FIRE

Prescribed Fire Behavior and Impact in an Eastern Spruce-Fir Slash Fuel Complex

MARTIN E. ALEXANDER
NORTHERN FOREST RESEARCH CENTRE
EDMONTON, ALBERTA

A.G. Randall (Univ. Maine Agric. Exp. Stn., Misc. Publ. 675, 1966) provided a well-documented account of a broadcast burn in clear-cut spruce-fir slash conducted on an experimental basis for hazard abatement and site preparation purposes. The purpose of the present paper is two-fold: (1) list the weather-dependent fuel moisture codes and relative fire behavior indexes of the Canadian Forest Fire Danger Rating System (CFFDRS) (Van Wagner, Can. For. Serv. Publ. 1333, 1974; Can. For. Serv., For. Tech. Rep. 25, 1978) associated with this experimental prescribed fire; and (2) compare the fire spread and intensity and the resulting slash and organic layer depletion with applicable CFFDRS indexes of absolute fire behavior and fire impact guidelines for central and western Canada.

The burn area consisted of a 4-ha cut block (about 200 × 200 m, oriented due north) located in the east-central part of Maine (45°15′N, 67°40′W). The terrain is level and the site is fairly well drained. Red spruce (*Picea rubens* Sarg.), white spruce (*P. glauca* (Moench) Voss), and balsam fir (*Abies balsamea* [L.] Mill.) comprised 60% of the merchantable overstory, with the remainder consisting of deciduous species and scattered conifers (Randall, Univ. Maine at Orono, Res. Life Sci. 21(8):1–15, 1974). The area was clear-cut in March–April 1965. All stems greater than 5 cm dbh were felled, and the pulpwood and sawlogs (202 m^3[stacked]/ha) were yarded with horses. The logging operation disturbed very little of the organic layer (preburn depth of 9.2 cm and weight of 83.5 t/ha) and left the area covered with a continuous layer of moderately heavy, needle-bearing slash (54.2 t/ha). No data are available on the weight by roundwood diameter-size class distribution. A 8-m wide fire guard, cleared to mineral soil, was bulldozed around the cut block.

Daily measurements of temperature, wind speed, and 24-h accumulated rainfall recorded at 1300 EDT were obtained from the fire-weather station at the Maine Forest Service's Topsfield Ranger Station (elevation: 152 m ASL), 19 km from the burning site (weather records provided by A.J. Simard, USDA Forest Service, East Lansing, Michigan). On-site weather observations were not available. Relative humidities were determined from wet-and dry-bulb thermometer readings. Wind velocities, measured at the US standard of 20 ft (6.1 m), were adjusted to the CFFDRS standard of 10 m (Turner and Lawson, Pac. For. Res. Cent. Inf. Rep. BC-X-177, 1978). All weather data were converted to metric units and processed by computer (Van Wagner and Pickett, Petawawa For. Exp. Stn. Inf. Rep. PS-X-58, 1975 (revised 1982)). The spring starting date for fire-danger rating calculations was 10 April. Standard fuel moisture code starting values were used.

A total of 132.5 mm of rain fell between 10 April and 11 June, 1965. The most recent significant rainfall (≥0.6 mm) prior to the burn date occurred 3 days earlier. On the day of the burn (11 June, 1965), dry-bulb temperature was 16.7°C, relative humidity was 46%, and wind speed (as measured at a height of 10 m in the open on level terrain) was 24 km/h. The standard CFFDRS fuel moisture code ratings were as follows: Fine Fuel Moisture Code (FFMC) 87, Duff Moisture Code (DMC) 35, and Drought Code (DC) 154. The relative fire behavior indexes of the CFFDRS, representing rate of spread, fuel available for combustion, and frontal fire intensity were as follows: Initial Spread Index (ISI) 9.4, Buildup Index (BUI) 45, and Fire Weather Index (FWI) 20 respectively. An FWI value of 16–21 is considered to be a very high level of fire danger in New Brunswick, based on the frequency of occurrence (T.L. Spinney, New Brunswick Dep. Nat. Resour., Fredericton, pers. comm.).

