CHARACTERIZING FUELS IN TREATED AREAS

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ABSTRACT

Small-log utilization or thinning operations followed by a fuel treatment such as prescribed fire can be used to change the composition and structure of fuelbeds, thereby mitigating deleterious fire effects and reducing the potential for catastrophic wildfires in some forested landscapes. We are developing a national system, Fuel Characteristic Classification (FCC), for fuel identification and assessment that accurately depicts the structural complexity and geographical diversity of all fuelbeds including those manipulated by humans. The FCC system can be used to easily assess the effectiveness of fuel manipulation activities. The system is designed to accommodate researchers and managers who operate at a variety of spatial scales. Users can generate a set of fuel characteristics by accessing existing fuelbed descriptions (fuelbed prototypes) that use generic information such as cover type and vegetation form. The system will incorporate a change-agent feature that enables the user to acquire fuelbed characteristics associated with natural and human disturbance such as wildfire, wind, small-log utilization, thinning, and prescribed fire. Fuelbed prototypes will provide the best available data characterizing the kind, quality, and abundance of fuels. Users can accept these default values or modify some or all of them by using more specific information about vegetation and fuel structure and composition. When the user has finished customizing the fuelbed data, the FCC system will calculate or infer quantitative fuel characteristics (i.e., physical, chemical, and structural properties). In addition, the FCC system will compute fuelbed-specific probable fire parameters, and assign a fuel model to run fire behavior software.

A large data library will feed the FCC system and will be populated with values acquired from the literature, photo series, fuel inventory reports, and expert knowledge. The Creating Opportunities program (Fritz Demonstration units) and the Fire and Fire Surrogate study (Hungry Bob units) in northeastern Washington and northeastern Oregon, respectively, are two projects that provided critical change-agent fuel information for the data library. These two studies provide data for mixed-conifer and ponderosa pine units that had been harvested for small-log utilization (Fritz), thinned, burned under prescription, or thinned and burned under prescription (Hungry Bob). Mechanical treatment (i.e., small-log utilization or thinning) caused a significant increase in small woody fuels. Application of prescribed fire after thinning reduced small woody fuel amounts to about preharvest levels.

Keywords: fuel characteristics, fuel loading, fire management, fire modeling, prescribed fire, small-log utilization, thinning

INTRODUCTION

Spatially explicit data describing fuel characteristics are required to operate fuel and fire management decision-support systems and vegetation dynamics models to assess the effects of silvicultural treatments such as small-log harvesting, thinning, prescribed fire, and mechanical treatment. Characterizing wildland fuelbeds has always been important to fire and fuel managers, and is becoming increasingly important to ecologists, air quality managers, and carbon balance modelers. Fuelbeds represent the potential energy that is manifested in fire behavior and fire effects, and must be characterized and mapped before any evaluation of fire potential can be made. Fuel mapping, hazard assessment, evaluation of fuel treatment options, and fire effects monitoring all require a consistent and scientifically applied fuel characterization system.

Although there are methods to measure fuelbeds (e.g., Brown 1974; Ottmar and Vihnanek 1998), it is often prohibitively difficult to inventory all of the fuelbed characteristics across large landscapes necessary to predict treatment outcomes or to make management decisions. Fuelbeds are complex in structure, vary widely in their physical attributes, and vary in their potential fire behavior and fire effects as well as in the options they present for fire control and use. The extreme variation in fuelbed characteristics is the expression of ecological processes working over time, of natural disturbance events, and of human manipulation. The need exists for an orderly method of classifying fuels and inferring fuelbed characteristics from limited observations that serves a variety of users, and that simplifies the complexity to a reasonable degree but does not oversimplify the description of wildland fuelbeds.

This paper will begin with a discussion of the Fuel Characteristic Classification system (FCC) that is being designed around a large fuels data library to provide fire and fuel managers and scientists with a nationally consistent and long-lasting ability to classify fuelbeds, provide numerical inputs into fire effects and dynamic vegetation models, and assign a customized fuel model for running fire behavior models (Sandberg and others 2001; National Interagency Fire Center 2002). We conclude with a discussion of fuel loading changes associated with small-log utilization (Quigley 1997), thinning, and prescribed fire studies (Fire and Fire Surrogate Study 2002) that will provide a partial data set for the FCC library.

FUELBED CLASSIFICATION

When designing the FCC system, nationwide applicability, usefulness at different spatial scales, and flexibility for a wide range of potential users with varying data supplies and needs were identified as important design criteria. The general design (Fig. 1) of the FCC system allows users to access a large data library with existing fuelbed

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descriptions (fuelbed prototypes) or to modify the existing descriptions and create custom fuelbeds.

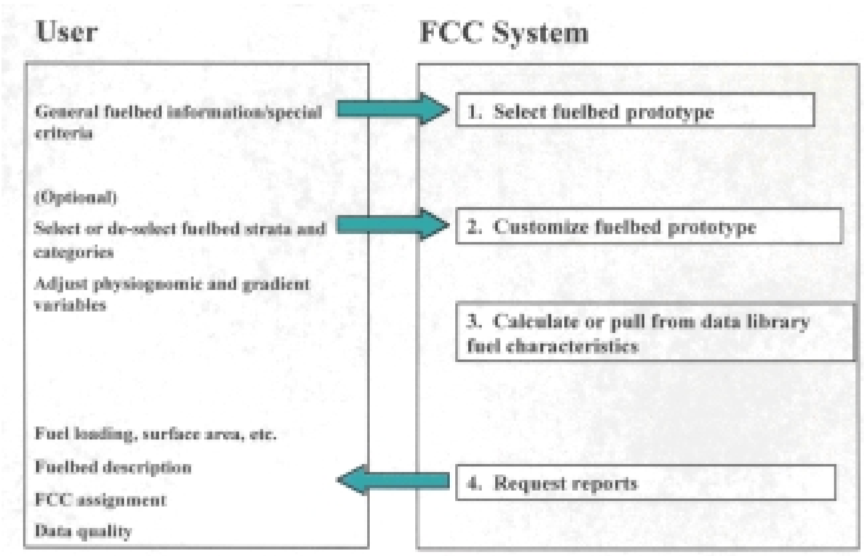


Figure 1.—User provides general fuelbed information and identifies a fuelbed prototype. The prototype identifies the kinds of fuel present (fuelbed strata and fuelbed categories) and their qualitative (physiognomy) and quantitative (gradient variable) features. The user can then adjust the prototpye information. The system assigns the fuelbed to a potential Fuel Characeristic Class (FCC).

