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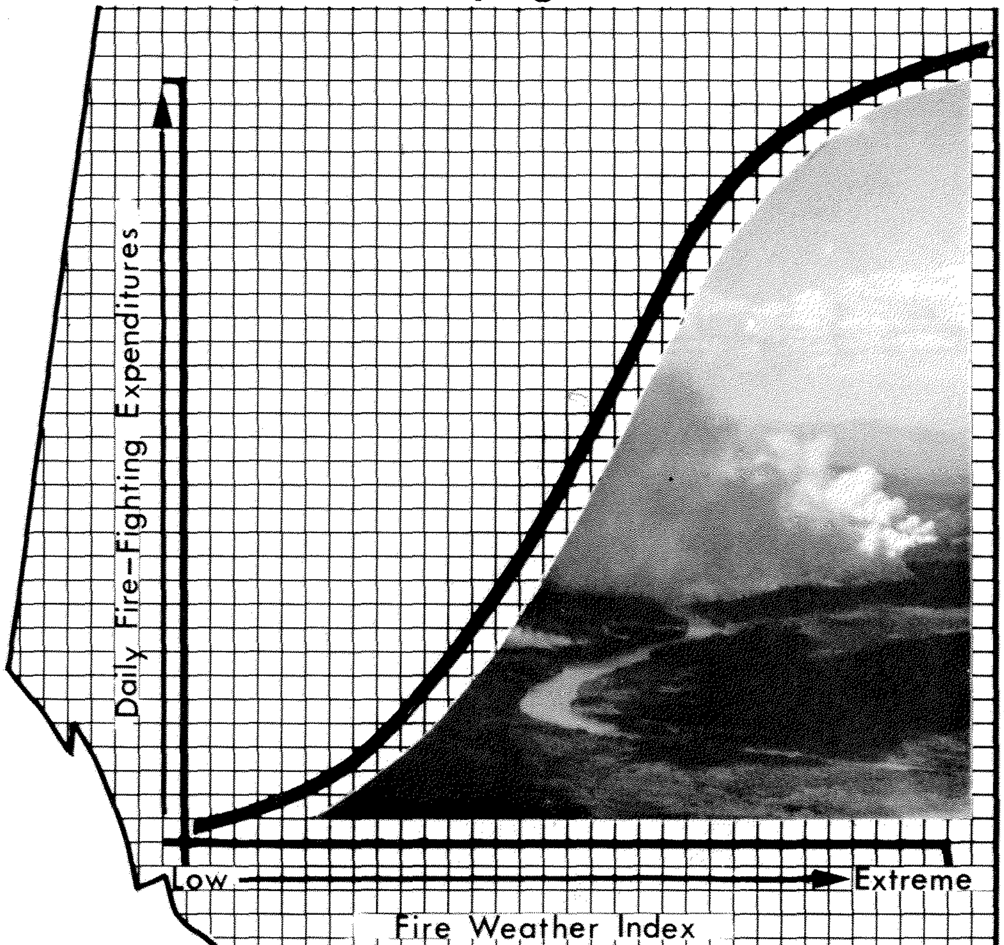
by A. D Kiil, R. S. Miyagawa, and D. Quintilio



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CALIBRATION AND PERFORMANCE OF THE CANADIAN FIRE WEATHER INDEX IN ALBERTA

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NORTHERN FOREST RESEARCH CENTRE
CANADIAN FORESTRY SERVICE
ENVIRONMENT CANADA
5320 - 122 STREET
EDMONTON, ALBERTA, CANADA
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ABSTRACT

This study, based on over 35,000 sets of daily weather observations and 2060 individual forest fires covering the 5-yr period from 1965 to 1969, calibrates and evaluates the reliability of the Fire Weather Index Tables in Alberta. The Fine Fuel Moisture Code (FFMC), the Initial Spread Index (ISI), and the Fire Weather Index (FWI) are good indicators of relative fire occurrence, whereas the Buildup Index (BUI) is the best measure of expected lightning-fire activity. Results generally indicate that fire business (fire occurrence, area burned, suppression costs, etc.) increases with increasing code and index levels. Although the average final sizes of Class E (>202 ha or 500 acres) fires were similar in spring and the remainder of the fire season, spring fires typically occurred on days with high to extreme ISI and low to moderate BUI compared to a general reversal of the magnitude of these two indices for summer fires. Study results and an interpretation of relevant data provide a base for refining the application of various codes and indices in support of fire planning and operational activities so as to improve the systems's performance.

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[1] Head, Liason and Development Section, Alberta Forest Service.

RESUME

La présente étude, fondée sur plus de 35 000 séries d'observations météorologiques quotidiennes et 2060 incendies de forêt pour une période de 5 ans, soit celle de 1965 à 1969, mesure et évalue la fiabilité des tables de l'indice forêt-météo en Alberta. Le code d'humidité du combustible léger (CHCL), l'indice d'expansion initiale (IEI), et l'indice forêt-météo (IFM) sont de bons indicateurs de l'apparition relative des feux, alors que l'indice d'accumulation (IA) constitue le meilleur indice de probabilité d'incendies causés par la foudre. Les résultats indiquent généralement que les activités relatives aux incendies (apparition, surface brûlée, coût de suppression, etc.) augmente en proportion du niveau des codes et indices. Même si les dimensions finales moyennes des incendies de la classe E (>202 ha ou 500 acres) étaient similaires au printemps et pour le reste de la saison des feux, les incendies du printemps prirent naissance durant les jours ou l'indice IEI était d'élevé à extrême et où l'IA était de bas à modéré, par compariaison à un renversement général de l'importance de ces deux indices lors des incendies d'été. Les résultats de cette étude ainsi qu'une interprétation des données y relatives fournissent une base de perfectionnement dans l'application des divers codes et indices pour appuyer la planification et les opérations de répression aux fins d'améliorer le rendement des diverses méthodes de lutte.

TABLE OF CONTENTS

INTRODUCTION

The Fire Weather Index Tables (Anon. 1970, Van Wagner 1974), which were the first phase in the development of a comprehensive Canadian fire danger rating system, were adopted by the Alberta Forest Service in 1971. The Tables predict the relative rate of spread, fire intensity, and the fuel available for combustion, and are commonly used in support of prevention, detection, suppression preparedness and suppression activities at both the provincial and district levels. By integrating the combined effects of four key weather factors, namely temperature, relative humidity, wind, and precipitation, the Tables reflect both the current potential of fires starting and spreading as well as the accumulated effects of drought on fire intensity. The Fire Weather Index (FWI) has provided a uniform and consistent scale for rating fire weather severity across Canada since 1970.

Components of the Tables convey information about some aspect of fuel moisture or fire behavior in a "standard" fuel type. However, since differences in fuel types are not reflected, it is essential that the key components of the system be calibrated to determine correlations between historical values of components and selected elements of fire business such as fire occurrence frequency, fire size, and suppression costs and damages. Such calibration studies enable the fire management agency to establish descriptive and numerical classes and guides for the establishment of preparedness levels for administrative and operational purposes.

This paper presents calibration results and related information about the reliability of the FWI and associated components in Alberta. Such historical correlations, based on operational data, will enable the fire manager to improve the interpretation and use of the FWI and component codes and indices. Also, the information helps to identify those components which require further refinement to improve the system's performance. Kiil and Quintilio (1969) reported on a similar study covering the previous Canadian Fire Danger Rating System.

DATA BASE AND CALIBRATION PROCEDURES

Fire weather data and computer printouts of individual forest fire reports were made available for study purposes by the Alberta Forest Service. For the basic calibration study over 35,000 sets of daily fire weather observations and 2060 individual fires, covering the 5-yr period from 1965 to 1969, were used to calculate daily fire-danger indices and to determine correlations between indices and aspects of fire behavior and fire control activities. The weather observations covering the 6-mon period from May to October were taken at a total of 49 forest fire weather stations distributed throughout the province, with each station representing an area of about 8550 km^2 (3300 mi^2) (Appendix I). For each station, relevant codes and indices were calculated daily during the 150- to 180-day fire seasons covered in the study. The next step in the procedure was to match the individual fires with the nearest fire weather station and the selected components of the danger rating system. The computerized analysis provided printouts of cumulative frequency distributions of weather factors, codes, and indices as a basis for characterizing fire season severity. Also, correlations were determined between various indices and aspects of fire business including fire occurrence frequencies, area burned, and suppression costs. In addition to the 1965-69 data base, individual forest fire statistics for the 4-yr period from 1971 to 1974 were available for characterizing Class E (>202 ha or 500 acres) fires.

RESULTS AND DISCUSSION

Frequency Distributions of Indices and Weather Parameters

Frequency distributions of indices and weather parameters for various FWI-related codes and indices, and weather parameters are given in Figures 1 and 2. With the exception of the Fine Fuel Moisture Code, all other frequency distributions approximate a typical asymptotic pattern. These summaries of fire frequencies indicate the probability of a given level of fire danger being exceeded.

Descriptive Danger Index Classes

Fire managers usually implement their preparedness and operational plans by means of descriptive or numerical danger index classes such as Low, Moderate, High, Very High,

