WILDFIRES AND THE FIRE WEATHER INDEX SYSTEM IN ONTARIO

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ABSTRACT

The performance of the Canadian Forest Fire Weather Index (FWI) is analyzed with respect to wildfire behavior in Ontario for a 7-year period (1965-1971). Lightning fires and man-caused fires are analyzed separately and regional differences in fire weather and fire behavior are reported.

RÉSUMÉ

L'auteur analyse l'Indice Forêt-Météo (IFM) par rapport au comportement des incendies de forêts en Ontario durant la période 1965-1971. Les incendies causés par la foudre et ceux causés par l'homme sont analysés séparément et l'auteur rapporte les différences régionales entre les conditions météorologiques et le comportement du feu.

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INTRODUCTION

The Canadian Forest Fire Weather Index (FWI) (Anon. 1970) was introduced provisionally in Ontario in 1969 and has been in use on a fully operational basis throughout the province since 1970. The collection and analysis of both fire weather and wildfire behavior data are part of a continuing study at the Great Lakes Forest Research Centre in Sault Ste. Marie to appraise the performance of the FWI with respect to fire activity in Ontario, and to calibrate it and its component indices for Ontario use.

An earlier report (Stocks 1971) analyzed the performance of the FWI in Ontario for the period between 1963 and 1968. This report updates and expands this analysis. Additional years of data have been collected and are investigated in more detail. Where possible, separate analyses of lightning fires and man-caused fires are conducted and differences among Ontario Ministry of Natural Resources (OMNR) regions throughout the province are emphasized.

Fire weather data have been collected from a total of 102 OMNR weather stations (91 of which are still operating in 1974) throughout Ontario for the period 1963-1973. These stations are located in Regions 1-5, i.e., the bulk of the protected fire area in this province (Fig. 1). Daily noon weather readings for each station for each year were run through a computer program (Simard 1970) to calculate the FWI and its component indices.

Information on individual wildfires was gathered from OMNR fire reports on file in Toronto. Parameters recorded were ignition date, fire location, fuel type, and final fire size. These fire report data were then merged with the computed FWI information measured at the station nearest the origin of the fire.

This report analyzes data for the 1965-1971 period as these are the years for which complete data on both lightning fires and man-caused fires are available for all five regions in Ontario.

ONTARIO FIRE WEATHER

Continuous weather records for the 1965-1971 period were available for a total of 73 stations within the five regions (Northwestern Region - 11 stations, North central - 11, Northern - 16, Northeastern - 18, Algonquin - 17). Each station record runs from the initiation of FWI calculations in early spring (April or early May) to the end of September each year.

With this weather information the percent FWI occurrence by individual regions can be calculated as shown in Table 1. The FWI class breakdown listed here was determined in an earlier report (Stocks 1971) and is used throughout Ontario. Figure 2 illustrates the cumulative percent FWI occurrence and from both this graph and Figure 1 it is evident that

