FIRE BEHAVIOR AND FUEL CONSUMPTION IN JACK PINE SLASH IN ONTARIO

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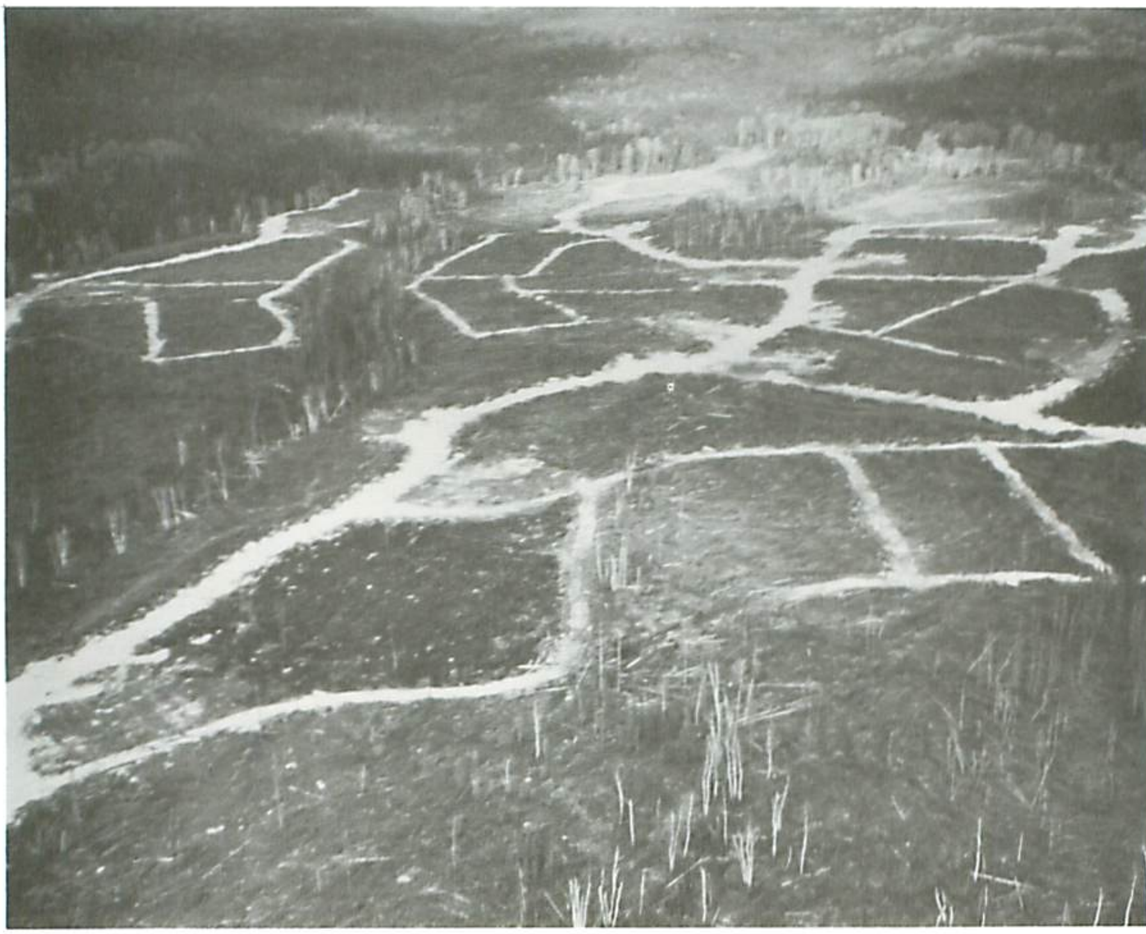
The capable and continuing assistance of the Ontario Ministry of Natural Resources (formerly the Ontario Department of Lands and Forests) in the conducting of these experimental fires is gratefully acknowledged. Sincere appreciation goes to those members of the Matheson Division fire staff (Swastika District) who ignited and suppressed all experimental burns.



Frontispiece. Aerial view of 12 jack pine slash plots burned on Area 2 in 1970 and 1971.

ABSTRACT

Results and analysis of 24 1-acre experimental fires in jack pine logging slash are presented. The behavior parameters, such as intensity, rate of spread and fuel consumption, and their relationship to fire weather are discussed in detail.

TABLE OF CONTENTS

INTRODUCTION

Controlled burning of jack pine [*Pinus banksiana* Lamb. (= *P. divaricata* (Ait.) Dumont)] logging slash is carried out by the Ontario Ministry of Natural Resources (formerly the Ontario Department of Lands and Forests) in many areas of northern Ontario to facilitate subsequent scarification and planting of both conventional stock and container seedlings. The use of fire to remove organic forest floor material in preparation for natural or artificial seeding of jack pine has been investigated in the past (Chrosciewicz 1959, 1967). However, research on fire behavior in jack pine slash, with a view to predicting rate of spread, fuel consumption, and intensity in this hazardous fuel type, has been nonexistent.

During the 1970 and 1971 fire seasons, 24 experimental fires, each 1 acre in size, were conducted in jack pine slash in northeastern Ontario. The relationship between weather conditions, as expressed by the Canadian Forest Fire Weather Index (Anon. 1970) and its component indexes, and fire behavior and fuel parameters measured on the fire sites was studied in detail and the results are reported here. A burning index for this fuel type (Stocks 1971), based on these data, will be developed for use during the 1972 fire season. After calculating the daily Fire Weather Index (FWI), the fire control officer in the field will be able to predict, using this burning index, a fire's intensity, rate of spread, and fuel consumption--should one start in jack pine slash on that day. Data from these fires will also be used to supplement that used in developing a forest fuel classification system for Ontario (Walker 1971).

In the future, controlled fires will be carried out to classify major Ontario forest types in terms of fire behavior and to develop burning indexes for these types. Experimental burning in jack pine stands is scheduled to begin in 1972.

DESCRIPTION OF AREAS

The experimental fires were carried out in Garrison and Tolstoi Townships in northeastern Ontario, 25 miles east and 20 miles south of Matheson, respectively. The burning sites were situated on flat, well-drained sandy soils with a typical podzolic profile.

