7.4 MODELING THE PROBABILITY OF SUSTAINED FLAMING IN CANADIAN FUEL TYPES: PREDICTIVE VALUE OF FIRE WEATHER INDEX COMPONENTS COMPARED WITH OBSERVATIONS OF SITE WEATHER AND FUEL MOISTURE CONDITIONS

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1. INTRODUCTION

Forest susceptibility to wildfire varies over multiple time scales. Daily, hourly, and instantaneous fluctuations can result from changes in weather variables that influence fire behaviour and fuel moisture content. Seasonal variations are associated with long-term weather trends and phenological changes in vegetation. The Canadian Fire Weather Index (FWI) System (Van Wagner 1987) has been used to provide daily and hourly ratings of forest fire susceptibility in Canada for over 30 years. The FWI system is based on an understanding of fundamental relationships between weather variables, fuel moisture conditions, and observed fire behaviour. These fundamental relationships have been explored in numerous studies in Canada and elsewhere through the use of small scale test fires (e.g., Lawson and Dalrymple 1996, Frandsen 1997, Lin 1999, Fernandes et al. 2002, Larjavaara et al. 2004, Tanskanen et al. 2005).

In typical small scale test fire experiments, the outcome of a fire ignition is categorized as either a success or a failure and logistic regression methods are used to model the probability of a successful fire ignition as a function of one or more independent variables. Independent variables used to model the probability of ignition generally fall into two groups: site variables that describe weather and fuel moisture conditions at the time of the fire; and fire weather index values that represent approximations of these conditions.

For operational purposes, fire management organizations require models to predict the probability of sustained flaming in an area from fire weather index values that are readily available to them each day. Daily FWI values that are calculated at multiple weather stations across a jurisdiction are commonly interpolated to provide continuous spatial ratings of fire susceptibility across a jurisdiction. These spatial coverages of fire susceptibility can be associated with a fuel map to identify FWI component values that correspond to a particular fuel type in a given area on a given day. While it is possible to produce similar spatial coverages of site variables relevant to fire ignition (e.g., weather, fuek moisture content), the time and resources associated with a large-scale daily fuel moisture sampling regime would make this alternative impractical. By modeling the probability of sustained flaming with FWI values, fast and inexpensive assessments of fuel-specific fire susceptibility can be obtained for an area.

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While the practical advantages of modeling with FWI components are clear, the degree to which predictions of fire sustainability based on FWI components approximate predictions based on site variables has been relatively unexplored. We used data from small scale test fires to investigate the likelihood that short-duration sustained flaming would develop in forest ground fuels that had direct contact with a small and short-lived flame source. Models were developed for 10 fuel categories that represent unique combinations of forest cover, ground fuel type, and in some cases, season. For each fuel category, we compared the predictive ability of models composed of FWI components to models that used site observations of weather variables and fuel moisture content to predict the probability of sustained flaming.

2. METHODS

2.1 Test fire data

Canadian federal government fire researchers initiated a small scale test fire program in the 1930s. By 1940, program procedures had been standardized, and between 1940 and 1961, 20 643 small scale test fires were conducted at 9 field stations across Canada. The test fire program involved daily weather documentation, systematic fuel moisture sampling, and detailed evaluations of the outcomes of small scale experimental test fires conducted at sites chosen to reflect representative fuel types across the country (Paul 1964). Results were used to develop early systems for rating fire susceptibility on a given day. These early systems were instrumental in the development of the Canadian Fire Weather Index (FWI) System (Van Wagner 1987).

Data collected during the test fire program has been assembled in the Canadian small scale test fire database (Beverly and Wotton, *in preparation*). Each test fire record in the database contains information on the location of the fire; weather conditions recorded both on site and at a nearby weather station; a description of the fuels and a measure of fuel moisture content; observations of test fire behaviour; and FWI components calculated from weather station data.

Not all test fire records are complete, and while all records include weather observations from a nearby weather station, relatively few include observations of site weather conditions at the time of the fire. Only 1845 test fire records contain site observations of temperature and relative humidity, and 1662 (90%) of these test fires were conducted at 7 sites located at 2 field stations: Fort

Smith, Northwest Territories (5 sites), and 100 Mile House, British Columbia (2 sites).

These sites were selected for an investigation of the predictive ability of FWI components in comparison with site variables for modeling the probability of sustained flaming. Test fire records (345) from one site in Fort Smith were dropped from the analysis due to a lack of site descriptive data. Of the remaining records, only those that contained a fuel moisture measurement for the ground fuel type consumed by the fire (e.g., grass, lichen, moss, needles, leaf) were included in the analysis.

For each of the six sites, remaining data was divided into categories that reflected unique fuel conditions based on forest cover, ground fuel type, and in some cases, season. Some fuel categories were excluded from the analysis because they had insufficient numbers of test fires. In total, 10 fuel categories and 1027 test fires were included in the analysis.

2.2 Study sites

Four of the six study sites included in the analysis were located near Fort Smith, Northwest Territories (60°00'N, 111°53'W) and two were located near 100 Mile House, British Columbia (51°39'N, 121°17'W). Study sites were within a 4.8 km and 2.9 km radius of a weather station established at Fort Smith and 100 Mile House locations, respectively. Test fire sites were typically square or rectangular, ranging from 232 to 3716 m^2 in size, and surrounded by a 0.5 m trench cleared to mineral soil (Macleod 1948). Detailed descriptions of the 6 test fire sites are provided in Table 1.

Table 1. Site descriptions.