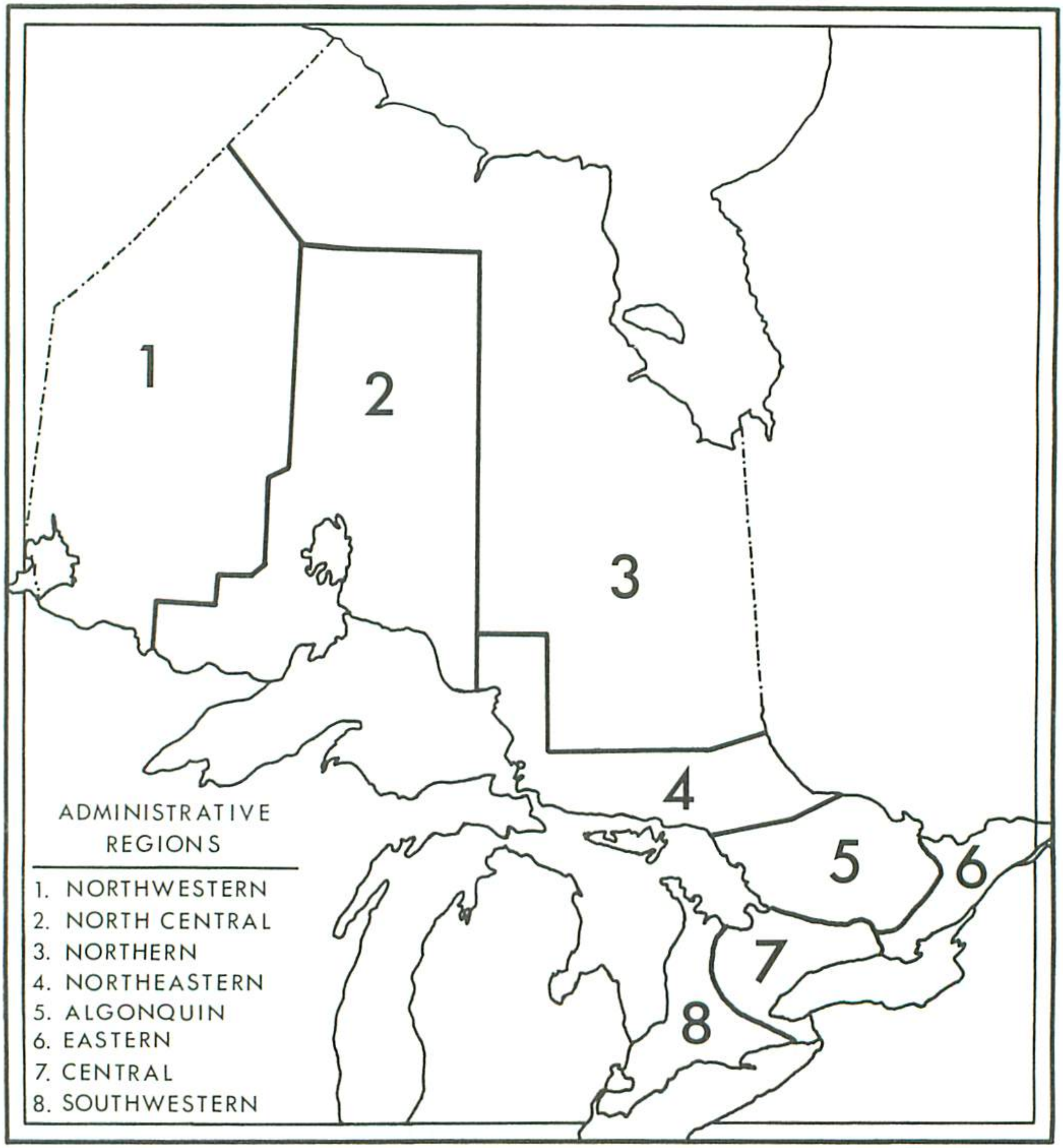

Figure 1. Ontario Ministry of Natural Resources administrative regions.

Table 1. Percent FWI occurrence by OMNR regions (1965-1971)

	% Occurrence					
FWI class	Region 1	Region 2	Region 3	Region 4	Region 5	Average
Very low (0)	27.6	34.5	34.2	29.8	26.4	30.2
Low (1-3)	26.9	30.5	29.3	28.5	26.9	28.3
Moderate (4-10)	27.9	24.4	24.5	26.7	28.6	26.6
High (11-22)	14.5	9.3	10.1	12.5	15.4	12.6
Extreme (23+)	3.1	1.3	1.9	2.5	2.7	2.3

significantly less severe fire weather conditions occur in regions 2 and 3 than in regions 1, 4 and 5. The Northwestern and Algonquin regions have the highest percentage of HIGH and EXTREME FWI conditions and consequently the lowest percentage of VERY LOW and LOW danger days.

ONTARIO WILDFIRES

Ontario Ministry of Natural Resources statistical records indicate that during the 1965-1971 period, a total of 9,737 fires burned over 205,736 acres[1] in Ontario. This study deals with 7,799 fires which consumed 157,593 acres during this same 7-year period. The remaining fires were ignored because they occurred in very early spring or after September 30 when weather records were not available. Wildfires for which fire report information was incomplete were also excluded from this analysis.

Wildfire information for the 1965-1971 period is summarized in Table 2 by regions and causative agency. The number of lightning fires as a percentage of total fires decreases from Region 1 (40.0%) through Region 5 (14.2%) as one moves east and south across the province. The influence of lightning fires is most evident in regions 1 and 2 with Region 1 having the greatest number of fires and acres lost, and Region 2 having the greatest acreage consumed on a per-fire basis. If all regions are combined, lightning fires account for 22.1% of the total number of

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[1] 1 acre = 0.4 hectares.