The user can select a fuelbed prototype with as little information as the ecoregion (Bailey 1997), vegetation physiognomy (7 types), and change agent (e.g., fire, thinning, wind, etc.). The user can also choose to be more precise and select a fuelbed prototype by selecting the fuelbed strata, fuelbed categories, and answering specific questions. The selected prototype provides the best available data to characterize fuel type (fuelbed strata and categories), quality (physiognomy), and relative abundance (gradient variables). The user can accept default values or, using site-specific knowledge, modify some or all of the fuelbed properties. When the user has completed editing the qualitative and quantitative fuelbed data, the FCC system calculates quantitative fuel characteristics (physical, chemical, and structural properties) and probable fire effects and fire behavior parameters specific to the fuelbed in question. Each user-described fuelbed is also assigned to a fire behavior or fire danger fuel model (Andrews and Bevins 1999; Anderson 1982; Deeming et al. 1977).

GENERAL FUELBED MODEL

Fuelbeds are structurally complex and diverse in the biological origin of their components, hence their physical attributes. A comprehensive system of fuel characterization requires a model that captures this complexity and diversity. The model presented here divides fuelbeds into 6 horizontal fuelbed stata representing unique combustion environments (Fig. 2). Fuelbed strata can be spatially attributed. It provides the flexibility of allowing the user to include, combine, or exclude as much detail as needed to suit an application. Each fuelbed stratum is broken into one or more fuelbed categories with specific combustion characteristics (Table 1, Fig. 2). The low vegetation stratum, for example, includes a grass/sedge category and a forb category. There are sixteen fuelbed categories in total.

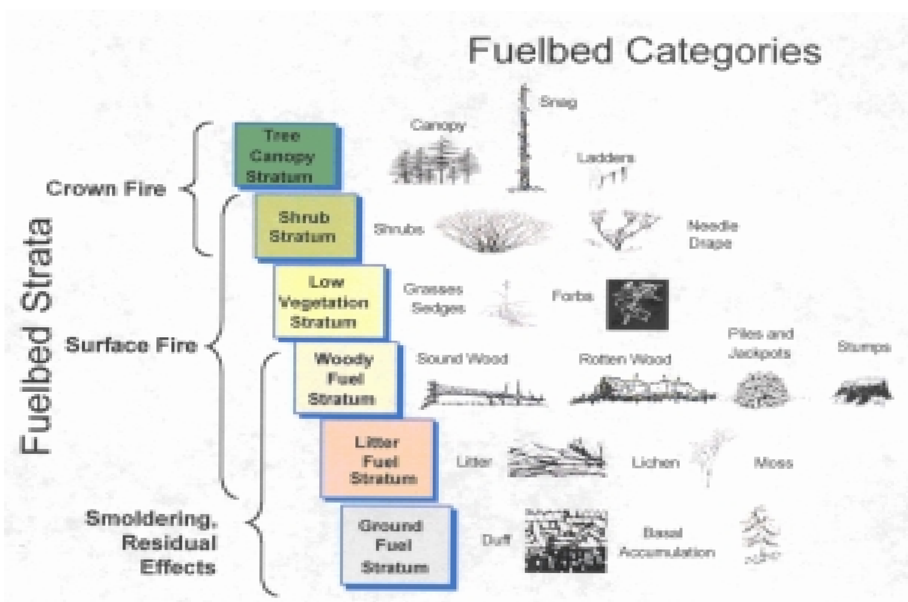


Figure 2.—Fuelbed strata and fuelbed categories including combustion environments.

Table 1.—Fuelbed strata and categories, and their physiognomic and gradient variables.

Fuelbed Strata	Fuelbed Categories	Physiognomic Variables	Gradient Variables
Canopy	Tree	Canopy Structure Crown Type	Canopy Height Height to Live Crown Percentage Cover
	Snag	Snag Class	Diameter Height Snags per Acre
	Ladder Fuels	Vegetation Type	Significance
Shrub	Shrub	Foliage Type Growth Habit Accelerant Potential	Percentage Cover Height Percentage Live Vegetation
	Needle Drape		Significance
Low Vegetation	Grass/Sedge	Leaf Blade Thickness Growth Habit	Percentage Cover Height Percentage Live Vegetation
	Forb		Percentage Cover Height
Woody Fuel	Sound Wood	Size Class	Loading (tons per acre) Fuelbed Depth
	Rotten Wood	Size Class	Loading (tons per acre)
	Stumps	Decay Class	Stems per Acre Diameter
	Woody Accumulations	Piles, Windrows or Jackpots Clean or Dirty	Height Width Length Number per Acre
Litter Fuel	Moss	Moss Type	Percentage Cover Depth
	Lichen		Percentage Cover Depth
	Litter	Litter Type Litter Arrangement	Percentage Cover Depth
Ground Fuel	Duff	Character	Depth Percentage Rotten Wood
	Basal Accumulation	Accumulation Type: e.g. litter, bark slough	Depth Trees per Acre Affected

Each fuelbed category is described by physiognomic and gradient variables. Physiognomic variables capture qualitative features of the category, including morphological, chemical, and physical features. The grass and sedge category includes physiognomic variables for leaf blade thickness (which is used to infer surface area to volume ratio) and growth habit (which is used to infer the distribution of fuel). Where physiognomic criteria are based on vegetation features, the system includes species lists that provide physiognomic information based on vegetation features. The user is asked to provide either a species name or the physiognomic information.

Gradient variables characterize the relative abundance of fuel. The grass and sedge category includes the gradient variables percentage cover, height, and percentage live (of total biomass). With these estimates of fuel character (physiognomic variables) and abundance (gradient variables), the system calculates total fuel loading, fuel surface area, and other parameters required as inputs by fire models.

