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NATIONAL FIRE BEHAVIOUR PREDICTION SYSTEM

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ABSTRACT

The estimation of fire behaviour is an important component of any fire management approach, allowing the determination of the impacts of fire on ecosystem components and supporting forest fire management decision-making. Fire behaviour prediction combines quantitative and qualitative information based on experience and scientific principles of describing the combustion and behaviour of fire influence by topography, weather and fuel. Predictions are based on mathematical models that integrate important factors in a consistent way. The National Fire Behaviour Prediction (NFBP) system will consist of four primary components (fuel models, fuel moisture models, wind models, and fire behaviour models) to predict fire characteristics (e.g., rate of spread, flame height, fireline intensity, onset of crowning spotting potential, etc). This paper will focus on the fire behaviour component of the NFBP system. This component integrates a suite of models covering the main fuel types of Australia, eucalyptus forests, exotic pine plantations, grasslands, shrublands and Mallee-heath.

The desired accomplishments of the proposed National Fire Behaviour Prediction Systems is to provide fire managers with better operating models to implement prescribed burning programs, suppression resources, risk and biodiversity management programs. The fuel type specificity of the fire models, its greater accuracy and updated calculation methods allow also for more accurate simulations of the impact of hypothetical climate change scenarios on fire potential and risk in Australia.

INTRODUCTION

Recent extreme bushfire seasons have increased the focus on how rural fire and land management activities determine landscape level fuel dynamics, fire regimes, bushfire risk and bushland urban planning. There is need to improve ecosystems health and to reduce the likelihood of catastrophic fires. Recommendations from the Council of Australian Governments (COAG) National Inquiry on Bushfire Mitigation and Management (Ellis et al. 2004) that the provision of additional resources jointly by the Australian Government and the state and territory governments to accelerate the research necessary for the characterisation of fuel loads and dynamics for Australian ecosystems (both natural and exotic), the characterisation of fire behaviour and ecological responses, the development of 'burning guides' from this information, and the compilation of this information and knowledge in nationally accessible databases.

Current weather patterns, society perception of fire, and land management agencies policies and constrains have increased the complexity and magnitude of the wildland fire problem. Information is the key in sound decision making to mitigate detrimental effects of wildland fire. The ability to predict and comprehend fire behaviour in relation to its drivers is fundamental to a safe, effective and ecosystem enhancing fire management decision-making. Fire behaviour, "the manner in which fuel ignites, flame develops, and fire spread and exhibits other related phenomena as determined by the interaction of fuels, weather and topography" (Merrill and Alexander 1987) is a vital component on the decision making process related to prescribed fire use planning and execution, dispatching, fire-fighting safety, definition of bushfire suppression strategies and tactics, evaluating fuel treatments effectiveness and recurrence.

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A review of the pertinent fire behaviour research carried out in Australia in the past 30 years (e.g., Cheney et al 1992, Burrows 1994, Marsden-Smedley and Catchpole 1995, McCaw 1997, Gould et al. 2007, Cheney and Sullivan 2008, Burrows et al. 2009) and the tools currently used by fire managers reveals a large disconnection between the knowledge available and the knowledge used.

This is partially due to the lack of effective technology-transfer programs and a considerable technology gap regarding the format decision support tools are available to users. A lack of sophistication is manifest in the broad reliance on slide rules introduced by McArthur (1966, 1967) and tables (Sneeuwjagt and Peet 1985) to support fire management decision-making. It is paradoxical that although the cost of fire fighting, our understanding of fire phenomena and the complexity of the fire manager job increased significantly through time, the tools that are used to predict fire behaviour and support decision making at any temporal and spatial scale are based in technology introduced in the 1950's.

The use of slide rules, tables and other field guides have a role in producing first approximations of fire behaviour characteristics and intended mainly to be used as a field reference guides. Nonetheless, precise fire behaviour predictions, combining spatially explicit fuel and topography information with detailed weather forecast, are best made using computing-based representation of fire behaviour models. The integration of new technologies, such as, Geographical Information Systems, satellite information, large computing power, internet and handheld devices, to harness available datasets and conduct fire behaviour simulations, either at the local or landscape level, is episodic, and unfortunately not the norm.