The prescribed fire was started at 1407 EDT and ignition was completed in 23 min with no difficulty using a single hand-held drip torch. The firing pattern consisted principally of a single head fire with backfiring to secure control lines. Complete fire coverage was attained. Forward rate of fire spread was 10.1 m/min and flame heights averaged 4.6–6.1 m. Woody slash fuels were reduced by 59% (32.2 t/ha), and nearly complete consumption of roundwood pieces less than 5 cm in diameter was achieved (Randall 1966). Depth of burn was 4.6 cm, a 50% duff depth reduction that left a 4.6-cm postburn duff depth. Duff consumption by weight amounted to 31.7 t/ha (a 38% reduction). After a short time, only thin and scattered smoke remained (Randall, pers. comm.). No mineral soil was exposed. Frontal fire intensity was recalculated to be 14 865 kW/m on the basis of the measured rate of advance, quantity of slash and organic matter consumed during passage of the active fire front (conservatively estimated at 90% of total fuel consumed), and a reduction of the standard heat of combustion value of 18 700 kJ/kg according to the fuel moisture content data given in Randall's (1966) report (Alexander, Can. J. Bot. 60:349–357, 1982a). The available fuel energy amounted to 87 441 kJ/m^2. No major control problems were encountered, although some crown scorch did occur along the block fringe. Patrol and mop-up operations were completed by 1215 EDT the following day without any deep, persistent burning occurring.

Muraro (Suppl. BC-3, Can. For. Fire Behavior Syst., Can. For. Serv., Pac. For. Res. Cent., Victoria, B.C., 1971 (unpublished) developed a general and specific Fire Behavior Index (FBI) in the form of tables for the white spruce–subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) slash fuel complex in north-central British Columbia. Both of these indexes are applicable to tractor-skidded logging operations and require topographic (terrain slope) and weather (CFFDRS fuel moisture codes and wind velocity) inputs. The general FBI, reflecting fire behavior in 2–3 year old logging slash with an average loading of 146.5 t/ha and an organic layer of 97.6 t/ha, indicated a fire spread rate of 7.0 m/min and a frontal fire intensity of 7990 kW/m for the Randall burn. The specific FBI, tailored to variable but known fuel conditions (such as age of slash, slash loading, and organic layer loading), predicted a linear rate of spread of 10.5 m/min and an intensity of 7887 kW/m at the fire front. Muraro's (1971) fire impact guidelines indicated a 4.3-cm depth of burn, slash fuel reduction of 15.6 t/ha, 65% reduction of fuel size class diameters less than 7.6 cm in diameter, and 40% mineral soil exposure.

From Muraro's (1971) tables, Van Wagner (Petawawa For. Exp. Stn. Inf. Rep. PS-X-42, 1973 (revised 1980)) formulated two regression equations for estimating rate of fire spread (uncorrected for slash age). Van Wagner's first equation produced an estimated fire spread rate of 5.6 m/min, using the ISI (the combined effect of wind speed and FFMC on the rate of forward spread without the influence of variable quantities of fuel). The second equation indicated a spread rate of 5.8 m/min, using the ISI–BUI (a combination that reflects the effect of an increasing amount of available fuel on fire spread rate).