Fuelbed Prototypes

The FCC system provides a set of prepared fuelbed descriptions or prototypes designed to cover most major fuelbed types throughout the United States and represent a generalized classification of vegetation type (both vegetation form and cover type) and of fire potential (both effects and behavior). Fuelbed prototypes provide default information about the fuelbed categories present and their physiognomic and gradient variables based on the best available published and unpublished data. Default information can be modified by selecting or deselecting categories, and by adjusting the physiognomic and gradient variables when more site-specific data are available.

The FCC system will allow authorized users to add new fuelbed prototypes to the system database, so that the system can make more refined distinctions as new data become available. General fuelbed information including ecoregion division, vegetation form, change agent, cover type, and structure class, will be used to organize the fuelbed prototypes.

Fuelbed prototypes will be organized by ecoregion division (Bailey 1997) to improve prototype selection when only very general information such as vegetation form is available. Vegetation form describes the gross physiognomic structure of a landscape unit. Options include conifer forest, hardwood forest, mixed forest, shrubland, grassland, and savanna. For example, the system will provide the user with a choice of all the conifer forest prototypes available for a certain ecoregion division. Vegetation form can also be used with remote sensing data where only very general information about vegetation is available. Change agents are elements such as fire suppression, insect and disease-caused mortality, wind, timber harvesting, thinning, and small-log utilization that significantly alter fuelbeds. Fuelbed prototypes reflect a range of conditions resulting from these agents. The FCC system uses a synthetic classification of cover type based on leading vegetation and fire potential classifications and, whenever possible, crosswalks to existing cover type classifications (e.g., Eyre 1980; Shiflet 1994). Structure class applies mainly to forests and captures the number of canopy layers, relative tree size, developmental stage of the understory, and the relative degree of stand closure. Descriptions of vegetation structure class are used to fine-tune which fuelbed categories are present and to partition fuels in canopy layers.

Output: Fuel Characteristics

The FCC system has the ability to provide users with continuous fuel characteristics, based on user input, and fuelbed prototypes. Several output formats will be available and will include (1) user-provided name and description, (2) input information provided by the user, (3) values inferred by the FCC system, (4) fuel characteristics generated by the system (e.g., fuel loading, fuel surface area, etc.), (5) FCC assignment (see Fig. 3 and text below), (6) National Fire Danger Rating System (NFDRS) and Northern Forest Fire Laboratory (NFFL) fuel model assignments (Andrews and Bevins 1999; Anderson 1982; Deeming et al. 1977), and (7) a reliability or data quality index.

Fuel characteristics are calculated or inferred by using the best available published and, where necessary, unpublished information. This information includes species-specific allometric equations, photo series and other published fuels data, and relations between physiognomic features and physical parameters, such as surface area to volume ratio, bulk density, and flammability. This information is stored in an FCC data library with a rule base that links information to the appropriate fuelbed.

Fuel Characteristic Class

To provide users with a consistent means of classifying fuelbeds for comparison and communication, the FCC system includes a set of potential fuel characteristic classes based on three key attributes (Fig. 3): indices of potential spread rate or reaction intensity, crowning potential, and fire effects based on biomass consumption and residence time. The FCC number assigned to each fuelbed indicates the level of each index. For example, FCC# 743 will have a spread rate index of 7, a crowning potential index of 4 and a fire effects index of 3.

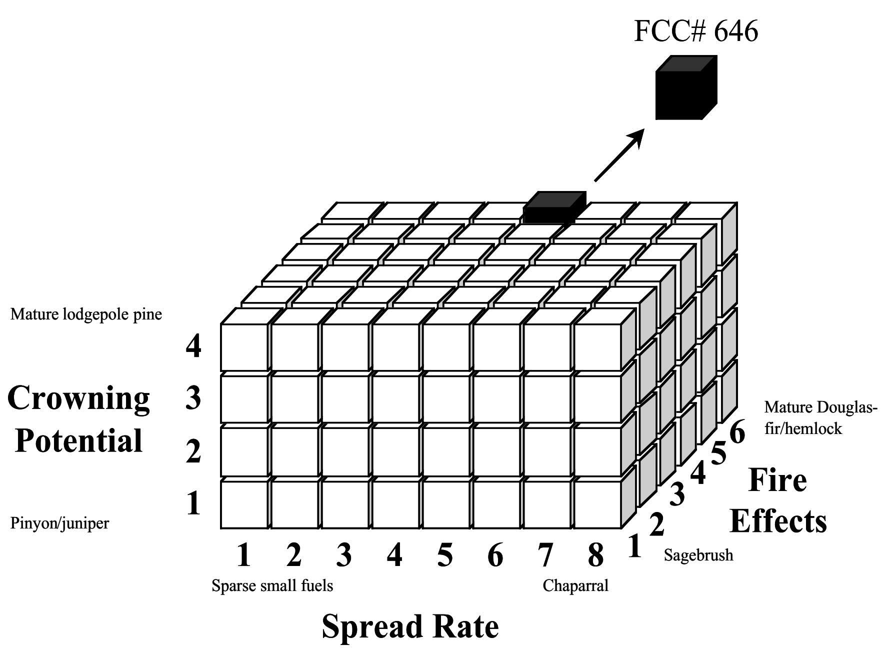


Figure 3.—The potential fuel characteristic classes grouped by three critical attributes of spread rate, crowning potential, and fire effects to provide a consistent means of classifying fuelbed output for comparison and communication.

IMPLEMENTATION

A series of regional workshops were held around the United States designed to ensure national applicability of the system. Based on the workshop feedback, a system was designed. Database and user-interface engineering, and collation of data to populate the FCC data library, is ongoing. A user-friendly interface will allow practitioners to (1) select fuelbed prototypes based on general fuelbed information and accept default fuel characteristics, (2) select fuelbed prototypes and modify default settings based on site-specific knowledge, (3) create custom fuelbeds (and custom fuelbed databases), (4) search existing fuelbed prototypes by specified criteria (e.g., spread rate index), or (5) work in batch mode where the FCC system will read a file containing geographic information system or inventory data and generate fuel characteristics for each data record.

