum, maximum, and modal fuels data were more accessible by estimation than arithmetic mean and standard errors. Each fuelbed is given a ranking (1–5) based on how much of the data came from experience (expert opinion), published literature, or other databases: 1, based on expert opinion only; 2, based on expert opinion with <35% modal data used; 3, based on expert opinion with 35%–85% modal data; 4, based on >85% modal data, with expert opinion; and 5, indicates >85% of the data for modal, minimum, and maximum values are based on literature, photo series, or other data sources. This ranking is displayed when an FCCS fuelbed is selected and viewed.

Several variables or analogous equivalents are present among strata. Percent cover, defined as surface area by crown projection of area covered, is used to express the relative importance of a fuelbed category within a fuelbed. Height (m) is the distance from the base to the top of a fuelbed category, whereas depth (cm) is the distance from the top downward. Live foliar moisture (%) is the water content of a live fuel expressed as a percentage of its oven-dry weight. Default values represent low-end moisture conditions. Density (stems·ha^{-1}) is the number per unit area. Diameter (cm) and diameter at breast height (DBH; cm) represent a modal value for the stratum, category, or subcategory rather than individual elements (i.e., tree). Where appropriate, species designations are required and must be associated with a relative cover (%), the relative amount of a fixed area covered by a species or fuelbed category. Variables specific to strata, categories, or subcategories are discussed within the context of their respective arrangement. To facilitate discussion we begin with the canopy and finish with ground fuels.

© 2007 NRC Canada

Table 1. Fuel Characteristic Classification System (FCCS) fuelbed variables and affected fire potentials.

Stratum	Category	Subcategory	Variables	Affected fire potentials
Canopy	Trees	Total canopy cover	Percent cover (%)	C
		Overstory, midstory, and understory	Percent cover (%)	C, A
			Height (m)	C, A
			Height to live crown (m)	C, A
			Live foliar moisture content (%)	C
			Density (no.· ha^{-1})	
			Diameter at breast height (DBH; cm)	
			Species and relative cover (%)	C, A
	Snags	Class 1 (foliage present), class 1 (foliage absent), class 2 (branches and bark present), and class 3 (rotten; no branches and bark)	Stem density (number ha^{-1})	C, A
			Diameter (cm)	A
			Height (m)	C, A
			Species and relative cover (%)	C, A
	Ladder fuels		Type	C, A
			Minimum height (m)	C
			Maximum height (m)	C
			Vertical continuity between the canopy and lower strata (yes/no)	C
Shrub	Primary layer and secondary layer		Percent cover (%)	S, A
			Height (m)	A
			Percent live (%)	S
			Live foliar moisture content (%)	S
			Species and relative cover (%)	S, A
			Needle drape on shrubs sufficient to affect fire behaviour (yes/no)	S
Nonwoody fuels	Primary layer and secondary layer		Percent cover (%)	S, A
			Height (m)	A
			Percentage live (%)	S
			Live foliar moisture content (%)	S
			Loading (Mg ha^{-1})	S, A
			Species and relative cover (%)	S, A
Woody fuels	All woody		Total percent cover of all downed and dead woody fuel (%)	S, A
			Depth (m)	S
	Sound wood	Loadings 0–7.5 cm diameter	Loading by size-class (Mg ha^{-1})[a]	S, A
		Loadings >7.5 cm diameter	Loading by size-class (Mg ·ha^{-1})[a]	S, A
			Species and relative cover (%)	S, A
	Rotten wood	Loadings >7.5 cm	Loading by size-class (Mg·ha^{-1})	S, A
			Species and relative cover (%)	S, A
	Stumps	Sound	Density (no.·ha^{-1})	A
		Rotten	Diameter (cm)	A
		Lightered–pitchy	Height (m)	A
			Species and relative cover (%)	A
	Woody fuel accumulations	Piles	Width (m)	A
		Jackpots	Length (m)	A
		Windrows	Height (m)	A
			Density (no.·ha^{-1})	A
Litter–lichen–moss	Litter		Arrangement (fluffy, perched, or freshly fallen)	S, A
			Type[b]	S, A
			For overall litter	
			Depth (cm)	S, A
			Percent cover (%)	S, A
			For each litter type	
			Relative cover (%)	S, A
	Lichen		Depth (cm)	S, A
			Percent cover (%)	S, A
	Moss		Type (spaghnum or other moss)	S, A
			Depth (cm)	A
			Percent cover (%)	S, A
	Duff	Percent rotten wood	Percent rotten (%)	
Ground fuels		Upper duff layer	Type[c]	A
		Lower duff layer	Depth (cm)	A
			Percent cover (%)	A

© 2007 NRC Canada

Table 1 (*concluded*).

