FIRE DANGER RATINGS ASSOCIATED WITH NEW ZEALAND'S MAJOR PINE PLANTATION WILDFIRES[1]

H.G. Pearce[2] and M.E. Alexander[3]

ABSTRACT: Forest and rural fire managers in New Zealand have used a slightly modified version of the Canadian Forest Fire Weather Index (FWI) System for rating fire danger since October 1980. Recently, the system's six standard components were historically calculated from daily weather observations assembled for nine wildfires that occurred within or near the country's commercial exotic pine plantations. This paper serves to document the three FWI System fuel moisture code and three fire behaviour index values for nine plantation forest and grass fire incidents that took place between 1946 and 1988. The resulting information is already proving useful as a source of data for research purposes and in administrative studies as well as interpretive material in fire behaviour awareness training.
KEYWORDS: Canadian Forest Fire Weather Index System; fire behaviour; fire management; fire weather; forest fire; fuel types.

INTRODUCTION

Establishment of exotic conifer plantations in New Zealand began nearly a century ago (Familton 1990). The area of plantation forests currently amounts to ≈ 1.3 million hectares or roughly about 5% of the country's land mass (NZFOA 1993), with radiata pine (*Pinus radiata*) comprising nearly 90% of this total. Safeguarding these areas from wildfires has been the major concern of the former New Zealand Forest Service (NZFS) and forest industry almost from day one and many advances in fire control technology and management have occurred over the intervening years (Cooper 1990). Interest in the systematic observation of fire weather conditions for the purpose of appraising forest fuel flammability begun by NZFS in the mid 1920s accelerated in the late 30s. Work on a method of fire danger rating eventually followed (e.g., Dacre 1946). The NZFS Fire Danger Meter, based to a large extent on research done in the southeastern U.S.A, was produced in 1948 and subsequently used without change, other than metrification in 1973, for over 30 years. As a result of a review and evaluation undertaken by Valentine (1978), the Canadian Forest Fire Weather Index (FWI) System (Van Wagner 1987) was adopted, with relevant adjustments for season and latitude, as the initial basis for a national system of fire danger rating at the start of the 180-81 fire season. In this paper, we present the six component ratings of the FWI System, which have been historically calculated, for nine of probably the most notable wildfires to have destroyed or threatened portions of New Zealand's exotic forest estate since 1946 (fig. 1).

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[2] H.G. Pearce, New Zealand Forest Research Institute, Forest Technology Division, Resource Evaluation and Planning Group, Private Bag 3020, Rotorua, New Zealand.

[3] M.E. Alexander, Natural Resources Canada, Canadian Forest Service, Northwest Region, Northern Forestry Centre, 5320 - 122 Street, Edmonton, Alberta, Canada T6H 3S5.