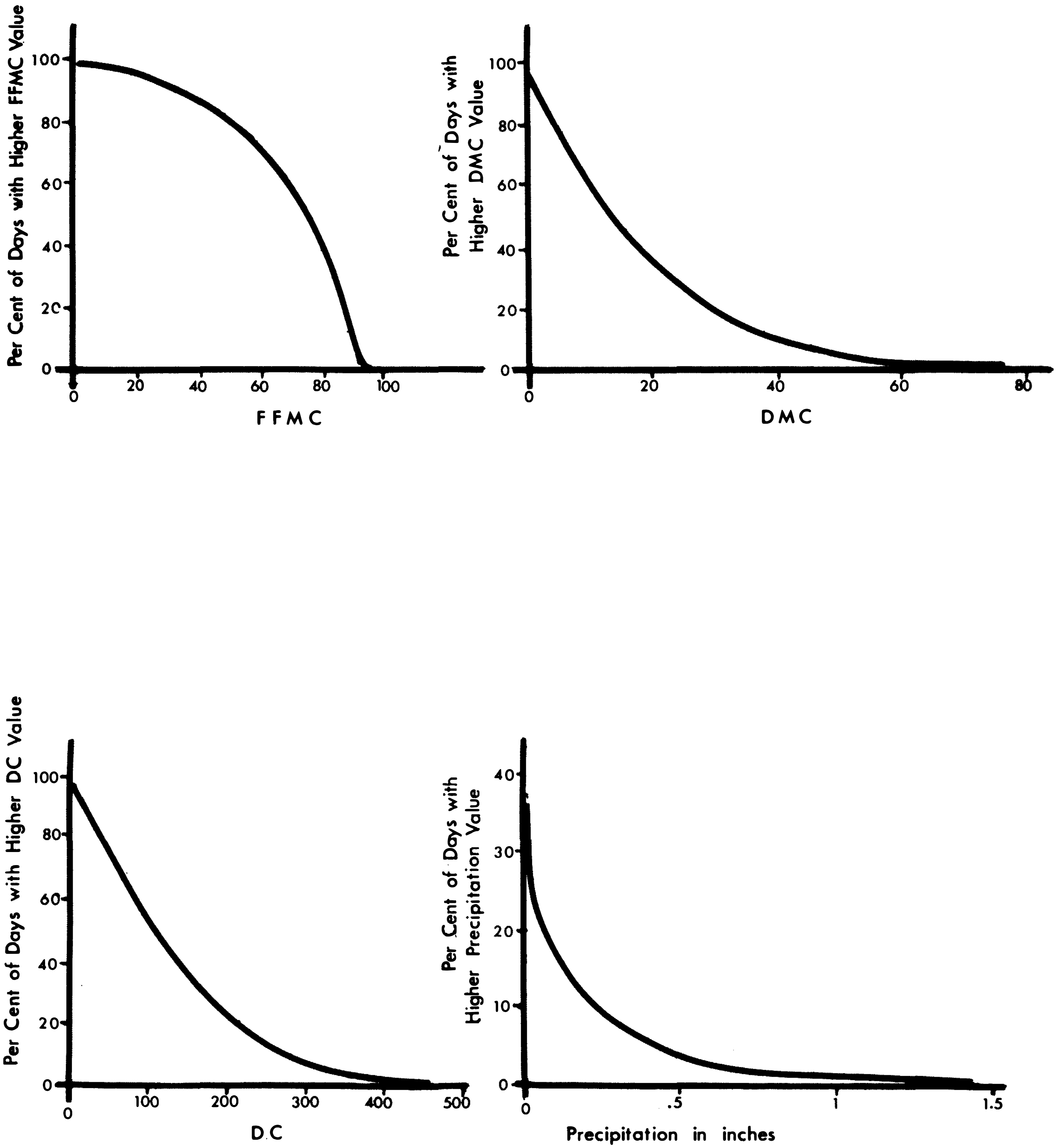


FIGURE 1 - Frequency distribution of FFMC, DMC, DC and Precipitation in Alberta, based on 30,124 observations during the five-year period 1965-69.

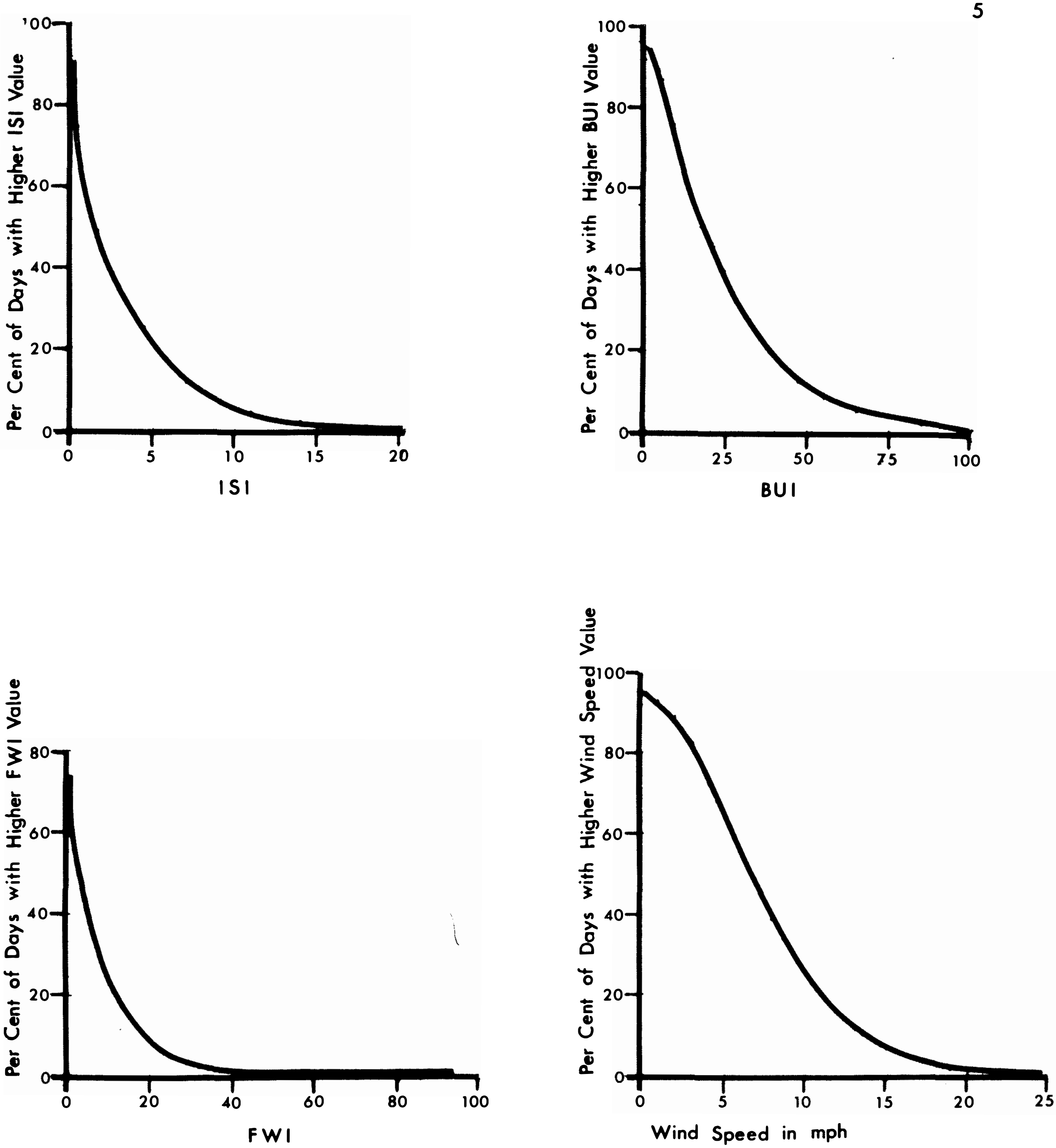


FIGURE 2 — Frequency distribution of ISI, BUI, FWI and Wind Speed in Alberta, based on 30,124 observations during the five-year period 1965-69

and Extreme. These classes are derived from cumulative frequency distribution curves shown in Figures 1 and 2, depending on the intended end use of the data. For example, an FWI greater than 30 can be expected on 3% of the days during the average fire season. Danger index classes can be selected arbitrarily by using the above frequency distribution curves according to particular objectives and operational requirements of the management agency. Table 1 shows the class limits of the three codes and three indices of the danger rating system for selected percentages of recorded days for each of Low, Moderate, High, Very High, and Extreme descriptive classes.

Weather conditions experienced during the 5-yr study period are probably representative of the "average" fire season in Alberta. Considerable variation can be expected in the percentage frequency distributions between seasons as well as within fire seasons. The fire planner needs to take special care of short- and long-term cyclic patterns associated with fire incidence, fuels, and behavior. Furthermore, local fire weather and operational conditions may dictate the use of different class limits to obtain the same percentage distribution of days per class. Alternatively, index ranges may be kept constant by changing the distribution of days in each descriptive danger class. Depending on prevailing weather patterns, geographical location, and presence of a variety of ignition sources, the

Table 1. Class limits for selected[1] descriptive classes of codes and indices of the Fire Weather Index Tables (based on 5-yr period 1965-69)

Descriptive Danger Class	Selected Number of days/ class in percent	Fine Fuel Moisture Code (FFMC)	Duff Moisture Code (DMC)	Drought Code (DC)	Initial Spread Index (ISI)	Buildup Index (BUI)[2]	Fire Weather Index (FWI)
Low	30	0-63	0-8	0-80	0-0.7	0-12	0-0.1
Moderate	40	64-84	9-25	81-190	0.8-4.0	13-33	0.2-8
High	20	85-88	26-43	191-320	4.1-8.0	34-58	8.1-18
Very High	7	89-91	44-58	321-425	8.1-16.0	59-88	18.1-30
Extreme	3	92+	59+	426+	16.1+	89+	30.1+

[1] The percentages of days for each descriptive danger class can be selected rather arbitrarily, as in Table 1, or on the basis of anticipated planning and operational requirements of a particular fire management agency, as in Table 2.

[2] The term Buildup Index (BUI) replaces the old term Adjusted Duff Moisture Code (ADMC).

active fire season in Alberta may last from fewer than 100 days to in excess of 200 days. The normal fire season lasts about 180 days, with the summer season twice as long as either spring or fall.

Fire Occurrence

During the 5-yr study period, two out of every three fires were man-caused, the remainder being of lightning origin. The daily rate of fire occurrence in spring, summer, and fall was in a ratio of 4:3:1, with lightning the single most important fire cause during the summer season.

The distribution of days and fires by Fine Fuel Moisture Code (FFMC), Initial Spread Index (ISI), Buildup Index (BUI), and FWI classes is shown in Table 2. The FFMC, the ISI, and the FWI reflect a higher fire expectancy with increasing Index value, whereas fire incidence levels off at BUI of about 75. With the exception of the BUI, all indices correlate better with relative occurrence of man-caused rather than lightning-caused fires. In the case of the FFMC, relative fire occurrence of man-caused fires increases 17-fold from Low to Extreme class, compared to only a 3-fold increase for lightning-caused fires.

The association between the BUI and the FWI, and relative occurrence of man-caused and lightning-caused fires are shown in Figures 3 and 4. The relative occurrence of man-caused fires increases with FWI, but the incidence of

Table 2. Distribution of days and fires by Fine Fuel Moisture Code, Initial Spread Index, Buildup Index, and Fire Weather Index Classes in Alberta (based on 5-yr period 1965-69)

Code or Index	Descriptive Danger Class	Selected Index Ranges	Percent of Days	Percent of Fires	Relative fire Occurrence[1]
	Low	0-60	25	9	1
	Moderate	61-80	30	21	2
FFMC	High	81-86	23	23	3
	Very High	87-90	16	26	5
	Extreme	91+	6	21	10
			100	100	
	Low	0.0-1.0	38	16	1
	Moderate	1.1-3.0	23	18	2
ISI	High	3.1-8.0	27	32	3
	Very High	8.1-16.0	9	21	5
	Extreme	16.1+	3	13	10
			100	100	
	Low	0-25	51	30	1
	Moderate	26-50	35	41	2
BUI	High	51-75	9	19	4
	Very High	76-100	3	6	4
	Extreme	101+	2	4	4
			100	100	
	Low	0.0-0.1	27	9	1
	Moderate	0.2-8.0	43	31	2
FWI	High	8.1-16.0	17	25	4
	Very High	16.1-25.0	9	19	6
	Extreme	25.1+	4	16	12
			100	100	

[1]The ratio of percentage of days to percentage of fires for the Low class was converted to 1. The relative fire occurrence for each successive class is proportional to the value for the Low class.