Fuel Category	Site	Location	Cover type	Ground fuel	Site Description*
1. grass-spring 2. grass-summer	80108	100 Mile House, British Columbia	grass	grass	Open site, scattered Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco), on a southwest slope
	80110	100 Mile House, British Columbia	grass	grass	Open site, scattered Lodgepole pine (*Pinus contorta* Dougl.), exposed southwest slope
3. pine-lichen 4. pine-moss 5. pine-needles	90101	Fort Smith, Northwest Territories	jack pine	lichen, moss, needles	Dense, even-aged, 85-year old jack pine (*Pinus banksiana* Lamb.) stand of fire origin, located about four chains from the weather station. Average DBH is 10 cm and maximum tree height is 20 m. Park like appearance with a low density of minor vegetation. Hylocomium and *Calliergon* spp. mosses and *Cladonia* spp. are the predominant surface fuels, with scattered needles and twigs, and clumps of *Linnea, Vaccinium, Arctostaphylos* spp. and grass. Scattered Shepherdia and Salix [spp.] bushes also occur. The soil profile consists of the above mentioned surface fuels overlying a thin, partly decomposed layer, followed by a 1.3 cm decomposed layer. The full organic layer is normally less than 5 cm deep over fine sand.
6. mixedwood-moss 7. mixedwood-needles,leaf-summer	90105	Fort Smith, Northwest Territories	mixedwood	moss, needles, leaf	Mature, uneven-aged white spruce (*Picea glauca* (Moench) Voss)-aspen (*Populus* spp.) -jack pine stand with a basal area of 147 sq ft per acre. Evidence of fire 45 to 50 years ago was found on this test fire site. High bush cranberry (*Viburnum opulus* L. var. *americanum* (Mill.) Ait.) and *Shepherdia* [spp.] bushes cover 20-30 percent of the understory. Dominant surface fuels include *Hylocomium* and *Calliergon* spp. mosses, leaves and needles. The full organic layer varies from 1.3 to 3.8 cm.
8. spruce-moss	90103	Fort Smith, Northwest Territories	spruce	moss	very dense, 85-year old, even-aged black spruce (*Picea mariana (Mill.) BSP*) stand. A large proportion of the trees are suppressed, giving the stand an all-aged appearance. *Hylocomium* spp. moss, 1.3-12.7 cm deep covers 100 percent of the ground surface. The organic layer reaches a depth of 18 cm in spots, overlying very fine silty sand.
9. aspen-grass-summer 10.aspen-leaf-summer	90106	Fort Smith, Northwest Territories	aspen	grass, leaf	Pure, 60-year old even-aged aspen stand. Profuse minor vegetation during summer months consisting of clumps of *Salix* spp., *Shepherdia* spp. and Rose (*Rosa* spp.) bushes. Underneath this shrub layer is a fairly complete cover of *Epilobium, Lathyrus, Vicia* spp. and grass. The litter layer consists of 100 percent leaf cover, 0.6 – 1.3 cm in depth

**Source*: unpublished progress reports on forest fire research - Fort Smith (1961) and 100 Mile House (1957)

2.3 Test fire procedures

Test fires were conducted between May and September (Table 2). Once procedures at a site were initiated for a given year, the site was visited daily. Test fires were attempted on all rain-free days, provided that an informal on-site assessment indicated that fuel moisture was not overly saturated. The majority of test fires (91%) occurred on days when the Fine Fuel Moisture Code (FFMC) was ≥70. We used this value as an objective criterion for determining whether or not a given day would be a test fire day. Test fires conducted on days with an FFMC <70 were not included in the analysis, to reflect increasing variability in the relationship between FFMC values and fuel moisture measurements taken during moister conditions (see Wotton and Beverly, paper 7.5).

Table 2. Duration of sampling by site and year.

Site	1958	1959	1961
80108	May 7 – Sept 5	May 7 – Sept 2	–
80110	Aug 28 – Sept 5	May 7 – Sept 2	–
90101	–	–	May 18 – Sept 11
90103	–	–	May 26 – Sept 12
90105	–	–	June 14 – Aug 29
90106	–	–	May 20 – Aug 31

Fires were ignited in both spring and summer seasons, although the majority (88%) occurred during summer conditions. We used phenological records to categorize test fires in grass and leaf fuels according to season. Spring fires represent conditions prior to the onset of leaf flush, and summer fires represent conditions after leaf-flush but prior to the onset of leaf-fall.

Test fire procedures are described by Macleod (1948) and Paul (1964). We acquired additional methodological details from unpublished historical documents, including test fire field notebooks, original test fire field data cards, and annual progress reports that summarized fire research activities at test fire field stations active in Canada between 1940 and 1961.

The majority of test fires (98%) occurred between 0800 h and 1700 h. Test fires were ignited by placing the flame of a large, household sized wooden match in contact with ground fuel. A match ignition can be described as contact with a flame 35-40 mm in length for a duration of 15-20 s.

If the match extinguished before the ground fuel ignited the procedure was repeated. Sixty percent of the 1027 test fires were ignited with a single attempt, and 73% were ignited with 3 attempts or less. In a small number of cases (3%), match ignition of ground fuels could not be achieved after repeated attempts. In these situations, we classified the outcome of the test fire as “no sustained flaming.”

Once ground fuels were ignited, the fire was observed for 120 s. Fires became extinct before 120 s, either as a result of poor burning conditions or through the action of investigators seeking to limit aggressive fire behaviour. Weakly burning fires were sometimes observed for more than 120 s to establish evidence of flame sustainability. The average observation period was 103 s with a range of 15 to 300 s.

Researchers documented observed test fire behaviour by assigning each fire a qualitative rating, called the vigor code (Table 3). We classified the outcome of a test fire as achieving “sustained flaming” if the vigor code was 3-5.

Table 3. Vigor code descriptions (Mactavish 1960).