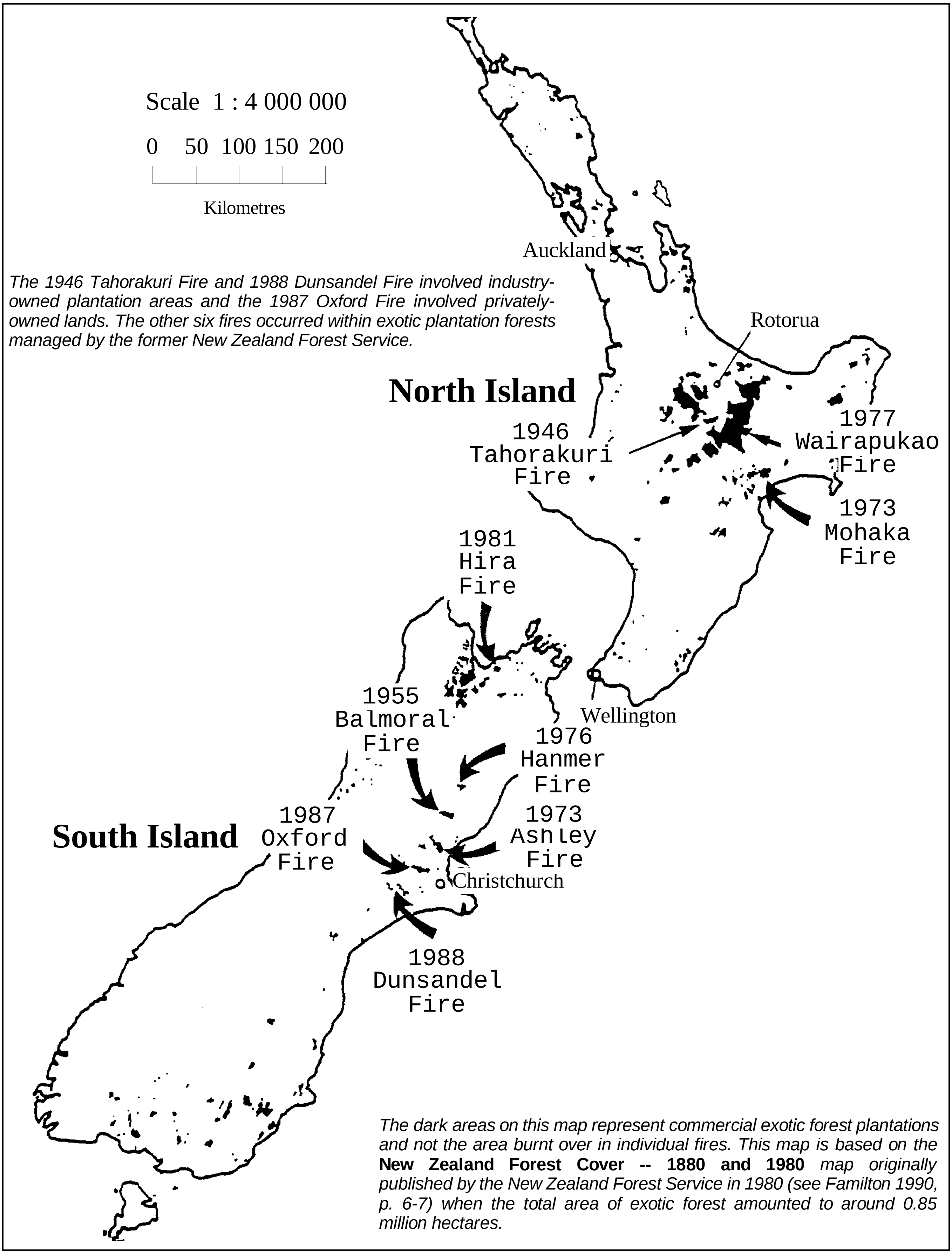
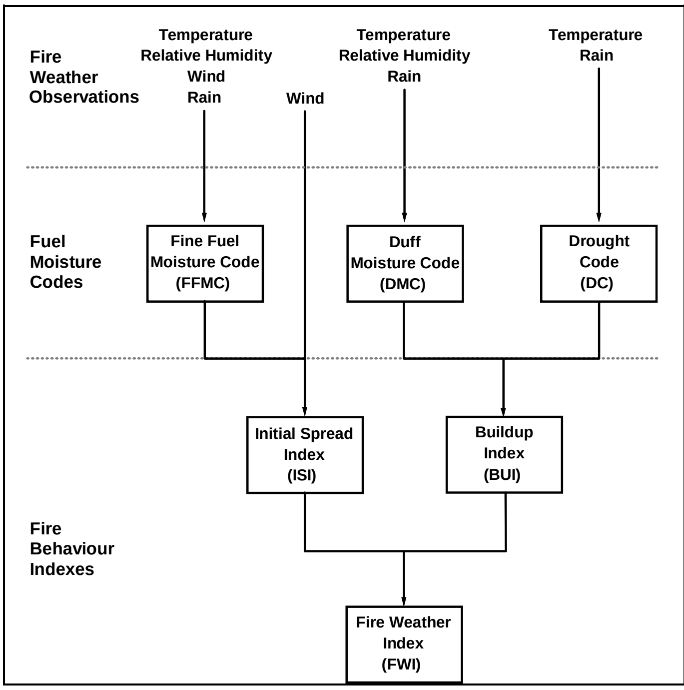


Figure 1. Geographical location of the nine New Zealand wildfires selected for study.

