

## ADOPTION VS. ADAPTATION: LESSONS FROM APPLYING THE CANADIAN FOREST FIRE DANGER RATING SYSTEM IN NEW ZEALAND

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### SUMMARY

In 1980, the New Zealand Forest Service *adopted* the Fire Weather Index (FWI) System module of the Canadian Forest Fire Danger Rating System for rating fire danger in exotic pine plantations. In the years that followed, the maximum benefits of what was to become the New Zealand Fire Danger Rating System were never fully realised due to a lack of technology transfer and a failure to *adapt* it to the local fire environment. After a lapse of 15 years, a fire research programme was re-initiated in 1992 to address these issues. Based on the New Zealand experience, this paper highlights the issues and opportunities associated with the adoption and/or adaptation of overseas fire danger rating systems. Significant savings in the time and cost of development can be made by adopting an existing fire danger rating system. However, predictive errors can result if no effort is made to assess the basic fire behaviour relationships that underpin the adopted system when it is applied to a fire environment that is distinctly different from the one it was designed for. The importance of this validation is illustrated through application of the Initial Spread Index component of the FWI System to the prediction of head fire rate of spread in New Zealand's native heathland fuel complexes.

## INTRODUCTION

Fire danger is a general term used to express an assessment of both fixed and variable factors of the fire environment that determine ease of ignition, rate of spread, difficulty of control and fire impact (Merrill and Alexander 1987). It is apparent from this definition that a knowledge of how various components of the fire environment (i.e., fuels, weather and topography) influence fire behaviour is a necessary starting point for the development of a fire danger rating system. While this may be an obvious statement, there are many examples of fire danger rating systems being applied without any knowledge of whether the underpinning relationships will or can produce reliable estimates of fire behaviour and subsequent fire danger.

Fire danger rating systems integrate and evaluate the factors that influence fire danger to produce qualitative and/or numerical indices of fire potential (Stocks *et al.* 1989). All fire danger rating systems "have the common objective of obtaining a relatively simple and comparable measure of fuel flammability from day to day" (Chandler *et al.* 1983). The simplest systems achieve this by using only temperature and relative humidity to provide an index of ignition potential (Cheney 1991). More complex systems also incorporate relationships between weather variables, fuel moisture status and fire behaviour to produce indicators which provide a quantitative measure of difficulty of control in terms of flame length or fire intensity and the potential for damage or impact (Countryman 1966).

The development of a fire danger rating system that adequately describes the fire environment and meets a range of user needs can be time consuming and costly. For example, the Canadian Forest Fire Danger Rating System (CFFDRS) is the result of a concerted research effort over a period of some 70 years (Stocks *et al.* 1989). N.D. Burrows<sup>1</sup> (*pers. comm.*) has estimated that an investment of A\$ 6 million has been required over a 40 year period to produce the fire danger rating, fire behaviour and associated fire management systems used in Western Australia today. Therefore, the adoption of an existing fire danger rating system can save fire management agencies a considerable amount of time and money that would otherwise need to be spent on basic research and development. For this reason, adoption of existing systems is common, and examples include the use of the CFFDRS in

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whole or part in Fiji (Alexander 1989), Alaska (Alexander and Cole 1995) and New Zealand (Valentine 1978). The use of the McArthur Forest Fire Danger Rating System (McArthur 1967, 1973) in a range of fuel types (e.g., coniferous forest, open heath, woodland, dry sclerophyll forest and tall forest) by many Australian fire management agencies provides further examples of a system being adopted or applied (Krusel *et al.* 1993) in favour of the development of more relevant alternatives.

Even though it is possible to reduce the costs of research and development, the costs of applying a deficient fire danger rating system can be much greater because a fire danger rating system provides information which supports fire protection decision making (Fig. 1a) in the areas of fire prevention (e.g., public warnings, permit issue, fuel reduction burning), presuppression (e.g., preparedness and training, initial attack planning) and suppression (e.g., fire behaviour prediction, strategies and tactics).