Furthermore, the overly reliance on the old methods to predict fire behaviour results in a lack of integration of recent research on fuel moisture (e.g., Matthews et al. 2007), fuel dynamics (Gould et al 2007) and wind speed (Sullivan and Knight 2001), decreasing the certainty of fire predictions.

The situation in Australia contrasts with the evolution of fire management decision support systems in the US and Canada. It is well accepted that in the 1960's these three countries had the most advanced fire behaviour research programs in the world. At that time the technologies used by fire practitioners were comparable, although the development of the grassland and forest fire danger meters (McArthur 1966, 1967) gave Australian fire managers a tool still inexistent to others in North America, the capacity to predict rate of spread and intensity from information on weather and fuel characteristics.

The advent of reliable fire behaviour models in both the USA and Canada, in the mid-seventies and late eighties respectively, was accompanied by the development of computer software of various levels of complexity that allow fire managers to simulate fire propagation at a range of spatial and temporal scales, e.g., BEHAVE, FARSITE, PROMETHEUS, FSPro (Andrews and Finney 2007, Tymstra et al. 2006). These systems not only form the backbone of effective fire management programs in these countries but are also extensively used in research applications.

In Australia there have been attempts to provide users with computer-based simulation systems (Colman and Sullivan 1996) although they seemed to not have been adopted by the fire management community.

CONCEPT

This paper presents a proposal for a National Fire Behaviour Prediction (NFBP) system aimed at addressing the needs of fire managers in regards to fire behaviour information, namely quantifying fuel hazard, assessing fire danger and predicting site specific fire behaviour. The purpose of the system is to integrate all available and peer-reviewed fire behaviour knowledge into a set of user-friendly tools that can be used by fire managers to deal with fire management issues over a range of spatial and temporal scales, and complexity levels. The availability of such a system will improve fuel management programs, lead to more effective and safe firefighting, enhance protection of rural communities and reduce detrimental effects to natural resources.