Code	Description
1	At 2 minutes the fire is burning very weakly on one front only and goes out by itself
2	At 2 minutes the fire is burning slowly and poorly on two or more fronts and seems likely to go out on its own accord rather than continue indefinitely
3	At two minutes no sign of fire going out by itself, burning fairly briskly, but not on all fronts
4	Fire burning briskly at 2 minutes on all fronts with tendency to become progressively stronger, but no difficulty in putting it out with feet (stomping)
5	As for #4 but difficult or impossible to put out fire with feet after two minutes
9	Fire goes out before 2 minutes

2.3 Statistical Analysis

We modeled the probability of sustained flaming with logistic regression by classifying the outcome of a test fire as either “sustained flaming” (1), or “no sustained flaming” (0):

$$P(sf) = \frac{1}{1 + e^{-(b_0 + b_1 x_1 + \ldots + b_n x_n)}} \qquad [1]$$

where $P(sf)$ is the probability of sustained flaming, $x_{1\text{-n}}$ are the independent variables, and $b_{0\text{-n}}$ are regression coefficients.

For each of the 10 fuel categories, probability of sustained flaming was modeled as a function of two separate groups of independent variables: (1) Canadian Fire Weather Index (FWI) System components; and (2) site measurements of weather and fuel moisture conditions.

The FWI system contains three fuel moisture codes that account for daily and hourly changes in the fuel moisture content of ground fuels layered at increasing forest floor depths. Moisture code values are calculated for individual weather stations from consecutive, daily observations of weather conditions (dry-bulb temperature, relative humidity, 10-m open wind speed, and precipitation) recorded throughout the fire season. Relative daily ratings of potential fire intensity, spread rate, and fuel consumption are provided by three fire behaviour indices generated from the moisture codes, for a total of 6 FWI system components (Van Wagner 1987):

Fine Fuel Moisture Code (FFMC): represents the moisture content of litter and other cured fine fuels.

Duff Moisture Code (DMC): represents the moisture content of loosely compacted, decomposing organic matter.

Drought Code (DC): represents moisture conditions in a deep layer of compact organic matter.

Initial Spread Index (ISI): a combination of wind and FFMC that represents the rate of fire spread independent of fuel quantities.

Buildup Index (BUI): a combination of the DMC and DC that represents the total fuel available to the spreading fire.

Fire Weather Index (FWI): a combination of the ISI and BUI that represents the intensity of the spreading fire as energy output rate per unit length of fire front.

The FFMC value represents litter moisture content at peak burning conditions, approximately 1600 hr LST. We used documentation of the timing of fires during the day to produce a diurnally adjusted Fine Fuel Moisture Content value (DFFMC) for each test fire record (i.e, Van Wagner 1972, Lawson et al. 1996). This DFFMC value was then used to calculate a diurnally adjusted Initial Spread Index (DISI) and a diurnally adjusted Fire Weather Index (DFWI).

Fuel moisture content is commonly used to predict fire ignition potential and sustainability (e.g., Frandsen 1997, Lin 1999). We used records of fuel moisture content for the ground fuel type consumed by the test fire (e.g., grass, lichen, moss, needles, leaf) as an independent site variable.

We also included two site weather variables that are commonly used as predictors of fire ignition and sustainability: relative humidity and temperature (e.g., Lin 1999). Vapour pressure deficit, a measure of evaporative drying potential, was calculated from measurements of site relative humidity and temperature for each test fire record, and included as a fourth site variable in the analysis.

Wind is known to influence fire behaviour and has also been used as a predictor in models of fire ignition and sustainability (e.g., Lawson et al. 1994, Lin 1999, Fernandes et al. 2002), but was not included as a predictor of sustained flaming in this study because test fire records do not include site wind speed measurements at the time of the fire. Approximately 80% of the test fire records do contain a qualitative rating of site wind conditions, and 90% of these fires were conducted with wind speeds ≤ 4.8 km/h, which suggests that wind speed likely did not have a major influence on test fire outcomes.

Maximum likelihood estimates of model parameters were computed with SAS LOGISTIC (SAS Institute Inc. 1995). Model selection between and within the two groups of independent variables, (A) FWI components and (B) site variables, was based on Akaike's Information Criterion (AIC). Model predictive ability and goodness of fit was assessed by the likelihood ratio x^2 test, the Wald x^2 test for individual parameters, and the C statistic.

3. RESULTS

Average moisture content of ground fuels and relative humidity at the time of the fire were significantly lower for fires that achieved sustained flaming as compared with fires that did not achieve sustained flaming for all fuel categories (Table A-1). Average temperature and vapour pressure deficit at the time of the fire were significantly higher for fires that achieved sustained flaming as compared with fires that did not achieve sustained flaming, for all fuel categories, with the exception of average temperatures associated with test fires in fuel category 9 (aspen-grass-summer), which did not differ between the two test fire outcomes.

Fires that achieved sustained flaming were associated with a higher proportion of FWI component values that exceeded median values (calculated from all test fires and all fuel categories), as compared with fires that did not achieve sustained flaming (Table A-2). Exceptions were found in fuel category 9 (aspen-grass-summer), where the proportion of both DFFMC values and BUI values exceeding median values did not differ significantly between the two test fire outcomes. For fuel category 1 (spring-grass) there were no significant differences in the proportion of FWI components exceeding median values between the two test fire outcomes, with the exception of BUI.

The proportion of test fires associated with a Drought Code (DC) that exceeded the median value was not significantly different between the two test fire outcomes for 6 of the 10 fuel categories. For fuel categories 8-10, the proportion of fires with a DC that exceeded the median value was significantly greater for fires with no sustained flaming, reflecting a seasonal trend rather than the influence of fuel moisture conditions in the deep organic layer on ignition processes. These results are consistent with other studies that indicate ignition outcomes are related to all FWI components, except the DC (i.e., Tanskanen et al. 2005), and as a result, we limited further analysis to DFFMC, DMC, DISI, BUI and DFWI.