Efforts are also underway to ensure that the FCC system will link with existing fire and landscape assessment models. Linkages with the Fire and Fuels Extension to the Forest Vegetation Simulator (FFE-FVS)(Crookston 2000; Wykoff and others 1982), CONSUME (model that predicts fuel consumption and emissions)(Ottmar and others [in press]), the Fire Effects Tradeoff Model (a model to evaluate the tradeoffs between wildfires and prescribed fires)(Schaaf 1996), and FASTRACS (a database model designed to compile fuels information)(FASTRACS 2000) are currently in progress. Additional linkages to other fire models such as Behave (Andrews and Bevins 1999), Farsite (Finney 1999), and FOFEM (Reinhardt and Keane 2000; Reinhardt et al. 1997) are anticipated.

A prototype of the FCC system will be tested beginning in the middle of 2002, and the system will be fully operational by late 2003 (Fig. 4). The FCC system is designed to evolve. Data quality will be indexed and protocols will be in place to append new information and replace imprecise information. The objective is to provide detailed fuels data to a large number of potential users over a broad geographic area. The FCC system has been designed so it may eventually have international applicability. The FCC system will be web based and will adapt and respond to the needs and input of users.

FRITZ AND HUNGRY BOB STUDIES FOR POPULATING THE FCC DATA LIBRARY

The Creating Opportunities (CROP) and the Fire and Fire Surrogate (FFS) projects are large, multidisciplinary studies examining the effects of treatments (small-log harvesting for CROP, and thinning and prescribed fire for FFS) on whole forest conditions (Quigley 1997; Fire and Fire Surrogate Study 2002). One element of these studies was to quantify the amount and character of woody and forest floor fuels before and after treatments. These data will be used to populate the data library of the Fuel Characteristic Class system to represent the change agents of small-log utilization, thinning, and prescribed fire.

The Fritz demonstration area is located on the Colville National Forest in northeastern Washington and is part of the CROP project (Quigley 1997). Eight units were selected within the demonstration area, four on flat ground and four on steep ground (greater than 40% slope). Initial stand

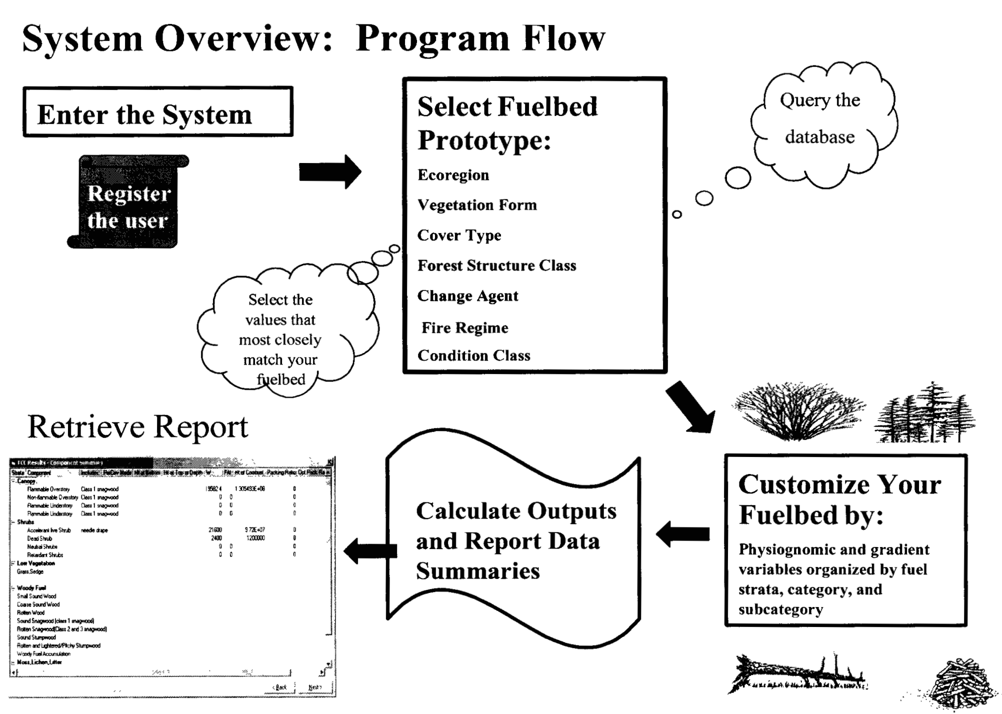


Figure 4.—Fuel characteristic classification system program flow.

conditions were a dense mixture of second-growth lodgepole pine, grand fir, and Douglas-fir. Trees less than 4 inches in diameter were removed during the project.

The Hungry Bob study is located on the Wallowa-Whitman National Forest in northeastern Oregon and is part of the FFS study (Weatherspoon 2002). Initial stand conditions were primarily second-growth ponderosa pine with some Douglas-fir. Slopes typically did not exceed 30%. Commercial thinning, prescribed fire, and commercial thinning followed by prescribed fire were the treatments. We will only consider the treatments that included thinning in this paper.

Permanent plots were established on a systematic grid in each unit (Fig. 5). Unit size dictated the actual number of plots established per unit (Fritz 10-18, Hungry Bob 18-35). Transects were permanently established (endpoints were marked) radiating out from each plot center. The transects were used to estimate woody fuel amount and composition (Brown 1974). Forest floor depth (litter and duff) was measured at three locations along each transect.

Fritz Demonstration Area (Small-Log Utilization)

Large increases in woody material loading after the small-log utilization treatment were noted for all size classes less than 9 inches in diameter for all units (Fig. 6a, Appendix A). Loading of woody material greater than 9 inches in diameter decreased slightly for all units. This general decrease in the large-log category appears to be a result of the harvesting operation. Logs that were counted as woody material prior to treatment were crushed by machinery and not recognizable as woody material after the treatment. Ground disturbance from mechanical operations limited our ability to detect changes in the forest floor depth owing to treatment, although we did observe a 3–16% increase in mineral soil exposure.