Two areas were located in Garrison Township with seven plots being burned on Area 1 and two on Area 2 in 1970. Ten remaining plots on Area 2 were burned in 1971 along with five plots (Area 3) in

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Tolstoi Township. Stand characteristics before logging are listed in Table 1.

Table 1. Stand characteristics before logging

	Avg age (yr)	Avg stump diam (in.)	Avg no. stems/acre	Avg ht (ft)	Species composition	Avg % stocking	Avg stump basal area (sq ft)
Area 1	80	6.03	754	60	jP 90%,bS 10%	90	161.9
Area 2	80	6.60	685	60	jP 80%,bS 20%	80	177.6
Area 3	55	4.74	1180	55	jP 100%	90	158.0

Area 1 was a portion of a 2000-acre jack pine cutover, logged for pulp in the winter of 1969. Area 2 was part of a 150-acre block clear cut in late 1968, while Area 3 was clear cut in the winter of 1970-71. Virtually all needles were retained on the jack pine slash burned in Area 3, while jack pine residue in Areas 1 and 2 retained a fair percentage of needles and black spruce [*Picea mariana* (Mill.) B.S.P.] slash was needleless. Firelines 8 feet wide were cleared by hand for the initial seven burns, with a bulldozer being used to construct 16-foot firelines around the last 17 burn areas. Each slash plot was 1 acre in area (2 x 5 chains) and plot orientation was generally in an east-west direction, to take advantage of prevailing winds from the westerly quadrat.

FUEL DESCRIPTION

Weights of all slash fuels on each plot were determined before and after each burn, using the line-intersect sampling technique (Van Wagner 1968). In the case of the first nine burns (1970), the total length of line sampled on each plot was 3 chains, in the form of a 2- x 1-chain cross intersecting at the center of the plot. The diameter of any piece of slash crossed by the 3-chain line was tallied. The sampling procedure was changed somewhat for the remaining 15 plots, burned in 1971, to reduce the chance of error owing to orientation of slash pieces. Six 100-foot lines radiating at 60° from the center of each plot were laid out and all material greater than 2 inches in diameter was tallied along the full length of each line. Fifty-foot and 5-foot sections on each line were used to tally fuel sizes of 1/2 to 2 inches, and up to 1/2 inch, respectively. In some cases the lines were shorter than 100 feet because of interference from fire line construction on the plot edges.

Organic layer loading and depth were determined from 27 1-square-foot samples removed at points located on a 1/2-chain grid pattern throughout each plot.

Tables 2(a), 2(b), and 2(c) show the distribution of initial fuel loading for plots on Areas 1, 2, and 3, respectively. Slash fuel weights for different size classes are expressed in tons per acre and duff depths and weights are included.

Table 2a. Distribution of initial fuel loading: Area 1

Plot no.	Slash fuel, T/acre, and % total slash weight						Total slash weight T/acre	Duff	
	0-1/2"	1/2-1"	1-2"	2-3"	3-4"	> 4"		Depth (in.)	Weight (T/acre)
1/70	2.83 17.3%	0.94 5.7%	1.35 8.3%	2.22 13.9%	2.80 17.5%	6.10 37.3%	16.24	2.63	35.50
2/70	3.02 17.5%	1.00 5.8%	1.83 10.6%	2.72 15.6%	5.28 30.5%	3.49 20.0%	17.34	2.91	40.07
4/70	3.70 15.0%	0.86 3.5%	1.57 6.4%	5.26 21.3%	5.97 24.2%	7.31 29.6%	24.67	2.81	38.55
5/70	2.77 13.7%	0.86 4.2%	1.37 6.8%	2.40 11.8%	5.47 27.1%	7.37 36.4%	20.24	3.01	41.82
6/70	3.53 14.3%	1.20 4.9%	1.83 7.5%	6.19 24.8%	6.69 27.2%	5.26 21.3%	24.70	2.76	37.68
7/70	2.48 14.7%	0.96 5.7%	0.96 5.7%	3.00 18.2%	4.82 28.7%	4.44 26.9%	16.66	3.14	45.30
8/70	3.52 17.7%	1.24 6.3%	1.32 6.6%	2.88 14.5%	4.25 21.4%	6.67 33.5%	19.88	3.10	44.87

Table 2b. Distribution of initial fuel loading: Area 2

Plot no.	Slash fuel, T/acre, and % total slash weight 0-1/2"	1/2-1"	1-2"	2-3"	3-4"	> 4"	Total slash weight T/acre	Duff Depth (in.)	Duff Weight (tons/acre)
9/70	3.45 10.5%	1.32 4.9%	1.32 4.2%	2.60 11.2%	3.91 14.7%	7.40 37.0%	20.00	3.07	44.87
10/70	4.23 17.2%	1.03 4.3%	1.02 4.3%	2.70 10.7%	7.42 30.1%	8.20 33.4%	24.62	2.62	36.37
1/71	3.37 10.5%	1.52 4.9%	1.32 4.2%	3.45 11.2%	4.61 14.7%	17.02 54.5%	31.29	3.85	33.76
2/71	1.62 5.0%	1.52 5.0%	1.30 4.3%	2.99 10.0%	5.47 17.9%	17.63 57.8%	30.53	4.30	50.53
3/71	2.40 10.1%	1.07 4.6%	0.82 3.7%	2.82 11.9%	4.58 19.3%	12.05 50.4%	23.74	2.75	41.38
4/71	2.83 5.4%	1.72 3.3%	1.49 2.9%	3.33 6.2%	6.45 12.4%	36.80 69.8%	52.62	2.85	38.77
5/71	2.61 12.4%	0.82 4.1%	1.46 7.2%	1.17 5.7%	4.01 19.0%	11.03 51.6%	21.10	3.40	43.34
6/71	4.01 14.7%	0.65 4.2%	1.51 5.7%	3.89 14.6%	7.01 26.2%	9.51 34.6%	26.58	3.13	37.24
7/71	2.54 10.7%	0.89 3.6%	0.91 3.6%	2.46 9.8%	3.97 16.1%	13.57 56.2%	24.34	2.89	36.81
8/71	2.35 10.3%	1.09 4.7%	1.09 4.7%	3.25 14.1%	5.21 22.4%	10.25 43.8%	23.24	3.99	43.78
9/71	2.87 10.4%	1.36 4.8%	0.91 3.2%	2.65 9.6%	5.70 20.8%	13.62 51.2%	27.11	2.53	36.15
10/71	2.97 13.7%	1.09 4.9%	0.65 2.9%	2.57 11.8%	4.61 20.6%	10.37 46.1%	22.26	2.35	29.40