METHODS

Of the nine wildfires selected for study, the only one that has been formally written up in any detail is the 1955 Balmoral Fire (Prior 1958), and even this effort has some shortcomings as a case study report on fire behaviour. Some general details on the 1946 Tahorakuri Fire (Fenton 1951, Church and Stanley-Harris 1967, McLean 1992) and 1988 Dunsandel Fire (Studholme 1989) have been published. Unpublished reports prepared by NZFS or private forest companies on all nine of the fires exist; unfortunately there's no longer a central depository for such information, especially with the demise of the NZFS in 1987. Where possible, specifics on silvicultural histories were obtained from compartment recordkeeping systems. Other than what exists in local newspaper accounts, photographic documentation, especially during the major runs, was exceedingly scarce although it became obvious during the searching for photos and other documents that considerable material had been "lost" or worst yet, destroyed, over the years, due in part to the break up of the NZFS into three different and new government departments.

Calculation of the FWI System components (fig. 2) is dependent on a continuous record of four weather observations taken each day during the fire season at noon local standard time (1 p.m. daylight time). Ideally, temperature and relative humidity (RH) should be based on dry- and wet-bulb thermometers housed in a double louvered meteorological instrument shelter or Stevenson screen. Wind speed is observed at the international standard height of 10 m in the "open" and the rain measurement constitutes the 24-hour accumulated total. In most cases, the required data was readily available from fire weather stations within the plantation area or from other meteorological stations in the immediate vicinity. Generally there was only one relevant station per fire, although there were two exceptions. It was assumed that all of the weather data was collected correctly, the instruments were well maintained and that the station was properly established. In the case of the 1988 Dunsandel Fire, fire weather records from a nearby fire weather station (Eyrewell Forest) were combined with more localized rainfall data (at Darfield). Unfortunately, the fire weather data collected at the Balmoral Forest preceding the fire there in 1955 could not be found although many efforts were made to locate it (e.g., Alexander 1991). In the end, the 9 a.m. dew-point temperatures and 24-hour rainfall totals coupled with the maximum temperatures and hourly as well as climatological normals were used to estimate the required inputs for



FFMC - A numerical rating of the moisture content of litter and other cured fine fuels. This code is an indicator of the relative ease of ignition and flammability of fine fuel.

DMC - A numerical rating of the average moisture content of loosely compacted organic layers of moderate depth. This code gives an indication of fuel consumption in moderate duff layers and medium-size woody material.

DC - A numerical rating of average moisture content of deep, compact, organic layers. This code is a useful indicator of seasonal drought effects on forest fuels, and amount of smouldering in deep duff layers and large logs.

ISI - A numerical rating of the expected rate of fire spread. It combines the effects of wind and **FFMC** on rate of spread without the influence of variable quantities of fuel.

BUI - A numerical rating of the total amount of fuel available for combustion that combines **DMC** and **DC**.

FWI - A numerical rating of fire intensity that combines **ISI** and **BUI**. It is suitable as a general index of fire danger.

Figure 2. Structure diagram for the Fire Weather Index (FWI) System and component definitions.