Hungry Bob Study Area (Thinning and Prescribed Fire)

As with the Fritz units, large increases in woody material loading after the thinning operations were observed for all size classes less than 3 inches in diameter for all sites (Fig. 6b, Appendix B). Loading of woody material 3–9 inches and >9 inches in diameter changed little after thinning. The units that were burned after thinning showed a substantial reduction in loading of woody material in all size classes. Overall woody material loading was reduced below even initial conditions for three of the four units that were burned. The number of large rotten logs were reduced in three of four units after thinning in both treatment blocks, and virtually eliminated by burning in thin and burn treatment block.

Treatment Effects

Large increases in the less-than-3-inch diameter size class woody fuels after mechanical treatment indicates that initially there may be a large increase in potential rate of spread, flame height, and fireline intensity if a surface fire occurs within any of the units. If thinning or small-log utilization operations are followed by prescribed fire, the elevated risk is mitigated. However, the application of prescribed fire is not appropriate in all ecosystems (i.e., appropriate in ponderosa pine ecosystem at Hungry Bob, but maybe not in mixed-conifer ecosystem at Fritz). Although we did not specifically analyze crown fire potential (Scott 1999) we believe there will be a reduction because of decreased tree density and the resulting decrease in crown bulk density. However, this decrease may be partially offset by the potential for more intense fire behavior as a result of large increases in small-diameter downed woody material after small-log utilization or thinning.

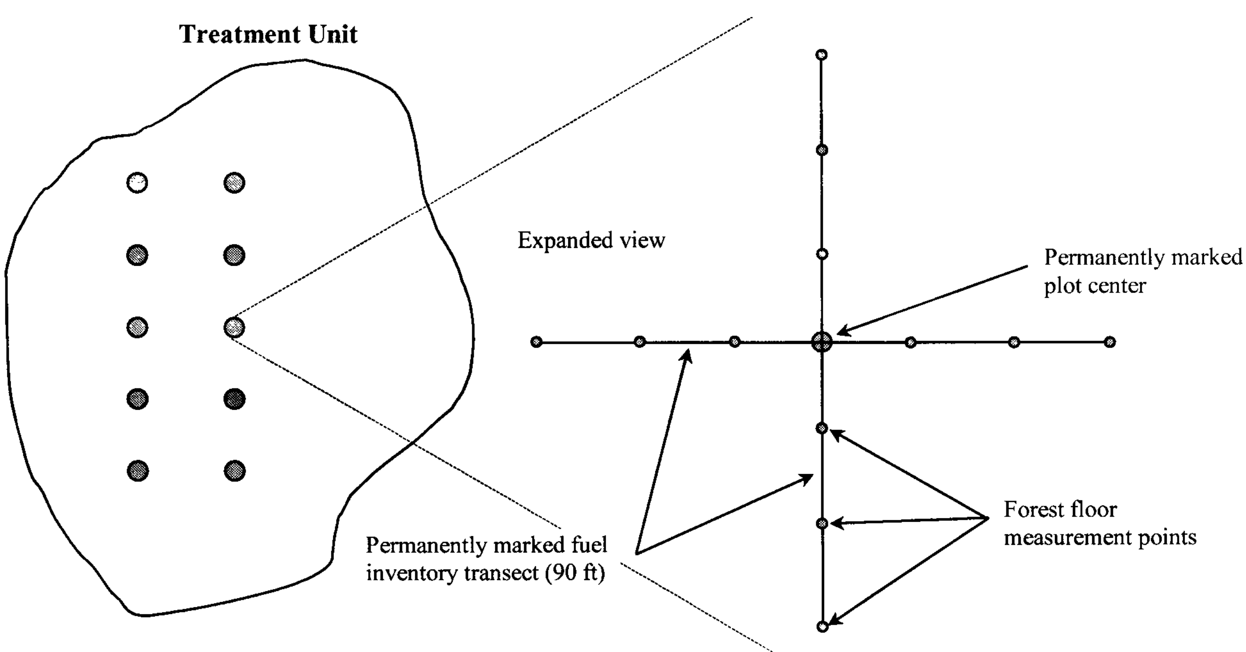
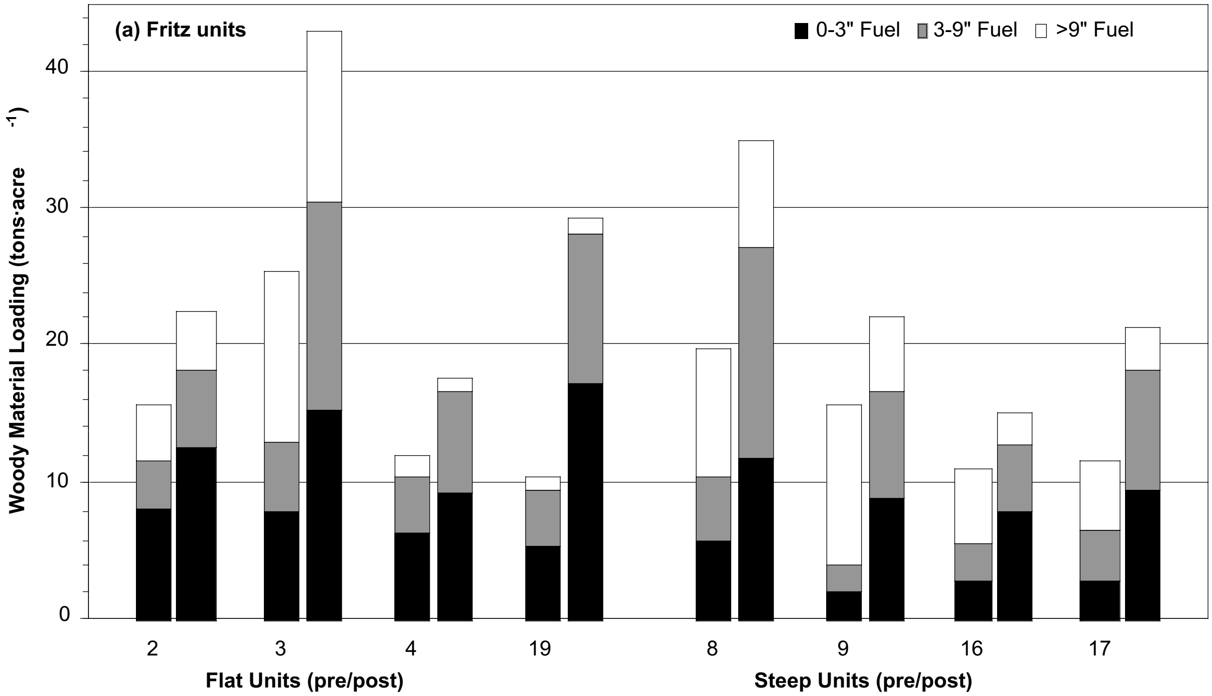


Figure 5.—Plot layout.