Table 2c. Distribution of initial fuel loading: Area 3

Plot no.	Slash fuel, T/acre, and % total slash weight 0-1/2"	1/2-1"	1-2"	2-3"	3-4"	> 4"	Total slash weight T/acre	Duff Depth (in.)	Duff Weight (tons/acre)
11/71	2.79 12.5%	1.27 5.7%	2.78 12.5%	6.44 28.4%	6.86 29.4%	2.54 11.5%	22.68	2.17	17.64
12/71	1.97 10.1%	1.24 6.7%	2.72 14.6%	5.29 27.0%	5.79 30.3%	2.35 12.3%	19.36	2.07	24.18
13/71	2.79 7.2%	1.75 4.5%	2.84 7.3%	7.80 20.2%	12.72 32.2%	10.76 27.0%	38.66	2.17	22.22
14/71	3.99 16.5%	1.78 7.3%	3.76 15.6%	5.55 22.9%	6.15 25.7%	2.48 10.1%	23.71	1.88	22.65
15/71	3.23 20.7%	1.14 7.3%	2.43 15.5%	4.54 29.0%	3.38 21.6%	0.93 5.9%	15.65	2.11	20.04

The distribution of initial slash fuel loading by size class, averaged within each of the three areas, is presented in graph form in Figure 1.

Four parameters useful in fully describing the physical characteristics of a fuel complex (Muraro 1968) are shown in Table 3, where the average weight, volume, surface area, and fineness of each fuel size class are shown for Areas 1, 2, and 3.

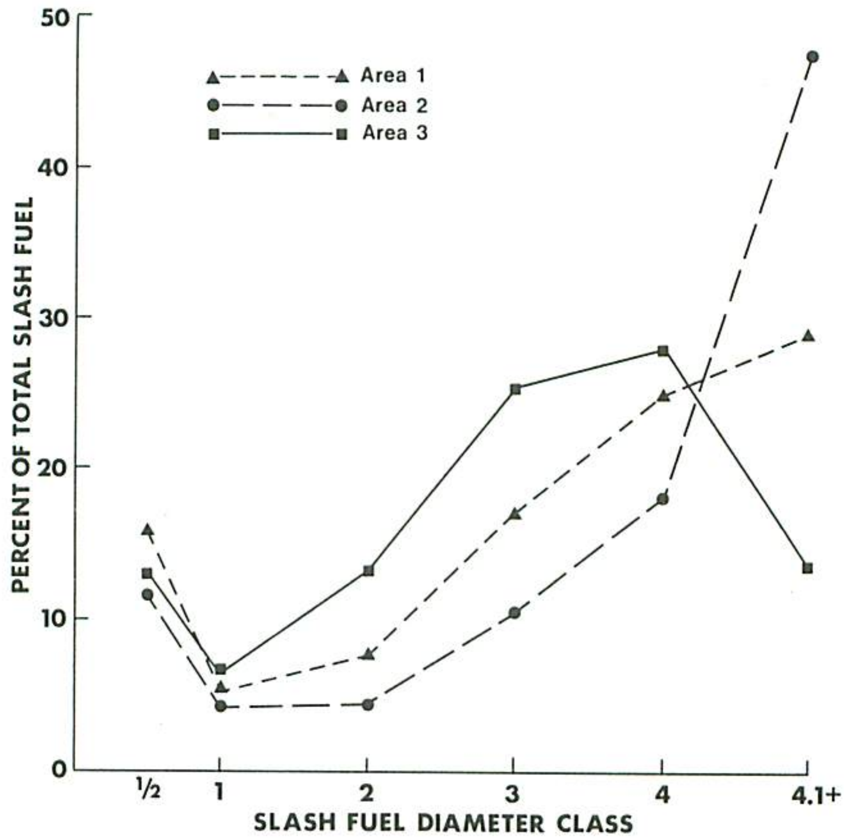

Figure 1. Distribution of initial slash fuel loading by size class.

Table 3. Average, by diameter classes, of weight, volume, surface area, and fineness of slash fuel for each area

Fuel class	Avg wt lb/ft^2	Avg vol ft^3/ft^2	Avg surface area ft^2/ft^2	Avg fineness ft^2/ft^3
Area 1				
0-1/2	0.14	0.36	1.31	3.63
1/2-1	0.05	0.12	0.11	0.97
1-2	0.07	0.17	0.08	0.50
2-3	0.16	0.41	0.11	0.28
3-4	0.23	0.58	0.12	0.21
>4	0.27	0.67	0.11	0.17
Area 2				
0-1/2	0.13	0.33	1.49	4.52
1/2-1	0.05	0.14	0.14	1.00
1-2	0.05	0.13	0.06	0.46
2-3	0.13	0.33	0.09	0.27
3-4	0.23	0.57	0.12	0.21
>4	0.63	1.57	0.24	0.15
Area 3				
0-1/2	0.14	0.34	1.47	4.32
1/2-1	0.07	0.17	0.18	1.10
1-2	0.13	0.33	0.17	0.52
2-3	0.27	0.68	0.20	0.30
3-4	0.32	0.80	0.18	0.22
>4	0.17	0.44	0.07	0.15

Photographs of a typical plot before and after burning are shown in Figure 2.

Figure 2. Plot 3/71 before and after burning.

