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Modelling ignition probability of thinned lodgepole pine stands

Contents

Abstract

Fuel management, including thinning, is an important issue for communities and resource users striving to protect their values. Thinning reduces fuel loading in the overstorey and can lower the likelihood of a sustained crown fire. However, surface fuel loading can increase in thinned stands as a result of harvesting, and could adversely affect fire behaviour and likelihood of sustained ignition. This report describes tests that were done to measure the probability of sustained ignition for thinned lodgepole pine stands where surface fuels, including logging slash, were left in place, and for stands where surface fuels were removed by piling and burning.

Keywords

Fire management, Ignition, Wildfires, Thinning, Lodgepole pine, Logging slash, Debris management.

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Introduction

Predicting the likelihood of sustained ignition can help fire managers plan and allocate firefighting resources. For example, Lawson et al. (1993) determined ignition probabilities due to human causes for mature lodgepole pine and white spruce–subalpine fir forest types in British Columbia. Using a logistic regression model, they produced tables that allow the user to cross-reference relevant Canadian Forest Fire Danger Rating System (CFFDRS) component values with the corresponding probability of ignition in the two forest types. The tables can easily be used operationally and were incorporated in the Canadian Fire Behaviour Prediction field manual derived from the CFFDRS (Taylor et al. 1997; Lawson and Dalrymple 1996). More recently, Beverly and Wotton (2005) developed ignition probability models for eight boreal forest types also using CFFDRS variables.

There is, however, limited ignition probability data for stands that have undergone fuel management, including thinning. In a study that looked at the effect of stand structure, Tanskanen et al. (2005) found that pine stands and stands with smaller canopies had a greater likelihood of ignition compared to closed stands such as spruce. This result makes sense, as open stands will result in drier surface conditions compared to closed stands. In fuel-managed stands with open canopies, however, some or most surface fuels are removed and thus the ignition probability is unknown.

Forest fuel management, including thinning, needs to be effective at reducing potential fire behaviour from an unmanageable to a manageable state, and at reducing ignition probability. Thinning is done to remove overstorey and understorey fuel but may result in increased surface fuel loading such as logging slash. Logically, as surface fuel loading increases so does the number of points where sustained ignition can occur. To provide a

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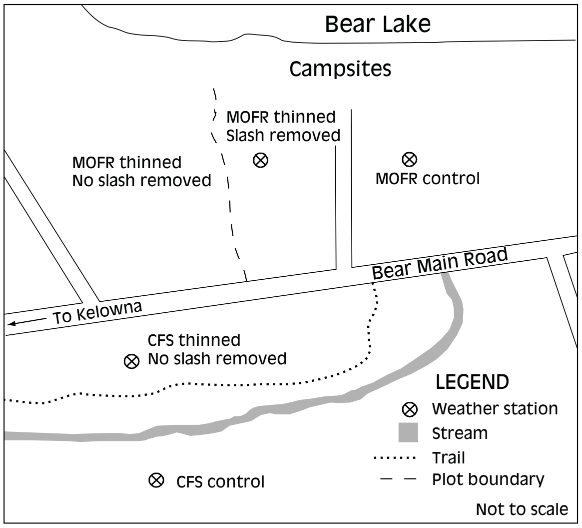

Figure 1. Plot layout and weather station locations

Figure 2. CFS unthinned site (control).

starting point for modelling ignition probability in thinned stands, the Forest Engineering Research Institute of Canada (FERIC), the British Columbia Ministry of Forests and Range (MOFR), and the Canadian Forest Service (CFS) conducted ignition tests at a lodgepole pine thinning trial near Kelowna, B.C.

Objective

The objective of the study was to model ignition probability for thinned and unthinned mature lodgepole pine stands, and to compare the thinned stands that had surface fuel removed to those that did not.