The aim of this paper is to review the New Zealand experience of adopting the Fire Weather Index (FWI) System module (Fig. 1b) of the CFFDRS for fire danger rating, and of efforts to better adapt it to the local fire environment since re-instatement of a forest and rural fire research and technology transfer programme at the New Zealand Forest Research Institute (formerly FRI, now *Forest Research*) in 1992.

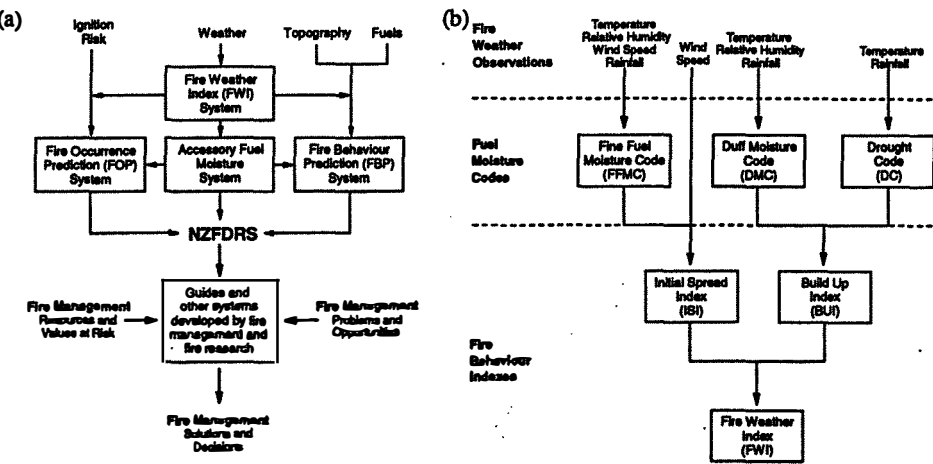


Figure 1. Simplified structure diagrams for (a) the New Zealand Fire Danger Rating System (NZFDRS) illustrating the linkage to fire management actions (after Alexander *et al.* 1996), and (b) the Fire Weather Index (FWI) System (after Anon. 1993).

## ADOPTION - THE HISTORY OF FIRE DANGER RATING IN NEW ZEALAND

The New Zealand Fire Danger Meter (NZFDM) was introduced in 1948, and formed the basis for fire danger rating in New Zealand for nearly 30 years. Valentine (1978) recognised that new and improved fire danger rating systems had since been developed and that a review of their potential application in New Zealand was warranted. He compared the relationships between fire environment factors and fire behaviour that underpinned the U.S. National Fire Danger Rating System (Deeming *et al.* 1972), the FWI System (Van Wagner 1974), and the McArthur Mk 4 Forest Fire Danger Meter (McArthur 1967) with those of the NZFDM. This comparison found that the Australian and Canadian systems had similar underpinning relationships (Van Wagner 1975), and provided evidence that the NZFDM grossly overestimated the influence of moisture content and underestimated the impact of wind speed and drought on fire danger.

In 1980, the former New Zealand Forest Service (NZFS) adopted the FWI System for rating fire danger in coniferous plantation forests. The FWI System was selected because it was simple to use (utilising only four universally collected weather elements), was based on sound scientific principles, had outstanding interpretative backup, was developed for coniferous forests and was being applied with success in a maritime climate (i.e., British Columbia) similar to that of New Zealand, and it provided indices which could be correlated to observed fire behaviour characteristics (Valentine 1978). These selection criteria still remain valid today.

Prior to 1987, the NZFS assumed the fire protection responsibility for all forest and rural areas, and its demise initiated significant changes in fire management throughout New Zealand. New and existing forestry companies maintained the protection of production forests, but many experienced people left the forest industry. The Department of Conservation was formed and the management and protection of indigenous flora and fauna was given a higher priority than ever before. Perhaps the greatest change occurred on private rural lands, where territorial authorities were obliged to meet their legal fire protection commitments. Regardless of vegetation cover, the FWI System came to be used for fire danger rating in all forest and rural fire areas of New Zealand with little or no regard for the consequences or implications of its use.