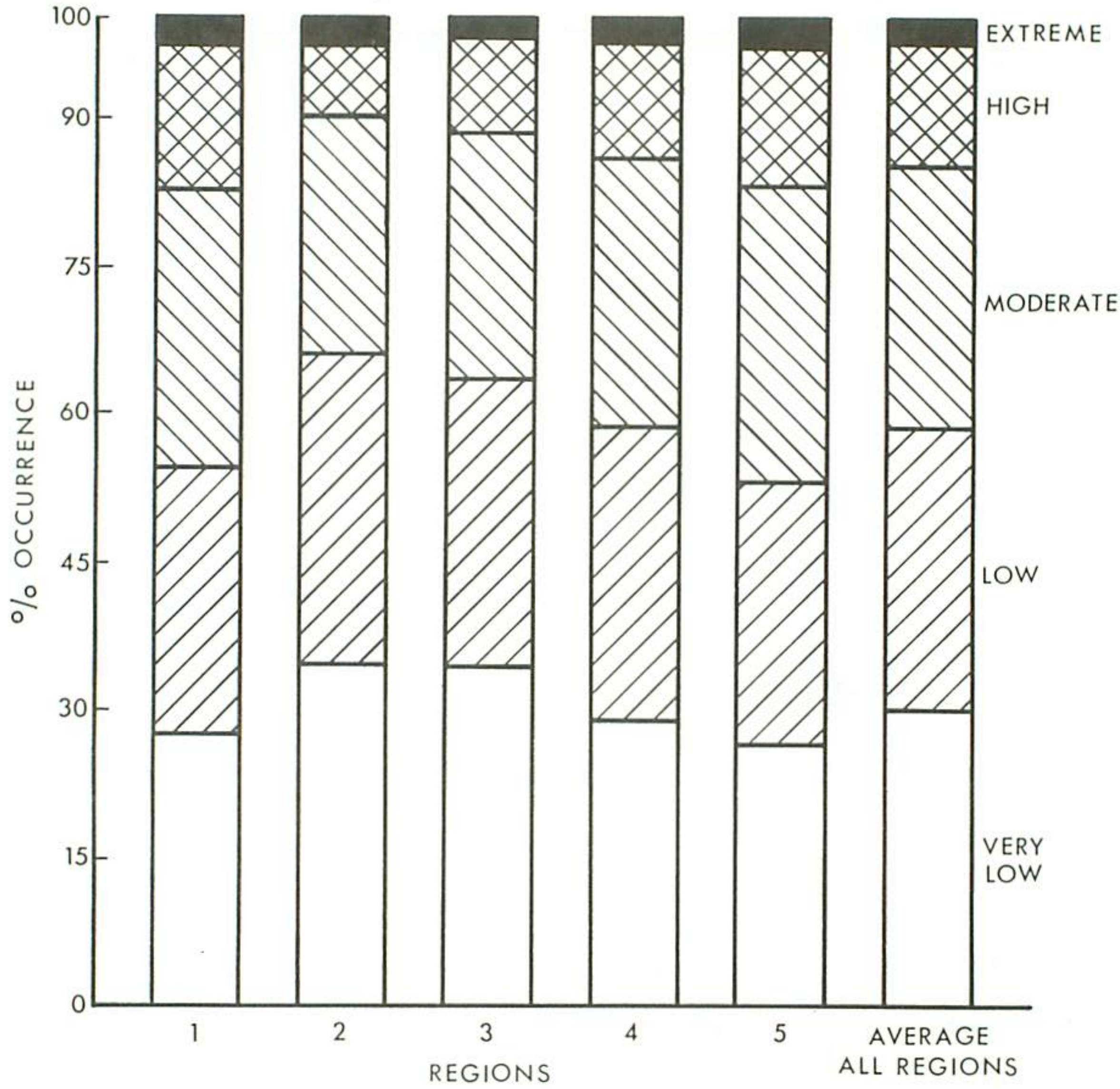

Figure 2. Cumulative % FWI occurrence for regions 1-5.

Table 2. Number of fires, total acreage burned and acreage per fire, by cause and region (1965-1971)

	Lightning fires					Man-caused fires				
			Acreage burned					Acreage burned		
Region	No.	% of total fires[a]	per fire	total	% of total fires[b]	No.	% of total fires[a]	per fire	total	% of total fires[b]
1	569	33.1	63.7	36,220	70.8	852	14.0	21.0	14,922	29.2
2	283	16.4	80.9	22,885	50.1	642	10.6	35.6	22,834	49.9
3	192	11.2	12.8	2,462	9.9	677	11.1	33.2	22,488	90.1
4	400	23.2	2.1	848	2.9	2,226	36.6	12.9	28,713	97.1
5	278	16.1	2.2	624	10.0	1,680	27.7	3.3	5,597	90.0
All regions	1,722	-	36.6	63,039	40.0	6,077	-	15.6	94,554	60.0

	All fires			
Region	Lightning fires as % of total	No.	Acres per fire	Total acres
1	40.0	1,421	36.0	51,142
2	30.6	925	49.4	45,719
3	22.1	869	28.7	24,950
4	15.2	2,626	11.3	29,561
5	14.2	1,958	3.2	6,221
All regions	22.1	7,799	20.2	157,593

[a] Expressed as a percentage of the total number of lightning fires and man-caused fires (1,722 and 6,077, respectively) for all regions combined.

[b] Expressed as a percentage of the total acreage consumed (all fires) within each region.

wildfires, and 40.0% of the total area burned. The average size of lightning fires was 36.6 acres while man-caused fires averaged 15.6 acres. This difference is no doubt due to the relative remoteness of lightning fires and the subsequent difficulties in detecting and controlling them. The impact of man-caused fires is much more noticeable in regions 3, 4 and 5 where more than 90% of the area burned is due to this type of fire. Regions 4 and 5 have by far the greatest number of man-caused fires in the province and Region 4 also has a great number of lightning fires, but these are relatively small owing to the heavier population of regions 4 and 5 and hence the greater probability of detection and the shorter travel time in these regions.