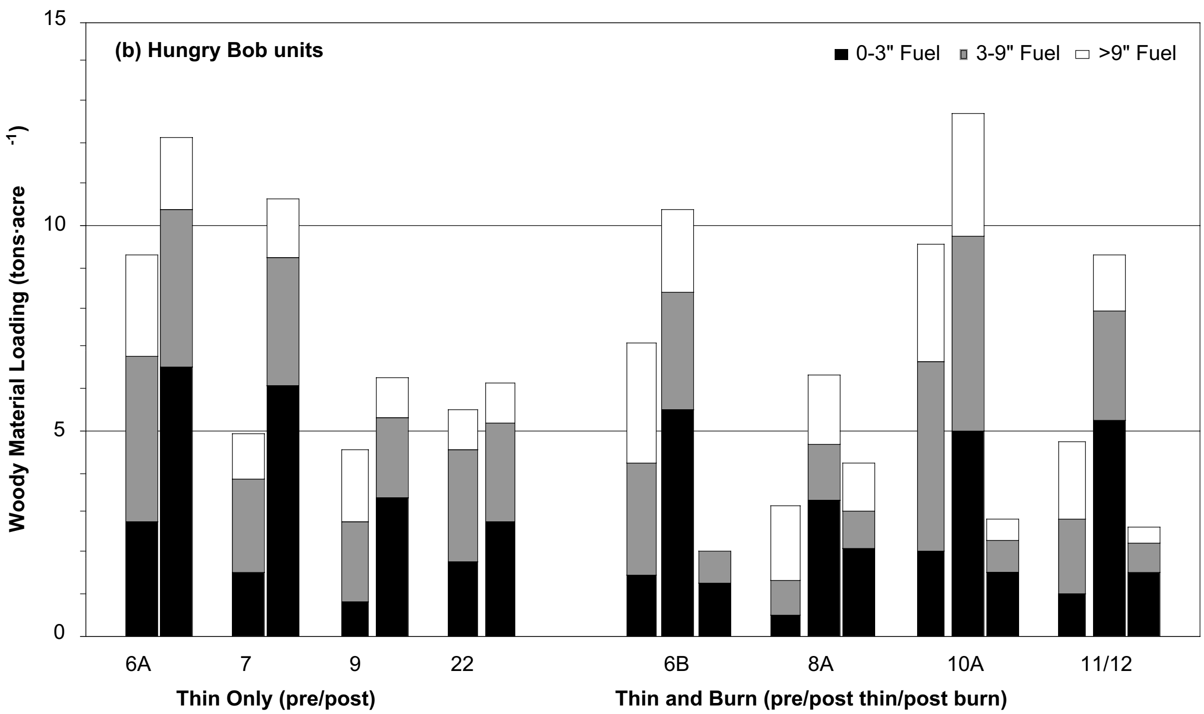


Figure 6.—Woody fuel summary data for (a) Fritz units and (b) Hunry Bob units.

LITERATURE CITED

Anderson, H.E. 1982. Aids to determining fuel models for estimating fire behavior. Gen. Tech. Rep. INT-122. USDA-Forest Service, Intermountain Forest and Range Experiment Station, Ogden, UT. 22 p.

Andrews, P.L. and C.D. Bevins. 1999. BEHAVE fire modeling system: redesign and expansion. Fire Management Notes 59(2): 16.

Bailey, R.G. 1997. Ecoregions map of North America. Misc. Publication 1548. USDA-Forest Service, Washington, DC.

Brown, J.K. 1974. Handbook for inventorying downed woody material. Gen. Tech. Rep. INT-16. USDA-Forest Service, Intermountain Forest and Range Experiment Station, Ogden, UT. 24 p.

Crookston, N.L. 2000. Adaptation of the fuels and fire extension to the forest vegetation simulator to meet the objectives of the JFSP. Abstract. National Interagency Fire Center, Joint Fire Science Program, Boise, ID.[http://www.nifc.gov/joint_fire_sci/jointfiresci.html]

Deeming, J.E., R.E. Burgan, and J.D. Cohen. 1977. The National Fire Danger Rating System-1978. Gen. Tech. Rep. INT-39. USDA-Forest Service, Intermountain Forest and Range Experiment Station, Ogden, UT. 63 p.

Eyre F.H. (ed.). 1980. Forest cover types of the United States and Canada. Society of American Foresters, Washington D.C. 148 p.

FASTRACS. 2002. Fuel analysis, smoke tracking, and report access computer system. [http://www.fs.fed.us/6/fire/fastracs]

Finney, M.A. and P.L. Andrews. 1999. FARSITE—a program for fire growth simulation. Fire Management Notes 59(2):13.

National Interagency Fire Center. 2002. Joint Fire Science Program. National Interagency Fire Center, Joint Fire Science Program, Boise, ID. [http://www.nifc.gov/joint_fire_sci/jointfiresci.html]

Ottmar, R.D. and R.E. Vihnanek. 1998. Stereo photo series for quantifying natural fuels. Volume I: mixed-conifer with mortality, western juniper, sagebrush, and grassland types in the interior Pacific Northwest. PMS 830. National Interagency Fire Center, National Wildfire Coordinating Group, Boise, ID. 73 p.