Site description

The research site was located at Bear Lake (1170 m elevation), approximately 22 km west of Kelowna (Figure 1). The research site occurs within the MSdm biogeoclimatic subzone and is characterized by mature lodgepole pine (*Pinus contorta* var. *latifolia*) with a minor component of spruce (*Picea* spp.) and Douglas-fir (*Pseudotsuga menziesii* var. *glauca)*. The lodgepole pine stand originated in 1925 after a stand-replacing fire. Fire scars indicate that a light intensity surface fire occurred in the early 1940s. The terrain throughout the site was generally flat, although the CFS control plot was located on a bench above the CFS thinned site.

Five plots were established by the MOFR or CFS on the research site:[4]

- MOFR control
- CFS control (Figure 2)
- MOFR thinned with no slash removed
- CFS thinned with no slash removed (Figure 3)
- MOFR thinned with slash removed (Figure 4)

Both thinned stands without slash removed were approximately 1 ha and the plot with the slash removed was approximately 0.75 ha. The stands were thinned from below using a single grip harvester. The removal of the logging slash (MOFR plot) was completed in 2000 and was done by hand piling and burning on-site.

Methods

Data collection

Pre- and post-thinning fuel inventories were done by the MOFR and CFS

[4] The site was developed as part of a forestry demonstration for Demo 2000.

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(Holloway 2002). Inventory sampling followed Trowbridge et al. (1989) and included surface litter depth, duff depth, and dead and down woody debris.

Fuel samples were collected for bark flakes (scraped from living tree boles), litter, small twigs (<0.5 cm diameter), large twigs (0.5–1.0 cm diameter), and duff (top 2 cm). Samples were collected at each site and at each ignition test. The samples were oven dried at 65°C for 48 hours to calculate moisture content.[5]

Temperature, wind speed and direction, relative humidity, and rainfall data were compiled from five weather stations. Four weather stations were located within the stands at the CFS sites, and the MOFR control and slash treated sites. The MOFR site without slash treatment was adjacent to the treated site so one station served for both plots. The fifth station was an MOFR fire weather station (Lambly) located within 500 m of the plots and met the requirements for calculating CFFDRS Fire Weather Indices (FWI) (Turner and Lawson 1978).

Figure 3. CFS thinned site with no slash removed.

Figure 4. MOFR thinned site with slash removed.

Figure 5. Ignition test in CFS thinned site with no slash removed.

Ignition trials

Ignition tests were performed on 10 days from June to August 2002. They were performed simultaneously in all plots at randomly selected points, usually at two-hour intervals.

The completion of the following sequence was recorded as one ignition test:

- A lit wooden match was placed on the forest floor.
- If the fire burned beyond the influence of the match and continued for two minutes with visible flames, it was considered a self-sustaining ignition (Figure 5).
- If the fire went out before two minutes, it was considered a failed ignition.
- If the ignition with a single match failed, the trial was repeated with two, three, and four matches, if required, lit simultaneously.

Analysis

Ignition probability was modelled for each study site using logistic regression. This technique modelled the probability of a binary event occurring (no ignition versus sustained ignition) based on a set of explanatory variables (Freund and Wilson 1998). The variables used for the models were fuel moisture (i.e., moisture content of litter, small twigs, large twigs, bark, and duff), weather data, and fire weather indices from the CFFDRS (Van Wagner 1987). The fire weather indices were designed to be calculated from open air weather stations (Turner and Lawson 1978) and only data from the MOFR fire weather station were used for this purpose. The fire weather indices used

5 Moisture content = (wet weight - dry weight)/dry weight.

for the analysis were the Fine Fuel Moisture Code (FFMC) and Initial Spread Index (ISI). The FFMC represents litter moisture content and is based on relative humidity, rainfall, temperature and wind speed (minor component). The ISI is based on FFMC and wind speed. The FWI indices were diurnally adjusted based on hourly readings from the weather station.

The logistic regression was performed as follows:

1. The independent variables were tested for multicollinearity. Significantly correlated variables were not used in the same models.
2. The logistic regression models were run for the independent variables.
3. The above models were evaluated to determine the one that best predicts ignition probability.