Correlation analysis indicated significant correlations between many independent variables. Uncorrelated independent variables for (A) FWI components and (B) site weather variables are shown in Table 4. Only combinations of uncorrelated independent variables were used in model building.

Table 4. Correlations between independent variables: (A) FWI components; (B) site weather variables. Numbers refer to fuel categories (1-10) where two independent variables were not significantly correlated.

(A)	**DFFMC**	**DMC**	**DISI**	**DBUI**
DMC	2,5-9			
DC	1,2,4-7,9,10	5		
DISI	–	5,7,9		
BUI	2, 5-9	–	5,7,9	
DFWI	–	–	–	–

(B)	**Relative humidity**	**Temperature**	**Vapour pressure deficit**
Temperature	9		
Vapour pressure deficit	–	–	
Moisture content	2,6,8	1,2,8,9	2,8

Table 5. Comparison of models composed of (A) FWI components and (B) site variables, by fuel category; p-values in brackets below significant independent variables; p-value for the likelihood ratio X^2 statistic; *C* statistic indicates concordance between predicted probabilities and observed outcomes; $AIC_B - AIC_A$ is the difference in Akaike's Information Criterion between models A and B.

Fuel category	n	Sustained flaming no	Sustained flaming yes	(A) FWI components		(x^2) p-value	*C*	(B) Site variables		(x^2) p-value	*C*	($AIC_B - AIC_A$)
1. grass-spring	52	9	43			–	–	-RH (0.0022)		<0.0001	0.90	–
2. grass-summer	118	21	97	DFFMC (<0.0001)		<0.0001	0.87	-RH (<0.0001)		<0.0001	0.88	-0.17[c]
3. pine-lichen	190	31	159	DFFMC (<0.0001)		<0.0001	0.92	-MC (<0.0001)		<0.0001	0.88	47.91[d]
4. pine-moss	129	42	87	DFWI <0.0001)		<0.0001	0.92	-MC (<0.0001)		<0.0001	0.92	1.60[c]
5. pine-needles	53	25	28	DISI (0.0028)	DMC (0.0118)	<0.0001	0.90	-MC (0.003)		<0.0001	0.87	5.94[e]
6. mixedwood-moss	111	63	48	DFFMC (0.0033)	DMC <0.0001)	<0.0001	0.89	-MC (0.001)	-RH (0.0007)	<0.0001	0.86	13.11[d]
7. mixedwood-needles,leaf-summer	54	49	5	DFFMC (0.0094)		<0.0001	0.96	VPD (0.0062)		<0.0001	0.97	-1.83[c]
8. spruce-moss	158	64	94	DFFMC (<0.0001)	DMC (<0.0001)	<0.0001	0.92	-MC (0.0002)	-RH <0.0001)	<0.0001	0.82	47.48[d]
9. aspen-grass-summer	31	18	13	DFWI (0.0053)		0.0004	0.82	-MC (0.0124)		0.0002	0.85	-1.36[c]
10. aspen-leaf-summer	131	101	30	DMC <0.0001)		<0.0001	0.88	-MC (<0.0001)		<0.0001	0.89	-8.34[f]

[c] Substantial evidence for both models.
[d] Model B is highly unlikely
[e] Considerably less support for model B
[f] Considerably less support for model A

FWI components were as good as, or better, than site variables at predicting the probability of sustained flaming for 8 of the 10 fuel categories. For each fuel category, the independent variables included in the best (A) FWI component model and (B) site variables model, are shown in Table 5. All models were highly significant with concordance between predicted probabilities and observed outcomes that ranged from 82 to 96%. For one category (1. grass-spring) FWI components were not useful for predicting sustained flaming and for another category (10. aspen-leaf-summer), the model based on FWI components had considerably less support than the model based on site variables. Probability of sustained flaming for fuel categories 1 and 10 (based on site variables) and 2-10 (based on FWI components) was predicted from the following models, (Eq. 2.01 -2.10, Fig. 1-7):

$$P(sf) = \frac{1}{1+e^{-(7.3703-0.1725RH)}} \qquad [2.01]$$

$$P(sf) = \frac{1}{1+e^{-(-23.3755+0.2895DFFMC)}} \qquad [2.02]$$

$$P(sf) = \frac{1}{1+e^{-(-34.8731+0.4304DFFMC)}} \qquad [2.03]$$

$$P(sf) = \frac{1}{1+e^{-(-4.414+0.3368DFWI)}} \qquad [2.04]$$

$$P(sf) = \frac{1}{1+e^{-(-4.8479+0.6032DISI+0.0258DMC)}} \qquad [2.05]$$

$$P(sf) = \frac{1}{1+e^{-(-24.3837+0.2407DFFMC+0.0638DMC)}} \qquad [2.06]$$

$$P(sf) = \frac{1}{1+e^{-(-127.8+1.3902DFFMC)}} \qquad [2.07]$$

$$P(sf) = \frac{1}{1+e^{-(-38.9+0.4117DFFMC+0.0679DMC)}} \qquad [2.08]$$

$$P(sf) = \frac{1}{1+e^{-(-3.6403+0.1558DFWI)}} \qquad [2.09]$$

$$P(sf) = \frac{1}{1+e^{-(2.8566-0.2456MC)}} \qquad [2.10a]$$

$$P(sf) = \frac{1}{1+e^{-(-4.1990+0.0421DMC)}} \qquad [2.10b]$$

where DFFMC is the diurnally adjusted Fine Fuel Moisture Code, DISI is the durinally adjusted Initial Spread Index calculated from DFFMC and the 10 m – open wind speed, DFWI is the Fire Weather Index calculated from the Buildup Index and DISI, DMC is the Duff Moisture Code, RH is relative humidity (%), and MC is moisture content (%) of the ground fuels specified by the fuel category (grass, lichen, moss, needles, leaf).