Ottmar, R.D., G.K. Anderson, P.J. DeHerrera, and T.E. Reinhardt [in press]. Consumer user's guide, Version 2.1.

Quigley, T. 1997. Research planning for evaluating silvicultural treatments in fire-created, overstocked, small-diameter forest stands. Study plan on file with the USDA-Forest Service, Pacific Northwest Research Station, Forestry Sciences Laboratory, Portland, OR. 12 p.

Reinhardt, E. D., R.E. Keane, J.K. Brown. 1997. First order fire effects model: FOFEM 4.0, users guide. Gen. Tech. Rep. INT-GTR-344. USDA-Forest Service, Intermountain Research Station, Ogden, UT. 65 p.

Reinhardt, E.D. and R.E. Keane. 2000. A national fire effects prediction model-revision of FOFEM. Abstract. National Interagency Fire Center, Joint Fire Science Program, Principle Investigators Meeting. [http://www.nifc.gov/joint_fire_sci/jointfiresci.html]

Sandberg, D.V., R.D. Ottmar, and G.H. Cushon. 2001. Characterizing fuels in the 21st century. International Journal of Wildland Fire 10: 381-387.

Scott, J.H. 1999. NEXUS: a system for assessing crown fire hazard. Fire Management Notes 59(2): 20.

Schaaf, M. 1996. Development of the fire emissions tradeoff model (FETM) and application at the Grande Ronde River basin, Oregon. Contact No. 53-82FT-03-2. USDA-Forest Service, Pacific Northwest Region, Portland, OR.

Shiflet T.N. (ed.). 1994. Rangeland cover types of the United States. Society for Range Management, Denver, CO. 152 p.

Weatherspoon, C. P. 2002. A long-term national study of the consequences of fire and fire surrogate treatments. 11 p. [http://ffs.fs.fed.us/docs/boise-paper2.doc]

Wykoff, W. R., N.L. Crookston, and A.R. Stage. 1982. User's guide to the stand prognosis model. Gen Tech. Rep. INT-133. USDA-Forest Service, Intermountain Forest and Range Experiment Station, Ogden, UT. 112 p.

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APPENDIX A: FRITZ STUDY FUELS DATA SUMMARY

Table A.1. Woody material loading summary for Fritz study

Unit	≤ 1.0 inch diameter			1–3 inch diameter			3–9 inch diameter			> 9 inch diameter			> 0 inch diameter		
	Pre	Post	Δ	Pre	Post	Δ	Pre	Post	Δ	Pre	Post	Δ	Pre	Post	Δ
							Tons per acre								
Fritz #2 (flat)	2.81	3.86	1.05	5.54	8.88	3.34	3.27	5.51	2.24	4.02	0.00	-4.02	15.64	18.25	2.61
Fritz #3 (flat)	2.85	5.95	3.10	5.28	9.36	4.08	5.08	15.37	10.29	12.22	12.44	0.22	25.43	43.12	17.69
Fritz #4 (flat)	2.37	3.25	0.88	4.12	6.05	1.93	3.97	7.47	3.50	13.2	7.60	-5.60	23.66	24.37	0.71
Fritz #19 (flat)	1.33	7.01	5.68	4.31	10.16	5.85	4.00	11.05	7.05	5.29	3.26	-2.03	14.93	31.48	16.55
Fritz #8 (steep)	2.82	5.15	2.33	3.12	6.59	3.47	4.77	15.54	10.77	9.27	7.65	-1.62	19.98	34.93	14.95
Fritz #9 (steep)	1.20	4.11	2.91	1.02	5.04	4.02	2.06	7.58	5.52	11.31	5.42	-5.89	15.59	22.15	6.56
Fritz #16 (steep)	1.52	3.83	2.31	1.37	4.19	2.82	2.80	4.94	2.14	5.50	2.28	-3.22	11.19	15.24	4.05
Fritz #17 (steep)	1.74	4.45	2.71	1.32	5.21	3.89	3.61	8.53	4.92	5.05	2.96	-2.09	11.72	21.15	9.43

Table A.2. Large woody material loading by size and decay class for Fritz study

Unit	3–9 inch diameter						> 9 inch diameter					
	Sound Material			Rotten Material			Sound Material			Rotten Material		
	Pre	Post	Δ	Pre	Post	Δ	Pre	Post	Δ	Pre	Post	Δ
						Tons per acre						
Fritz #2 (flat)	1.43	3.87	2.44	1.84	1.63	-0.21	1.86	2.35	0.49	2.16	2.07	-0.09
Fritz #3 (flat)	2.79	13.81	11.02	2.29	1.56	-0.73	2.06	2.97	0.91	10.16	9.47	-0.69
Fritz #4 (flat)	1.46	4.99	3.53	2.51	2.48	-0.03	1.72	0.00	-1.72	11.47	7.60	-3.87
Fritz #19 (flat)	2.58	9.92	7.34	1.43	1.13	-0.30	1.70	0.60	-1.1	3.59	2.66	-0.93
Fritz #8 (steep)	2.33	14.54	12.21	2.44	1.00	-1.44	0.52	0.73	0.21	8.75	6.92	-1.83
Fritz #9 (steep)	0.69	6.50	5.81	1.36	1.08	-0.28	0.53	1.24	0.71	10.87	4.19	-6.68
Fritz #16 (steep)	1.09	3.58	2.49	1.71	1.36	-0.35	0.58	0.46	-0.12	4.92	1.82	-3.10
Fritz #17 (steep)	1.53	7.51	5.98	2.08	1.02	-1.06	0.71	1.00	0.29	4.34	1.96	-2.38

APPENDIX B: HUNGRY BOB STUDY FUELS DATA SUMMARY

Table B.1. Woody material loading summary for thinning portion of Hungry Bob study