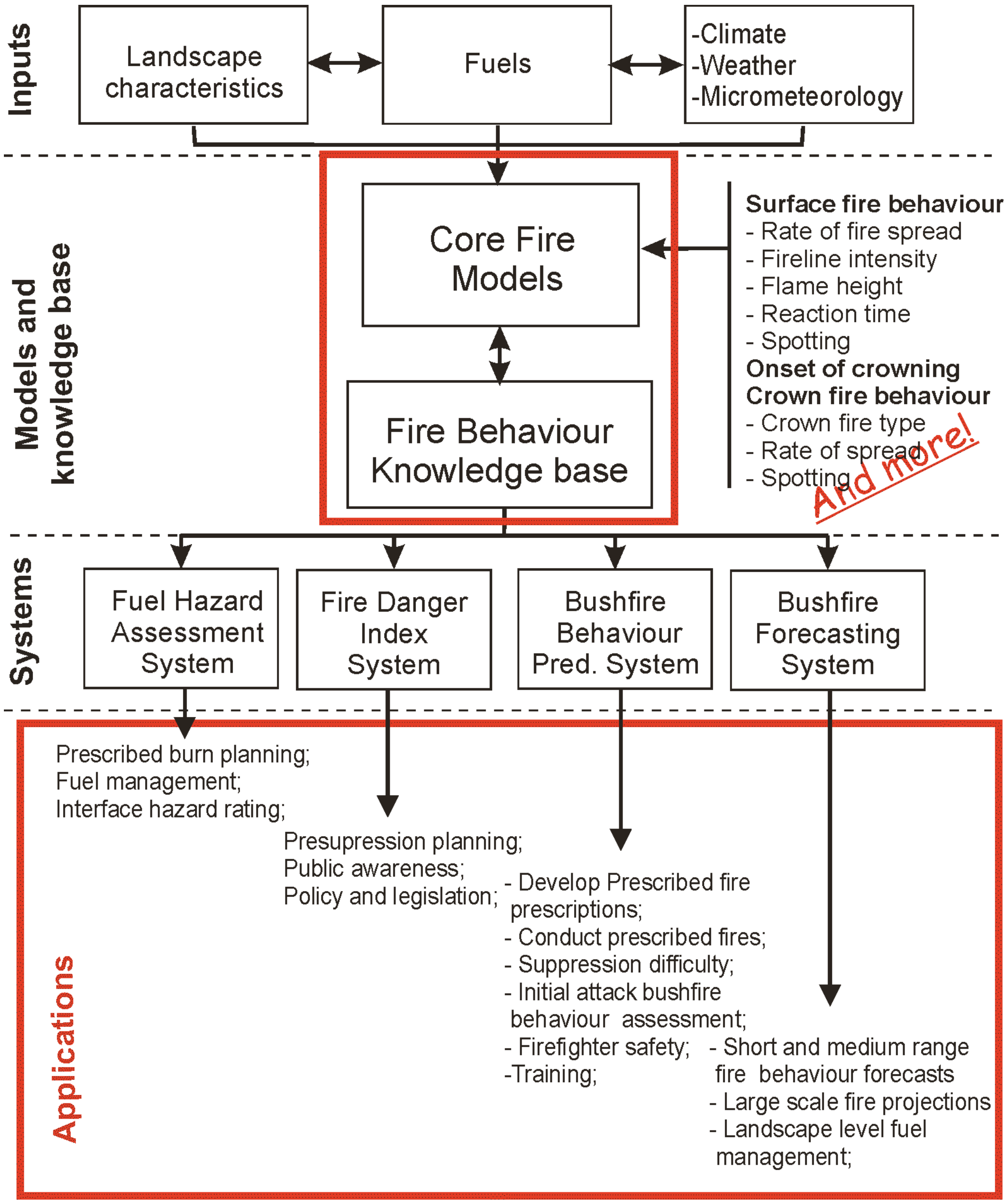

Figure 1. Flow diagram of the National Fire Behaviour Prediction System (NFBPS) illustrating the links between fire drivers, the knowledge base (models and data) and output systems.

The heart of the model system is composed by two distinct components (Fig. 1), the core fire models module and a fire behaviour knowledge base module. The core fire models module is the engine of the system, providing simulations of fire behaviour aimed at respond to a large array of fire management questions. Main physical fire behaviour quantities incorporated in the model are:

- Sustainability of fire spread
- Rate of surface fire spread and intensity;
- Flame dimensions (height, depth and angle) and residence time
- Spotting potential
- Onset of crowning and crown fire behaviour
- Coarse woody fuel consumption
- Initial fire development potential (area and perimeter assuming point source ignition)

Along with the above described fire behaviour models, an assortment of sub-models will provide accessory information related to first order fire effects:

- Burn patchiness;
- Scorch height;
- Emissions;