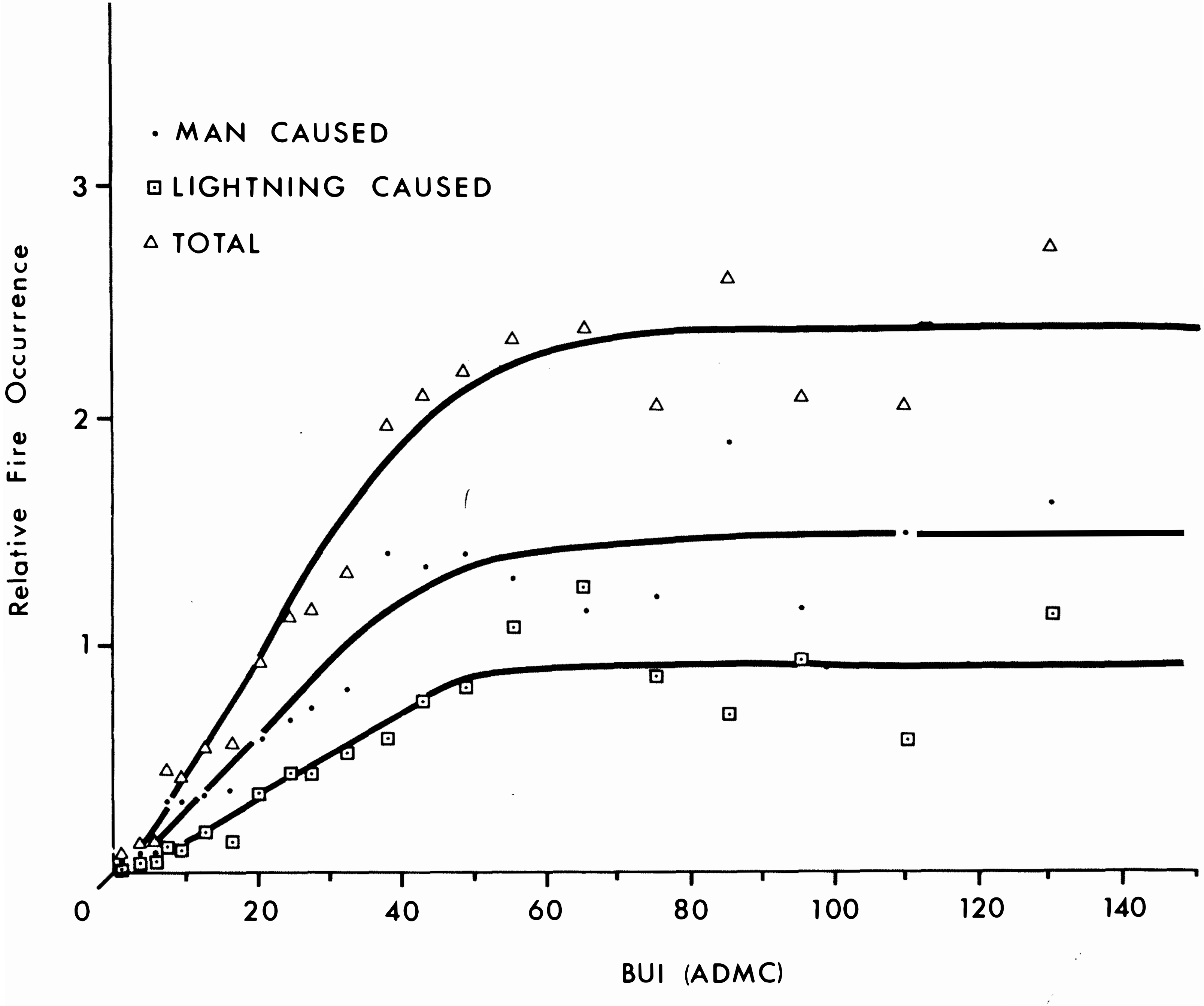


Figure 3. Relationship Between the BUI (ADMC) and Relative Fire Occurrence in Alberta, 1965–1969

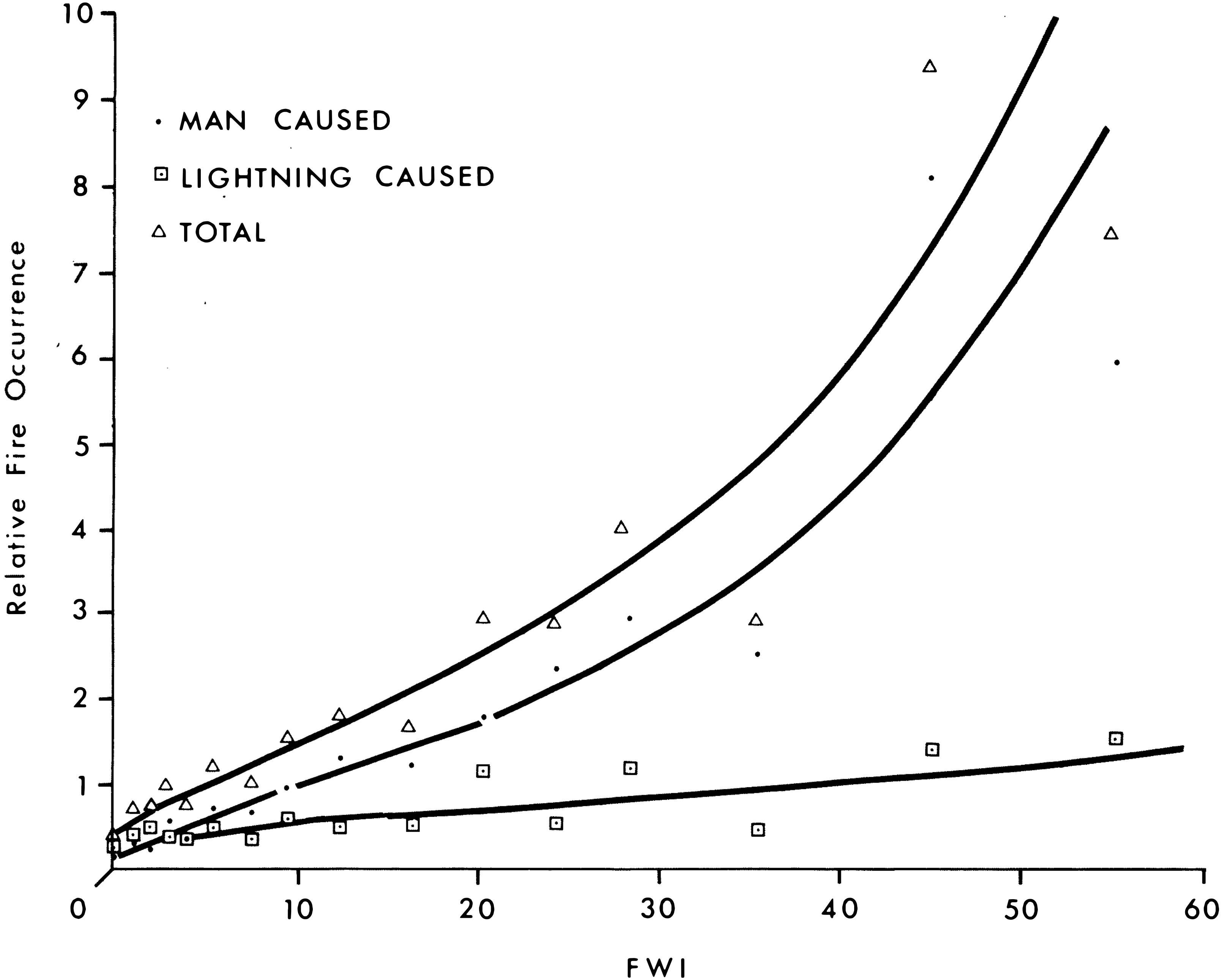


Figure 4. Relationship Between the FWI and Relative Fire Occurrence in Alberta, 1965 – 1969

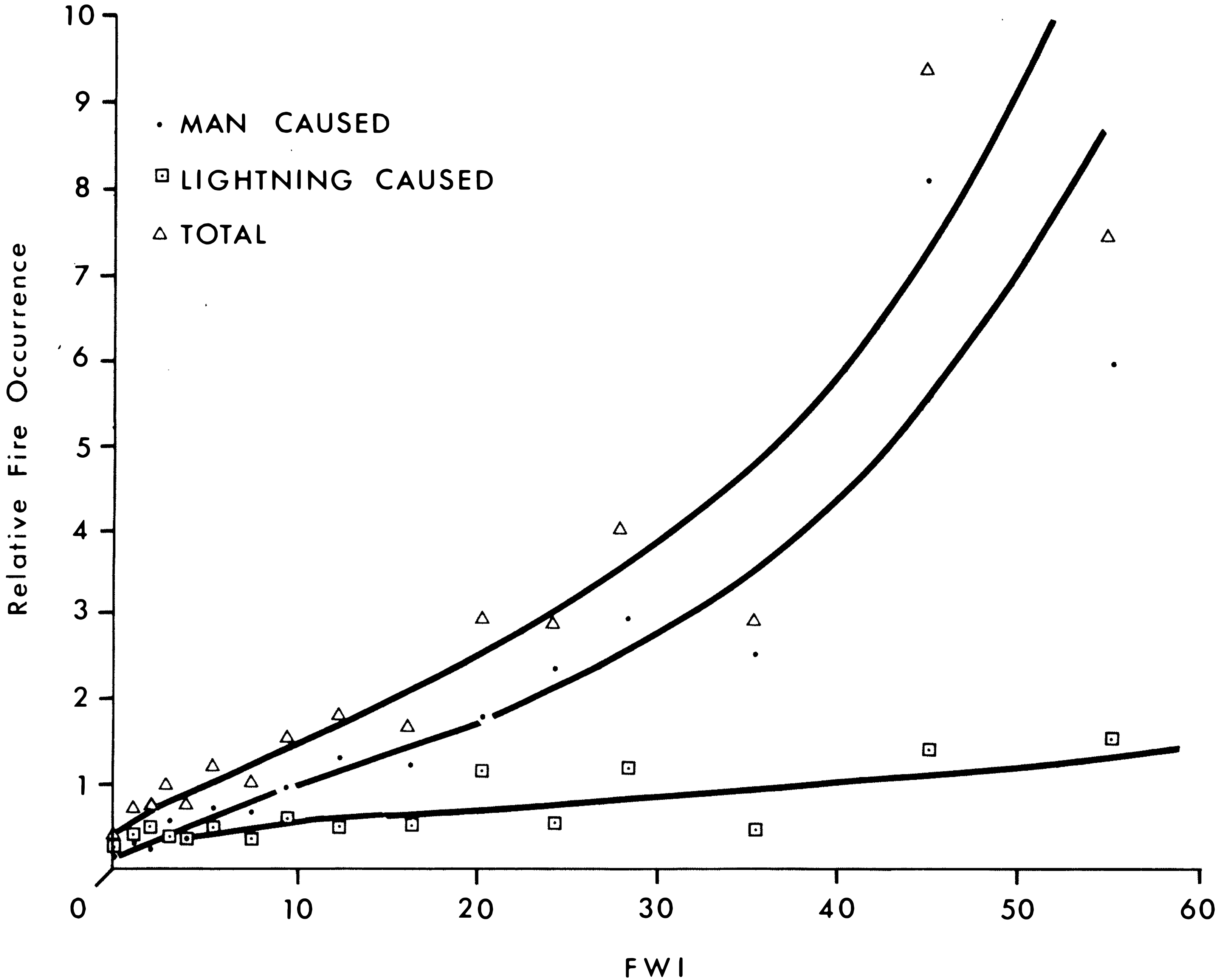


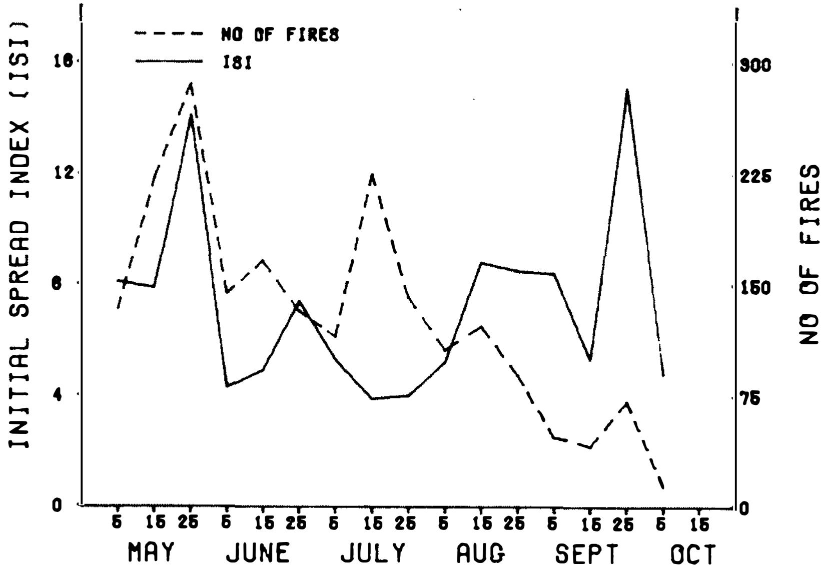
Figure 4. Relationship Between the FWI and Relative Fire Occurrence in Alberta, 1965 – 1969