the FWI System calculations. In the case of the Tahorakuri Forest, no weather data other than rainfall was recorded in 1945-46 (in fact, the daily entries could not be found but monthly total were obtained. A variety of sources were used to reconstruct the most likely weather record. Daily rainfall data for Taupo was obtained from the National Institute of Water and Atmospheric Research (NIWAR); the monthly totals for Taupo were in very close agreement with the information available for the Tahorakuri Forest. The same procedures used to estimate the 1 p.m. temperature and RH for the Balmoral Fire were also applied to the Tahorakuri Fire based on the climatological data that was available for Rotorua and Waiotapu; the 1 p.m. observations at fire weather stations in the nearby Kaingaroa Forest for the 2½ weeks preceding the major fire run as documented in Dacre's (1946) report were also used. Computer calculation of the weather data was undertaken in all cases (Van Wagner and Pickett 1985) using recent revisions to DMC and DC daylength constants relevant to New Zealand's location in the southern hemisphere (NRFA and NZ FRI 1993); October 1st was selected as a starting date (as has traditionally been done in the past) and standard fuel moisture code starting values were used. If the fire's major run occurred in the afternoon, then the weather recorded at the basic observation time was used on the day of the major run. However, if the major run of the fire took place in the morning (1955 Balmoral and 1973 Mohaka Fires) or late at night (1987 Oxford Fire) then the prevailing weather at that time was relied upon instead. If on-site weather observations or hourly data were available, especially for wind speeds, then this information was used in the final calculations.

RESULTS AND DISCUSSION

Collectively, the nine wildfires span a considerable range in many attributes and variables. In addition to time of day, there's the season. Final size, ignition agent, fuel type characteristics and topography (table 1), as well as short and long-term weather influences as reflected in the various FWI System component values (table 2 and fig. 3). It's noteworthy that five of the six South Island fires were influenced by strong, dry warm (föhn) winds locally referred to as a "Canterbury Nor'wester" (Beatson 1985). Although some familiarity with the FWI System upon the part of the reader has been presumed, in order to appreciate the results presented here, the component values for two well-publicized wildfire situations have been included in table 2. The Ash Wednesday fires of 16 February 1983 in southeastern Australia caused considerable loss of life and property damage, including 16,070 ha of pine plantation being burned over in the southeast region of South Australia (Keeves and Douglas 1983); table 2 values are for 1 p.m. at Penola, SA. Information is also included in table 2 for the North Fork Fire's major run near the Old Faithful Inn in Yellowstone National Park on 7 September 1988 (Thomas 1991).

Other than the 1981 Hira Fire (Spring Grove and Rabbit Island stations), the FWI System ratings associated with the other eight fires have never been previously known prior to this time. Furthermore, the historical generation of fire danger ratings represents a worthwhile contribution in itself. For example, the 1945-46 fire season, during which nearly a quarter of a million hectares of forest and rural lands were burnt over (NZFS 1946), has generally become the standard by which all other years or wildfire incidents in recent times are gauged against, yet this has been done without the benefit of knowing what the fire weather severity was until now (fig. 4). All of the weather stations used in this study were for the most part within 25 km of the fire locations and several were within a few kilometres or even less. Except for the case of the 1981 Hira Fire, all of the weather stations lie within less than 100 m elevation of the fire areas and in many instances considerably less. With the exception of the 1987 Oxford and 1988 Dunsandel Fires as well as the Nelson Airport readings for the Hira Fire, all of the wind speeds given in table 2 for the New Zealand fires are based on the Beaufort wind scale. For the 1946 Tahorakuri Fire, no other wind information exists in the region other than the 1 p.m. observation at the Waimihia station in the Kaingaroa Forest. In the case of the 1977 Wairapukao and 1981 Hira Fires,

Table 1. Statistical information and details on the fuel types, topography, and fire behaviour associated with nine of the most significant New Zealand wildfires involving exotic pine plantations selected for study.

Name of fire	Date of major run	Area burnt Total (ha)	Area burnt Pine (%)	Specific cause of the fire	Major tree species[1]	Primary age(s) (years)	Silviculture treatment(s) completed[2]	Generalised type of terrain	Predominant type of fire activity
Tahorakuri	09.02.46	30,738	43	Wildfire escape	RP,PP,MP	14 & 15	U	Undulating	Crown
Balmoral	26.11.55	3,152	100	Wildfire holdover	RP;CP,PP	24-32	PU;U	Flat	Crown
Ashley	07.02.73	194	100	Spark from grader	RP	11	TP	Broken	Crown
Mohaka	03.11.73	368	67	Debris burning escape	RP;CP	8-11	TP;U	Broken	Surface & Crown
Hanmer	22.03.73	798	67	Slash burn holdover	CP,PP	51 & 52	TP	Upsloping	Crown
Wairapukao	05.12.77	432	84	Slash burn escape	RP/PP	8/48	TP/U	Flat	Surface & Crown
Hira	05.02.81	1,972	47	Unknown (human)	RP	7-12	U & TP	Very broken	Crown
Oxford	04.02.87	≈6,046	0	Wildfire holdover	(grass)	-	-	Flat	Surface
Dunsandel	12.12.87	185	89	Lightning	RP	10	TP	Flat	Crown