FIRE BEHAVIOR

In most cases fires were ignited across the 2-chain width of the plot, but in some situations block ignition was along the 5-chain length, because of changing winds and the desirability of having the fires burn with the wind.

Wires attached with string to 27 stakes located on a 1/2-chain grid pattern throughout each plot were used to measure the rate of spread of each fire. Each wire was run from a stake over a sawhorse located alongside the plot and weighted to fall when the fire reached the stake and burned through the string. By recording the time at which each weight fell, the rate of spread could be calculated even when smoke obscured the fire front. Fire progress was also recorded, in most cases, on slide film.

The depth of burn of each fire was measured by using 27 to 60 steel pins positioned in the ground before burning so that a file mark on the side of each pin was level with the top of the organic layer. The pins were located on the 1/2-chain grid system in each plot and, in the 1971 burns, at various points along the slash fuel sampling lines as well. The bulk density of the different duff layers was determined from the square-foot duff samples taken on each plot and this, along with the depth of burn, was used to calculate the weight of organic material consumed by each fire.

Moisture content samples were taken for all slash fuel sizes and organic layers immediately before each burn.

Weather measurements (wind, rainfall, relative humidity, and temperature) were taken at a field weather station set up at the burning sites. Continuous readings were taken daily at noon throughout the fire season and the FWI and its component indexes calculated daily. Wind speed was measured 33 feet aboveground at noon and during each fire.

Fire intensities for each burn were calculated by using Byram's (1959) formula:

Fire intensity =	heat of combustion x	rate of spread x	fuel consumed
(BTU/sec/ft)	(BTU/lb)	(ft/sec)	(lb/sq ft)

Heats of combustion were obtained by reducing the gross value 9100 BTU/lb to values of 7700, 7800, 7900, and 8000 BTU/lb for the low, moderate, high, and extreme classes of the FWI, respectively. These reduced values take into account heat-yield losses owing to the separation and vaporization of bound water, and incomplete combustion of the slash fuels.

Six Provincial fire personnel were on hand to water down areas outside the bulldozed firelines before and during each burn and to extinguish any small spot fires resulting from the fires. Ignition of each block was carried out by a fire deputy of the Ontario Department of Lands and Forests using a kerosene or propane torch.

RESULTS AND DISCUSSION

Tables 2(a), 2(b), and 2(c) show that slash loadings vary somewhat among blocks. Slash weights generally ranged from 15 to 31 tons/acre with the exception of plots 4/71 and 13/71. Plot 4/71 had a number of large felled trembling aspen [*Populus tremuloides* Michx.] on it, resulting in a high loading of 52.62 tons/acre. Plot 13/71 had 38.66 tons of slash on it, primarily because of a high percentage of merchantable jack pine that was felled but not cut and removed.

Duff depths and loadings were fairly uniform on Areas 1 and 3, but considerable variations in depth (2.35 to 4.30 inches) and weight (23.75 to 50.53 tons/acre) were observed on Area 2. Shallower duffs were evident in the five plots on Area 3. The bulk densities for different duff layers averaged for the 24 plots were 0.26, 0.27, and 0.58 lb/sq ft (oven-dry weight) for the 0- to 1/2-inch, 1/2- to 1-inch, and 1- to 2-inch layers, respectively, or 1.11 lb/sq ft for the top 2 inches of duff.

Fuel quantity decreases between the 0- to 1/2-inch and 1/2- to 1-inch classes for all three areas (Fig. 1) and thereafter the percentage of total fuel contributed by each class increases with diameter. For fuels greater than 4 inches in diameter, however, the percentage of the total fuel that this class constitutes is different in the three areas. Fuels larger than 4 inches in diameter make up 52% of the total fuel on Area 2, 29% on Area 1, and only 15% on Area 3, where utilization was much higher, resulting in fewer large pieces.

This relationship is also evident in Table 3, where the higher proportion of fuel larger than 4 inches in diameter in Area 2 shows up in calculations of fuel weight, volume, and surface area. On all areas, a substantial decrease in both surface area and fineness between the 0- to 1/2-inch class and succeeding classes can also be seen.

The weather conditions on each fire day and the behavioral characteristics of each experimental fire are summarized in Table 4. The fires are arranged in order of occurrence with 1 burn being conducted under EXTREME conditions (FWI 23), 10 under HIGH conditions (FWI from 11-22), 12 under MODERATE conditions (FWI values 4-10), and 1 burn in the LOW range (1-3) of the FWI.

Fire behavior data (intensity, rate of spread, fuel consumption, etc.) for each of the 24 slash fires are presented in Table 4, along with FWI and weather information for each fire day.

Table 4a. Fire weather data for 24 jack pine slash fires

Fire #	Wind (mph)	Temp. (°F)	R.H. (%)	FFMC[a]	DMC[b]	DC[c]	ISI[d]	ADMC[e]	FWI[f]
1/70	7	78	30	85.8	17.7	57.9	4.3	20.1	6.9
2/70	9	69	53	86.6	20.4	64.8	5.5	22.8	9.3
4/70	10	67	35	86.0	8.8	129.7	5.6	15.0	7.5
5/70	4	87	41	89.4	13.2	138.9	5.4	21.3	8.8
6/70	4	85	38	90.5	17.6	147.9	6.2	27.1	11.2
7/70	7	83	46	90.6	21.3	156.7	8.1	31.8	15.0
8/70	4	86	39	86.1	19.5	180.2	3.5	30.7	7.4
9/70	5	72	32	83.9	9.2	190.3	2.9	16.4	4.1
10/70	4	76	42	85.0	10.2	170.8	3.0	17.7	4.5
1/71	7	84	53	81.4	44.8	215.7	2.5	59.0	8.3
2/71	11	62	42	78.9	12.0	145.5	2.7	19.9	4.3
3/71	16	81	36	90.3	19.5	162.2	15.9	30.0	24.0
4/71	14	65	57	85.5	21.9	182.3	7.2	33.7	14.3
5/71	12	66	49	87.1	27.3	210.0	7.5	41.2	16.4
6/71	10	79	35	90.2	31.5	218.4	9.8	46.3	21.0
7/71	11	68	72	72.4	14.1	212.8	1.5	24.3	2.6
8/71	15	73	43	88.5	10.8	177.4	11.7	18.7	15.3
9/71	9	65	45	83.8	11.0	192.3	3.9	19.2	6.2
10/71	10	79	47	88.9	13.5	206.1	8.2	23.2	12.9
11/71	6	61	45	86.4	15.3	214.0	4.2	26.0	7.9
12/71	5	63	74	85.1	18.4	226.5	3.3	30.6	7.1
13/71	13	74	47	88.8	24.2	241.2	10.2	38.7	19.8
14/71	9	69	29	89.4	22.6	249.8	8.0	36.8	16.2
15/71	9	69	29	89.4	22.6	249.8	8.0	36.8	16.2