One of the keys to successful adoption (and/or adaptation) of a fire danger rating system is the training and technology transfer that is carried out as part of the system's introduction

and implementation. In the case of New Zealand's adoption of the FWI System, the limited training that accompanied its introduction centred on how to calculate the System's outputs, and not on how the various components are related to the fire environment and fire potential. The lack of a major technology transfer effort resulted in most forest and rural fire managers having a generally poor understanding of the FWI System and of how it could support their decision-making. In many cases, it was expected that the System would work in New Zealand without any modification or that, where adaptation might be required, fire managers would in time learn to interpret the FWI System for their local situation although they weren't told how to go about doing this.

More widespread use of the FWI System, often by inexperienced fire managers, created a new imperative for improving the standards of fire danger rating. To support the research and development needs of forest and rural fire authorities, a fire research and technology transfer programme was re-established at FRI in 1992 following a lapse of 15 years (Alexander 1992-93). Since its inception, the programme has set about quantifying key features of the New Zealand fire environment and the effect these have on ensuing fire behaviour. The major aim of the programme is the development of the New Zealand Fire Danger Rating System (NZFDRS) (Fig. 1a) by extending the CFFDRS philosophy and concepts to local conditions.

## ADAPTATION - LESSONS FROM THE NEW ZEALAND EXPERIENCE

The FWI System was developed to rate fire potential in a reference fuel type. Therefore, the relative numerical outputs have different meanings in different fuel types, and no absolute measures of fire behaviour are provided. In order to rectify this problem, Valentine (1978) noted that "adoption of the Canadian FWI is the first phase of a development programme", and he recommended that "to make maximum use of the system second stage testing should aim at developing fire behaviour indices for specific NZ fuel types". His recommendation was never followed up and, as a result, the FWI System was vainly applied to many fuel types and applications for which it was not intended. It wasn't until the fire research programme at FRI was reconstituted in 1992 that the first experimental fires were carried out (Alexander *et al.* 1993).

Following the introduction of the FWI System, the Fire Danger Class Criteria (FDCC) originally recommended by Valentine (1978) were frequently altered without any objective basis, and were used by many fire authorities to support specific prevention and preparedness decisions rather than simply providing the general daily fire danger conditions over a broad area (Alexander 1994). This misuse of the FDCC was in part due to a lack of understanding of the FWI System, but also of the purpose of the criteria (Alexander 1994). However, local adaptations may also have been the result of a lack of user support for the original fire danger classes which were biased towards plantation forestry interests.

More recently, Alexander (1994) reviewed the basis of the FDCC and recommended that difficulty of control as determined by head fire intensity (Alexander 1992), rather than a fire danger index frequency, be used to define the fire danger classes. The delineation of classes in the new classification scheme is based on the effectiveness of various types of resources as fire intensity increases, up to a point (*EXTREME*) where fires are considered to be uncontrollable using conventional techniques (i.e., > 4000 kW/m). His review and analysis also included the addition of a *VERY HIGH* class, which recognises the transition between being able to suppress the fire and the likely occurrence of a campaign fire. In the new forest fire danger classification scheme, expected fire behaviour in the Conifer Plantation (C-6) Fuel Type of the Fire Behaviour Prediction (FBP) System module (see Fig. 1b) of the CFFDRS (Forestry Canada Fire Danger Group 1992) is used to represent fire danger in exotic pine plantations<sup>2</sup>. To cater for the increased application of the NZFDRS throughout the country, a FDCC applicable to grasslands was added using the fire behaviour relationships for the Natural (Standing) Grass (O-1b) Fuel Type in the FBP System.

Pearce and Alexander (1994) compared the FWI System components with general fire behaviour exhibited by several major New Zealand plantation wildfires, and found that burning conditions were correctly categorised by Alexander's (1994) forest FDCC (Fig. 2a). The criteria and associated suppression effectiveness guidelines correlated well with observed fire behaviour characteristics, and successfully predicted that most of these fires would be difficult, if not impossible, to control. The validation of the FDCC indicates that fire managers can confidently assess broad fire danger in forested areas, and that this application of the NZFDRS supports their fire protection planning and decision-making process.