Fig. 1

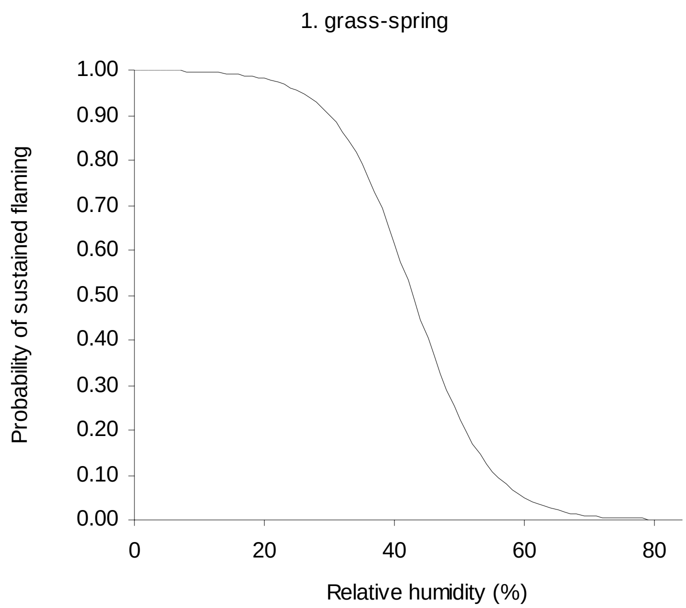


Fig. 2

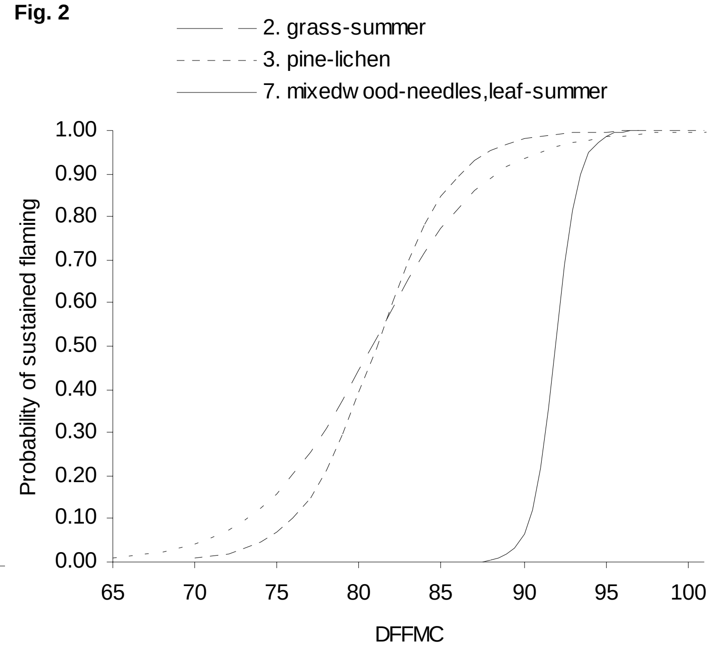


Fig. 3

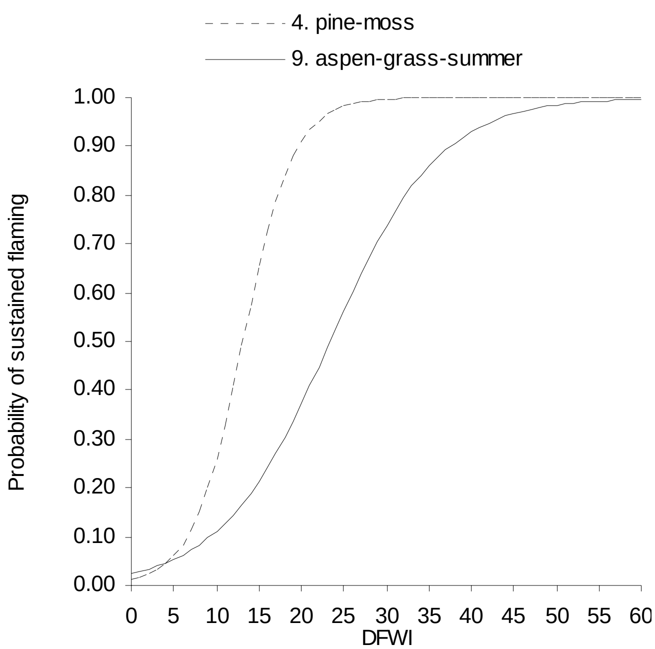


Fig. 4

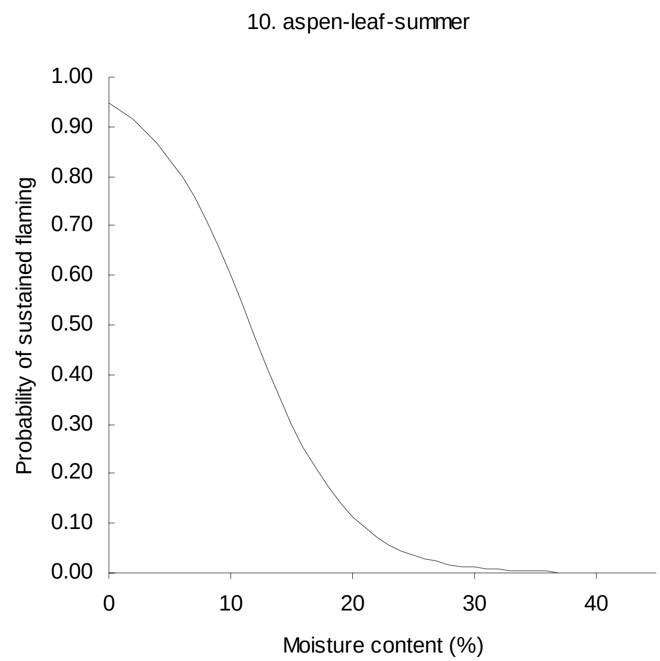


Fig. 5

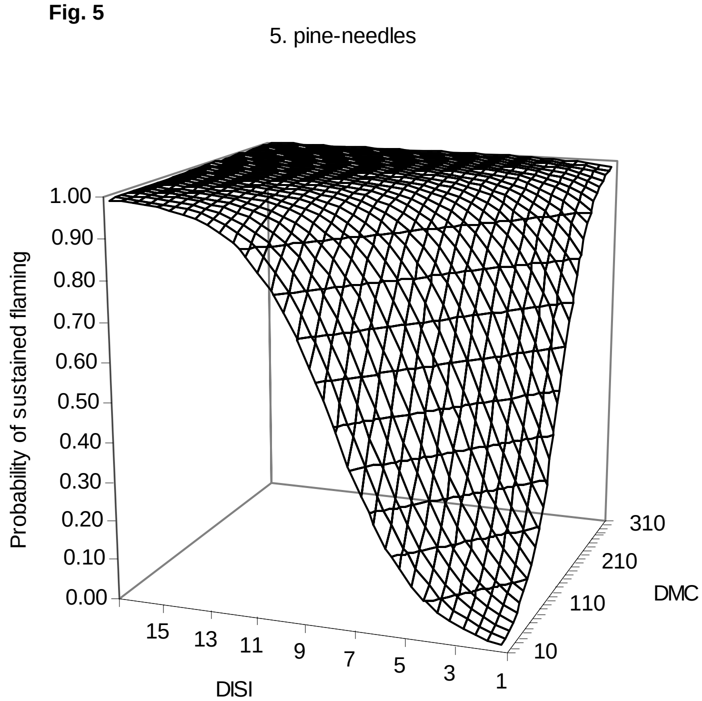


Fig. 6

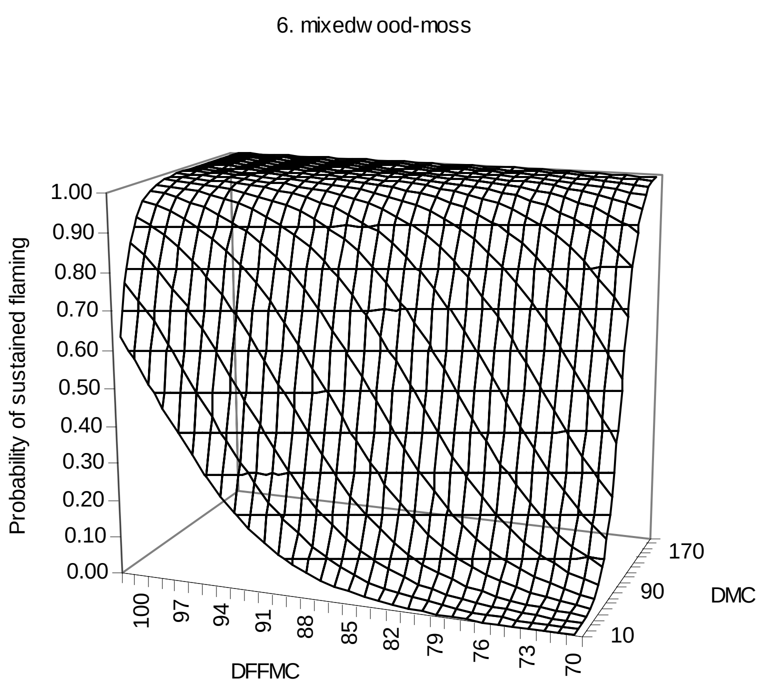