[a] Fine Fuel Moisture Code

[b] Duff Moisture Code

[c] Drought Code

[d] Initial Spread Index

[e] Adjusted Duff Moisture Code

[f] Fire Weather Index

Continued

Table 4b. Fire behavior data for 24 jack pine slash fires (concluded)

Fire #	Slash wt (T/acre)	Duff wt (T/acre)	Total fuel wt (T/acre)	Slash consumption (lb/sq ft)	Duff consumption (lb/sq ft)	Total fuel consumption (lb/sq ft)	Burn depth (in.)	R/S[a] (ft/sec)	H/C[b] (BTU/lb)	Intensity (BTU/sec/ft)
1/70	16.24	35.50	51.74	0.195	0.360	0.555	0.68	0.30	7800	1299
2/70	17.34	40.07	57.41	0.188	0.350	0.538	0.66	0.32	7800	1343
4/70	24.67	38.55	63.22	0.270	0.389	0.659	0.73	0.27	7800	1388
5/70	20.24	41.82	62.06	0.207	0.283	0.490	0.54	0.28	7800	1070
6/70	24.70	37.68	62.38	0.301	0.434	0.735	0.81	0.34	7900	1974
7/70	16.66	45.30	61.96	0.199	0.672	0.871	1.20	1.05	7900	7225
8/70	19.88	44.87	54.75	0.232	0.383	0.615	0.72	0.26	7800	1247
9/70	20.00	44.87	64.87	0.192	0.192	0.384	0.37	0.25	7800	749
10/70	24.62	36.37	60.99	0.216	0.208	0.424	0.40	0.25	7800	827
1/71	31.29	33.76	65.05	0.524	0.790	1.314	1.42	0.23	7800	2357
2/71	30.53	50.53	81.06	0.321	0.230	0.551	0.46	0.11	7800	473
3/71	23.74	41.38	65.12	0.431	0.606	1.037	1.27	2.06	8000	17090
4/71	52.62	38.77	91.39	0.760	0.519	1.279	0.98	0.81	7900	8184
5/71	21.10	43.34	64.44	0.401	0.555	0.956	1.04	0.50	7900	3776
6/71	26.58	37.24	63.82	0.709	0.890	1.599	1.58	0.59	7900	7453
7/71	24.34	36.81	61.15	0.233	0.230	0.463	0.46	0.10	7700	357
8/71	23.24	43.78	67.02	0.246	0.491	0.737	0.93	0.70	7900	4076
9/71	27.11	36.15	63.26	0.343	0.175	0.518	0.35	0.33	7800	1333
10/71	22.26	29.40	51.66	0.359	0.401	0.760	0.77	0.55	7900	3302
11/71	22.68	17.64	40.32	0.349	0.345	0.694	0.69	0.26	7800	1407
12/71	19.36	24.18	43.54	0.309	0.345	0.654	0.69	0.16	7800	816
13/71	38.66	22.22	60.88	0.871	0.505	1.376	0.97	1.16	7900	12610
14/71	23.71	22.65	46.36	0.585	0.405	0.990	0.77	1.21	7900	9463
15/71	15.65	20.04	35.69	0.370	0.410	0.780	0.78	1.37	7900	8442

[a] Rate of Spread

[b] Heat of Combustion

From these tables good relationships between certain fire parameters and various fire weather variables, such as the Initial Spread Index (ISI), Adjusted Duff Moisture Code (ADMC), and FWI, are evident.

Total slash consumption, (in lb/sq ft), shown in Figure 3 in terms of initial and residual loading, increases linearly with increasing ADMC and this relationship is shown in Figure 5. Duff consumption, shown initially in histogram form in Figure 4, is expressed in terms of depth of burn and plotted against the ADMC in Figure 6. A strong linear relationship exists. The total amount of fuel consumed (slash and duff combined) on each burn is also strongly related to the ADMC, increasing linearly with an increase in ADMC. This relationship is shown in Figure 7.

Figure 8 shows the very strong linear relationship between the rate of spread of each fire and the ISI calculated on that fire day.

Figure 9 is a plot of fire intensity (BTU/sec/ft) against FWI for each of the 24 fires. The Y-axis is logarithmic and an exponential curve (straight line) fits the data quite well.

It would be unwise to extrapolate any of the foregoing curves much past the range of the data since the relationships will obviously not continue linearly far beyond the limits shown. The amount of slash and duff on any area would be the theoretical, upper limit in estimating slash and duff consumption and a levelling off of the curves at higher ADMC values than those shown seems likely.