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<sup>2</sup> Based on nominal values for live crown base height (6 m) and foliar moisture content (145%) (Alexander 1994).

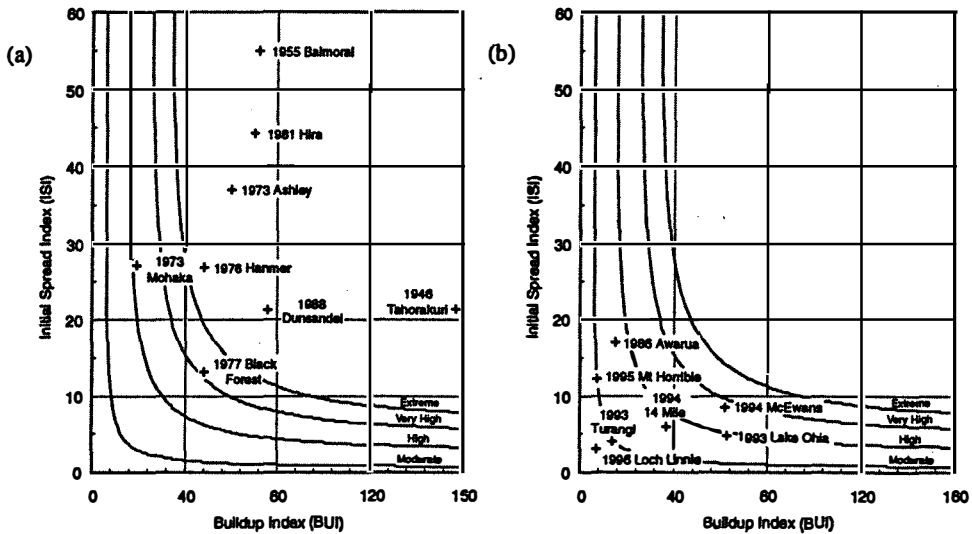


Figure 2. Initial Spread Index (ISI) and Buildup Index (BUI) combinations plotted for selected New Zealand (a) forest (after Pearce and Alexander 1994), and (b) scrub/wetland fires, against Alexander's (1994) forest fire danger class criteria.

The forest FDCC were not intended for use in scrublands (Alexander 1994). While fine fuel moisture content (as represented by the Fine Fuel Moisture Code) and wind are likely to control ignitability and spread, the forest classification scheme is inappropriate because the dryness of ground and surface fuels (as indicated by the Buildup Index) is unlikely to correlate well with fuel availability in these elevated fuels (Alexander 1994, Fogarty 1996a). However, the historical use of the FWI System in all fuel types, combined with the absence of a suitable alternative, has meant that fire managers have continued to use the forest FDCC to rate fire danger in scrublands.

The implications of using the forest FDCC beyond their original intent can be evaluated through a comparison of the FWI System components with the general fire behaviour exhibited by some New Zealand scrub and wetland fires which burnt at *LOW* to *HIGH* forest fire danger conditions (see Fig. 2b). Despite the relatively mild fire weather severity or burning conditions indicated by the forest FDCC, nearly all the fires exhibited extreme fire behaviour characteristics, burning areas that ranged from 12 to 1360 ha and costing NZ\$ 25,000 to NZ\$ 160,000 to suppress. The Loch Linnie Fire was the only wildfire that didn't display extreme fire behaviour. However, unlike a forest fire which is expected to be

self-extinguishing if the duff layer is sufficiently moist when the forest fire danger class is *LOW*, the fire spread freely and burnt 1000 hectares. The managers involved at the Mt Horrible Fire, and Turangi and Awarua wetland fires, which all occurred at *LOW* to *MODERATE* forest fire danger classes, described the resulting fire behaviour as "surprising". As suggested by Alexander (1994), the forest FDCC is not suitable for the assessment of fire danger in scrubland areas, and fire behaviour information is needed to develop more relevant guidelines.