Stratum	Category	Subcategory	Variables	Affected fire potentials
			Percent rotten wood total duff (%)	S, A
	Squirrel middens		Depth (cm)	A
			Radius (m)	A
			Density (no.·ha^{-1})	A
	Basal accumulations		Type[d]	A
			Depth (cm)	A
			Radius (m)	A
			Percent affected (%)	

Note: S, surface fire behaviour potential; C, crown fire behaviour potential; and A, available fuel potential.
[a]Sound wood size-classes: 0–0.6 cm, 0.7–2.5 cm, 2.6–7.5–cm, 7.6–22.9 cm, 23.0–50.8 cm, and >50.8 cm. Rotten wood size-classes: 7.6–22.9 cm, 23.0–50.8 cm, and >50.8 cm.
[b]Short needle pine, long needle pine, other conifer, deciduous hardwood, evergreen hardwood, palm frond, and grass.
[c]Upper duff types: dead litter and moss. Lower duff types: humus or muck and humic peat.
[d]Bark slough, branches, broadleaf deciduous, broadleaf evergreen, grass, needle litter, and palm fronds.

Canopy

The canopy stratum is the somewhat continuous coverage of branches and foliage formed collectively by crowns of adjacent trees and includes three categories: (1) trees, (2) snags, and (3) ladder fuels (Table 1 and Figs. 1 and 2). The tree category includes total canopy cover, overstory, midstory, and understory trees (Oliver and Larson 1996). Total canopy cover is the crown projection percent cover of all trees. The overstory includes the emergent, dominant and codominant trees. The understory includes seedlings, saplings, and other small trees. The midstory, if present, includes those trees below the overstory and above the understory. All trees are considered live and are generally taller than 1.37 m (exceptions are seedlings in the understory). Percent cover, height, and DBH represent values for the over-, mid-, and under-stories rather than individual trees. Height to live crown (m) is from the ground to the bottom of the live canopy. Live foliar moisture content mode, minimum, and maximum are 100%, 70%, and 300%, respectively. Density is the number of trees per unit area. Species and relative cover are included if the subcategory is present (Table 1).

Snags are standing dead trees taller than 1.37 m and include four subcategories: (1) class 1 with foliage, (2) class 1 without foliage, (3) class 2, and (4) class 3 (Maser et al. 1979). Class 1 snags have bark, branches, and tops intact, and are further distinguished by the presence or absence of foliage. Class 2 snags have shed fine branches, but retain coarse branches, and class 3 snags have extensive heartwood decay and no longer have bark or branches. Density, diameter, and height represent values for the subcategory. Species and relative cover are included if the subcategory is present (Table 1).

Ladder fuels provide vertical continuity between the surface and crown fuels. Minimum and maximum height from the ground is included for one of eight ladder fuel types (Table 1). Affirmation of pronounced vertical continuity between the surface and crown fuels provided by the ladder fuel is a choice within the system.

Shrubs and nonwoody fuels

Shrubs and nonwoody fuels may have two categories: (1) primary and (2) secondary. Shrubs are woody perennial plants that differ from trees owing to their low stature and multiple basal stems. The nonwoody fuels stratum includes herbaceous vegetation (i.e., forbs, grasses, rushes, and sedges). Percent cover and height represent values for this category. Percent live is the biomass that is alive in the category, not the percentage of individuals that are alive. Species and relative cover are included if the category is present (Table 1).

A few differences between the strata should be noted. The modes, minimums, and maximums of live foliar moisture content for shrubs and nonwoody fuels are 120%, 70%, and 300% and 75%, 70%, and 300%, respectively. Division of species into primary and secondary categories is optional. Distinction may occur because of pronounced differences in height, life form, species composition, or other defining attribute. Results from the tropical and subtropical regional workshops identified accumulated fallen needles on shrubs as an important fuel consideration. Therefore, needle drape is part of the shrub stratum and, if needle drape is sufficient to contribute to fire behaviour, it is indicated by a check mark in the shrub stratum. Loading is the mass per unit area (Mg·ha^{-1}), is in only the nonwoody stratum, and includes the biomass of the nonwoody fuels. Suggestions from all the workshops indicated few users would have shrub loading values, consequently, the value is calculated by using allometric equations and displayed in the reports (Riccardi et al. 2007).

Woody fuels

The woody fuels stratum includes continuous and discontinuous, downed and dead woody fuel. It is divided into five categories: (1) all downed and dead woody, (2) sound wood, (3) rotten wood, (4) stumps, and (5) woody fuel accumulations. Sound and rotten wood are considered continuous fuels whereas stumps and woody fuel accumulations are discontinuous fuels.

The all woody category describes the depth and percent cover of continuous downed and dead sound and rotten fuels (Table 1). Stumps and woody fuel accumulations are not included in this category. It is important to note that depth represents the value of continuous sound and rotten downed fuels across the entire fuelbed unit and not just at small-scale locations where the fuel is present. Percent cover is linear coverage because the measurement of intercept length (intercept distance) is used to estimate cover.

© 2007 NRC Canada