[1] RP = radiata pine (*Pinus radiata*); MP = maritime pine (*P. pinaster*); CP = corsican pine (*P. nigra* ssp. *laricio*); and PP = ponderosa pine (*P. ponderosa*).

[2] U = unthinned and unpruned, PU = pruned and unthinned, and TP = thinned and pruned.

Table 2. Fire weather observations, fuel moisture stick and fire danger ratings associated with the major run of nine of the most significant New Zealand wildfires involving exotic pine plantations selected for study; two globally well-known wildfires are included for comparison sake. NZ Forest Service Fire Danger Meter (FDM) ratings are given if they were available.

Name of fire	Dry-bulb temperature (°C)	RH (%)	10-m open wind Direction (from)	10-m open wind Speed (km/h)	Days since ≥ 0.6 mm rain	"Fire hazard" sticks 100 g (%)	"Fire hazard" sticks 400 g (%)	NZ Forest Service FDM Index	NZ Forest Service FDM Class	FFMC	DMC	DC	ISI	BUI	FWI
										Fire Weather Index System components					
Tahorakuri	28.9	29	SW	24	13	-	-	-	-	92.8	117	602	21.3	157	60
Balmoral	15.6	42	NW	55	3	11	≈11	7.2	H	88.5	64	205	55.0	72	79
Ashley	39.0	18	NW	24	9	11	10	9.5	E	96.8	37	378	36.9	60	57
Mohaka	20.0	55	NW	44	6	19	24	4.4	L	87.4	15	67	27.1	19	28
Hanmer	25.0	36	NW	34	12	12	11	8.0	E	90.9	37	168	26.9	48	42
Wairapukao[1]	25.0	28	NW	16	12	12	16	7.2	H	92.3	38	160	13.2	48	26
"	22.0	24	NW	24	10	12	15	7.7	H	92.6	27	74	20.8	28	28
Hira[2]	25.0	41	SW	46	5	-	-	-	-	90.1	45	384	44.3	70	69
"	25.0	44	S	44	5	-	-	-	-	89.0	33	422	34.2	55	52
"	25.0	35	SW	44	5	-	-	-	-	92.5	47	436	56.0	74	81
Oxford	20.6	34	NW	34	12	-	-	-	-	90.1	107	497	24.1	139	63
Dunsandel	29.0	39	NW/S	25	5	-	-	-	-	92.4	51	378	21.2	76	45
Ash Wednesday	40.2	9	NW/SW	36	20	-	-	-	-	98.9	142	832	88.6	199	142
Old Faithful	19.4	24	SW	25	25	-	-	-	-	93.9	183	787	25.0	232	70

[1] Values for Wairapukao (located 18 km north of the fire area) and Waimihia (located 24 km south of the fire area) fire weather stations, respectively.

[2] Values for Nelson Airport meteorological station (also used for missing data at Spring Grove) and fire weather stations at Rabbit Island and Spring Grove, respectively.