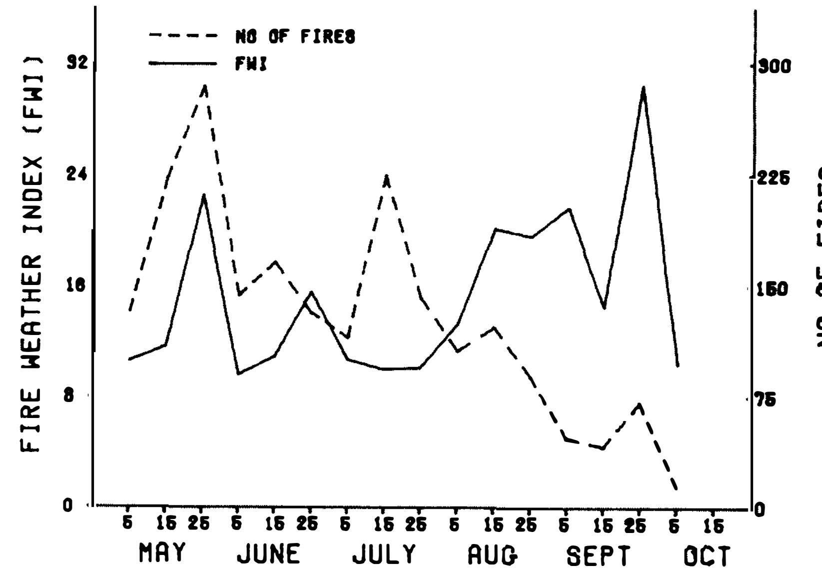
lightning-caused fires is relatively constant over the range of values. The BUI appears to be a good predictor of both man-caused and lightning-caused fires, with the best association at Index values up to about 50.

The relative occurrence of man-caused fires increased 22-fold as the ISI increased from Low to Extreme danger class. For all fires combined, ISI values higher than 8 occurred on 12% of the days, but these accounted for 34% of all fires. However, 42% of all man-caused fires occurred in the Very High or Extreme ISI classes, compared to only 17% of lightning-caused fires.

Figure 5 shows the average ISI, BUI, and FWI values on days when fires were reported. Early spring and fall fires tended to occur on days with relatively high ISI and FWI values, suggesting that these periods coincided with high winds and low relative humidities. As expected, the BUI values on days with fires increased progressively from a low in early spring to a high in late summer. The indices integrate the same weather factors in a consistent manner throughout the fire season. Thus the differences in the relationships between various indices and fire incidence are attributed to either typically cyclic fire weather patterns or to seasonal variation in the condition (flammability) of the fuels.

An indication of the magnitude of seasonal changes in fire weather severity is given in Figure 6. FFMC values in excess of 88 occur on over 31% of days in spring compared to





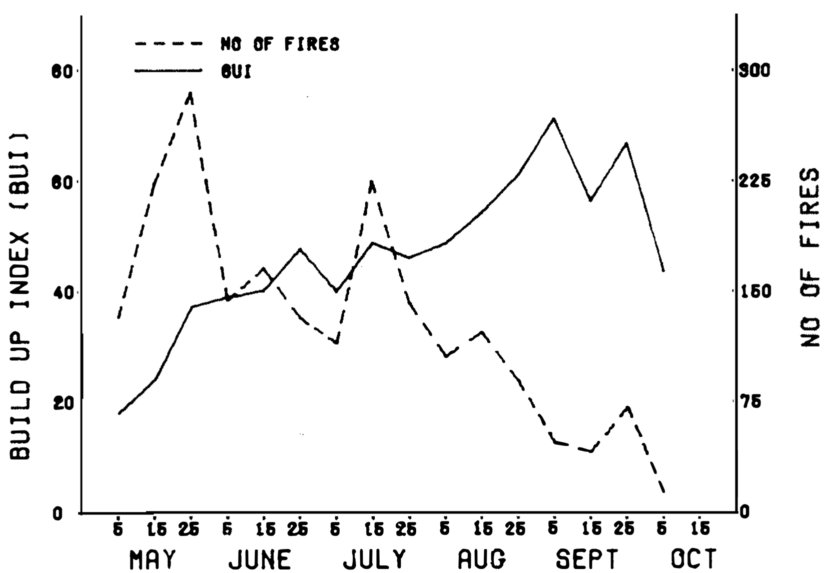


Figure 5. Average values for ISI, BUI, FWI, and number of fires, on days with fires, by 10-day periods, 1965-1969.

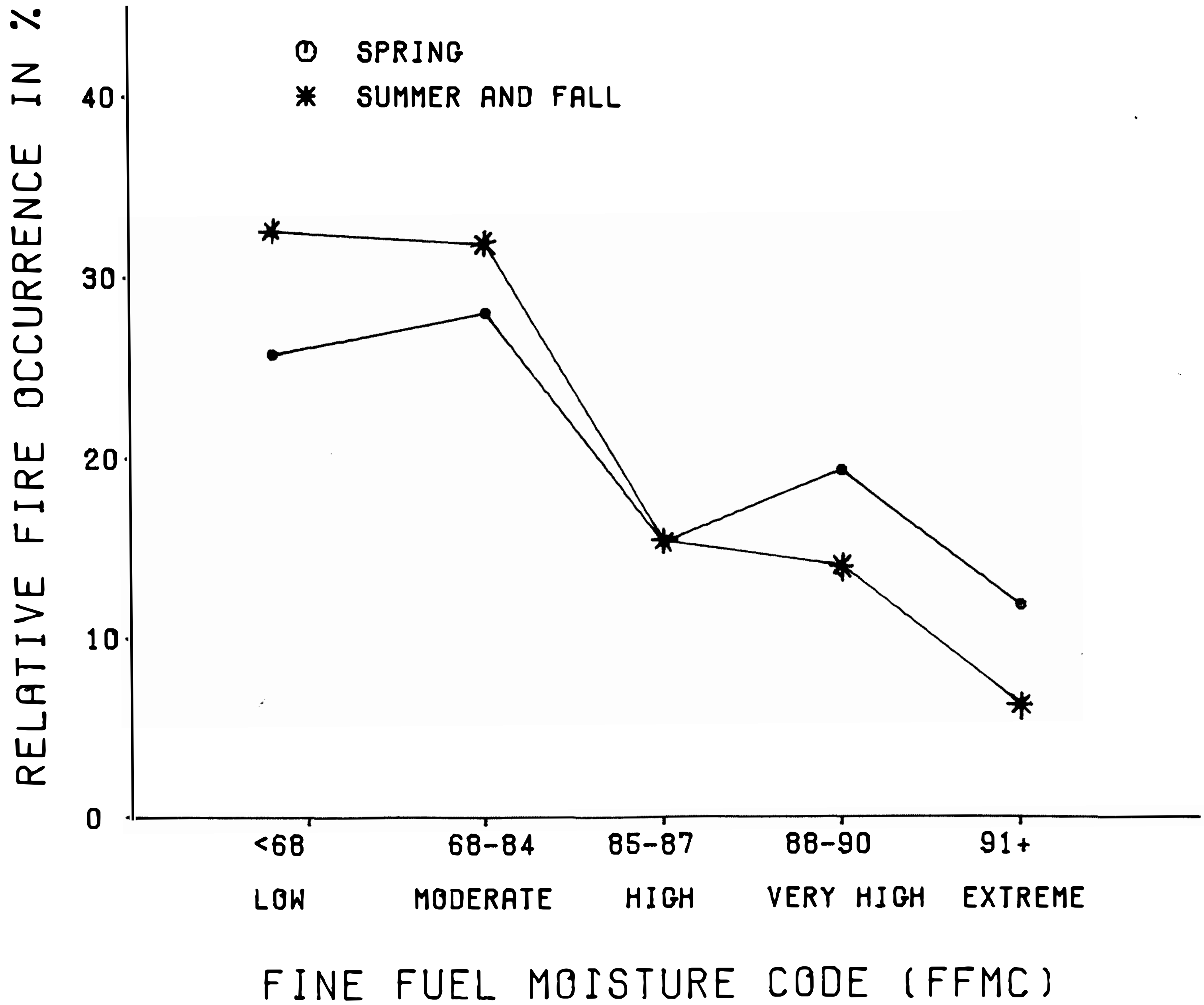


Fig. 6. Relative fire occurrence in spring, and summer and fall combined, by Fine Fuel Moisture Code classes, in Alberta, 1965-69.

only 20% of all days in summer and fall combined. Since FFMC of 88 or higher converts to an actual fine fuel moisture content of 13% or less, it is clear that ignition potential is highest during the spring season.

The FWI as an Indicator of Fire Business

The FWI and component codes and indices integrate the effects of weather factors on fuel moisture and fire behavior and tell the fire manager something about the expected suppression difficulty. While each code and index has a specific function within the modular framework of the danger rating system, calibrations are required to assess their reliability. Since the 5-yr period covered by the present analysis, fire control has undergone significant changes so that the specific correlations established on the basis of fire patterns and operational experience in 1965-69 may no longer be precise. Nevertheless, the results should be indicative of general trends and relationships to be expected between various indices and fire business.