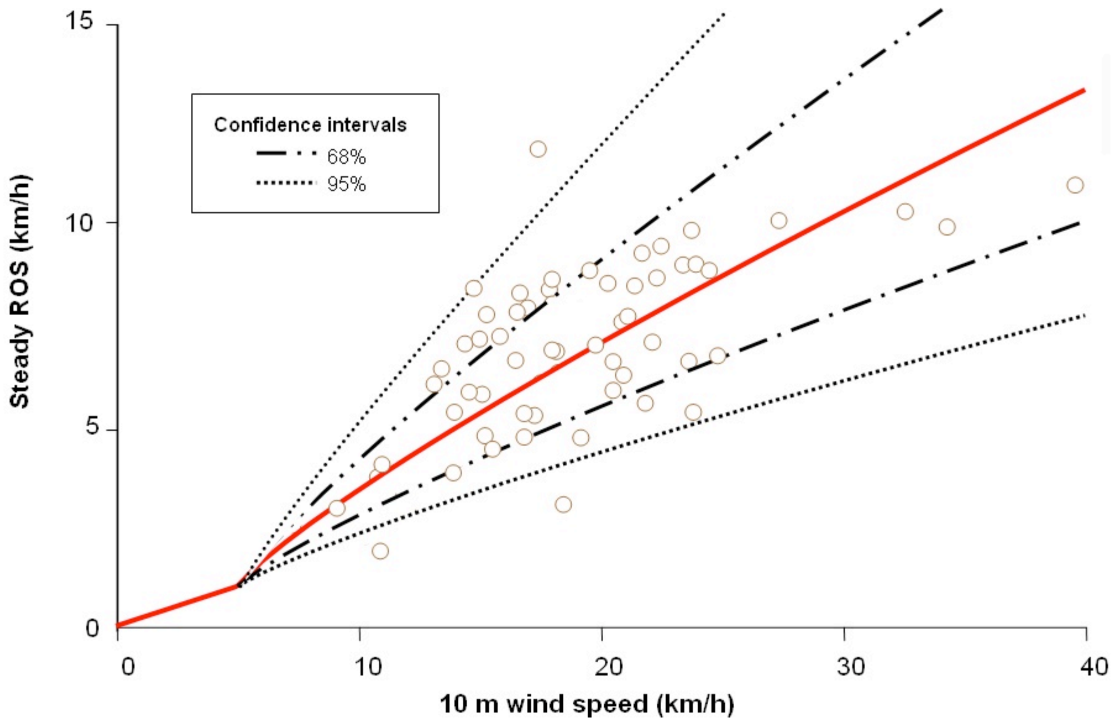

Figure 2. Prediction of Cheney et al (1998) natural pasture fire-spread model as a function of wind speed against experimental data. Data has been normalized for the effect of fuel moisture. The 68 and 95% prediction intervals are shown. Figure from Cheney et al. (1998).

The fire behaviour knowledge base module provides a setting where fire behaviour simulations can be compared with real world data. This module will incorporate all available fire behaviour data in Australian ecosystems and will allow users to visualize their simulations within the context of data, illustrating the uncertainty in the predictions and the limitations of the datasets. A grassfire rate of spread model (Cheney et al 1998) output as a function of wind speed (data corrected for fuel moisture effect) provides an example of such concept (Figure 2). The figure not only provides information on how rate of spread increases approximately linearly with wind speed, but also indicates the variability in observed fire spread.

For the area where the bulk of the data exists (wind speeds between 15 and 25 km/h) the rates of spread seem to spread +/-33% of the predicted value, with a few cases showing extreme variability. The graph also provides the bounds of the dataset used to build models, leading to caution by users when their simulations are required for conditions not covered by the existent datasets. The system considers that users can input their own datasets (collected in prescribed burns or wildfires) to verify simulations and strength the predictive capacity of the system. This analysis will provide users with an understanding of the predictive capacity of models, something that is only subconsciously acquired after a long career at predicting fire behaviour.

MODELLING UNCERTAINTY

The operational prediction of fire spread to support fire management operations relies on a deterministic approach where a single "best-guess" forecast is produced from the best estimate of the environmental conditions driving the fire. Although fire can be considered a phenomenon of low predictability and the estimation of input conditions for fire behaviour models are fraught with uncertainty, no error component is associated with these predictions. The NFBPS will incorporate modelling techniques that allow describing the inherent uncertainty in fire behaviour into the simulation process. Ensemble methods that consider the variability of model inputs and Monte Carlo sampling (Cruz, in press) will be integrated in the core fire modelling component. This will allow to describe prediction statistics and estimate the likelihood that extreme phenomena, e.g., onset of crowning, will occur. These outputs allow users to ascertain with some confidence what will and what will not happen. The probabilistic outputs from the ensemble method extend the range of questions that can be answered by fire behaviour models, enabling linkages between fire behaviour models and quantitative risk analysis.

In situations where users provide observed fire data to the system, data assimilation methods will be used to improve the prediction potential of the model system.

FUELS

The NFBPS will cater for a large variety of fuel types existent in Australia, incorporating research carried out since the 1980s.

- Grasslands
  - Natural grasslands (Cheney et al 1998)
  - Grazed grasslands (Cheney et al 1998)
  - Eaten out grasslands (Cheney et al 1998)
  - Grassland/woodland (Cheney and Andrews 2008)
  - Spinifex grasslands (Burrows et al. 2009)
- Shrubland
  - Coastal heaths (Catchpole et al, in preparation)
  - Bottongrass Moorlands (Marsden-Smedley and Catchpole 1995)
  - Mallee-heaths (McCaw 1997, Cruz et al, in preparation)
  - Mallee-spinifex
- Forest
  - Exotic pine plantations (Sneeuwjagt and Peet 1985, Cruz et al 2008a);
  - Dry sclerophyll eucalypt forest (Sneeuwjagt and Peet 1985, Burrows 1994, Cheney et al. 1992, Ellis 2000, Gould et al 2007);
- Logging slash

OUTPUT COMPONENTS

The NFBPS is comprised of several output modules that aim respond to the requirements of distinct applications of fire behaviour information (Figure 1). The four module systems are:

- Fuel Hazard Assessment System
- Fire Danger Rating System
- Fire Behaviour Prediction System
- Bushfire Forecasting System

Fuel Hazard Assessment System (FHA)

Fuel hazard assessment aims to describe qualitatively the contribution of fuel complex structure to potential fire behaviour (McCarthy et al 1998, Gould et al. 2007). It allows integrating information from the various fuel strata into an overall hazard. Within the NFBPS fuel hazard assessment is linked to the quantitative component of fire behaviour modelling and is used to support landscape level fuel management, namely evaluating the effectiveness of fuel modification treatments, prescribed burn planning and evaluate WUI (Wildland Urban Interface) specific fuel hazards and propose mitigation actions.

