

Probabilities of Sustained Ignition in Lodgepole Pine, Interior Douglas-fir, and White Spruce- Subalpine Fir Forest Types

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Introduction

Tables of sustained ignition probabilities are presented for four benchmark forest fuel types: dry- and moist-site lodgepole pine, white spruce-subalpine fir, and interior Douglas-fir. The look-up tables were derived from logistic regression equations that were fit to hundreds of small-scale match-fire and campfire observations made near Prince George and 100 Mile House, B.C. by Canadian Forest Service fire researchers. The field research studies were carried out in the 1950s and 1960s as part of the early development of the Canadian Forest Fire Danger Rating System, but the original data have been re-analyzed using current versions of components of the Canadian Forest Fire Weather Index System as predictors of ignition probability.

A complete scientific and technical description of the development of the lodgepole pine and spruce-subalpine fir equations is given in Lawson *et al.* (1994a), and is illustrated in a wall poster (Lawson *et al.* 1994b) as graphs with colour photos of the forest types. A computer application (Lawson *et al.* 1996) links these same equations with a new diurnal Fine Fuel Moisture Code program (Lawson, Armitage and Hoskins 1996). Derivation of the interior Douglas-fir equation is presented in the Appendix.

The following four equations are used to calculate the ignition probabilities presented in tables S1.1-S1.4:

Dry lodgepole pine
$$P = 1 / (1 + \exp(2.107 - 0.727 * ISI)) \dots\dots\dots S1.1$$

Moist lodgepole pine
$$P = 1 / (1 + \exp(2.146 - 0.009 * BUI - 0.349 * ISI)) \dots S1.2$$

White Spruce - subalpine fir
$$P = 1 / (1 + \exp(2.766 - 0.005 * DC - 0.396 * ISI)) \dots S1.3$$

Interior Douglas-fir
$$P = 1 / (1 + \exp(1.563 - 0.005 * BUI - 0.478 * ISI)) \dots S1.4$$

Probability of sustained ignition is not a standard output from the Canadian Forest Fire Behavior Prediction (FBP) System (Forestry Canada Fire Danger

Group 1992), but is included here as a supplement for the convenience of users. Potential uses include gauging the likelihood of fire starts or fire arrivals for preparedness planning of initial attack crew positioning and readiness, and judging spot-fire ignition potential for wildfires or prescribed fires. The ignition probabilities described here relate to the probability of an ignition from small fire brands, such as matches or camp fires persisting with flaming combustion (for at least 2 minutes for match fires and 15 minutes for campfires) and reaching the threshold condition for fire spread and growth. Camp fires were necessary for sustained ignition in the white spruce-subalpine fir forest type. Matches and camp fires were both potentially successful fire brands in the other forest types, depending on burning conditions.

Use of the Tables

The following steps form the procedure for using the Ignition Probability Tables (Table and Appendix numbers refer to Taylor *et al.* 1996).

1. Select the most appropriate forest type and/or variant from the four presented.

Detailed forest type descriptions and a photograph accompany each ignition probability table. Ignition probability differences among variants within a single FBP System fuel type should be expected. The “dry” and “moist” lodgepole pine forest types can be considered variants of C-3 (Mature Jack or Lodgepole Pine). The interior Douglas-fir forest type should be considered a variant of C-7 (Ponderosa pine - Douglas-fir). The white spruce-subalpine fir forest type can be considered a variant of C-2 (Boreal spruce), as shown by DeGroot (1993).

2. Determine the most representative Fine Fuel Moisture Code (FFMC), 10-m open wind speed, and Initial Spread Index (ISI) for the time of interest.
 - a) The hourly FFMC (Van Wagner 1977) should be used, if available. Alternatively, the diurnal FFMC (Tables A.1 - A.2, Appendix 5) may be used for any desired time of the day. The daily standard FFMC may be used to represent mid-afternoon (16:00 hr LST) conditions.

- b) Wind speed at 10 m in the open should be measured, forecasted, or estimated from the Beaufort Scale (Appendix 4) for the time of interest.
- c) For the “Dry” Lodgepole Pine forest type, enter Table S1.1 with FPMC and 10-m wind speed from 2a and 2b, above.

For other forest types and/or variants, determine the ISI using Table 3, with FPMC and 10-m open wind speed from 2a and 2b, above.

- 3. Determine the Buildup Index (BUI) or Drought Code (DC) from the nearest representative weather station, as required for a given forest type.
- 4. From the ignition probability table for the forest type of interest, find the probability-of-ignition value (%) at the intersection of the two required input values. Probability-of-ignition classes (low, medium, high) are differentially shaded in the body of each table.