Because the FWI System was designed to be used in a diverse range of fuel types occurring throughout Canada, it had to be modular, flexible and have fundamental relationships that are accordingly robust. The relationships that underpin the FWI System are based on factors derived from widespread and long term research (over 70 years) into fuel moisture responses, and from empirical fire behaviour studies involving several thousand small-scale test fires in mature pine stands (Van Wagner 1987). Incorporation of the best-available basic information into the FWI System has enabled Canadian fire researchers to correlate the System's relative numerical outputs to observed fire behaviour characteristics in several diverse fuel types based on a minimal number of larger-scale experimental fires (Alexander and Quintilio 1990) and wildfires (Alexander and Lanoville 1987).

One of the biggest tests of the relationships that underpin the FWI System will be the modelling of fire behaviour in New Zealand scrub fuels. The successful use of the Initial Spread Index (ISI) component of the FWI System as an independent variable in grassland fire behaviour models (see Forestry Canada Fire Danger Group 1992, p. 29, Fig. 10) indicates that the ISI may provide a suitable basis for modelling fire behaviour in other open fuel types such as scrubland. However, Rasmussen and Fogarty (1997) found that predictions from the FBP System grassland models differ from those provided by the recently developed Australian grassland model<sup>3</sup> (Cheney *et al.* 1998). Some of the differences may be due to the Australian model incorporating additional wildfire data, the influence of the head fire width on rate of spread (Cheney and Gould 1995), and the use of a different (i.e., linear) wind function. Further development of the FBP System grassland models may be warranted. Whatever the outcome, the correlation between ISI and head fire rate of spread in grasslands must still be considered a good result for a system developed largely from and for coniferous forests.

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<sup>3</sup> The fire data for both models was collected by the Bushfire Behaviour and Management Group, CSIRO Division of Forestry and Forest Products, Canberra, A.C.T., but some additional wildfire data was used in the Australian grassland fire behaviour model and more detailed analysis was done during its development.



From the discussion to date, it is evident that simply applying the CFFDRS without adaptation to New Zealand scrub fuels is not appropriate. Following the Canadian approach (McAlpine *et al.* 1990), it is necessary to compare the relative numerical outputs of the FWI System with the relevant fire environment or fire behaviour characteristics for fires burning over a wide range of conditions. Figure 3 illustrates selected comparisons for relatively homogenous native heathland fuels found in New Zealand's Far North region. A plot of head fire rate of spread against the ISI component (Fig. 3a) shows a low (0.25) correlation coefficient ( $r$ ). This may be the result of a similarly low correlation ( $r = 0.11$ ) between the commonly used FFMC (FF-scale) component of the FWI System (Van Wagner 1987) and the moisture content of fine, dead, elevated heathland fuels (Fig. 3b).