Fire Danger Rating System (FDR)

Fire Danger is a process systematically evaluating and integrating the individual and combined factors influencing fire potential (e.g., ignition, rate of spread, difficulty of control, fire impact) at a large spatial scale (Merrill and Alexander 1987). Fire danger is calculated to optimize pre-suppression planning, resource allocation, and initial attack fire fighting tactics. It is also a vital component of public awareness to potential fire hazard drives public policy related to certain fire issues. In NFBPS fire danger is intimately linked to fire behaviour. By integrating spatial information this adjusts fire potential to the specificity of a region vegetation cover and topography. This approach makes use of available datasets to provide detailed information on the local conditions, necessary for some applications, while still allowing the scale up of the results to regional of state wide fire danger analysis.

Fire Behaviour Prediction System (FBP)

The fire behaviour prediction system aims to provide the site specific fire behaviour information that is necessary to plan and conduct prescribed burns, support wildfire suppression strategies and tactics, advise firefighters of safety concerns (e.g., red flag warnings) and gauging fuel management effectiveness. The temporal and spatial scope of the simulations depend on the information available (point data vs. GIS database) and the intended use of the simulation output.

Bushfire Forecasting System (BF)

The Bushfire Forecasting System is a module that aims to extend the temporal and spatial scale of the FBP system to look at long range fire potential (5 to 20 days). This system will combine spatial information on vegetation and topography with long-term weather forecasts and climate data and produce probabilistic outputs of fire impact zones and impact severity.

FORMATS

The system will be available in different formats. The core system is software that has the capacity to be used at multiple spatial and temporal scales. The scale used for a particular simulation will depend solely upon the availability of the necessary inputs and the scope of the simulation. A user can carry out simple simulations with only a few basic input parameters (weather, fuel type, slope), extend such predictions for a 12- or 24-h period if forecasted weather is available, or simulate fire propagation across the landscape over complex topography under variable fuels and evolving weather conditions.

This later simulation will require spatially explicit information of fuels, topography and weather. Aside from stand alone computers running the software, it is envisioned that the system should also be able to run in a centralized server (localized in a Fire Behaviour Service Center) with the results being able to be visualised in mobile devises (laptops, smartphones, etc) through the internet. This will allow processor intensive simulations to be carried out quickly and the results could be available to a suit of users that would not have the time or training to run the simulations.

The system will be also available in different formats suitable for quick verification in field conditions namely slide rules, tables and nomograms. In these formats simplified version of the core models will be used to produce first approximations of fire behaviour characteristics and intended mainly to be used as field reference guides.

CONCLUDING REMARKS

Fire is a multifaceted phenomena, and knowledge of its behaviour is necessary to comprehend its likely impact on human live, property and natural resources, develop proactive fire management plans and establish effective fire suppression strategies and tactics. The increase in complexity of the land and fire manager job in face of new climate scenarios, weather extremes and conflicting land management objectives has not been accompanied by the development of decision support tools that allow fire prediction using the most up to date fire behaviour science and technologies.

We propose a decision support system to predict fire behaviour and impacts based on the integration of the latest fire behaviour and peer-reviewed science within state of the art IT tools. The success of fire behaviour prediction tools in supporting fire management decision-making in North America resulted in part from the extensive training received by users to understand how to use the model systems, and most importantly, the limitations associated with then and how they should be taken into consideration. There are still large areas of uncertainty in fire behaviour prediction and it is of utmost importance that users understand those. Failure to do so can lead to erroneous interpretations of output results, which at best can lead to a decrease in the trust users put on the models, and at worst can put lives and human property at risk. The development of the NFBPS needs to be accompanied by a well supported technology transfer program that ensures users are aware of system limitations and application bounds.

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