The distribution of wildfires by fuel type within the province is shown in Table 3. The nine fuel types listed resulted from an OMNR revision of their fire report form in 1971. The coding system previously in use was more complete and listed 20 fuel types, including many individual species. It was necessary to amalgamate fuel types 4 and 5 in this analysis as they represent conifer types with crowns continuous and crowns separate from the ground, respectively, and this type of information was not available from pre-1971 fire report forms. Hence all conifers, regardless of species and stand characteristics, were lumped together in this study.

It is most obvious that the vast majority of lightning fires occurred in the conifer fuel type and that they burned most readily in both conifer and slash fuel types. Among man-caused fires the "acreage burned" figures were high for slash and conifer types, while those for other fire types were fairly low. (The occurrence of one large fire in fuel type 8 resulted in an unrealistic "acreage burned" figure for this type.) An overwhelming number of man-caused fires occurred in the grass fuel type, although "acreage-per-fire" figures for grass fires were well behind those in both the slash and conifer fuel types.

Looking at all fires we see that the largest number occurred in grass, while the conifer fuel type ranked second with half as many fires, and all other fuel types were far behind. The largest total acreage lost was in the conifer fuel type, owing to its widespread distribution, especially in the far north where fires tend to be large. "Total acreage" figures were also quite high for both slash and grass fires with the average fire size of slash fires being highest (if fuel type 8 is ignored).

Table 4 examines fire starts in Ontario by months. It is quite evident that a definite seasonal pattern for both lightning fires and man-caused fires exists in the province. Average fire size and total acreage burned increased from April through June and then decreased, although the average size of man-caused fires increased somewhat in August. Lightning fire occurrence peaked in July (and was still quite high in August), while the greatest number of man-caused fires occurred

Table 3. Number and size of Ontario fires by fuel type and causative agency (1965-1971)

Fuel type	Code no.	Lightning			Man-caused			All fires		
		No. of fires	Total acreage	Acreage per fire	No. of fires	Total acreage	Acreage per fire	No. of fires	Total acreage	Acreage per fire
Grass	0	182	924	5.1	3,980	26,132	6.6	4,162	27,056	6.5
Slash	1	141	8,808	62.5	253	24,371	96.3	394	33,179	84.2
Shrubs, brush	2	27	38	1.4	179	503	2.8	206	541	2.6
Insect-killed conifer	3	6	2	0.3	2	2	1.0	8	4	0.5
Conifer	4 and 5	1,044	52,840	50.6	1,110	30,708	27.7	2,154	83,548	38.8
Mixedwood	6	158	253	1.6	281	1,870	6.7	439	2,123	4.8
Hardwood	7	134	131	1.0	226	47	2.9	360	778	2.2
Other (oldburn, blowdown, plantation)	8	30	43	1.4	46	10,321[a]	224.4[a]	76	10,364[a]	136.4[a]

[a] One large fire in a previously burned and unplanted area is the cause of these disproportionately large figures.

Table 4. Number and size of Ontario fires by month and causative agency (1965-1971)

Month	Lightning			Man-caused			All fires		
	No. of fires	Total acreage	Acreage per fire	No. of fires	Total acreage	Acreage per fire	No. of fires	Total acreage	Acreage per fire
April	3	42	14.0	434	3,239	7.5	437	3,281	7.5
May	109	9,848	90.3	2,031	23,920	11.8	2,140	33,768	15.8
June	364	41,729	114.6	1,054	55,628	52.8	1,418	97,357	68.7
July	633	6,602	10.4	1,246	2,527	2.0	1,879	9,129	4.9
August	517	4,286	8.3	946	8,722	9.2	1,463	13,008	8.9
September	96	532	5.5	366	518	1.4	462	1,050	2.3

in the month of May. April and September had the fewest number of fire starts, regardless of cause. It is also obvious from Table 4 that lightning fires tend to be larger than those caused by man, regardless of the time of year.

FIRE WEATHER AND FIRE BEHAVIOR

Table 5 illustrates the relationship between FWI occurrence, wildfire occurrence and wildfire size for the five FWI classes for both lightning fires and man-caused fires in Ontario. It can be seen that, even though percent FWI occurrence decreased with an increase in severity of FWI class, the percentage of fires occurring and area burned increased steadily. Looking at the combined fire figures, we see that although only 12-13% of a fire season's days fell into the HIGH class, these days had 31% of the total fires and 44% of the total acreage consumed in the province. By comparison, the VERY LOW class, which included 30% of the days in a fire season, accounted for only 6% of the fires that occurred and 1% of the area burned during the same period. It is also interesting to note that many more lightning fires than man-caused fires occurred in the lower FWI classes, again owing, probably, to the fact that a large number of lightning fires occur in unpopulated areas far removed from the nearest weather station. This increases the possibility that the FWI codes measured at the station are not representative of the area in which the fire originates. In addition, many lightning fires are reported as starting when a storm passes through an area and FWI conditions are lower, although often these fires are not discovered until a few days later, by which time the FWI codes have recovered.