The log-likelood chi-square test for model significance (<0.05) and the Wald statistic indicate the significance of an individual variable (<0.05). Comparisons among models were done with the Akiake Information Criterion (AIC). The lowest AIC value indicates the best model, values within 2 points of the lowest score are considered similarly strong models, values within 2–10 points are good predictors, and values greater than 10 are poor predictors. The AIC is not an absolute predictor, but compares the relative strength among models. Finally, the c-statistic indicates the model's ability to assign high probabilities to correct cases compared to incorrect cases (a value of 0.5 indicates the model can do no better than random assignment, and 1 indicates the model assigns higher probabilities to correct cases than to incorrect cases). Data from the thinned sites (no slash removed) and control sites were pooled together since the research plots were in close proximity (within 500 m).

Table 1. Pre- and post-treatment densities at the study sites (Holloway 2002)

Site	Density (stems/ha)	Crown closure (%)
MOFR		
Control	600	40
Thinned and slash removed		
pre-treatment	800	50
post-treatment	350	35
Thinned and no slash removed		
pre-treatment	1450	60
post-treatment	550	25
CFS		
Control	1950	70
Thinned and no slash removed		
pre-treatment	1600	60
post-treatment	400	20

Results and discussion

The thinning treatment removed over half of the trees in the thinned plots (Table 1). Thinning without slash removal increased surface fuel load by 11.6 and 12.9 tonnes per hectare (t/ha) compared to pre-treatment in the MOFR and CFS plots, respectively (Table 2).

Ignition tests

A summary of ignition tests for each site and time of day is given in Table 3. Fewer tests were done at the CFS sites because fire hazard was high and protection personnel were not available to assist. Ignition occurred most often in the thinned sites with no slash removed, and during the mid-afternoon. Table 2 shows that surface fuel loading in the small size classes (less than 0.5 cm and 0.5–1 cm) increased after thinning with no slash removed. Observations during the test ignitions suggested that the abundance of fuels in these size classes contributed to the likelihood of sustained ignition (Figure 5). The two control plots had similar fuel loads compared to the thinned with no slash removed plots but the bulk of the weight came from larger-sized fuels (i.e., greater than 7 cm diameter) (Table 2). These larger fuels did not ignite during the tests.

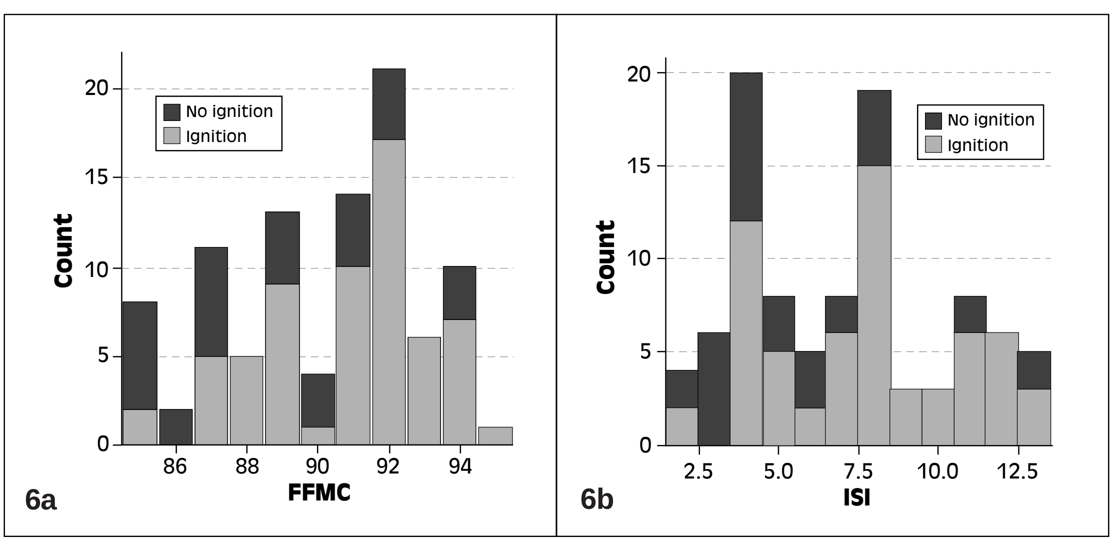
The higher frequency of sustained ignition in the afternoon was expected since fine fuels are driest during the day (Van Wagner 1977). The FFMC values (Figure 6a) during the tests indicated conditions for moderate to easy ignition (Van Wagner 1987). The ISI values in the range shown (Figure 6b) were not expected to result in fire rates of spread above