Fire size at discovery, initial attack, and control by FWI and FFMC classes are given in Table 3 and Figure 7. With the exception of man-caused fires in the Extreme class, fire size generally increased with FWI. This reduction in the size of man-caused fires is attributed to a generally greater public awareness of fire potential, reinforced by increasingly active fire prevention programs, and restrictions on forest travel and industrial operations. The difference in fire size between discovery, initial attack,

Table 3. Fire size at discovery, initial attack, and control by Fire Weather Index classes in Alberta, 1965-69

FWI	No. of Fires	Fire Size at Discovery	Fire Size at Initial Attack	Fire Size at Control
		<—— area in hectares(acres) ——>		
Man-caused Fires				
0.0-0.1	79	3.2(7.9)	3.8(9.4)	5.1(12.6)
0.2-8.0	334	3.3(8.1)	5.0(12.4)	49.2(121.6)
8.1-16.0	348	6.9(17.0)	27.9(69.0)	153.9(379.9)
16.1-25.0	267	13.9(34.2)	56.2(138.8)	869.1(2146.0)
25.1+	277	11.4(28.2)	23.2(57.4)	226.3(558.8)
Lightning-caused Fires				
0.0-0.1	111	0.7(1.8)	1.0(2.5)	2.0(4.9)
0.2-8.0	302	1.2(2.9)	3.3(8.2)	13.8(34.1)
8.1-16.0	161	1.8(4.5)	9.8(24.2)	117.9(291.1)
16.1-25.0	119	1.1(2.7)	6.2(15.3)	197.8(488.5)
25.1+	62	9.3(22.9)	74.4(183.8)	395.4(976.4)
All Fires				
0.0-0.1	190	1.7(4.3)	2.2(5.4)	3.3(8.1)
0.2-8.0	636	2.3(5.7)	4.2(10.4)	32.4(80.1)
8.1-16.0	509	5.3(13.0)	22.2(54.8)	145.5(351.8)
16.1-25.0	386	9.9(24.5)	40.8(100.7)	662.2(1635.0)
25.1+	339	11.0(27.2)	32.6(80.5)	257.2(635.1)

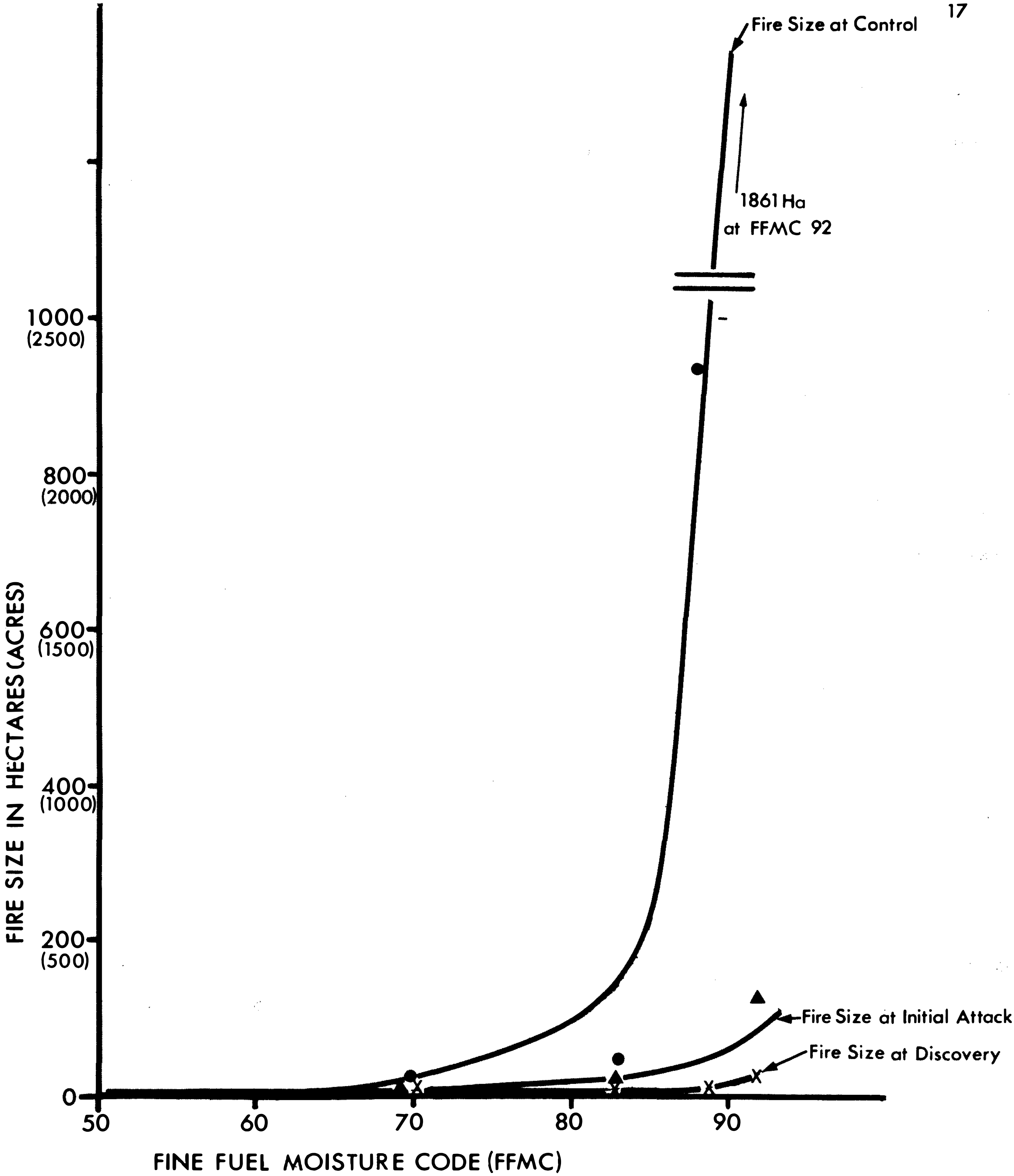


Figure. 7 Fire Size at Discovery, Initial Attack, and Control by FFMC in Alberta, 1965–69

(Basis: 197 Fires in Timber Fuel Type)

and control increased substantially with increasing FFMC and FWI. Without exception, average discovery sizes of man-caused fires exceeded those of lightning-caused fires, a situation attributed to the preponderance of settler fires in 1968.

Average final fire perimeters increased with increasing ISI and BUI in both spring and fall, although insufficient data precluded the confirmation of this trend over the full range of BUI values (Table 4). Furthermore, marked seasonal differences in fire perimeters existed between spring and summer, suggesting that seasonal influences such as weather and fuels need to be considered in calibrating the danger rating system. An examination of other data analyzed as part of this study suggests that maximum final perimeters and suppression costs were often associated with fires starting when ISI and BUI values were in the range of 5 to 16 and 25 to 75 respectively.

The figures in Tables 2 to 4 suggest that the FWI is a good predictor of the relative rate of fire spread and hence, of relative fire size at discovery, initial attack, and control. However, use of the information in support of various planning activities should be predicated on a thorough evaluation of the operational procedures and constraints in effect when the data were gathered, administrative considerations relating to fire protection policy on agricultural lands adjacent to forested areas, adequacy of the 5-yr period to reflect longer-term cyclic weather patterns, and reliability of individual fire

Table 4. Final fire perimeters in spring and summer by Initial Spread Index and Buildup Index classes in Alberta, 1965-69.

ISI	ISI Range	Spring	Summer
	Perimeter in metres(chains)		
Low	<1	1266 (62.9)	187 (9.3)
Moderate	1.1-3	1646 (81.8)	485 (24.1)
High	3.1-8	2744 (136.4)	702 (34.9)
Very High	8.1-16	10468 (520.3)	1058 (52.6)
Extreme	16.1+	4249 (211.2)	451 (22.4)

BUI	BUI Range	Spring	Summer
Low	0-25	1682 (83.6)	229 (11.4)
Moderate	26-50	8348 (414.9)	587 (29.2)
High	51-75	Insufficient data	752 (37.4)
Very High	76-100	"	1175 (58.4)
Extreme	101+	"	Insufficient data

reports. For example, debris burning on cleared lands adjacent to the forested zone in central Alberta was a major activity in the spring of 1968. Many of these fires burned for days before high winds carried them into standing timber. In all likelihood, the relatively large sizes of man-caused fires at discovery, initial attack, and control are attributable to a considerable extent to this situation. The extremely high incidence and rapid spread rates of the 1968 fires also had a significant effect on all other statistics analyzed in the present study. These and related considerations point to the need for the fire manager to question the relative magnitude of individual fire parameters; however, the validity of the trends in Table 3 is not affected. Similar trends and relationships were determined for ISI and BUI, but it would serve no useful purpose to include additional statistics of this nature.

Average spotting distances increased with wind speed, ISI, and FWI, but additional data will be required before the results can be used for predictive purposes. Reported spotting distances ranged from a few metres to about 1.9 km (1.2 mi), averaging about 30 m (100 ft), 15 m (50 ft), and 10 m (33 ft) in spring, summer, and fall, respectively. Average maximum spotting distances of over 300 m (980 ft) were recorded with wind speeds in excess of 40 km/h (25 mph).

Class E Fires (Larger than 202 ha or 500 acres)

Fires in the 202-ha and greater class usually account for most of the area burned and damages. Across Canada, the percentage of Class E fires has decreased from about 7.5% in the 1930's to 3.0% in the 1960's (Lockman 1969). During the 5-yr period from 1965-69 and the 4-yr period from 1971-74, Class E fires were responsible for 3.7 and 97%, and 2.5 and 92% of all fires and area burned in Alberta, respectively. Average size of the largest 1% of all fires was 18 144 ha (44,800 acres), a potentially useful measure of fire-fighting efficiency and savings. The operational performance of the fire danger rating system is particularly important in connection with Class E fires, since the ability to predict the occurrence of potential problem fires is likely to contribute significantly to reduction of damages and suppression costs. Suppression costs for Class E fires usually exceed 50% of total annual fire-fighting costs.

Not all Class E fires start during Extreme danger; however, there is a tendency for these fires to start at relatively high index levels (Figure 8). During the 5-yr period from 1965 to 1969, over 70% of all Class E fires occurred with FWI Very High or Extreme, compared to only 35% of all fires. Typically, a Class E fire started on a day with both ISI and FWI in Very High Danger class, and with the BUI at Moderate Danger.

Component codes and indices of the Fire Weather Index Tables were designed to serve as reliable predictors of expected fire weather severity on any given afternoon for which the indices have been calculated. However, the indices are not sensitive to seasonal condition of vegetation (cured