The Prescribed Fire Predictor (PFP) (Muraro, Can. For. Serv., Pac. For. Res. Cent., Victoria, B.C., 1975 (reprinted 1980)) is intended to estimate the fire behavior and impact of prescribed burning in postlogging slash fuel complexes following mechanical yarding. The PFP can be used for real-time prediction or as a planning aid. The PFP ranks the ease of ignition, spread rate, difficulty of control (anticipated if ignition were to occur in adjacent standing timber), and fire impact on a rating scale of 1 to 8 (Muraro, Can. For. Assoc. B.C. Fire Control Notes 13:26–32, 1977). Ignition, spread, and control ranks are defined by a color code, a descriptive phrase, and an explanatory text. Impacts are ranked numerically and, more importantly, by percentage. PFP calculation requires inputs of "on-site" or representative "off-site" weather data (CFFDRS fuel moisture codes and wind velocity), topographic features (terrain slope), site characteristics (organic layer depth, slash age, and stand decadence or type of logging), and fuel conditions. Fuel complex characteristics are assessed by a simple numerical rating of slash size, depth, continuity, and the presence of green or cured vegetation (B.C. Min. For., Form F.S. 117 part A, 1979). The total fuel hazard rating for Randall's preburn slash area was judged to be 15 (≥15 is considered an extreme hazard; 25 is the maximum rating). The PFP correctly interpreted the ignition and control difficulty; Ignition Rank 6 or "easy" (little effort at unfavorable locations yields moderate- to high-vigor flames) and Control Rank 4, described as "easy to moderately easy", were calculated. The PFP indicated an unadjusted Spread Rank 6 or "very fast" (maximum spread rates up to 10 m/min). The PFP slide-rule tables are based on zero wind speeds. The spread rank can be corrected for wind speed and direction relative to slope for winds less than 10 km/h (as measured at the standard height of 10 m in the open). According to Muraro (1977) this was the maximum wind speed allowable in order to avoid fringe damage. The three aspects of fire impact (Impact Rank 3) estimated by the PFP were 45% duff reduction, 30% mineral soil exposure, and 80% slash reduction for <2-cm diameter pieces and 65% for <7-cm pieces.

The B.C. Fire Behavior Rating System (BCFBRS) (B.C. Min. For., For. Prot. Handb. 12, 1982) is designed to assess the expected ease of ignition, rate of spread, and difficulty of control of wildfires for five broad fuel types based on the CFFDRS fuel moisture codes, BUI, and ISI. Fire behavior characteristics are described by ratings or classes determined from code and index charts. Each rating or class is described by a descriptive phrase accompanied by quantitative information or a qualitative interpretation. The Randall preburn slash fuel complex is best exemplified by Fuel Type E, described as uniformly distributed 1–2 year old slash (up to 50% needle retention) resulting from clear-cut logging of mature to overmature stands (such as white spruce–subalpine fir) with moderate to deep organic layers. The BCFBRS ease-of-ignition rating differs from the PFP ignition rank in that it refers to the likelihood of wildfire starts. Rate of spread is determined on the basis of the DMC and ISI (terrain slope assumed to be ≤20%). A fast spread class was indicated by the BCFBRS chart for Randall's burn, meaning that a forward rate of fire spread of less than 9.0 m/min could be expected. The difficulty-of-control rating refers to the tasks of containment and extinguishment and is determined by the fire spread rate and fuel available for combustion represented by the DMC and DC. For the Randall burn, the BCFBRS guide indicated a highly difficult situation characterized by a high intensity flame front and requiring intensive control and mop-up efforts.

McRae (Great Lakes For. Res. Cent. Rep. 0-X-316, 1980) presented equations and tables for estimating slash fuel consumption (needle foliage and roundwood pieces by ≤7 cm and ≥7 cm diameter size classes), and depth of burn. McRae's calculations are based on the BUI (combination of the DMC and DC that represents the total amount of fuel available for combustion), preburn slash fuel loadings, and organic layer depth. Equations and tables are available for five common slash fuel complexes found in northern Ontario. McRae's interim guidelines for the "upland spruce" slash type estimated a 6.6 cm depth of burn and a total slash fuel consumption of 30.7 t/ha for the Randall burn.

If basic fire weather readings were recorded, it is possible to reconstruct the burning conditions of past experimental fires expressed in terms of the CFFDRS codes and indexes. Such meteorological observations should be systematically archived or appendixed in the investigator's initial report because fire-danger rating systems periodically change or are modified and direct conversion of old to new ratings cannot be made reliably (Alexander, Can. J. For. Res. 12:1028–1029, 1982b). The Topsfield Station fire weather data has now been filed with the U.S. National Fire Weather Data Library at Fort Collins, Colorado (Furman and Brink, USDA Forest Serv. Gen. Tech. Rep. RM-19, 1975), under Station No. 170804[1].