Table 2. Summary of surface fuel load data and duff depth (Holloway 2002)

	MOFR sites				CFS sites		
		Thinned				Thinned	
	Control	Pre-treatment	Post - slash removed	Post - no slash removed	Control	Pre - treament	Post - no slash removed
Surface fuel load (t/ha)							
<0.5 cm	0.06	0.08	0.09	0.73	0.18	0.21	0.51
0.5–1.0 cm	0.33	0.30	0.03	1.47	1.04	0.40	1.72
1.1–3.0 cm	0.44	0.10	0.68	4.27	2.07	0.83	4.03
3.1–5.0 cm	0.39	0.00	0.00	2.35	2.37	1.37	4.55
5.1–7.0 cm	0.71	0.00	0.35	1.82	3.98	1.80	6.06
>7.1 cm	8.81	0.98	0.51	2.44	18.45	13.55	14.27
Total	10.74	1.46	1.66	13.08	28.09	18.16	31.14
Mean depth (cm)							
Litter	0.9	0.8	0.9	No change	1.2	1.1	No change
Duff	3.3	3.5	2.4	No change	6.8	2.6	No change

Table 3. Number of successful ignitions (number of tests in parentheses)

Local standard time (LST)	Control sites		Thinned sites			Total
	MOFR	CFS	MOFR- no slash removed	MOFR- slash removed	CFS- no slash removed	
0600	0 (3)	0 (2)	0 (3)	0 (3)	0 (2)	0 (13)
0800	0 (5)	1 (4)	1 (5)	0 (5)	0 (4)	2 (23)
0900	0 (1)	0 (1)	0 (1)	0 (1)	1 (1)	1 (5)
1000	1 (8)	0 (7)	3 (8)	0 (8)	4 (7)	8 (38)
1100	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)	0 (5)
1200	2 (9)	0 (9)	5 (9)	1 (9)	8 (9)	16 (45)
1400	0 (7)	2 (7)	6 (7)	3 (7)	5 (7)	16 (35)
1500	0 (1)	0 (1)	0 (1)	0 (1)	1 (1)	1 (5)
1600	0 (5)	0 (5)	5 (5)	1 (5)	4 (5)	10 (25)
1800	1 (1)	0 (1)	0 (1)	1 (1)	0 (1)	2 (5)
Total	4 (41)	3 (38)	20 (41)	6 (41)	23 (38)	56 (199)



Figures 6a and 6b. Ignition count as a function of FFMC and ISI values for the MOFR with no slash removed and CFS thinned sites (pooled data).

6 m/min for a mature lodgepole pine fuel type (C3); however, an intermittent crown fire could occur if fuels were dry enough (Taylor et al. 1997). The relative humidity (Figure 7a) and temperature (Figure 7b) trends followed normal patterns and this weather trend was reflected in the moisture content of dead and down surface fuels (Figures 8a and 8b).