References

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“Dry” lodgepole pine forest-type characteristics

- * Pure, moderately dense stands of mature lodgepole pine;
- * scattered pine understory;
- * sandy well-drained soils, low-productivity sites dominated by feather-moss and *Cladina* (lichen); B.C. biogeoclimatic classification SBSmk1/03 is typical;
- * forest floor shallow (3-5 cm), low bulk density; and
- * fire-carrying fuels - lichen, bearberry (*Arctostaphylos uva-ursi*), feathermoss (*Pleurozium schreberi*; *Dicranum* spp.), needle litter.



Table S1.1

“Dry” lodgepole pine forest type - probability of sustained ignition (%) and ignition class

		10-m Open Wind Speed (km/h)										
FFMC		0	5	10	15	20	25	30	35	40	45	≥50
70		16	18	21	24	30	38	49	63	79	91	97
72		17	19	21	26	32	40	53	68	82	93	98
74		17	19	23	27	34	44	57	73	87	95	99
76		18	21	24	30	38	49	64	79	91	97	99
78		19	23	27	34	44	58	73	87	95	99	100
80		22	26	32	41	54	69	84	94	98	100	100
82		26	32	40	52	68	82	93	98	100	100	100
84		32	40	53	68	83	93	98	100	100	100	100
86		41	54	69	84	94	98	100	100	100	100	100
88		56	71	85	95	99	100	100	100	100	100	100
90		73	87	95	99	100	100	100	100	100	100	100
92		88	96	99	100	100	100	100	100	100	100	100
94		97	99	100	100	100	100	100	100	100	100	100
96		99	100	100	100	100	100	100	100	100	100	100
≥98		100	100	100	100	100	100	100	100	100	100	100

Ignition		Probability %
	Class	
	LOW	0-49
	MEDIUM	50-75
	HIGH	76-100

“Moist” lodgepole pine forest-type characteristics

- * Mixed, well-stocked stands of mature lodgepole pine-Douglas-fir;
- * significant understory of lodgepole pine, trembling aspen, white spruce, and subalpine fir;
- * moderately well-drained soils typically derived from unstratified glacial deposits, medium site productivity, *Cornus canadensis* (bunchberry), scattered *Cladina* (lichen), feather mosses, and *Vaccinium membranaceum* (black huckleberry); B.C. biogeoclimatic classification SBSmk1/05 is typical;
- * forest floor shallow (3-5 cm), low bulk density; and
- * fire-carrying fuels - feather moss, needle litter.



Table S1.2

“Moist” lodgepole pine forest type - probability of sustained igniton (%) and ignition class.

Buildup Index (BUI)

ISI	0	21	31	41	61	81	121	161
	20	30	40	60	80	120	160	200
0.5	13	15	16	18	21	26	33	41
1	15	17	19	21	24	29	37	46
1.5	18	20	21	24	27	33	41	50
2	20	23	24	27	31	37	45	54
2.5	23	26	28	31	34	41	50	59
3	27	29	31	34	38	45	54	63
4	34	37	39	43	47	54	62	70
5	42	46	48	51	56	62	70	77
6	51	54	57	60	64	70	77	83
7	60	63	65	68	72	77	83	87
8	68	70	72	75	78	82	87	91
9	75	77	79	81	84	87	91	93
10	81	83	84	86	88	90	93	95
11	86	87	88	90	91	93	95	96
12	89	91	91	92	94	95	96	97
13	92	93	94	94	95	96	97	98
14	94	95	95	96	97	97	98	99
15	96	96	97	97	98	98	99	99
18	99	99	99	99	99	99	100	100

Ignition Class		Probability %
	LOW	0-49
	MEDIUM	50-75
	HIGH	76-100

White spruce-subalpine fir forest-type characteristics

- * Mixed, moderately dense stands of mature white (and/or Engelmann) spruce-subalpine fir, with scattered mature birch and Douglas-fir;
- * significant understory of subalpine fir;
- * soils range from loamy sands to sticky, poorly drained clays on moderately well-drained to imperfectly drained sites; herb and shrub layers dominated by *Aralia nudicaulis* (sarsaparilla), *Gymnocarpium dryopteris* (oak fern), *Vaccinium* (huckleberry) and *Cornus* (bunchberry) spp., *Oplopanax horridus* (devil's club) on wettest sites; mosses patchy; B.C. biogeoclimatic classification SBSmk1/07 (drier) and SBSmk1/08 (wetter) are typical;
- * forest floors moderate to deep (6-12 cm), moderate to high bulk density; and
- * fire-carrying fuels - litter, feather moss.