Unit	≤ 1.0 inch diameter Pre-thin	≤ 1.0 inch diameter Post-thin	≤ 1.0 inch diameter Δ thin	1–3 inch diameter Pre-thin	1–3 inch diameter Post-thin	1–3 inch diameter Δ thin	3–9 inch diameter Pre-thin	3–9 inch diameter Post-thin	3–9 inch diameter Δ thin	> 9 inch diameter Pre-thin	> 9 inch diameter Post-thin	> 9 inch diameter Δ thin	> 0 inch diameter Pre-thin	> 0 inch diameter Post-thin	> 0 inch diameter Δ thin
							Tons per acre								
HB #6A (thin only)	0.97	3.12	2.15	1.86	3.43	1.57	3.94	3.87	-0.07	2.55	1.71	-0.84	9.32	12.13	2.81
HB #7 (thin only)	0.66	3.38	2.72	0.99	2.73	1.74	2.20	3.17	0.97	1.08	1.41	0.33	4.93	10.69	5.76
HB #9 (thin only)	0.27	1.59	1.32	0.57	1.84	1.27	1.98	1.91	-0.07	1.74	0.98	-0.76	4.56	6.32	1.76
HB #22 (thin only)	0.74	1.36	0.62	1.08	1.45	0.37	2.74	2.38	-0.36	0.97	1.05	0.08	5.53	6.24	0.71
HB #6B (thin/burn)	0.07	2.85	2.78	1.44	2.64	1.20	2.75	2.88	0.13	2.87	2.10	-0.77	7.13	10.47	3.34
HB #8A (thin/burn)	0.06	1.90	1.84	0.48	1.45	0.97	0.80	1.29	0.49	1.92	1.72	-0.20	3.26	6.36	3.10
HB #10A (thin/burn)	0.88	2.27	1.39	1.21	2.77	1.56	4.63	4.70	0.07	2.88	2.96	0.08	9.60	12.70	3.10
HB #11/12 (thin/burn)	0.24	2.49	2.25	0.78	2.75	1.97	1.85	2.70	0.85	1.92	1.37	-0.55	4.79	9.31	4.52

Table B.2. Large woody material loading by size and decay class for thinning portion of Hungry Bob study

Unit	3–9 inch diameter Sound Material Pre-thin	3–9 inch diameter Sound Material Post-thin	3–9 inch diameter Sound Material Δ thin	3–9 inch diameter Rotten Material Pre-thin	3–9 inch diameter Rotten Material Post-thin	3–9 inch diameter Rotten Material Δ thin	> 9 inch diameter Sound Material Pre-thin	> 9 inch diameter Sound Material Post-thin	> 9 inch diameter Sound Material Δ thin	> 9 inch diameter Rotten Material Pre-thin	> 9 inch diameter Rotten Material Post-thin	> 9 inch diameter Rotten Material Δ thin
						Tons per acre						
HB #6A (thin only)	2.02	2.63	0.61	1.92	1.24	-0.68	0.60	0.41	-0.19	1.95	1.30	-0.65
HB #7 (thin only)	1.25	2.46	1.21	0.96	0.96	0.00	0.37	1.22	0.85	0.71	0.19	-0.52
HB #9 (thin only)	0.17	1.26	1.09	1.81	0.65	-1.16	0.27	0.64	0.37	1.47	0.34	-1.13
HB #22 (thin only)	1.93	1.34	-0.59	0.82	1.04	0.22	0.75	0.47	-0.28	0.22	0.58	0.36
HB #6B (thin/burn)	1.01	1.80	0.79	1.75	1.09	-0.66	0.15	0.27	0.12	2.71	1.83	-0.88
HB #8A (thin/burn)	0.55	0.90	0.35	0.25	0.39	0.14	1.41	1.51	0.10	0.51	0.21	-0.30
HB #10A (thin/burn)	3.18	2.60	-0.58	1.45	2.10	0.65	0.74	0.29	-0.45	2.14	2.67	0.53
HB #11/12 (thin/burn)	1.14	2.00	0.86	0.71	0.70	-0.01	0.88	0.73	-0.15	1.04	0.64	-0.40

Table B.3. Woody material loading summary for burning portion of Hungry Bob study

Unit	≤ 1.0 inch diameter			1–3 inch diameter			3–9 inch diameter			> 9 inch diameter			> 0 inch diameter		
	Post-thin	Post-burn	Δ burn	Post-thin	Post-burn	Δ burn	Post-thin	Post-burn	Δ burn	Post-thin	Post-burn	Δ burn	Post-thin	Post-burn	Δ burn
	Tons per acre														
HB #6B (thin/burn)	2.85	0.70	-2.15	2.64	0.63	-2.01	2.88	0.73	-2.15	2.10	0.00	-2.10	10.47	2.06	-8.41
HB #8A (thin/burn)	1.90	1.28	-0.62	1.45	0.88	-0.57	1.29	0.92	-0.37	1.72	1.15	-0.57	6.36	4.23	-2.13
HB #10A (thin/burn)	2.27	0.86	-1.41	2.77	0.74	-2.03	4.70	0.77	-3.93	2.96	0.51	-2.45	12.70	2.88	-9.82
HB #11/12 (thin/burn)	2.49	0.87	-1.62	2.75	0.73	-2.02	2.70	0.70	-2.00	1.37	0.43	-0.94	9.31	2.73	-6.58

Table B.4. Large woody material loading by size and decay class for burning portion of Hungry Bob study

Unit	3–9 inch diameter						> 9 inch diameter					
	Sound Material			Rotten Material			Sound Material			Rotten Material		
	Post-thin	Post-burn	Δ burn	Post-thin	Post-burn	Δ burn	Post-thin	Post-burn	Δ burn	Post-thin	Post-burn	Δ burn
	Tons per acre											
HB #6B (thin/burn)	1.80	0.61	-1.19	1.09	0.12	-0.97	0.27	0.00	-0.27	1.83	0.00	-1.83
HB #8A (thin/burn)	0.90	0.76	-0.14	0.39	0.16	-0.23	1.51	0.94	-0.57	0.21	0.21	0.00
HB #10A (thin/burn)	2.60	0.55	-2.05	2.10	0.23	-1.87	0.29	0.18	-0.11	2.67	0.33	-2.34
HB #11/12 (thin/burn)	2.00	0.62	-1.38	0.70	0.07	-0.63	0.73	0.43	-0.30	0.64	0.00	-0.64