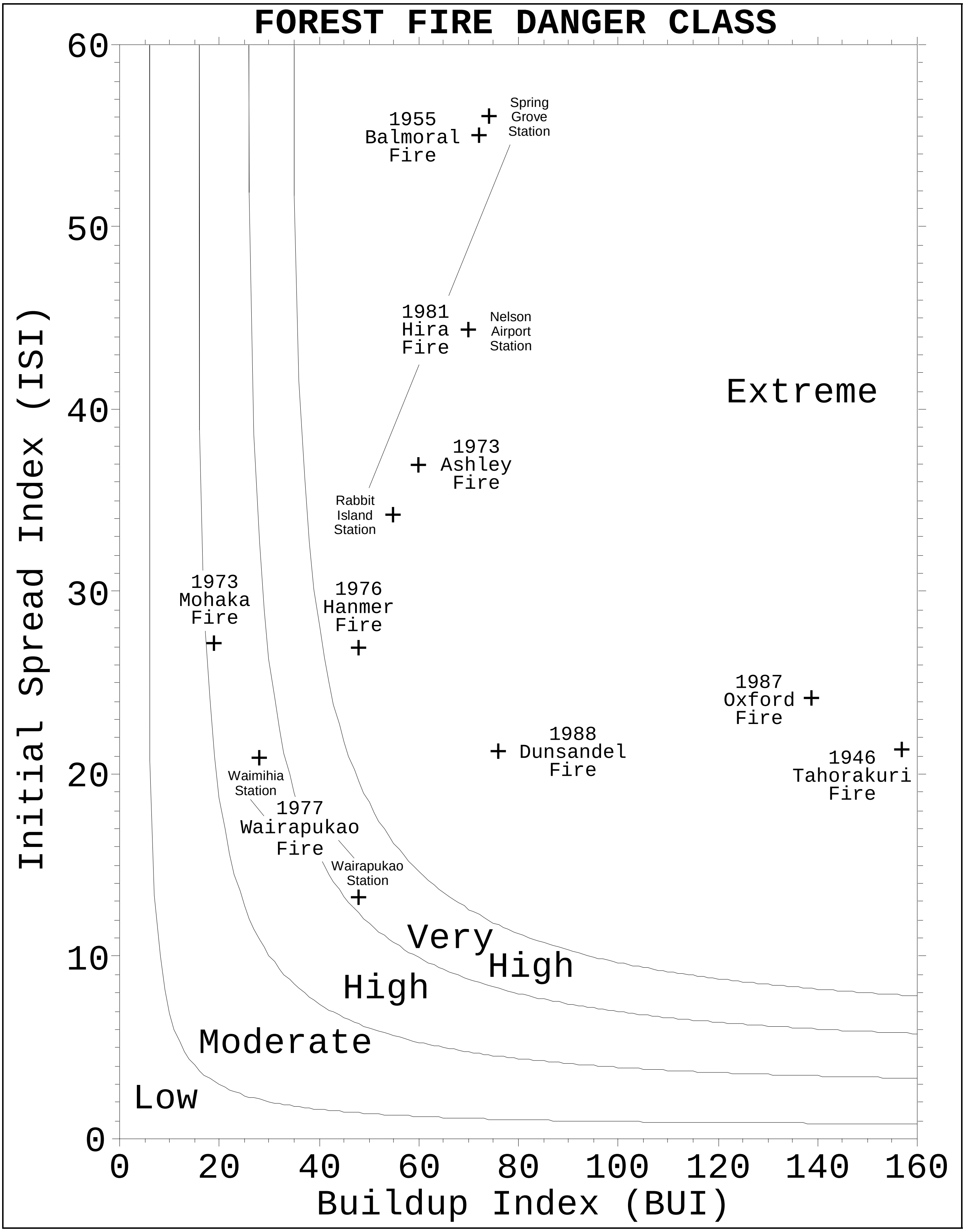


Figure 3. Pertinent values from table 2 for the nine New Zealand wildfires selected for study plotted on a slightly expanded graphical version of the fire danger class criteria for forest areas in New Zealand as described by Alexander (1994).