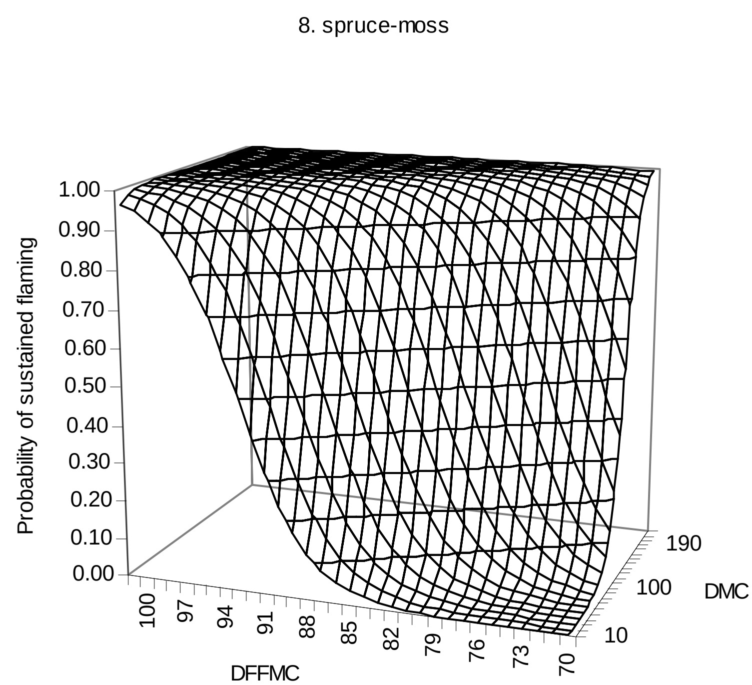


Fig. 7



4. DISCUSSION AND CONCLUSION

Results indicate that sustained flaming ignition is driven primarily by moisture content of fine fuels. Duff moisture content and relative humidity represent secondary influences on sustained flaming ignition for some fuel categories.