Table 5. Relationship between % FWI occurrence, % wildfire occurrence and % acreage burned and FWI classes for Ontario lightning fires and man-caused fires (1965-1971)

		% Fires			% Acreage burned		
FWI class	% FWI occurrence	Lightning	Man-caused	All fires	Lightning	Man-caused	All fires
Very low	30.23	13.3	4.3	6.3	0.9	1.0	1.0
Low	28.32	23.6	15.4	17.2	8.8	6.3	7.3
Moderate	26.55	27.6	33.1	31.9	27.0	11.2	17.5
High	12.56	26.0	32.3	30.9	30.4	52.8	43.8
Extreme	2.34	9.5	14.9	13.7	32.9	28.7	30.4

The relationship expressed in Table 5 held true, for the most part, for all regions, although the number and size of fires varied among regions. Most fires occurred in the middle FWI classes, but this was due, in large part, to the fact that most fire days fell within these classes. For example, many more fires (in total) occurred under HIGH than under EXTREME conditions, but since HIGH conditions existed approximately five times more often than did EXTREME conditions, it is obvious that the possibility of a fire on a given EXTREME day is greater than on a HIGH day. Thus we must consider the distribution of fire season days within each FWI class to reflect accurately the possibility of a fire's occurrence on a given day.

This fact is taken into account in Table 6 by applying the percent FWI distribution values for each region (from Table 1) to the total number of fire days in each region for the 1965-1971 period (i.e., if Region 1 had 1,085 fire season days, $\frac{27.55}{100}$ x 1085 or 299 days would fall within the VERY LOW class and $\frac{14.54}{100}$ x 1085 or 158 days would fall within the HIGH class). Table 6 separates lightning fires and man-caused fires while Figure 3 combines all fires and presents regional data in histogram form.

With this consideration of the distribution of fire season days by FWI class it becomes obvious that the chance of fire occurrence increased steadily, during the 1965-1971 period, with a rise in FWI class. From Figure 3 it can be seen that this pattern of fire occurrence by FWI class was similar for all regions, although the actual number of fires per day varied greatly between regions, with Region 4 significantly higher than the others. This relationship generally held true for both lightning fires and man-caused fires in all regions although there were always fewer lightning fires than man-caused fires and the chance of their occurrence was less.

The application of the average percentage distribution figures of days for each FWI class (Table 1) to each of the other five codes in the FWI system made it possible to establish class boundaries for each code. The results are shown in Table 7. Although with the exception of the FWI these code breakdowns are not used in Ontario, they are useful here in simplifying data analysis.

Acreage per fire and percentage of fires growing to more than one acre are useful criteria in measuring the effectiveness of the FWI and its component codes with respect to fire behavior prediction. Table 8 looks at these criteria for both lightning fires and man-caused fires by danger classes of the FWI and its component codes. As expected, the FWI was closely related to both parameters of fire size but, somewhat surprisingly, the Adjusted Duff Moisture Code (ADMC) was not. Fire size for both lightning fires and man-caused wildfires increased steadily with increasing FWI, whereas a decrease in fire size at higher ADMC

Table 6. Number of fires per day that the FWI is in each FWI class, by regions, for lightning fires and man-caused fires (1965-1971)

FWI Class	Fire	Region 1	Region 2	Region 3	Region 4	Region 5	Average
Very low	Lightning-caused	0.18	0.13	0.10	0.16	0.12	0.14
	Man-caused	0.08	0.14	0.08	0.21	0.30	0.16
	Combined	0.26	0.27	0.18	0.37	0.42	0.30
Low	Lightning-caused	0.48	0.17	0.11	0.19	0.29	0.26
	Man-caused	0.39	0.47	0.43	0.81	0.94	0.61
	Combined	0.87	0.64	0.54	1.10	1.23	0.87
Moderate	Lightning-caused	0.55	0.38	0.17	0.36	0.18	0.33
	Man-caused	0.87	0.83	0.87	2.33	1.94	1.40
	Combined	1.42	1.21	1.04	2.69	2.12	1.73
High	Lightning-caused	0.91	0.76	0.63	0.65	0.42	0.66
	Man-caused	1.97	1.90	2.00	5.50	2.86	2.88
	Combined	2.88	2.66	2.63	6.15	3.28	3.54
Extreme	Lightning-caused	1.85	0.50	0.55	2.29	0.63	1.29
	Man-caused	4.03	2.79	3.80	17.07	5.77	7.11
	Combined	5.88	3.29	4.35	19.36	6.40	8.40
		Total number of fire season days (1965-1971)					
		1,085	1,057	1,057	1,092	1,134	5,425