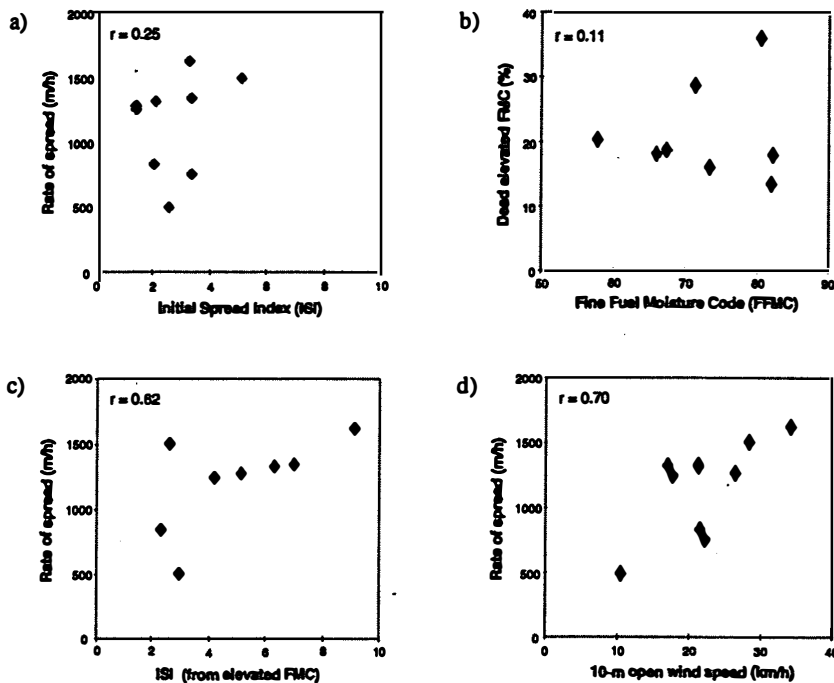


Figure 3. Relationships between (a) observed rate of fire spread and Initial Spread Index (ISI), (b) fuel moisture content of fine dead elevated fuels and Fine Fuel Moisture Code (FFMC), (c) rate of spread and ISI recalculated from dead elevated fine fuel moisture content, and (d) rate of spread and 10-m open wind speed, derived from experimental burning in native New Zealand heath fuels.

This suggests that an alternative method of calculating FFMC (e.g., the FX-scale<sup>4</sup>) may be required. Figure 3c further shows that if the influence of the poor correlation between FFMC and observed moisture content is removed, and FFMC and ISI are recalculated from actual moisture content, the ISI could be a better predictor of rate of spread in heathland fuels. However, the plot of rate of spread versus wind speed (Fig. 3d) shows a stronger relationship ( $r = 0.70$ ), suggesting that the fine fuel moisture and/or wind functions in Van Wagner's (1987) ISI equation may also need modifying.

Early in the development of the CFFDRS, Canadian fire researchers recognised that adaptation of the System to other fire environments might require modifications to some of the elements to better represent the relationships between the new environment and fire behaviour. For example, the degree of grassland curing is used in the FBP System to model grassland fire behaviour (Forestry Canada Fire Danger Group 1992), while the Accessory Fuel Moisture System (Stocks *et al.* 1989) provides users with the ability to model diurnal variations in the FFMC (Lawson *et al.* 1996) and, in turn, the ISI and FWI components of the FWI System. In the case of scrubland, it may be necessary to adapt the underpinning relationships and/or to add other predictor variables to produce a model which can be used as a basis for predicting fire behaviour in as wide a range of scrub types as possible. Continued involvement with the International Heathland Fire Behaviour Modelling Group (Catchpole *et al.* 1998) should help New Zealand fire researchers and other participants to more efficiently produce robust models for predicting fire behaviour in these unique fuel complexes.

## IMPLICATIONS FOR FIRE MANAGEMENT AND RESEARCH

The adoption of an existing fire danger rating system can significantly reduce the time and expense involved in developing a unique system. However, the adoption of the FWI System for rating fire danger in New Zealand's exotic pine plantations failed to provide managers with a system they could confidently apply to their broader fire protection decision making. The New Zealand experience clearly demonstrates the need to adapt and interpret the

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<sup>4</sup> The FX-scale is a faster responding scale developed to improve the resolution of the FFMC at the dry end of the moisture range in hot, dry conditions (Lawson *et al.* 1996). It may better correlate with moisture content in open, exposed scrub fuels.

CFFDRS for the local fire environment in order to produce a comprehensive and robust NZFDRS.

From this overview of fire danger rating practices in New Zealand, it is possible to identify some important steps in the adaptation of an existing fire danger rating system to a new fire environment. These include the need to:

1. Clearly define selection criteria and identify the required applications of the system. Some essential criteria for a fire danger rating system are that it (Muraro 1969, Valentine 1978):
  - be nationally applicable so that training and public awareness programmes are consistent and comprehensive;
  - be able to interpret the full range of conditions that may occur within a given fire environment (i.e., applicable over the full range of climate and fuel types);
  - relate directly to measurable fire environment (e.g., fuel moisture, fuel availability) and fire behaviour (e.g., rate of fire spread, fire intensity) characteristics;
  - be able to predict extreme fire behaviour so that "unexpected" fire behaviour does not occur;
  - be able to predict daily worst case conditions, and fire danger index values and fire behaviour at any time of the day;
  - utilise easy to collect weather parameters;
  - be flexible, adaptable and modular for easy upgrade;
  - be compatible with both computer and manual systems for effective information transfer.
2. Review the available systems against the key selection criteria and user requirements, and select the most appropriate system or systems for further testing (e.g., Valentine 1978, Peet 1980).
3. Investigate the basis and underlying relationships that underpin each system to determine their applicability in the local fire environment, using one or more of the following tests:
  - assess relationships between system outputs and relevant fire environment components, such as FFMC and actual fine, dead fuel moisture content (e.g., Pech 1989);