Table S1.3

White spruce - subalpine fir forest type - probability of sustained ignition (%) and ignition class

		Drought Code (DC)							
		0	101	201	301	401	501	601	701
ISI		100	200	300	400	500	600	700	800
0.5		9	14	21	31	42	55	66	77
1		11	17	25	35	47	59	71	80
1.5		13	19	28	40	52	64	75	83
2		15	23	33	44	57	68	78	86
2.5		18	26	37	49	62	73	81	88
3		21	30	42	54	66	76	84	90
4		28	39	52	64	74	83	89	93
5		37	49	61	72	81	88	92	95
6		47	59	70	80	87	91	95	97
7		56	68	78	85	91	94	96	98
8		66	76	84	90	93	96	97	98
9		74	82	89	93	95	97	98	99
10		81	87	92	95	97	98	99	99
11		86	91	94	97	98	99	99	100
12		90	94	96	98	99	99	99	100
13		93	96	97	98	99	99	100	100
14		95	97	98	99	99	100	100	100
15		97	98	99	99	100	100	100	100
18		99	99	100	100	100	100	100	100

Ignition Class

LOW

MEDIUM

HIGH

Probability %

0-49

50-75

76-100

Interior Douglas-fir forest-type characteristics

- * Well-stocked stands of interior Douglas-fir of varying age classes, including large, mature overstory trees with a significant understory;
- * forest floor shallow (less than 3 cm); and
- * fire-carrying fuels - grass covers the ground except under fir thickets, where needle litter and patchy moss predominates. Grass is assumed to be greater than 50% cured (dead), although the degree of curing is not a variable used in the ignition probability model.



Table S1.4
Interior Douglas- fir - probability of sustained ignition (%) and igni-
tion class

		Buildup Index (BUI)							
		0 20	21 30	31 40	41 60	61 80	81 120	121 160	161 200
ISI		22	23	24	25	27	30	35	40
0.5		22	23	24	25	27	30	35	40
1		26	28	29	30	32	36	40	45
1.5		31	33	34	36	38	41	46	51
2		36	38	39	41	44	47	52	57
2.5		42	44	45	47	50	53	58	63
3		48	50	51	53	56	59	64	68
4		60	62	63	65	67	70	74	78
5		71	72	73	75	76	79	82	85
6		79	81	81	83	84	86	88	90
7		86	87	88	88	89	91	92	94
8		91	92	92	92	93	94	95	96
9		94	95	95	95	96	96	97	97
10		96	97	97	97	97	98	98	98
11		98	98	98	98	98	99	99	99
12		99	99	99	99	99	99	99	99
13		99	99	99	99	99	99	100	100
14		99	99	100	100	100	100	100	100
15		100	100	100	100	100	100	100	100

	Ignition	
	Class	Probability %
	LOW	0-49
	MEDIUM	50-75
	HIGH	76-100

APPENDIX

Derivation of the Interior Douglas-fir Ignition Probability Table S1.4

Background

The equation for probability of sustained ignition used to produce Table S1.4 was derived from analysis of a data set collected during the years 1957-1959 near 100 Mile House, B.C. by Dr. P.M. Paul, now retired research scientist, Canadian Forest Service. The test-fire program there resulted in publication of the Cariboo, British Columbia, Forest Fire Danger Tables in 1965, while the study sites themselves were described in detail in annual progress reports,¹ which were used for decisions about data selection for the present analysis and for the site photograph.

The data for site BC-801 were obtained from a national data base on test fires conducted in Canada between 1931-1961 as part of a Canadian forest Service program of regional forest fire danger table development, which preceded the present national fire danger rating system. The test fire data base, consisting of some 20 000 fires, has been edited, merged with current version FWI System component values, and assembled in modern computer formats, as described by T. Lynham.²

¹ Paul, P.M. 1957, 1958, 1959. Progress report on forest fire research, 100 Mile House, B.C., Can. For. Serv., For. Fire Res. Inst., File No. 668. Ottawa, Ont.

² Lynham, T.J. and D.L. Martell. 1989. Preliminary report on a national database of experimental fires in Canada. P41-44 in: Proc. National Workshop on forest fire occurrence prediction, May 3-4, 1989, Winnipeg, Man.

Lynham, T.J. 1992. Summary of data manipulations to Forestry Canada's 20 000 test-fire data base for addition of Can. FWI values. Rep. On file, GLFC, Sault Ste. Marie, Ont.

Analysis of 100 Mile House data

Data analysis followed the same steps described by Lawson *et al.* (1994a). Two suitable study sites were chosen for characterization as “interior Douglas-fir” from the nine available; specifically, forest type “D-1, Fir-grass/ moss” (site code 80104) and “D-4, Fir- grass/ needle” (site 80107) (photo of D-4 included with Table S1.4). Site descriptions are included here as they were presented in Paul (1957):

Site D1 – Douglas-fir in varying age classes. Large mature fir predominates, but there is an abundance of older immature (81-120 years) with well-established young growth in understory...

Intermingled with the grass, which is ubiquitous except under the trees, are patches of moss...