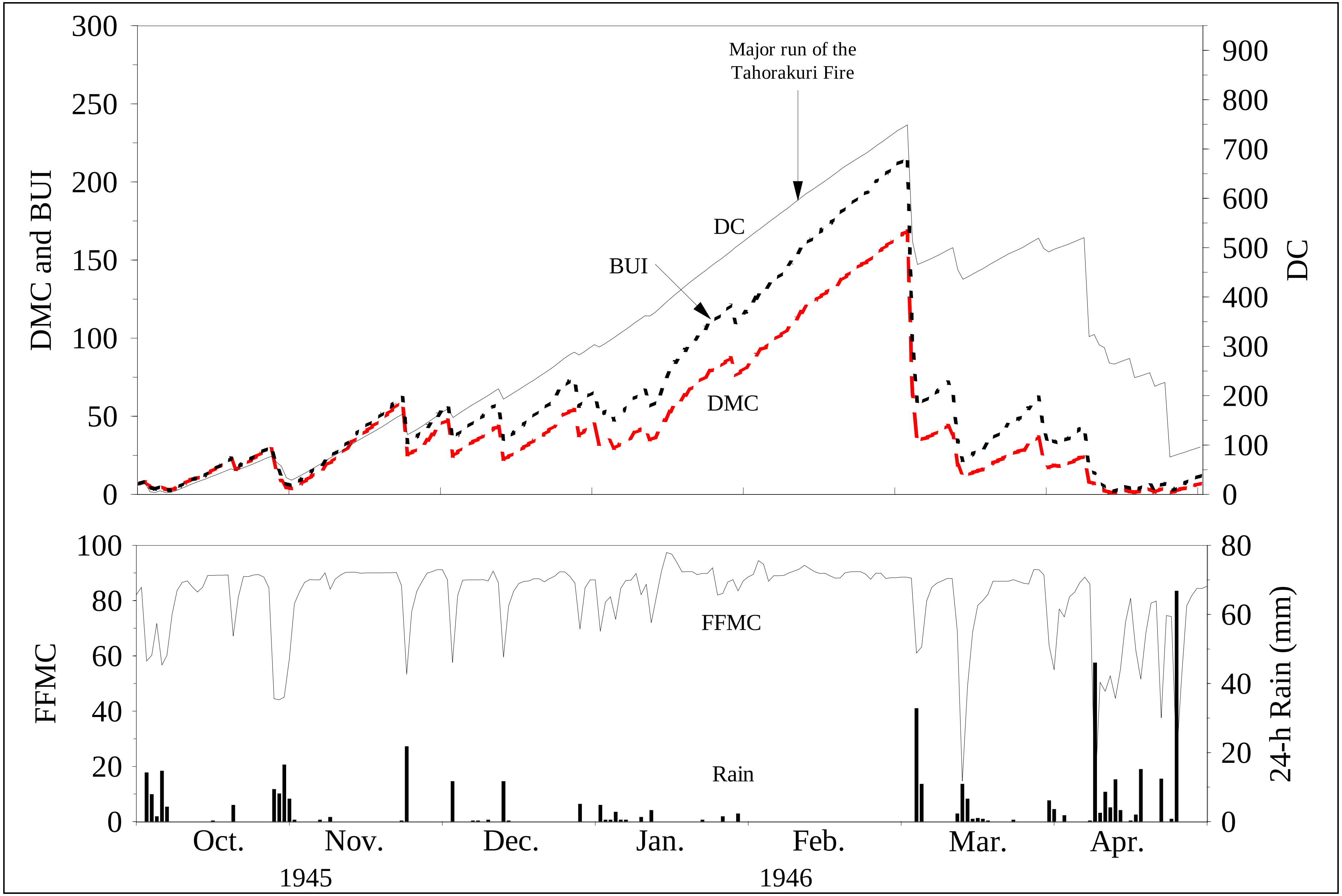


Figure 4. The likely seasonal trends in the daily rainfall and fuel moisture indicators of the FWI System during the 1945-46 fire season as reconstructed for the Tahorakuri Forest area north of Taupo, Central North Island, New Zealand.

where there's more than one possible representative weather station, the spatial variability in weather conditions and fire danger ratings is apparent (table 2) although with the Hira Fire, where the Nelson Airport and Rabbit Island stations are located 7 km from each other and both are less than 15 km from Spring Grove, this made no difference in the fire danger class (fig. 3). However, it did for the Wairapukao Fire where the two stations are located 42 km away from each other.