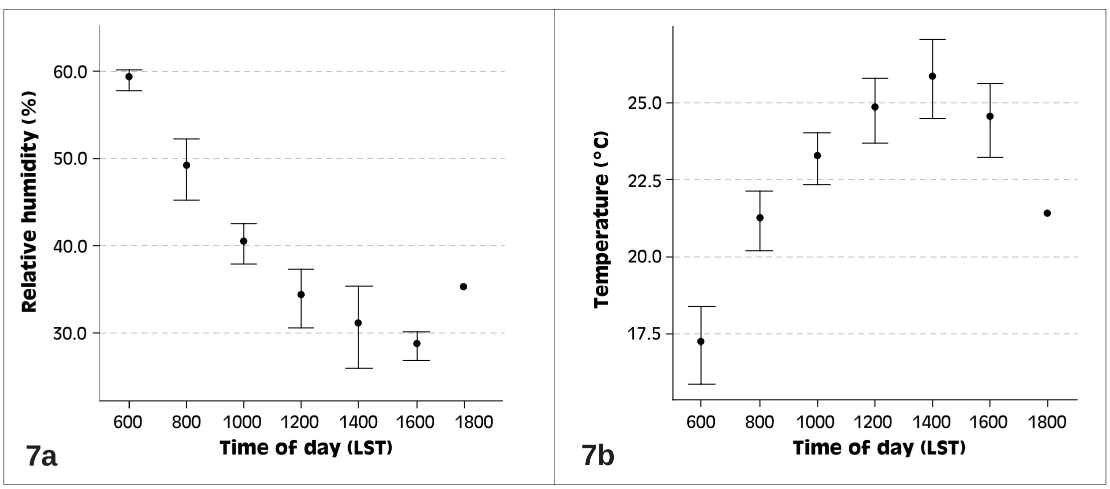
Ignition probability

The logistic regression for the control and thinned with slash removed datasets did not result in models where the independent variables significantly improved ignition probability compared to a random model. Results from these data were not useful for predicting ignition; however, other models have been developed for pine forest fuel types (see Lawson et al. 1993 and Beverly and Wotton 2005).

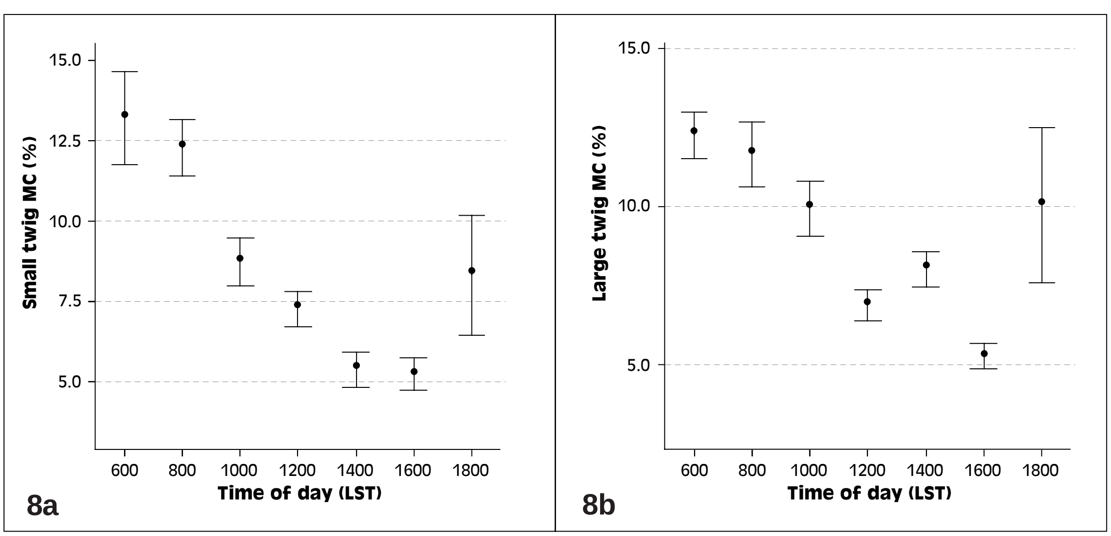
Predicting ignition for the thinned with no slash removed plot was successful (Table 4). Correlation indicated a significant relationship among all of the variables except the bark and duff moisture contents. Therefore, all of the explanatory variables were modelled independently. Bark and duff were combined with the other variables but did not improve any of the models.

Table 4 shows that relative humidity is the best predictor for ignition probability, as it had the lowest AIC score. Based on the AIC difference, the twig moisture content variables are good substitute predictors, but the FFMC and ISI are not recommended in place of relative humidity even though the models were statistically significant.

Relative humidity does not account for rainfall. Concern over ignition is not likely to be high following rainfall, but practitioners may prefer to use the FFMC or ISI models,



Figures 7a and 7b. Relative humidity and temperature values taken during the ignition tests. Values are mean +/- standard error.



Figures 8a and 8b. Moisture content of small twigs and large twigs during the ignition tests. Values are mean +/- standard error.