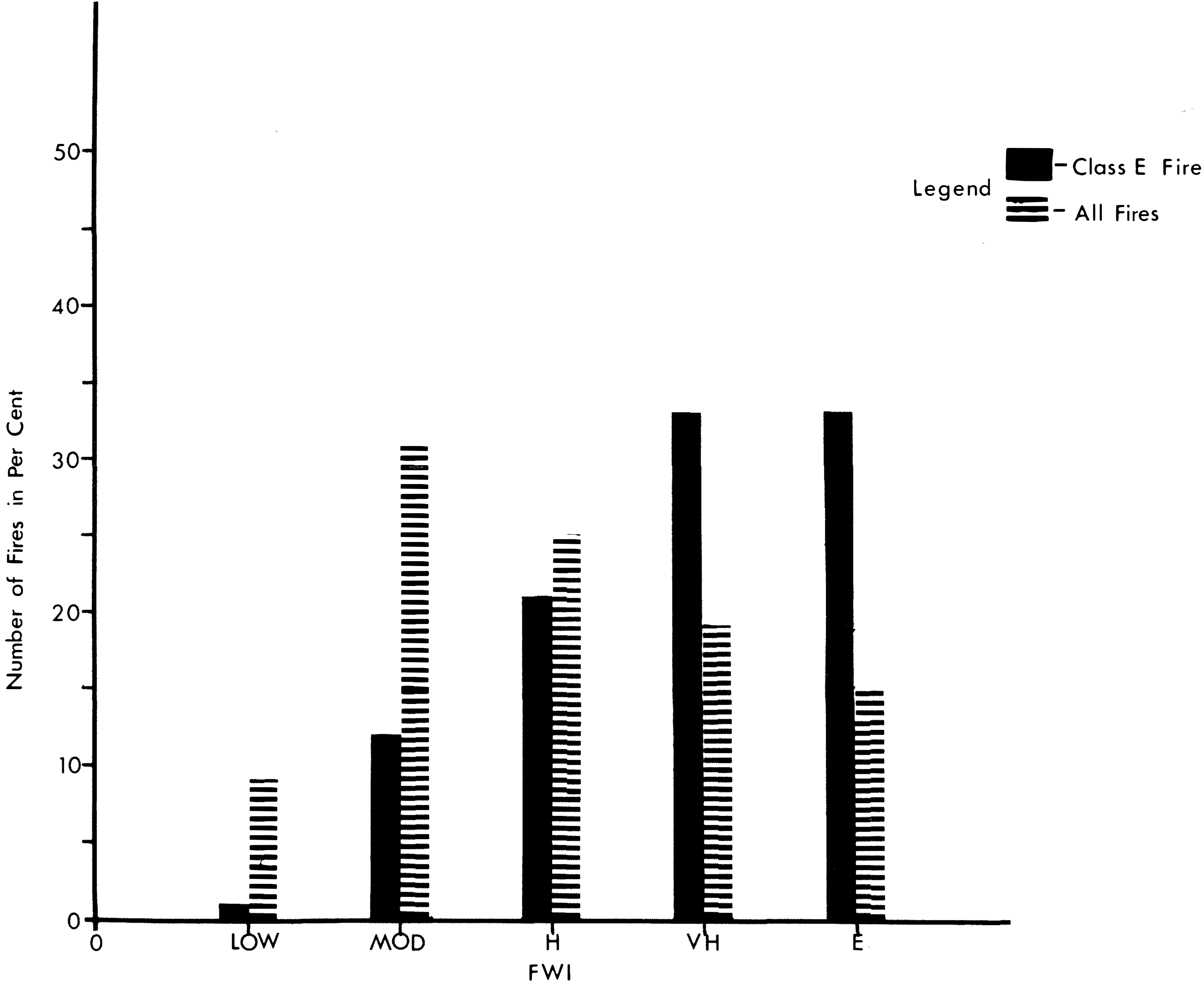


Figure 8. Relationship Between Fire Weather Index and Per Cent of Fires for: Class E Fires, 1965–1969, 1971–1974 and all Fires, 1965–1969

vs green), the effect of lesser vegetation on dead fuel moisture, the size and distribution of distinct vegetation (fuel) types in a large area, effects of latitude and elevation on fire weather, and the seasonal changes in foliar moisture content. As well, a Class E fire may burn for several days or even weeks; hence, an index calculated on the day of ignition may not be indicative of burning conditions over the lifetime of the fire. Nevertheless, the FWI appears capable of reflecting potentially severe burning conditions, provided the fire manager is willing to interpret the index (indices) in light of local conditions.

It is highly significant that more than three out of every four Class E fires occurred in spring between May 1 and June 10. A comparison of frequency distributions for ISI, BUI, and FWI in spring and during the entire year reveals that the fire weather is more severe in spring than during the rest of the fire season. High ISI and FWI values occurred more frequently in spring than during the entire year; in fact, ISI of 7.1 and higher occurred on 26% of the days in the spring and only 14% of the days during the entire fire season. Frequency distributions for BUI on days with Class E fires were almost identical for both periods.

During the 9-yr period covered by the study of Class E fires (1965-69 and 1971-74), the relative number of fires per day increased with the FWI (Figure 9). The Low and Moderate FWI classes accounted for 70% of the days during the entire fire season; however, these days had only 13% of all fires. By contrast, 66% of all fires occurred on only

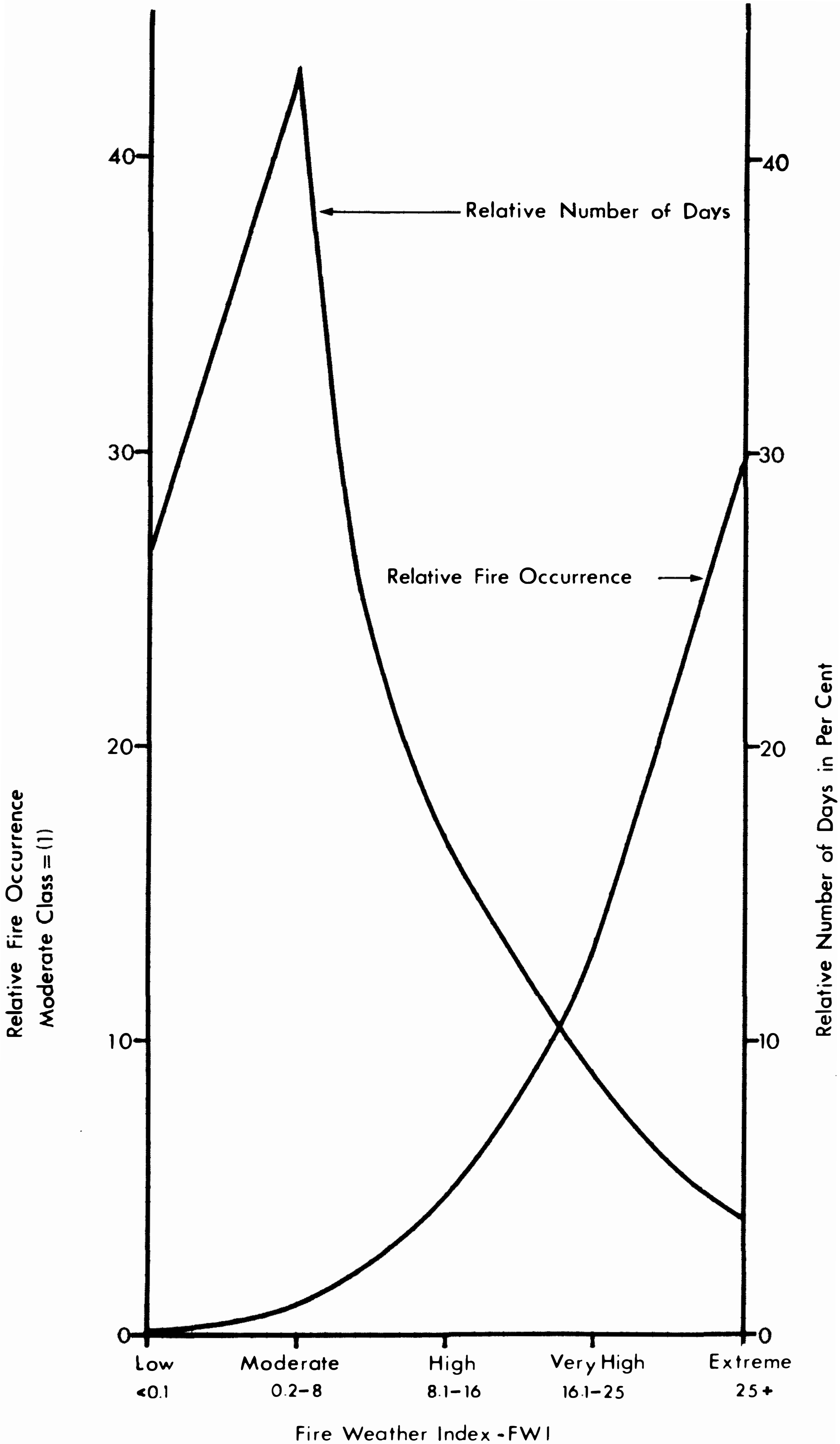


Figure 9. Fire Weather and Fire Occurrence of Class E Fires in Relation to the FWI in Alberta 1965–69 and 1971–74 Combined

13% of the days when the FWI was Very High or Extreme. In relation to the Moderate danger class, the daily rate of fire occurrence increased about 4-, 13- and 30-fold in the High, Very High, and Extreme classes. On the basis of 40-day spring (May 1 to June 10) and 120-day summer-fall (June 11 to October 10) fire seasons, Class E fires amounted to about one fire every 4 days in the spring compared to about one every 30 days during summer and fall. Surprisingly, average size of spring and summer-fall Class E fires was similar -- 4155 ha (10,268 acres) in spring and 3666 ha (9,060 acres) in summer-fall.

One-fourth of all Class E fires in spring were categorized as crown fires at initial attack, with the remainder being surface fires. By contrast, over 50% of Class E fires in summer were crowning at initial attack. The greater tendency for potential Class E fires to crown sooner after ignition in summer than in spring needs to be substantiated further, but it is conceivable that the spring foliar moisture dip is not the sole or even the prime factor responsible for the usually severe spring fire situation. Foliar moisture samples collected in 1965, 1967, and 1968 support the now well-documented phenomenon of a spring dip in conifer foliage moisture content. Minimum values of 68-70% moisture content were recorded during the 1968 spring fire season, in contrast to maximum values in excess of 125% during the summer and fall. The decrease in the moisture content of conifer foliage coincides with flushing and early growth of aspens and conifers, reaching a minimum before aspen leaves are fully developed. A very gradual increase in conifer foliage moisture content coincides with development of lesser vegetation under forest canopies and leafing out of hardwoods. The moisture content of hardwood leaves decreases from a maximum of over 300% in early spring to about 140% in midsummer. Appendix II provides a schematic representation of the key phenologic and foliar moisture content developments in Alberta in spring and early summer.

In addition to important seasonal differences in fuels, lack of adequate suppression resources in multiple fire situations may have a profound effect on final size of large fires. Use of historical data to support this contention requires careful scrutiny, but general relationships should prove useful in evaluating the reliability of the danger rating system in relation to fire-fighting activities. For Class E fires starting with FWI less than 10, elapsed time from start to discovery was 9.6 h compared to 2.6 h for fires starting at FWI of 10 or higher. Similarly, elapsed times from initial attack to control were 55 h and 99 h for fires starting at FWI less than 10 and more than 10 respectively. It is apparent that, despite the nearly fourfold increase in elapsed time from start to discovery, Class E fires starting on days with FWI of less than 10 are easier to control than those on days with higher FWI's. The actual elapsed times are of lesser importance than the differences at the two FWI levels, for many eventual Class E fires were given low priority during multiple fire situations. Miyagawa (1975) concluded that about 80% of

Class E fires of lightning origin were due to lack of adequate and rapid initial attack forces.

Discussion

The results of this study should prove useful to the fire manager for evaluating the operational reliability of the new Canadian Fire Weather Index Tables in support of fire management planning and operations. General trends and relationships are evident and indicate the system's usefulness as an important tool in fire management. In addition to the information on frequency distributions of various indices and weather factors, prediction of fire occurrence, fire size, and characterization of Class E fires, the study provided some clues about spotting distances, effects of fuel types on fire size, and expected differences in suppression costs for different combinations of indices.

The frequency distributions in Figures 1 and 2 and Table 1 are intended to serve as a basis for refining descriptive danger classes (Low, Moderate, High, etc.) according to needs of the user agency. These distributions are representative of the average fire weather across Alberta; important regional differences may exist but these need to be delineated through further detailed analysis.