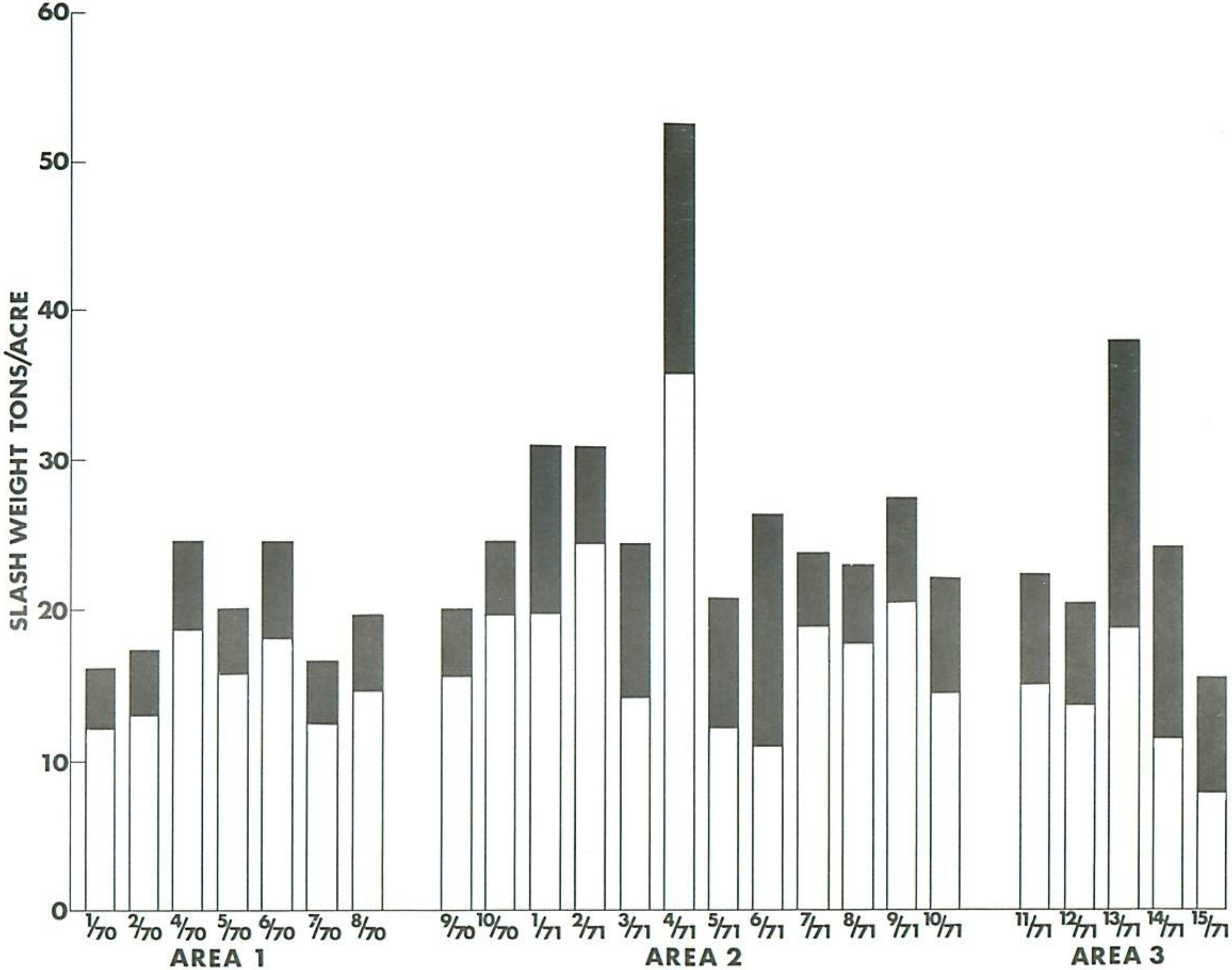

Figure 3. Initial and residual slash weights (tons/acre) for 24 1-acre blocks.