- compare fire danger outputs derived from historical weather records with measures of fire activity such as fire occurrence or fire load<sup>5</sup> (Kiil *et al.* 1977, Krusel *et al.* 1993);
  - use general information available on fire behaviour and suppression difficulty from historical wildfires to broadly test performance (e.g., Pearce and Alexander 1994, Pearce *et al.* 1994);
  - compare model performance with detailed fire behaviour data collected at experimental burning trials and wildfires (e.g., Alexander *et al.* 1993, Marsden-Smedley and Catchpole 1995, Fogarty *et al.* 1997, Rasmussen and Fogarty 1997).
4. Assess the strengths and weaknesses of each fire danger rating system in relation to the key selection criteria and performance during preliminary tests. Select the most appropriate system.
5. Based on the limitations of the chosen system, carry out research to adapt and interpret it to better fit the local fire environment. The successful adaptation of a system means that some or all of the system may need to be validated or adjusted and, if necessary, new components or relationships developed to cater for unique situations:
- Validation is the process of ensuring that the system or its components correlate with relevant fire environment components or fire behaviour characteristics. This would include the documentation of several experimental fires and/or well-chronicled wildfires to test existing models for fire danger rating and fire behaviour prediction (e.g., use of the FBP System Conifer Plantation (C-6) Fuel Type in New Zealand as described by Fogarty *et al.* 1997).
  - Adjustment involves altering the outputs of a system or its components to better correlate with the relevant element of the fire environment or fire behaviour characteristic. For example, this might include an alternative method of calculating the FPMC (e.g., use of the FX-scale) in order to improve correlation between the existing ISI component and fire spread in scrubland fuel types. This can also involve the realignment of fire behaviour predictions with actual observations using regression techniques based on a minimum number of fires covering a range of burning conditions (Rothermel and Rinehart 1983).

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<sup>5</sup> "The number and magnitude (i.e., fire size class and frontal fire intensity) of all fires requiring suppression action during a given period within a specified area" (Merrill and Alexander 1987).

- Developing new fire danger rating system components or models to cater for unique features of the fire environment may include the development of a new moisture code for predicting moisture status of fine, dead elevated fuels in scrubland vegetation (e.g., if the FPMC using the FX-scale, as opposed to the FF-scale, didn't improve the predictions). It might also involve the onerous task of developing a comprehensive fire behaviour model based on numerous experimental fires carried out over a wide range of conditions supplemented with selected wildfire observations (e.g., Marsden-Smedley and Catchpole 1995).

The flexibility and strength of the underpinning relationships in the adopted fire danger rating system are critical to successful adaptation using any of the methods described here.

Assessing the applicability of a fire danger rating system is not a one-off activity, and there is a need for ongoing validation of the adopted system, particularly in light of changes in fire management needs or the advent of new and improved approaches to fire danger rating. Another key step in the adoption and/or adaptation of a fire danger rating system is the training and technology transfer that accompanies the system's introduction and implementation (De Groot 1989, McAlpine *et al.* 1990). However, the demands of users will increase both as their level of knowledge and expertise increases, and as the complexity and capability of the fire danger rating system increases (Kiil *et al.* 1986). Hence, it is essential that technology transfer continues as adaptations to the system are made (Fogarty 1994, 1996b, Pearce 1996). This will also have the added benefit of involving users in the adaptation process, thereby improving their understanding and confidence in the new system.

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# III International Conference on Forest Fire Research



## 14<sup>th</sup> Conference on Fire and Forest Meteorology

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