Site D4 – is located on the southwest slope of the ridge at a slightly lower elevation than D1, which occurs on a bench near the summit of the hill. It is well stocked, with the fir trees attaining a very good size, although smaller than the mature and overmature trees of D1. Young reproduction, up to 4 feet, is extensive, and there is a fairly complete ground cover of grass, although it is continuously broken by patches of fir needles.

Paul (1957, 1958, and 1959) reported progression of grass curing through the test-fire seasons. Curing started in late May 1957 as 75-80%, decreasing to 35- 45 % by mid- July, and increasing again during September to about 70 % by late September. However, in 1958 (a drier summer) grass was 75-85% cured by late August. Grass curing could not be analyzed as an independent variable in the model, but an assumption could be made that test fires were usually conducted when grass was 50% or more cured.

Before the test-fire data were analyzed for the two sites, diurnally adjusted FFMC and ISI were calculated for each test fire using the diurnal FFMC program from Lawson, Armitage and Hoskins (1996) and the noon 10-m open wind speed recorded at the headquarters weather station. A dependent binary variable, “ignition”, was defined as “yes” if the burned area for match fires was more than 0.30 ft², and “no” if less than or equal to 0.30 ft². This area criterion was chosen arbitrarily after inspecting the data and comparing them with results from a separate analysis on “vigor” class (on file, Pacific Forestry Centre). While the burned-area threshold for successful ignition

was larger than the 0.05 ft² used by Lawson *et al.* (1994a) for lodgepole pine match fires, the interior Douglas-fir forest types were faster spreading, being grass dominated.

Logistic regression was used to develop a preliminary model of “ignition” as predicted from diurnally adjusted FFMC, DMC, DC, ISI, and BUI. A total of 391 match fires (no camp fires) were available from sites D-1 and D-4 combined, with all D-1 fires recording an area greater than 0, while 80% of D-4 fires burned an area greater than 0.

A logistic regression equation that included ISI and BUI produced the statistically best results from the two independent variables (adding DMC increased the *r*² and total correct statistics slightly). The equation for probability of sustained ignition in interior Douglas-fir is

$$P = 1 / (1 + \exp (1.563 - 0.005 * \text{BUI} - 0.478 \text{ ISI}))$$

The equation is plotted in three dimensions in Figure 1, and Table 1 summarizes the observed and expected outcomes by decile and overall goodness-of-fit.

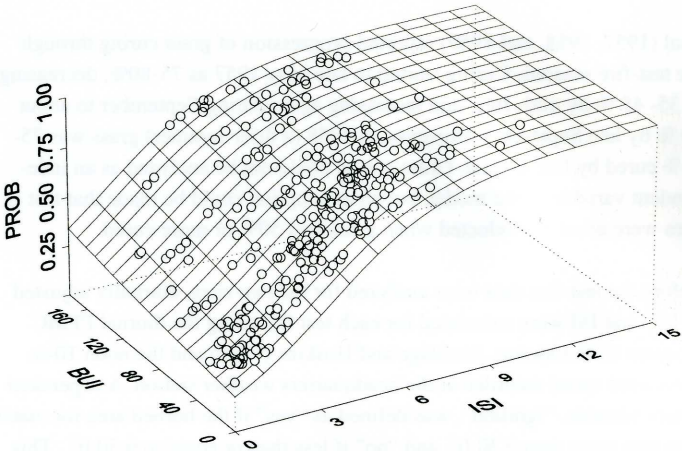


Figure 1. Probability of sustained ignition vs. Initial Spread Index (ISI) and Buildup Index (BUI) for interior Douglas-fir forest type. Plotted points represent test fires from sites D1 and D4, 100 Mile House, B.C.

Table 1. Logistic regression statistics: observed and expected outcomes by decile, overall goodness-of-fit, and success of prediction by the model, interior Douglas-fir forest type.

P	P	Total	<u>Ignition</u>		<u>No Ignition</u>		χ^2	P-value	R ²
Upper Limit	Avg.	Fires	Obs.	Exp	Obs.	Exp	(8 df)		
0.307	0.262	38	13	10.0	25	28.0			
0.414	0.350	39	17	13.7	22	25.3			
0.589	0.509	40	16	20.4	24	19.6			
0.657	0.616	39	18	24.0	21	15.0			
0.743	0.704	39	27	27.5	12	11.5			
0.790	0.766	38	29	29.1	9	8.9			
0/843	0.820	40	36	32.8	4	7.2			
0.883	0.860	39	36	33.5	3	5.5			
0.923	0.902	38	35	34.3	3	3.7			
1.000	0.947	41	37	38.8	4	2.2			
							13.1	0.106	0.189

Success of prediction by the model

	Ignition Predicted	No Ignition Predicted	Total
Ignition	197.6	66.4	264
No Ignition	66.4	60.6	127
Predicted Total	264.0	127.0	391
Proportion Correct	0.749	0.477	
Total Correct	0.661		
Success Index	0.073	0.153	