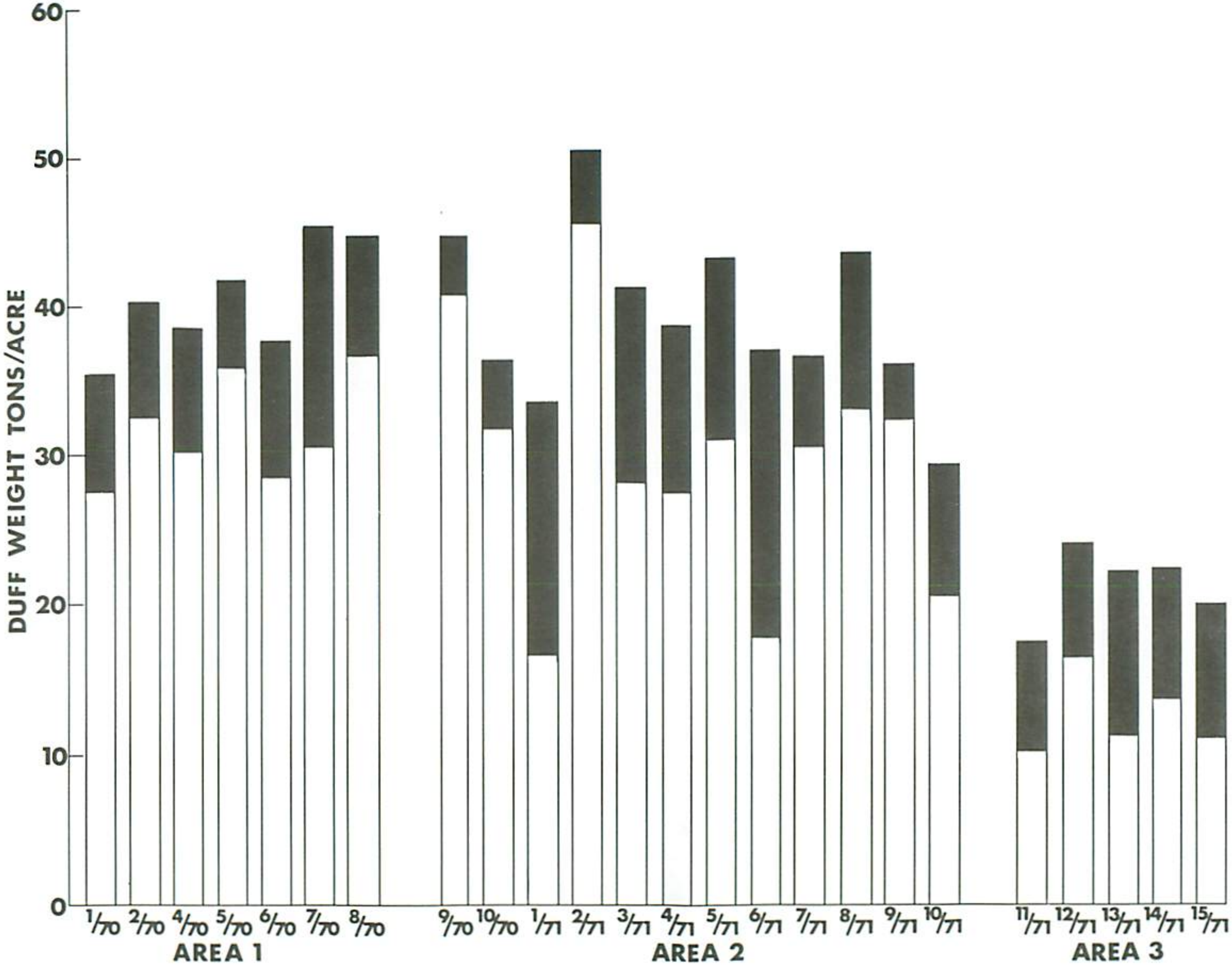

Figure 4. Initial and residual duff weights (tons/acre) for 24 1-acre blocks.

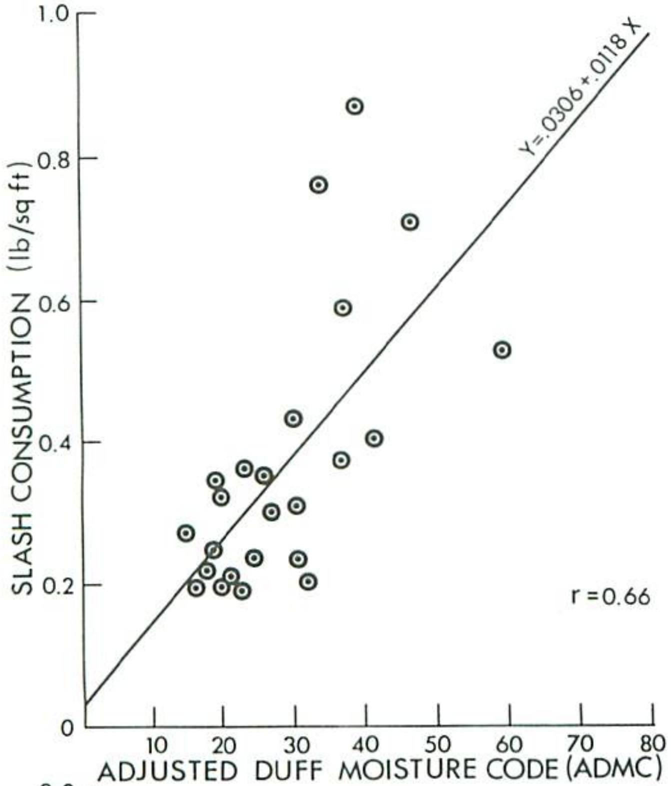

Figure 5. Relationship between total slash consumption (lb/ sq ft) and ADMC.

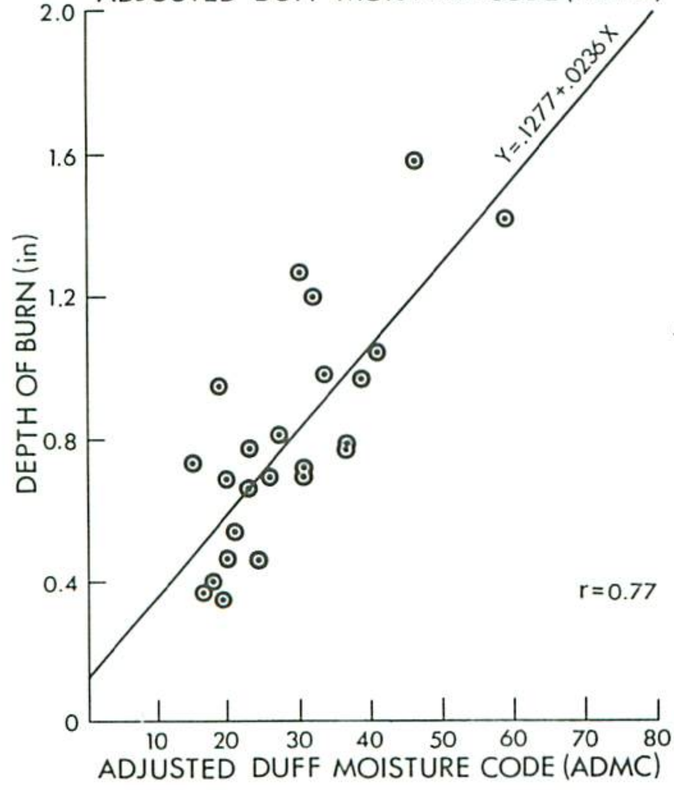

Figure 6. Relationship between duff consumption (lb/sq ft) and ADMC.

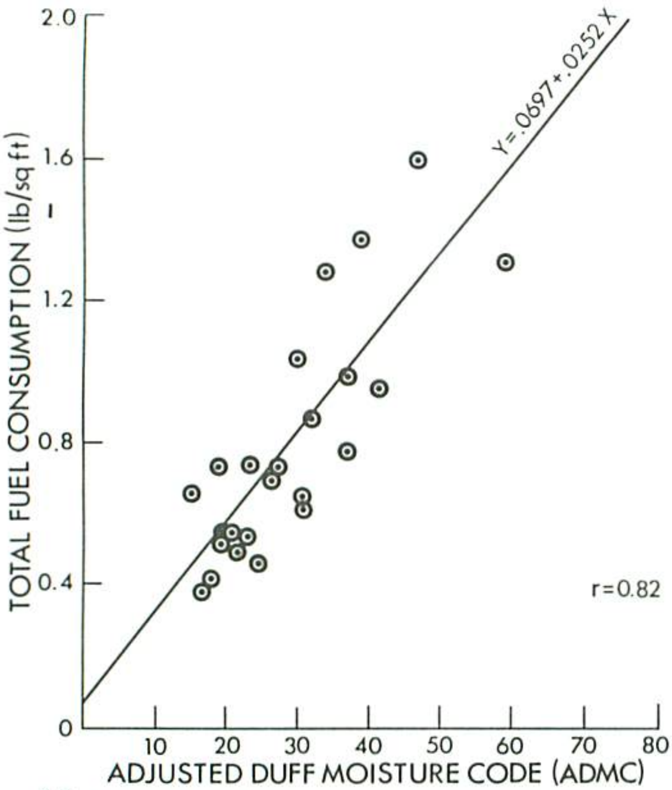

Figure 7. Relationship between total fuel consumption (lb/sq ft) and ADMC.