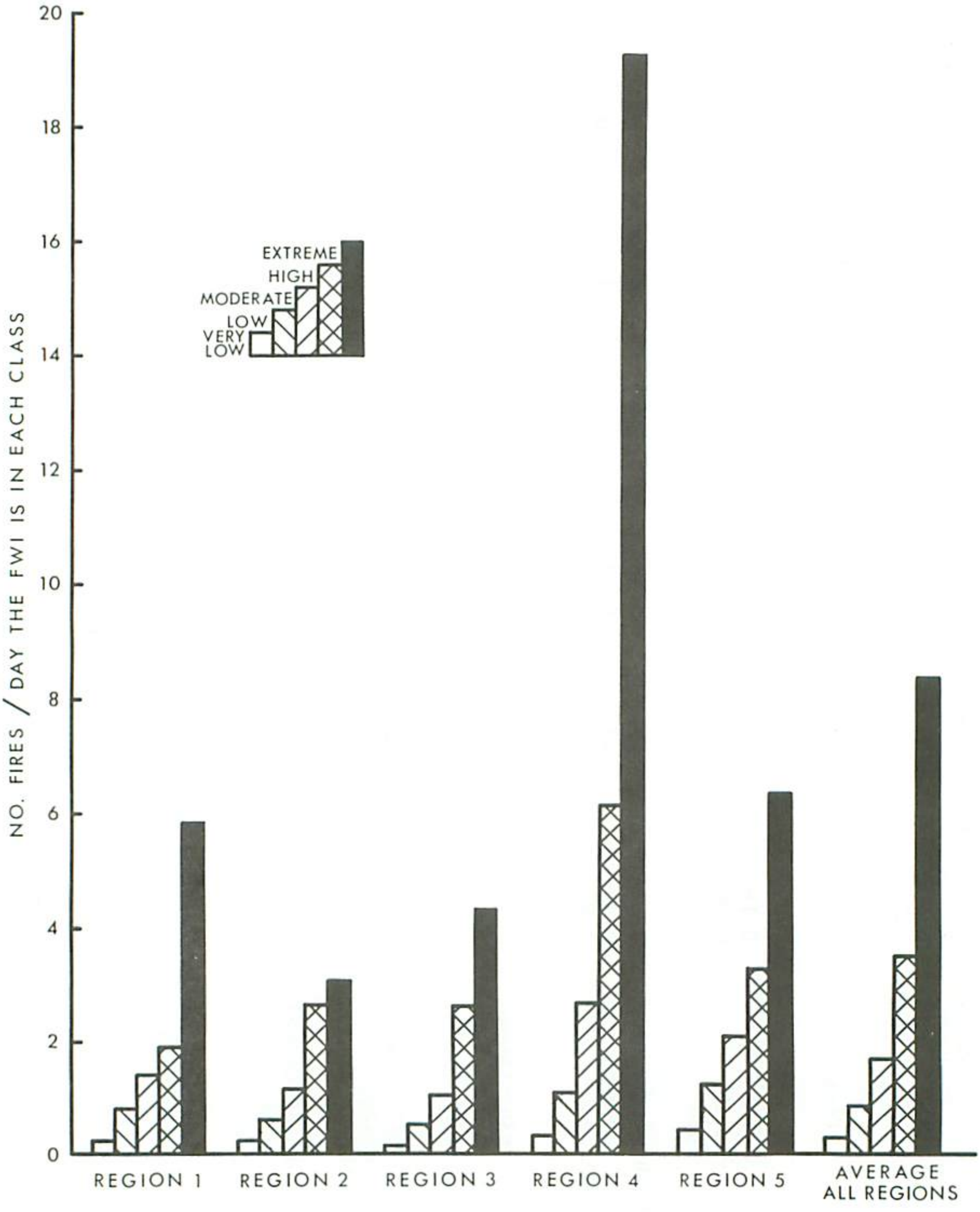

Figure 3. Number of fires per day that the FWI is in each FWI class for all fires (by region).

Table 7. Danger class breakdown for FWI and component indices in Ontario

Class	% Occurrence	FFMC	DMC	DC	ISI	ADMC	FWI
Very low	30.2	0-63	0-8	0-60	0-0.7	0-11	0
Low	28.3	64-80	9-15	61-140	0.8-2.2	12-20	1-3
Moderate	26.6	81-86	16-30	141-240	2.3-5.0	21-36	4-10
High	12.6	87-90	31-50	241-340	5.1-10.0	37-60	11-22
Extreme	2.3	91+	51+	341+	10.+	61+	23+

values was evident. A closer look reveals that both the Initial Spread Index (ISI) and the Fine Fuel Moisture Code (FFMC) were very strongly correlated with fire size for both types of wildfire. This strong relationship with the ISI contributed significantly to the close correlation between FWI and fire size. Since the ISI is an indicator of expected rate of spread, this strong relationship with fire size is understandable. On the other hand, both heavier fuel moisture codes, namely the Duff Moisture Code (DMC) and the Drought Code (DC), are very poor indicators of fire size for all fires and this accounts for the poor correlation between fire size and the ADMC. Perhaps this poor correlation is partially explained by the fact that large fires often occur in the spring in Ontario, while the ADMC and other heavier fuel moisture codes are still relatively low.