The differences between observed and predicted fire behavior and impact values are usually well within the range of expected natural variation exhibited by forest fires (Table 1). It is apparent that time since cutting (i.e., fuel bed settling and needle retention in terms of slash aging) must be considered in prediction schemes for fire spread in coniferous slash fuels.

To compare realistically the calculated frontal fire intensity for the Randall burn with the estimate from Muraro's (1971) specific FBI for white spruce–

[1] In addition, a copy of the fire weather observations record is available, at a nominal charge, from the Depository of Unpublished Data, CISTI, National Research Council of Canada, Ottawa, Canada K1A 0S2.

TABLE 1

Fire behavior characteristics and fire impact on fuels in an eastern spruce-fir slash fuel complex

Parameter	Observed value	Predicted values				
		Muraro (1971)	Van Wagner (1973)	Muraro (1975)	B.C. Min. For. (1975)	McRae (1980)
Fire behavior characteristics						
Rate of spread (m/min)	10.1	7.0 10.5	5.6 5.8	—	<9.0	—
Frontal fire intensity (kW/m)	14 865 8 172[1]	7991 7887	—	—	—	—
Fire impact: organic layer						
Depth of burn (cm)	4.6	4.1	—	—	—	6.6
Duff depth reduction (%)	50	65	—	45	—	—
Mineral soil exposure (%)	0.	40	—	30	—	—
Fire impact: slash layer						
Foliage & woody fuel consumption (t/ha)	32.2	15.6	—	—	—	30.7
Roundwood depletion[2] (%/cm)	≃100/5	65/<7.6	—	80/<2 65/<7	—	—

[1] See also discussion in text. [2] Refers to the percent reduction by weight for slash pieces of less than a given diameter.

TABLE 2

Fire Weather Observations for 1300 EDT at Topsfield Ranger Station, Maine, April 10 to June 11, 1965 (elevation: 153 m ASL)

Date		Dry-bulb temperature (°C)	Relative humidity (%)	Wind speed[1] (km/h)	24-h rain[2] (mm)
April	10	8.9	67	15	0.0
	11	9.4	38	9	0.0
	12	1.7	100	11	0.0
	13	1.7	100	15	12.7
	14	5.6	55	15	0.0
	15	11.7	53	17	0.0
	16	5.0	100	31	20.3
	17	6.7	64	22	8.9
	18	8.9	36	18	0.0
	19	11.1	36	15	0.0
	20	9.4	49	22	0.0
	21	12.2	33	7	0.0
	22	5.0	92	7	9.7
	23	5.6	28	9	0.1
	24	3.9	83	15	0.0
	25	9.4	21	11	0.0
	26	7.2	51	11	0.0
	27	6.7	85	7	4.3
	28	10.6	63	7	3.0
	29	15.6	40	13	0.0
	30	17.2	43	17	0.0
May	1	14.4	38	24	0.0
	2	20.6	38	24	0.0
	3	12.8	39	7	0.0
	4	17.8	48	2	0.8
	5	12.2	33	24	0.0
	6	12.8	39	20	0.0
	7	14.4	47	13	0.0
	8	15.0	58	18	0.0
	9	22.8	58	22	0.1
	10	17.8	43	18	0.0
	11	7.8	100	20	14.0
	12	16.1	59	7	0.1
	13	12.2	43	4	0.0
	14	13.9	41	20	6.6
	15	16.1	24	20	0.0
	16	15.6	54	13	0.0
	17	8.3	86	22	2.5
	18	9.4	100	17	27.4
	19	10.0	87	4	1.3
May	20	12.2	78	0	0.1
	21	16.1	41	13	4.6
	22	22.8	40	20	0.1
	23	15.0	30	15	0.0
	24	19.4	31	17	0.0
	25	20.6	26	22	0.0
	26	17.2	43	18	0.1
	27	8.9	73	13	0.1
	28	20.6	55	6	6.9
	29	17.2	38	24	1.0
	30	15.6	58	2	1.3
	31	13.3	71	2	0.1
June	1	15.6	58	11	2.8
	2	16.7	46	6	0.0
	3	13.9	56	11	0.1
	4	11.1	87	11	1.0
	5	14.4	67	11	0.0
	6	26.7	45	18	0.0
	7	18.3	57	2	0.0
	8	20.6	72	9	2.5
	9	26.7	87	15	0.0
	10	27.2	51	18	0.0
	11	16.7	46	24	0.0