Each of the wildfires selected for study holds a significant place in the history of forest and rural fire management in New Zealand. The 1946 Tahorakuri Fire (also called the Taupo Fire) that affected private holdings, still represents the single largest pine plantation wildfire to have ever occurred in the country and for that matter in Australasia. The 1945-46 fire season and specifically the Tahorakuri Fire more than any other event helped to galvanize the need for quantum improvements in fire protection, including modern legislation which can still be traced to the present day. The 1955 Balmoral Fire holds the "record" for being the second largest New Zealand plantation fire and the largest for a state or government-owned exotic forest. The fire was referred to as a "grievous" event in the 1955-56 NZFS annual report and a commission of inquiry was established. The 1973 Ashley Fire occurred on the very day that New Zealand recorded its maximum air temperature of 42ºC in nearby Rangiora (Beatson 1985). The 1973 Mohaka Fire, resulting from a farmer's non-permitted fire near the forest's boundary, illustrated that stern legal action would be taken in such cases (the individual was found guilty in civil court and required to pay all costs) as well as the need for fostering better relations with neighbouring landowners. The 1976 Hanmer Fire, which also resulted in a commission of inquiry, and the 1977 Wairapukao Fire (also called the Black Forest Fire) drew attention to the need for improvements in prescribed fire planning and execution as well as fire suppression training in the former case. On the 1981 Hira Fire, the third largest plantation fire in New Zealand's history, a house was burnt to the ground and a crew of 10 firefighters were overrun by the advancing front but fortunately escaped without injury. The 1987 Oxford Fire came within 100 m of the 6,388 ha of pine plantation comprising the Eyrewell Forest. The 1988 Dunsandel Fire constitutes the last major project fire involving pine plantations (i.e., >100 ha); suppression costs were considerable in view of the fire's size and location.

All of the fires except for the 1973 Mohaka and 1977 Wairapukao Fires essentially spread unimpeded by continuous crowning, until the winds abated, at rates typical for crown fires in conifer forests for the prevailing burning conditions (tables 1 and 2) of around 1-2 km/h, although within the perimeter of any fire one could find evidence of gentle surface to high-intensity crown fire activity. The Mohaka Fire crowned out only in the Corsican pine (*P. nigra* spp. *laricio*) and it's felt that if heavier bulldozers had been available for initial attack, it could have been held to a much smaller size. Containment of the Wairapukao Fire was aided by a two lane road. Observed fire characteristics correlated well with existing FWI System based guidelines (e.g., Muraro 1975, Alexander and De Groot 1988). A discussion of observed versus predicted fire behaviour in a quantitative sense (Forestry Canada Fire Danger Group 1992) is beyond the scope of this paper. Burning conditions were correctly categorized according to the fire danger class criteria (fig. 3) recently devised by the New Zealand Forest Research Institute (NZ FRI) and Canadian Forest Service (CFS). Some of the shortcomings in the NZFS Fire Danger Meter, such as the improper weighting of the relative importance of wind on fire behaviour (Valentine 1978, NZFS 1979) and perhaps placing too much emphasis on the two fuel moisture indicator sticks (Valentine 1972) were clearly illustrated in the case of the 1973 Mohaka Fire (table 2).

FIRE MANAGEMENT IMPLICATIONS

This study has served to highlight the need for adherence to the long held principles established for fire danger assessment (Nelson 1955) and the importance of wildfire documentation as one means of adding to our knowledge base on fire behaviour (Alexander and Pearce 1992). As well it reinforces the value that fire weather/danger monitoring and forecasting has in being able to anticipate potential fire loads. A similar summary and analysis of other plantation fires (e.g., 1940 Eyrewell, 1970 Mawhera, 1971 Slopedown, 1972 Rankleburn and 1975 Waimea Fires) or other major wildfires in different fuel types should be considered if sufficient fire information and the required weather data are available.

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