For all codes and indices except the BUI, the percentage of High and Very High danger class days tended to be higher in spring than during the entire year, but these differences were usually less than 10%. The daily incidence of all fires in spring, summer, and fall was in a ratio of about 4:3:1 suggesting that a higher ignition potential and incidence of multiple fires, rather than the lack of sensitivity of various codes and indices to changes in fire weather conditions, may be a prime reason for the relatively higher fire load in spring.

On days with fires, average ISI and FWI values generally ranged from 5 to 15 and from 10 to 25 respectively, with peak values occurring in late spring and early fall (Figure 5). The average BUI increased steadily from a low of about 20 in early spring to over 70 in September. By contrast, fire incidence was highest in late spring and decreased steadily toward fall, with a peak in mid-July. The significance of these trends is that the same index values in different seasons will not necessarily result in the same rate of fire occurrence. This observation should not detract from the accuracy or usefulness of the ISI, BUI, or FWI for predicting relative fire occurrence and behavior, but suggests that factors such as the composition, condition, and the aerial distribution of different fuels within the fuel complex, fire cause (lightning vs man), and fire weather severity must be considered if a fire danger rating system is to satisfactorily reflect the

Table 5. Fire occurrence, area burned, and suppression costs of 2060 fires in Alberta covering the 5-yr period 1965-69

FWI Class	Class Range	No. of Fires	Number of Days in %	Number of Fires in %	Relative Fire Occurrence /day	Area Burned in %	Relative Area Burned /day	Suppression Costs in %	Relative Suppression Costs/day
Low	less than 0.1	190	27	9	0.4	0	0	2	0.4
Moderate	0.2 - 8	636	43	31	1.0	5	1.0	8	1.0
High	8.1 - 16	509	17	25	2.1	17	8.3	17	5.3
Very High	16.1 - 25	386	9	19	2.9	58	53.6	45	26.3
Extreme	25.1 and over	339	4	16	5.6	20	41.7	28	36.8
TOTAL		2060	100	100		100		100	

expected level of fire activity in different seasons. In the interim, the fire manager can improve the usefulness of the system by interpreting index classes according to his knowledge of the region.

A scrutiny of Table 5 and interpretation of available data on multiple fires suggest that the greatest opportunity for further savings in fire-fighting costs and damages lies with fires starting in the Very High danger class. A further evaluation of these fires, utilizing 10-15 yr of fire statistics, appears warranted to better characterize potential problem fires and to refine the fire manager's ability to predict the occurrence and severity of major outbreaks.

During the 9-yr study period (1965-69 and 1971-74), Alberta experienced 104 Class E fires in spring and 34 during the remainder of the fire season. On a daily basis, there were eight times as many Class E fires in the spring as in the summer and fall seasons. Yet, the final average size of spring fires exceeded that of summer and fall fires by only 13%.

Average fire size increased with BUI to a maximum at BUI of 50 in spring and BUI 75 during the remainder of the fire season, but decreased at higher values. FWI values were substantially higher in spring compared to summer and fall (ratio of about 2:1). While the relatively small number of Class E fires precludes a thorough assessment of the various factors contributing to the total fire load, the available data nevertheless suggest that in relation to the ISI or FWI, the BUI becomes relatively more important as a key indicator of fire size and control difficulty as the fire season progresses.

Very High and Extreme classes of both ISI and FWI occurred more frequently in spring than during the entire year, suggesting that the danger rating system is sensitive to seasonal differences in fire weather severity. The moisture content of conifer foliage is lowest during the spring period when the incidence of problem fires is highest. Perhaps more importantly, the peak spring fire season usually occurs before the development of full leafing out of hardwood trees and lesser vegetation under forest canopies (Appendices II and III). In contrast to midsummer conditions, differences in the flammability of fuels in hardwood, mixedwood, and conifer stands are minimized, enabling fire to spread rapidly over large areas comprising a wide variety of vegetation types. In other words, severe fire weather conditions, low conifer foliar moisture content, and the presence of cured and highly flammable fuels in all vegetation types facilitate rapid spread of fire during the spring fire season in May and the first half of June.

A decrease in fire weather severity, a lower ignition potential, a gradual increase in the moisture content of conifer foliage, and a relatively rapid invasion of lush lesser vegetation under forest canopies and leafing out of hardwood species appear to be the main reasons for a reduction in the proportion of Class E fires during the summer. However, it is interesting to note that the proportion of eventual Class E fires categorized as "crowning at initial attack" is higher in summer than in spring. Given identical weather conditions in spring and summer, the shade provided by the lesser vegetation and hardwood canopies in summer reduces evaporation and hence, increases the moisture content of the top layer of the organic forest floor and other dead forest fuels. Furthermore, the presence of lush green vegetation increases the energy required to drive off the moisture and to raise the fuel temperature to the ignition point. Thus, identical ISI and FWI values in spring and summer do not reflect identical fuel moisture or wind values at the forest floor. While the low moisture content levels in conifer foliage in spring may contribute to rapid spread of crown fires, the development of lesser vegetation, an increase in the moisture content of surface fuels, and marked differences in fuel flammability between hardwoods and conifers may well override any effects of gradually increasing conifer foliage moisture levels from spring to summer (Appendix III). However, the development of an extended period of drought, as reflected by the BUI, appears to compensate for the presence of lush vegetation and relatively high conifer foliage moisture contents in summer.

There is good evidence (Appendix IV and data on file) that the BUI relates directly to final size of Class E fires and that there is no marked difference in the average size of large spring and summer fires. Thus the available evidence suggests that the ISI is probably the best single indicator of fire potential in the spring, whereas the BUI does a better job in summer and fall. Obviously, a combination of ISI and BUI will do a better job of integrating total fire business over the entire fire season. In doing so, it is important to distinguish between potential and actual fire occurrence; the codes and indices should not be held accountable for disaster situations brought about by multiple fires and lack of sufficient detection and suppression resources to tackle all fires at an early stage. The findings of this study suggest that the danger rating system is a relatively well discriminating operational tool, provided that a meaningful calibration is carried out to optimize the use of various components as indicators of fire business.

In relation to suppression activities, weather, fuels, and terrain features can be expected to exert an increasingly greater effect on final fire size as fire potential progresses from low to extreme danger levels. Weather appears to be the main limiting factor to fire propagation in spring when the continuity of fuels is highest, whereas the development of drought, coupled with its effect on increasing the continuity of flammable fuels, may be the key factors contributing to large fires during the growing season. Differences in flammability attributable to slope, aspect, and elevation, including marked differences in rainfall between adjacent valleys, are accentuated in mountainous terrain such as the East Slopes region. Thus slow-growing spruce-fir stands at high elevations or on north-facing slopes may be comparable to mixedwood stands with lush understory vegetation in terms of their immunity to rapid fire spread during all but the most prolonged periods of drought. In instances when the moisture deficiency in heavy fuels spans several fire seasons or even years, the Drought Code (DC) should prove to be a useful indicator of fire persistence.

The descriptive terms Low, Moderate, High, Very High, and Extreme were derived from an arbitrary percentage frequency of days to help the fire manager familiarize himself with the range of potential weather and fire conditions to be expected in a province, region, or district. In general, these descriptive classes serve as meaningful indicators of expected relative fire activity, suggesting that the danger rating system is sensitive to current and cumulative weather effects on fuels and fire behavior. Although the BUI relates directly to fire occurrence and fire size to a maximum value of about 50 and 75 in spring and summer, respectively, it does not suggest an increase in fire severity at higher Index levels. A longer period of fire history may demonstrate that fire load increases at BUI values in excess of 75. Nevertheless, we recommend that the present BUI classes be adjusted, preferably in a two-way table including the ISI, to reflect the actual fire load experience in Alberta during the study period or any other period considered suitable for this purpose. In addition to its inherent capability to reflect the buildup of drought, the BUI appears to be the best indicator of lightning-caused fire incidence. Thus the flexibility and general usefulness of the system can be increased by using the FFMC, ISI, and BUI as well as the FWI, with the applicability and reliability of each index determined according to calibration of fire history and the needs of the user agency.

Work is underway to develop a fuel appraisal procedure and to calibrate the danger rating system to better reflect important differences in fire behavior between critical fuels. For planning purposes, the usefulness of the various indices can be increased by preparation of tables and related guidelines giving fire occurrence, fire size, expected fire load (number of fires x an index of fire intensity), difficulty of suppression, allocation of resources, etc. for different levels and combinations of indices. Probably, the greatest improvement in the use of the existing system may be derived from the preparation and assessment of new guidelines to incorporate fire danger rating indices into the planning process, rather than through the provision of more refined indicators of fire behavior.

CCNCLUSIONS

The results of this calibration study support the following conclusions:

1. The Fine Fuel Moisture Code, the Initial Spread Index, and the Fire Weather Index are reliable indicators of relative fire occurrence and behavior of man-caused fires. The Buildup Index correlates well with the relative incidence of lightning-caused fires.
2. The Fire Weather Index and components are particularly sensitive to burning conditions likely to contribute to the development of Class E fires. The indices appear to be reliable indicators of relative differences in fire occurrence and behavior between danger classes, but they do not gauge seasonal differences in risk or in the actual number of fires on any given day.
3. There are distinct seasonal patterns in the magnitude of individual codes and indices, suggesting that the same code or index number has a different meaning in spring, summer, and fall. This, coupled with highly variable fire incidence between seasons, dictates that the fire manager should adjust planning and operational schedules accordingly.
4. An interpretation of study results and relevant data on file at the Northern Forest Research Centre

suggests that the codes and indices of the Fire Weather Index system are sensitive to weather factors and fuel moisture levels which in turn reflect expected fire occurrence and key aspects of total fire business. While the Fire Weather Index system does not adequately reflect fire incidence and behavior attributable to differences in risk and the fuel complex, the calibration results nevertheless contribute to the fire manager's ability to select the most appropriate code or index to achieve a specific fire management function.

5. Very High and Extreme classes of both Initial Spread Index and Fire Weather Index occurred more frequently in spring than during the entire year. Other factors contributing to the typically severe spring fire season in Alberta include the markedly higher fire frequency, the low moisture content and aerial continuity of highly flammable cured fuels in all vegetation types, and the relatively low foliar moisture content of conifers.