Table 4. Logistic regression summary for thinned lodgepole pine with no slash removed

Model variables	Model chi-square test	Wald statistic	AIC	AIC difference	c-statistic
Relative humidity	<0.001	<0.001	74.989		0.885
Large twig MC	0.001	0.002	77.180	2.191	0.874
Small twig MC	<0.001	<0.001	81.446	6.457	0.861
Temperature	<0.001	<0.001	83.079	8.090	0.860
Litter MC	<0.001	<0.001	97.131	22.142	0.843
FFMC	0.001	0.001	111.836	36.847	0.719
ISI	0.001	0.002	112.338	37.349	0.704
Bark MC	0.078	0.115	113.351	38.362	0.752
Duff MC	0.447	0.446	117.683	42.694	0.558

Equations for significant models:

1) Relative humidity $P = 1 / 1 + e^{-(7.359 - 0.173 \text{ Rh})}$

2) Large twig MC $P = 1 / 1 + e^{-(5.475 - 0.537 \text{ large twig MC})}$

3) Small twig MC $P = 1 / 1 + e^{-(4.636 - 0.467 \text{ small twig MC})}$

4) Litter MC $P = 1 / 1 + e^{-(2.908 + -0.227 \text{ litter})}$

5) FFMC $P = 1 / 1 + e^{-(-25.05 + 0.287 \text{ FFMC})}$

6) ISI $P = 1 / 1 + e^{-(1.013 + 0.258 \text{ ISI})}$

Table 5. Ignition probability for thinned lodgepole pine pooled data using relative humidity values

Relative humidity	Ignition probability value	Ignition probability class
12	0.99	High
14	0.99	High
16	0.99	High
18	0.99	High
20	0.98	High
22	0.97	High
24	0.96	High
26	0.95	High
28	0.93	High
30	0.90	High
32	0.86	High
34	0.81	High
36	0.76	High
38	0.69	Medium
40	0.61	Medium
42	0.52	Medium
44	0.44	Low
46	0.35	Low
48	0.28	Low
50	0.22	Low
52	0.16	Low
54	0.12	Low
56	0.09	Low
58	0.06	Low
60	0.05	Low
62	0.03	Low

which do account for rainfall, in some conditions.

Equation 1 was used to generate a lookup table (Table 5) that can be used by fire operations staff. Lawson and Dalrymple (1996) developed similar tables for other fuel types and designated low, medium, and high ignition classes based on 0–49, 50–75, and 76–100 per cent ignition probability, respectively. Using the same class divisions for Table 5 indicates that relative humidity values below 42 can result in at least medium ignition probability.

The ignition tests were done within three years of thinning. No conifer regeneration had established and grass and shrub abundance was minimal. Ignition probability might change over time depending on stand dynamics. However, persistence of logging slash, especially elevated fine fuels, will result in continuous hazard (Fahnestock and Dieterich 1962).

Conclusions

Sustained ignition occurred more frequently on the sites with available fine fuels (i.e., thinned with no slash removed) and during the afternoon, as was expected. The difference in ignition frequency between sites with slash removed and with no slash removed demonstrates the value of debris disposal following thinning as a means of reducing ignition potential.

Ignition probability models were generated for thinned lodgepole pine sites with no slash removed using relative humidity values. Sustained ignition can be expected to occur on these sites when relative humidity falls below 30%. Fine fuel moisture codes recorded during the tests suggested moderate to easy conditions for sustained ignition according to the CFFDRS FWI System. Models for control and thinned with slash removed sites were not used because the independent variables did not result in better precision compared to a random model. However, it is important to recognize that ignitions did still occur on these sites.

Implementation

The results of this study can be used operationally for thinned lodgepole pine stands with no slash removed. For example, firefighters can use Table 5 to relate relative humidity and the initial spread index to the likelihood of a sustained ignition from a small ignition source such as a match. Practitioners should keep in mind that the tests were done three years after thinning, and that surface fuel load and physical arrangement, along with ignition probability, may change over time. Other models are being developed by FERIC for commercially thinned white spruce stands.

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