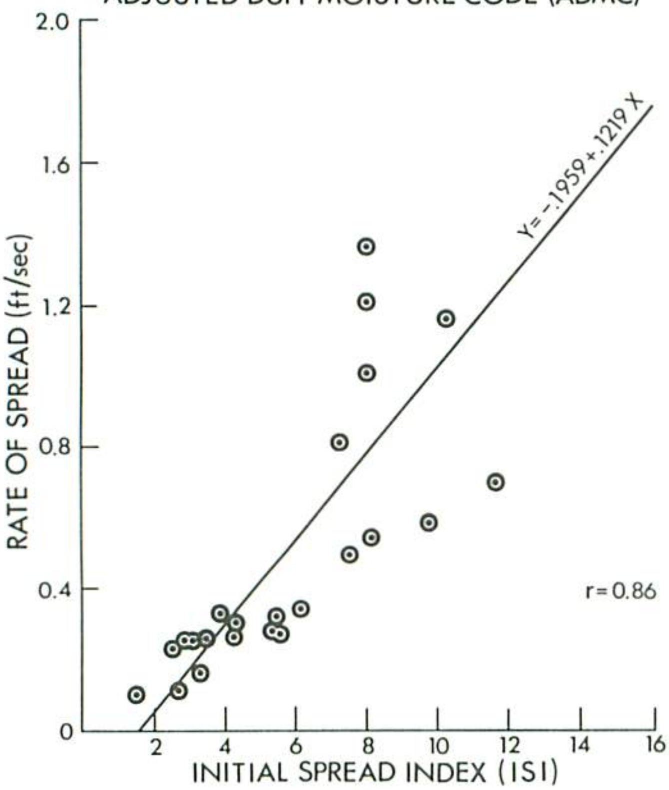

Figure 8. Relationship between rate of spread (ft/sec) and ISI.

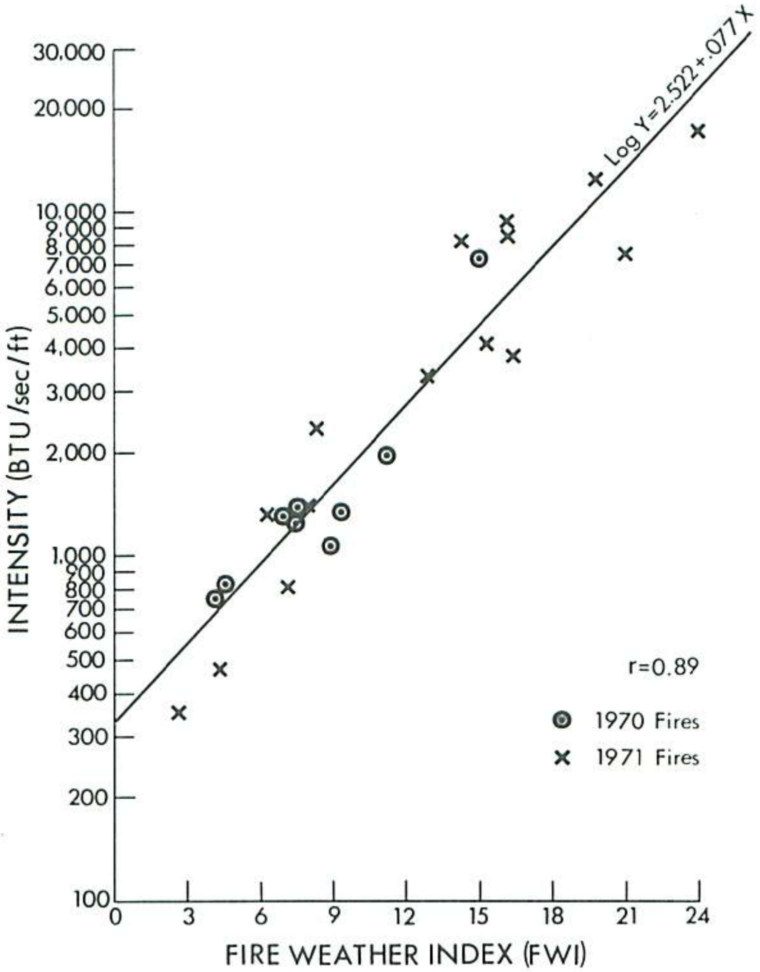

Figure 9. Relationship between fire intensity (BTU/sec/ft) and the FWI for 24 experimental slash fires.

CONCLUSIONS

This analysis of 24 jack pine slash fires conducted over a 2-year period on three somewhat different sites indicates a strong relationship between certain measurable fire characteristics and various components of the FWI.

The ADMC is strongly correlated with fuel consumption in jack pine slash fires while the ISI correlates well with the rate of spread of these fires. The FWI itself is strongly related to overall fire intensity.

The foregoing relationships reveal the FWI and certain of its component indexes as usable indicators of fire behavior in this fuel type, and a burning index to predict such parameters as rate of spread, fuel consumption, and intensity from these indexes will be forthcoming in the very near future.

With the production of a burning index for jack pine slash, work in this fuel type will end. Experimental burning in mature jack pine timber will begin during the 1972 field season.

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