6. During the 5-yr study period, the sizes of man-caused fires at discovery, initial attack, and control increased with the Fire Weather Index from the Low to the Very High class, but decreased in the Extreme class. The corresponding sizes of lightning-caused fires continued to increase from the Low to the Extreme classes. Increased fire preventions efforts (public awareness, forest closures, bans on open fires, etc.) on days with the Fire Weather

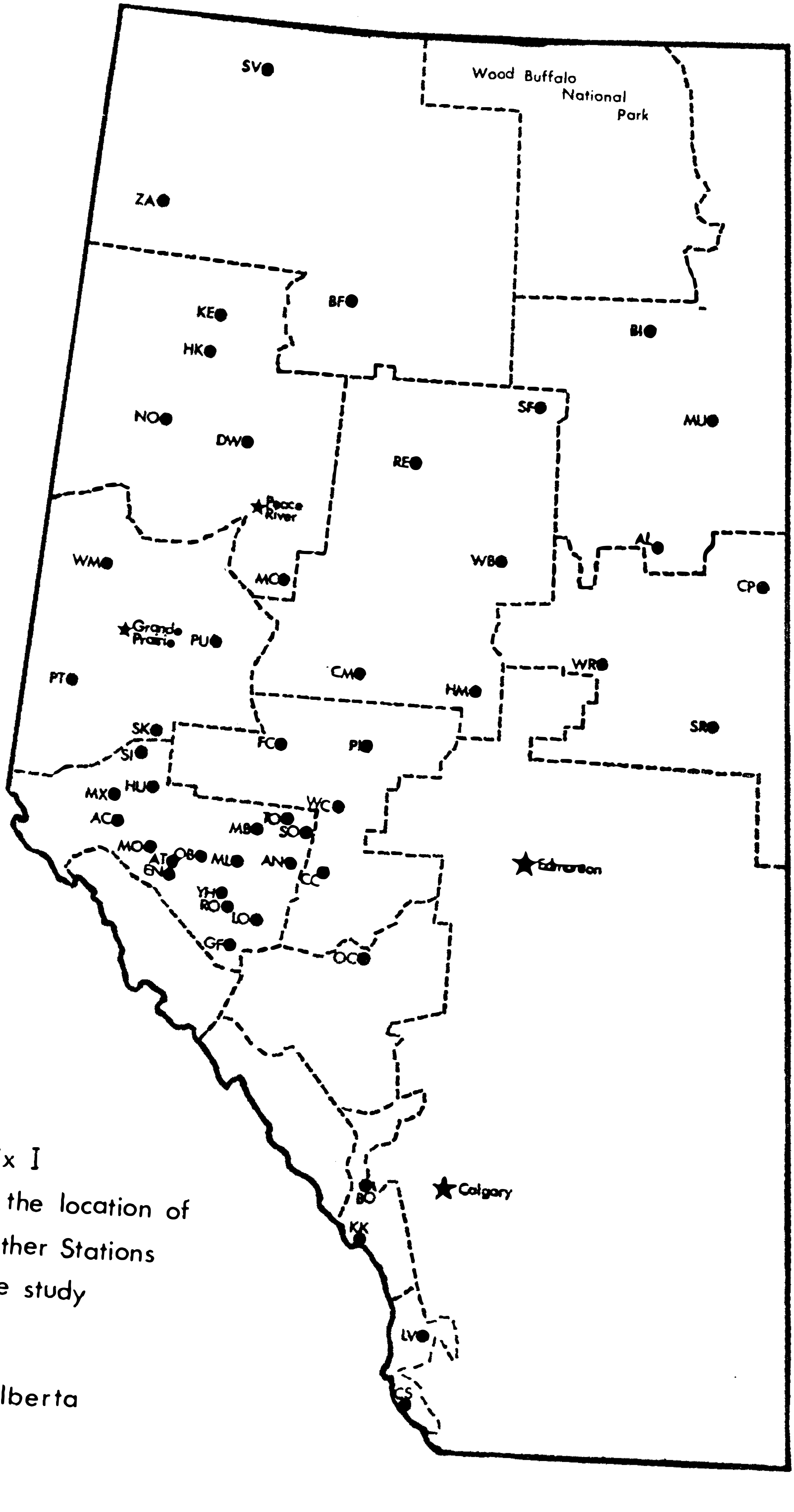
Index in the Extreme range is a likely reason for the reduced man-caused acreage burned on those days. While the daily rate of fire occurrence increases with the Fire Weather Index, it is conceivable that there is a higher likelihood of consecutive days with High and Very High index values than with Extreme days. Fires escaping initial attack may therefore continue to burn for several days or even weeks during increasingly severe burning conditions, whereas escaped fires which started on Extreme days may be more likely to come under the influence of a less favorable weather regime for rapid fire spread. Unless fire-fighting resources are already committed to cope with a particularly heavy fire load during High and Very High days, the even greater alertness of the fire management agency is probably the key factor responsible for the reduction in the average size of fires starting on Extreme days.

7. Minimum conifer foliage moisture content values can be expected shortly after initiation of leader growth. The spring foliar dip coincides roughly with the leafing out of hardwood species such as aspen. In fact, the period during which aspen leaves are 25 to 75% of full size often coincides with peak fire activity.

8. A further calibration of the Fire Weather Index system is required to assess its reliability and usefulness with changing risk, fire incidence, and weather patterns. Such assessments would also prove

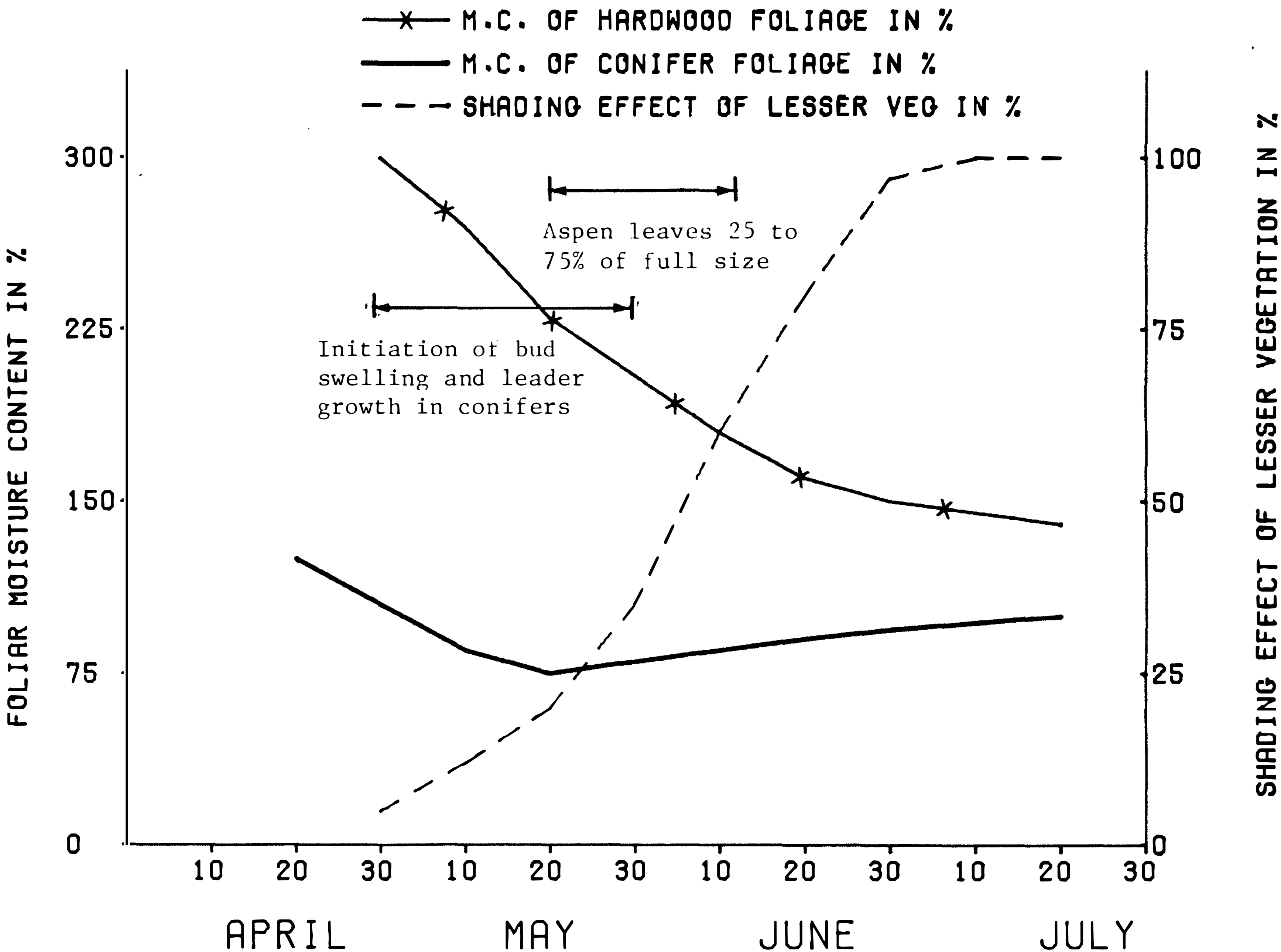
useful in support of fire management planning and in gauging the magnitude and effectiveness of improvements in fire suppression methods.

Work is underway to measure differences in fire business attributable to fuels, and a calibration study covering a 15-yr period will be completed by 1980.



Appendix I
Map showing the location of 49 Fire Weather Stations used in the study

Province of Alberta



Appendix II. Schematic representation of vegetative development and moisture content of foliage in spring and early summer in Alberta.

Appendix III. Comparison of estimated weight and moisture content of fuels in a lodgepole pine stand[1] during periods of high fire weather severity in spring and summer

Fuel component	Spring		Summer		Increase in amount of water from spring to summer
	Oven-dry weight	Estimated amount of water in fuel	Oven-dry weight	Estimated amount of water in fuel	
	Oven-dry weight in t/ha (tons/acre)				
Tree foliage	10.8[5] (4.8)	9.0[6] (4.0)	9.0 (4.0)	10.1[7] (4.5)	1.1 (0.5)
Bark[2]	4.5 (2.0)	0.4[8] (0.2)	4.5 (2.0)	0.4[8] (0.2)	0 (0)
Twigs <1.27 cm (<1/2") dia.	4.5 (2.0)	3.6[9] (1.6)	4.5 (2.0)	3.6[9] (1.6)	0 (0)
Lesser vegetation[3]	1.1 (0.5)	0.7[10] (0.3)	2.2 (1.0)	3.4[11] (1.5)	2.7 (1.2)
Litter layer[4]	4.5 (2.0)	0.4 (0.2)	4.5 (2.0)	0.7 (0.3)	0.3 (0.1)
Top 2.5 cm (1") of fermentation (F) layer	11.2 (5.0)	11.2 (5.0)	11.2 (5.0)	12.3 (5.5)	1.1 (0.5)

1 Lodgepole pine stand - Age: 75 yr
No. of trees/ha (acre): 1482 (600)
Basal area: 29 m^2/ha (125 ft^2/acre)
Total above-ground biomass in t/ha (tons/acre): 152 (68)

2 Includes the loose, flaky portion likely to be consumed by fire

3 Includes herbs and shrubs including cured material in spring prior to onset of the current year's growth

4 Represents a layer about 2.54 cm or 1" deep

5 Assumes temporary % increase in weight of dry matter

6 Based on 83% Moisture Content (M.C.)

7 Based on 113% M.C.

8 Based on 10% M.C.

9 Based on 80% M.C.

10 Based on 60% M.C. (Comb. of cured and green vegetation)

11 Based on 150% M.C.

Appendix IV. Average size of Class E fires in spring (May 1-June 10) and summer-fall (June 11-October 15), by BUI and FWI

BUI Class	Spring			Summer-Fall		
	Avg. FWI	Number of Fires	Avg. Fire Size in hectares (acres)	Avg. FWI	Number of Fires	Avg. Fire Size in hectares (acres)
0-25	13	16	2630 (6,500)	5	2	530 (1,300)
26-50	22	66	5140 (12,700)	12	8	3930 (9,700)
51-75	28	18	1260 (3,100)	19	20	5390 (13,300)
Average for all BUI Classes	22	N/A	4130 (10,200)	16	N/A	4660 (11,500)

Basis - 130 Class E fires covering 9-yr period 1965-69 and 1971-74 inclusive.

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