Results indicated that models developed from Fire Weather Index (FWI) components were as effective as models developed from site variables at predicting the probability of sustained flaming for 8 of the 10 fuel categories. In 5 of these fuel categories, probability of sustained flaming was driven by the diurnally adjusted Fine Fuel Moisture Code (DFFMC). The diurnally adjusted Initial Spread Index (DISI) or Fire Weather Index (DFWI) were key determinants of the probability of sustained flaming for 3 fuel categories. While a significant independent variable in 4 of the FWI component models, the Duff Moisture Code (DMC) tended to represent a secondary influence on the probability of sustained flaming. These results are consistent with the findings of Wotton and Beverly (paper 7.5) that DMC has an influence on fuel moisture that is not accounted for in the FFMC model.

FWI components were not useful for predicting sustained flaming in spring grass fuels, where test fire outcomes were driven by site relative humidity at the time of the fire. FWI components had limited usefulness for modeling the probability of sustained flaming in aspen leaf fuels during summer conditions. Although a model using the Duff Moisture Code (DMC) was developed for this fuel category, it had considerably less support than one using observations of moisture contents of leaf ground fuels.

This study has shown that FWI components are highly effective substitutes for site variables for modeling the likelihood that short-duration sustained flaming will develop in forest ground fuels that have direct contact with a small and short-lived flame source. Future analysis of test fire data contained in the Canadian small scale test fire database will focus on developing a suite of fuel-specific models for modeling the probability of sustained flaming.

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Appendix

Table A-1. Temperature, relative humidity, vapour pressure deficit, and moisture content for the two test fire outcomes: no sustained flaming and sustained flaming.

	No sustained flaming				Sustained flaming			
1. grass-spring	N	Mean	Std	Range	N	Mean	Std	Range
Temperature (ºC)	9	14.9	4.6	8.3–24.4	43	20.2	4.4	11.7–29.4
Relative humidity (%)	9	41.7	9.3	31.0–61.0	43	26.7	8.5	12.0–48.0
Vapour pressure deficit	9	10.5	4.2	4.3–19.3	43	18.2	6.1	7.7–32.9
Moisture content (%)	9	16.2	10.2	2.5–31.7	43	9.1	5.5	1.9–36.6
2. grass-summer								
Temperature (ºC)	21	17.7	5.8	7.2–28.9	97	23.9	4.3	12.8–32.2
Relative humidity (%)	21	44.3	12.6	22.0–79.0	97	29.3	7.9	17.0–63.0
Vapour pressure deficit	21	12.6	6.6	2.1–31.1	97	21.9	7.2	8.4–36.6
Moisture content (%)	21	16.6	8.8	6.9–38.0	97	13.2	18.9	1.7–149.1
3. pine-lichen								
Temperature (ºC)	31	19.4	3.8	12.2–27.8	159	22.7	4.5	11.7–33.3
Relative humidity (%)	31	52.5	11.0	37.0–76.0	159	42.7	11.4	24.0–79.0
Vapour pressure deficit	31	11.2	4.2	4.1–23.5	159	16.7	6.5	3.7–37.8
Moisture content (%)	31	24.7	10.7	12.6–56.5	159	13.0	9.3	2.9–108.8
4. pine-moss								
Temperature (ºC)	42	20.1	4.3	11.7–27.8	87	23.4	5.4	8.9–33.3
Relative humidity (%)	42	50.5	11.3	32.0–79.0	87	40.2	11.5	22.0–77.0
Vapour pressure deficit	42	12.3	4.9	4.1–23.5	87	18.5	7.8	3.7–37.8
Moisture content (%)	42	56.1	51.9	12.0–208.2	87	11.9	5.1	2.7–36.4
5. pine-needles								
Temperature (ºC)	25	21.0	3.3	13.3–28.3	28	23.6	5.4	13.3–33.3
Relative humidity (%)	25	48.4	11.4	26.0–76.0	28	40.2	12.7	19.0–77.0
Vapour pressure deficit	25	13.4	5.0	4.6–28.5	28	19.0	8.9	3.7–37.8
Moisture content (%)	25	17.1	8.5	6.0–36.4	28	10.0	2.7	5.9–19.6
6. mixedwood-moss								
Temperature (ºC)	63	21.8	4.2	11.7–31.1	48	24.4	5.9	11.1–32.8
Relative humidity (%)	63	49.7	10.0	32.0–78.0	48	39.5	11.3	20.0–62.0
Vapour pressure deficit	63	13.8	5.2	4.9–26.2	48	20.1	8.8	6.0–37.3
Moisture content (%)	63	62.1	67.5	13.7–377.8	48	17.4	16.2	8.3–91.2
7. mixedwood-needles/leaf-summer								
Temperature (ºC)	49	22.2	4.5	11.1–31.1	5	30.0	2.0	27.8–32.8
Relative humidity (%)	49	46.8	8.8	28.0–75.0	5	29.8	11.4	20.0–49.0
Vapour pressure deficit	49	14.9	5.1	6.0–28.0	5	30.2	7.1	19.0–37.3
Moisture content (%)	49	17.1	7.1	7.5–39.9	5	8.3	2.5	6.6–12.7
8. spruce-moss								
Temperature (ºC)	64	21.0	3.7	12.2–27.8	94	23.0	4.9	11.1–33.3
Relative humidity (%)	64	50.4	11.6	30.0–85.0	94	38.7	10.3	18.0–64.0
Vapour pressure deficit	64	13.0	5.0	2.2–23.4	94	18.3	7.3	6.1–38.4
Moisture content (%)	64	82.9	53.6	5.6–213.5	94	56.4	51.6	5.6–215.3
9. aspen-grass-summer								
Temperature (ºC)	18	19.6[a]	4.6	12.2–29.4	13	21.2[a]	5.7	12.2–29.4
Relative humidity (%)	18	55.4	15.4	26.0–82.0	13	42.2	13.1	26.0–74.0
Vapour pressure deficit	18	10.8	6.4	4.8–30.4	13	16.2	8.9	5.1–30.4
Moisture content (%)	18	18.6	6.2	8.9–32.7	13	11.8	3.0	8.9–19.1