[1] As measured at a height of 10 m in the open on level terrain.
[2] Accumulated between 1300 and 1300 EDT.

subalpine fir slash, it is necessary to consider his estimates of fuel consumption in the propagating flame front and the heat content value used. In considering the proportion of total fuel consumed in each category that contributed to the energy output rate of an advancing fire front, Muraro assumed a 100% consumption for the <2.54 cm slash fuel diameter size class, 80% for the 2.54−12.7 cm class, 40% for the ≥ 12.7 cm class, and 30% for the organic layer. For the Randall burn, only total loading for woody slash fuels is known. Muraro started with 19 990 kJ/kg as a high heat of combustion value, which was subsequently reduced for heat losses due to vaporization (1263 kJ/kg), radiation (1860 kJ/kg), incomplete combustion (930 kJ/kg), and fuel moisture content (24 kJ/kg per moisture content percentage point, (Alexander, 1982a)). On the basis of these considerations and an arbitrary 80% woody slash fuel consumption, a frontal fire intensity of 8172 kW/m is obtained. The close agreement with the predicted value is somewhat fortuitous in view of the unknown weight by size class distribution for the Randall burn.

The two measures of duff consumption were predicted with a fair degree of accuracy. Minor differences between measured and estimated values are due to many factors, primarily organic layer heterogeneity and physical properties, and physiographic site characteristics. Muraro's (1971, 1975) guides clearly overestimated the amount of bared mineral soil, probably because of longer burn-out times (secondary and smouldering combustion) associated with heavier fuel loadings and older slash conditions of the documented prescribed fires upon which the guides are based.

McRae's (1980) tables for estimating slash fuel consumption were remarkably accurate. The large overestimation by Muraro's (1971) table remains unexplained. Estimates of roundwood diameter reduction appear reasonable, although close scrutiny is hampered because data on woody fuel consumption by diameter size classes for the Randall burn are not available. The lack of an accepted metric classification of roundwood diameters in forest-fire fuel sampling further hinders study, though this problem has been somewhat resolved by the standardization of preburn and postburn inventory of downed woody fuel diameter size classes (McRae et al., Great Lakes For. Res. Cent. Rep. 0-X-287, 1979; Van Wagner, Petawawa Natl. For. Inst. Inf. Rep. PI-X-12, 1982).

The existing package of CFFDRS aids for fire behavior estimation and guides for fire impact assessment is a valuable tool in fire-use planning and decision making, though it is no substitute for experience and good judgement. With proper

interpretation, managers can certainly benefit from CFFDRS applications in areas lacking localized prescribed burning field studies and trials.

ERRATUM

In Vol. 4, No. 1, "Prescribed fire behavior and impact in an eastern spruce-fir slash fuel complex", on page 7, column 1, line 37−38 should have read "underestimation by Muraro's (1971) table remains unexplained." Also Table 2, which refers to the footnote on page 5, was mistakenly included in the article.

Alexander, M.E. 1984. Prescribed fire behavior and impact in an eastern spruce-fir slash fuel complex. Canadian Forestry Service Research Notes 4: 3-7, 25.

Environment Canada / Environnement Canada

Canadian Forestry Service / Service canadien des forêts

ISSN 0228-9989

canadian forestry service research notes

Vol. 4, No. 1, January – March 1984

Canada