Figure 4 illustrates the relationship between "relative fire occurrence" and the FWI and three of its component codes for all regions and types of fire combined. The term "relative fire occurrence" refers to the level of fire occurrence expressed as a fraction or multiple of what it would be on a day of an *average* code value. To obtain these "relative" figures each code was arbitrarily broken into approximately 20 sections. The number of fires per code occurrence was then calculated for each section. An overall average code value (all stations, all years) was then computed, the section into which this value fell was identified and assigned a value of unity, and fire occurrence in all other sections was expressed in relation to this figure.

From Figure 4 it is evident that the strong relationships between relative fire occurrence and the ISI, ADMC and FWI are linear while this relationship is distinctly exponential for the FFMC. The curves shown represent man-caused fires but the relationships are similar in the case of lightning fires. Within the range of data analyzed, a doubling in value of the ISI, ADMC or FWI results in a corresponding doubling of

Table 8. Size of lightning fires and man-caused fires in Ontario by danger class for the FWI and its component codes (1965-1971)

	FFMC						DMC					
	Acreage per fire			% Fires > 1 acre			Acreage per fire			% Fires > 1 acre		
	L[a]	M-c[b]	All fires	L	M-c	All fires	L	M-c	All fires	L	M-c	All fires
Very low	2.9	2.5	2.8	21.9	25.5	23.4	5.8	11.1	10.8	29.5	60.2	58.1
Low	22.1	5.0	10.0	36.8	37.5	37.3	20.1	35.4	32.9	33.6	40.3	39.2
Moderate	16.1	5.1	7.0	36.7	39.4	38.9	71.8	9.1	30.2	37.0	23.7	28.2
High	27.4	17.4	19.1	41.8	39.5	39.8	14.1	2.3	5.9	36.5	23.8	27.6
Extreme	365.6	64.4	103.9	56.5	50.8	51.6	3.8	1.5	2.5	43.6	27.8	34.4

	DC						ISI					
	Acreage per fire			% Fires > 1 acre			Acreage per fire			% Fires > 1 acre		
	L	M-c	All fires	L	M-c	All fires	L	M-c	All fires	L	M-c	All fires
Very low	117.1	5.3	30.4	46.1	49.9	49.0	2.3	2.3	2.3	23.0	27.5	25.1
Low	80.6	6.5	23.1	44.6	45.8	45.5	17.2	5.6	9.3	32.5	37.5	35.9
Moderate	14.7	15.1	15.1	33.3	39.1	37.9	19.1	4.1	7.0	39.5	37.3	37.7
High	6.4	35.6	28.0	30.6	34.2	33.3	48.2	22.3	26.6	40.7	40.4	40.4
Extreme	0.9	3.6	3.2	28.1	28.5	28.4	151.9	32.2	48.7	50.5	46.5	47.1

	ADMC						FWI					
	Acreage per fire			% Fires > 1 acre			Acreage per fire			% Fires > 1 acre		
	L	M-c	All fires	L	M-c	All fires	L	M-c	All fires	L	M-c	All fires
Very low	7.2	6.5	6.6	28.7	58.3	54.5	2.6	3.7	3.2	19.7	30.9	25.7
Low	18.8	11.3	12.5	37.8	48.4	46.7	13.6	6.4	8.6	31.9	43.2	39.8
Moderate	75.7	20.0	34.7	36.4	36.5	36.5	35.8	5.3	11.1	40.1	40.9	40.7
High	13.0	22.6	20.3	32.8	29.9	30.6	42.8	25.5	28.7	40.2	38.0	38.4
Extreme	2.8	3.4	3.2	38.8	28.1	30.9	126.3	30.0	44.8	51.7	39.5	40.6