10. aspen-leaf-summer								
Temperature (ºC)	101	21.0	4.9	8.9–32.2	30	23.5	5.5	12.2–32.2
Relative humidity (%)	101	52.6	12.7	30.0–84.0	30	39.4	10.3	29.0–68.0
Vapour pressure deficit	101	12.9	6.5	2.7–33.7	30	19.0	8.0	6.5–33.7
Moisture content (%)	101	32.1	24.3	8.0–121.1	30	12.0	4.6	6.731.4

[a]Not significantly different between the two test fire outcomes: no sustained flaming and sustained flaming (Wilcoxon rank sum test, p>0.05)

Table A-2. FWI component values that exceeded median values (calculated for all fires and for all fuel categories) for the two test fire outcomes: no sustained flaming and sustained flaming.

	No sustained flaming			**Sustained flaming**		
	n	**proportion**	**count**	**n**	**proportion**	**count**
1. grass-spring						
DFFMC ≥89	9	0.44[b]	4	43	0.65[b]	28
DMC ≥49	9	0.33[b]	3	43	0.19[b]	8
DISI ≥7	9	0.44[b]	4	43	0.49[b]	21
BUI ≥69	9	0.22	2	43	0.02	1
DC ≥333	9	0.00	0	43	0.00	0
DFWI ≥17	9	0.44[b]	4	43	0.35[b]	15
2. grass-summer						
DFFMC ≥89	21	0.10	2	97	0.63	61
DMC ≥49	21	0.29	6	97	0.59	57
DISI ≥7	21	0.00	0	97	0.38	37
BUI ≥69	21	0.29	6	97	0.59	57
DC ≥333	21	0.24	5	97	0.48	47
DFWI ≥17	21	0.05	1	97	0.66	64
3. pine-lichen						
DFFMC ≥89	31	0.00	0	159	0.42	67
DMC ≥49	31	0.13	4	159	0.55	87
DISI ≥7	31	0.06	2	159	0.40	63
BUI ≥69	31	0.26	8	159	0.55	88
DC ≥333	31	0.58[b]	18	159	0.48[b]	77
DFWI ≥17	31	0.03	1	159	0.52	83
4. pine-moss						
DFFMC ≥89	42	0.02	1	87	0.66	57
DMC ≥49	42	0.26	11	87	0.68	59
DISI ≥7	42	0.07	3	87	0.55	48
BUI ≥69	42	0.26	11	87	0.63	55
DC ≥333	42	0.64[b]	27	87	0.49[b]	43
DFWI ≥17	42	0.05	2	87	0.77	67
5. pine-needles						
DFFMC ≥89	25	0.08	2	28	0.57	16
DMC ≥49	25	0.12	3	28	0.61	17
DISI ≥7	25	0.08	2	28	0.54	15
BUI ≥69	25	0.16	4	28	0.61	17
DC ≥333	25	0.60[b]	15	28	0.43[b]	12
DFWI ≥17	25	0.20	5	28	0.79	22
6. mixedwood-moss						
DFFMC ≥89	63	0.17	11	48	0.60	29
DMC ≥49	63	0.21	13	48	0.77	37
DISI ≥7	63	0.14	9	48	0.52	25

BUI ≥69	63	0.25	16	48	0.77	37
DC ≥333	63	0.68[b]	43	48	0.58[b]	28
DFWI ≥17	63	0.17	11	48	0.73	35
7. mixedwood-needles/leaf-summer						
DFFMC ≥89	49	0.37	18	5	1.00	5
DMC ≥49	49	0.31	15	5	0.80	4
DISI ≥7	49	0.27	13	5	0.80	4
BUI ≥69	49	0.35	17	5	0.80	4
DC ≥333	49	0.67[b]	33	5	0.80[b]	4
DFWI ≥17	49	0.35	17	5	1.00	5
8. spruce-moss						
DFFMC ≥89	64	0.11	7	94	0.61	57
DMC ≥49	64	0.20	13	94	0.76	71
DISI ≥7	64	0.13	8	94	0.50	47
BUI ≥69	64	0.27	17	94	0.69	65
DC ≥333	64	0.63	40	94	0.37	35
DFWI ≥17	64	0.16	10	94	0.70	66
9. aspen-grass-summer						
DFFMC ≥89	18	0.06[b]	1	13	0.31[b]	4
DMC ≥49	18	0.50	9	13	0.85	11
DISI ≥7	18	0.11	2	13	0.62	8
BUI ≥69	18	0.67[b]	12	13	0.85[b]	11
DC ≥333	18	0.44	8	13	0.15	2
DFWI ≥17	18	0.22	4	13	0.92	12
10. aspen-leaf-summer						
DFFMC ≥89	101	0.19	19	30	0.60	18
DMC ≥49	101	0.44	44	30	1.00	30
DISI ≥7	101	0.29	29	30	0.63	19
BUI ≥69	101	0.46	46	30	1.00	30
DC ≥333	101	0.63	64	30	0.30	9
DFWI ≥17	101	0.39	39	30	0.97	29

[b]Not significantly different between the two test fire outcomes: sustained flaming and no sustained flaming (X^2, 1 df, p>0.05)