[a] L = Lightning fire

[b] M-c = Man-caused fire

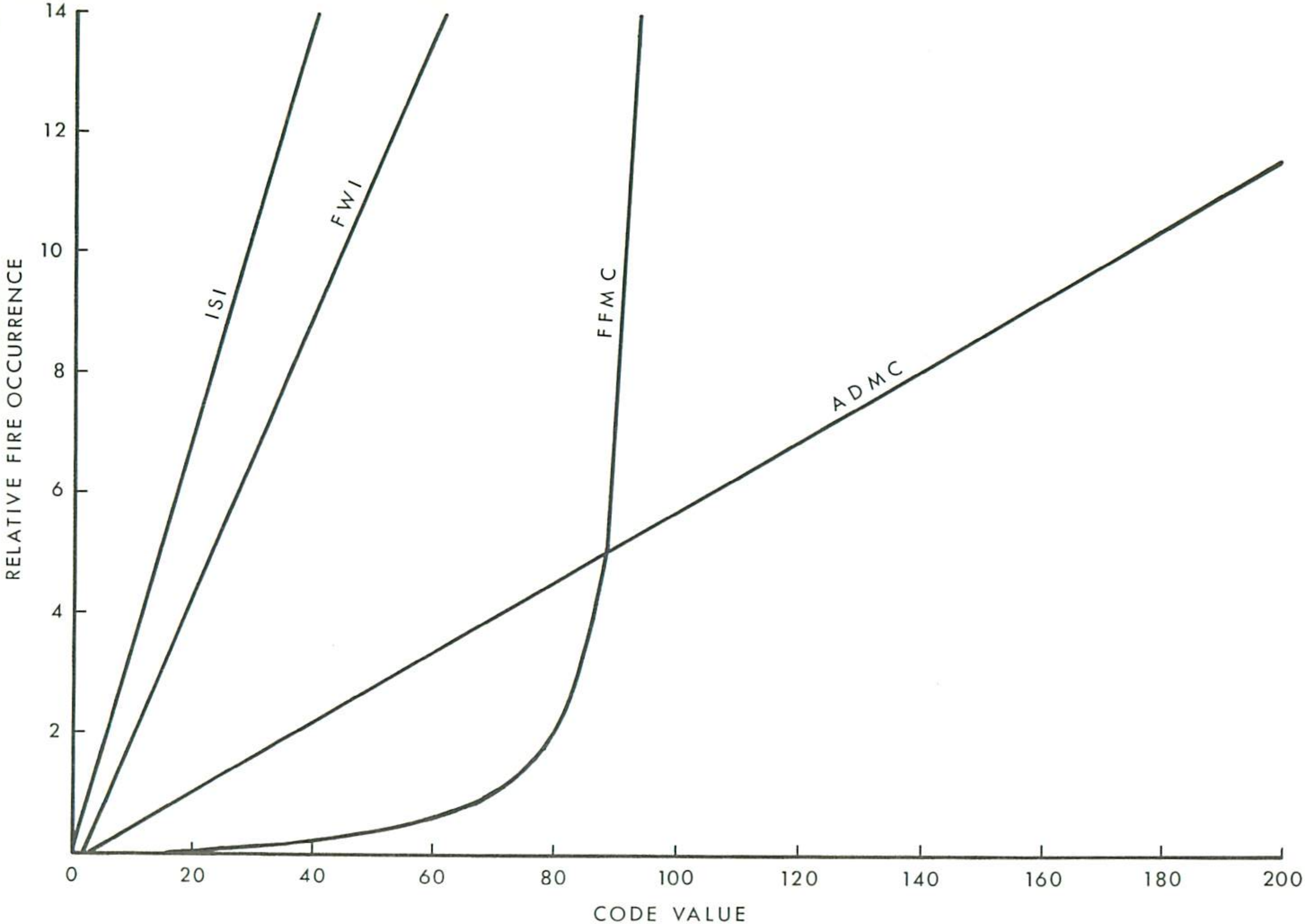

Figure 4. Relationship between relative fire occurrence and the FFMC, ISI, ADMC and FWI in Ontario (1965-1971).

relative fire occurrence. The relative fire occurrence per FFMC plot is distinctly curvilinear, with a gradual increase in relative fire occurrence at FFMC values below 70; however, beyond this point the increase is quite pronounced.

CONCLUSIONS

As a result of this analysis of wildfires and the FWI system in Ontario for the 1965-1971 period, a number of conclusions can be drawn:

1. In general, severe fire weather occurs less frequently in regions 2 and 3 than in regions 1, 4 and 5.

2. Throughout the province the size of the average lightning fire is more than double that of the average man-caused fire (36.6 acres as opposed to 15.6). The percentage of total fires caused by lightning varies greatly between regions, ranging from a high of 40.0% in Region 1 to a low of 14.2% in Region 5.

3. "Acreage burned" figures are highest in the conifer and slash fuel types for both lightning fires and man-caused fires. In terms of total number of fires the vast majority of lightning fires start in the conifer fuel type while the greatest number of man-caused fires start in grass fuels.

4. A definite seasonal pattern of fire occurrence exists in Ontario for both lightning fires and man-caused fires with "acreage burned" figures increasing from April through June and then decreasing. Lightning fire occurrence is highest in July and August while man-caused fire occurrence peaks in July. Spring fires are largest, regardless of cause.

5. The chance of fire occurrence increases steadily with a rise in FWI class and the pattern of fire occurrence by FWI class is similar for the five regions studied.

6. The FWI, ISI, and FFMC are strongly correlated with fire size in Ontario for both types of wildfire while the ADMC, DMC and DC are not.

7. A strong linear relationship exists between relative fire occurrence and the FWI, ISI and ADMC for the data analyzed, with a doubling of these code values resulting, approximately, in a corresponding doubling in relative fire occurrence. A strong exponential relationship between the FFMC and relative fire occurrence is also evident.

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