INTRODUCTION / INTRODUCTION

Overview of the International Crown Fire Modelling Experiment (ICFME)

B.J. Stocks, M.E. Alexander, and R.A. Lanoville

Abstract: The International Crown Fire Modelling Experiment (ICFME), carried out between 1995 and 2001 in Canada's Northwest Territories, involved 18 experimental high-intensity crown fires, with more than 100 participants representing 30 organizations from 14 countries. ICFME has provided valuable new data and insights into the nature and characteristics of crowning forest fires, which will assist in addressing fire management problems and opportunities affecting both people and ecosystems in future decades. ICFME evolved as the result of a number of converging issues: the recognition that the US and Canada could not continue separate approaches to fire behaviour model development, the opening of Russia to the western world, increased communication, and the formation of international associations to facilitate collaboration. While the initial impetus for ICFME was the desire to improve the physical modeling of crown fire propagation and spread, the project also created the opportunity to examine many other aspects and impacts of crown fires. This special issue of the *Canadian Journal of Forest Research* devoted to ICFME is intended to summarize most of the major research results from the project.

Résumé : Dans le cadre de L'Expérience internationale de modélisation des feux de cimes (EIMFC), 18 feux de cimes expérimentaux de forte intensité ont été provoqués dans les Territoires du Nord-Ouest du Canada. L'EIMFC, qui a mobilisé une centaine de chercheurs issus de 30 organismes et représentant 14 pays, a fourni de riches données et renseignements sur la nature et les caractéristiques des feux de cimes en forêt, qui contribueront indubitablement à résoudre les difficultés de gestion des incendies qui affectent l'homme et les écosystèmes. Plusieurs facteurs ont influé sur la progression de L'EIMFC, notamment la mise en évidence du fait que les É.-U. et le Canada se devaient d'unir leurs efforts dans l'élaboration de modèles de comportement des feux, l'ouverture du rideau de fer en Russie, la multiplication des échanges et la constitution d'associations internationales destinées à favoriser la collaboration. Si cette expérience internationale avait pour principale visée d'améliorer la modélisation physique de la transmission et de la propagation du feu, elle a toutefois aussi permis d'examiner plusieurs autres aspects et facteurs d'incidence des feux de cimes. Le présent numéro de la *Revue canadienne de recherche forestière* consacré à L'EIMFC constitue une synthèse des constatations les plus marquantes de cette expérience.

[Traduit par la Rédaction]

Introduction

While some progress has been made in predicting and modeling the initiation and behaviour of crown fires at northern latitudes, a complete understanding of the phenomena has proven an elusive goal over the past half century. The transition from surface to crowning fires represents a threshold beyond which suppression actions most often fail, and crown fires, spreading quickly at high intensity levels, continue to account for the vast proportion of the area burned in northern forests (Weber and Stocks 1998; Stocks et al. 2003), creating significant economic loss, and increasingly threatening human life and property. The International Crown Fire Modelling Experiment (ICFME) was designed to address modelling the propagation and spread of crown fires, using both modern instrumentation and a collaborative, multi-disciplinary international approach.

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Background and genesis of ICFME

During the 1990s, a number of converging fire research issues made the development of ICFME both timely and relevant (Stocks and Conard 2000). Forest fire research scientists in Canada and the United States had worked independently for much of the previous half century on the development of fire danger and fire behaviour prediction systems, always using

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new research knowledge to improve and update systems that, when issued, have been used by fire management agencies throughout North America and various regions around the world to aid in predicting the occurrence and behaviour of forest fires. The Canadian approach to the quantitative prediction of fire behaviour has been largely empirical in nature (Stocks et al. 1989) An extensive experimental burning program, including many high-intensity crown fires, was carried out by the Canadian Forest Service (CFS) in cooperation with Canadian fire management agencies over a 20-year period beginning in the early 1960s in several major fuel types (Stocks et al. 2004), including conifer fuel types prone to crowning (Stocks and Hartley 1995). These experimental fires, combined with the monitoring and documentation of numerous free-burning wildfires, led to the development of a fire behaviour database that constitutes the foundation of the empirically based Canadian Forest Fire Behavior Prediction System (Forestry Canada Fire Danger Group 1992).

Concurrently, for many decades, fire researchers with the United States Forest Service had been conducting extensive research into fire behaviour, focusing primarily on the development of a semi-physical model of surface fire spread that was largely based on laboratory fires. This model (Rothermel 1972) was subsequently used as a foundation in the development of a national system of fire danger rating (Deeming et al. 1977), the BEHAVE System (Andrews and Chase 1989), and other fire behaviour prediction systems (e.g., Finney 1998). Using a limited number of wildfire observations, Rothermel (1991*a*) subsequently calibrated his surface fire model to produce a simple crown fire rate of spread, in response to the inability of his surface fire model to predict crown fire spread during the 1988 Yellowstone National Park fire situation (Rothermel 1991*b*).

CFS fire researchers had come to the realization that it was physically and logistically impossible to develop empirically based fire behaviour models for all major Canadian fuel types, while American researchers had also recognized the limitations of the Rothermel (1972, 1991*a*) models in the prediction of high-intensity crown fire behaviour. Neither national approach would result in a model or system robust enough to encompass the full range of fire behaviour across fuel types required by fire management agencies in both countries. As a result, Canadian and American fire researchers began exploring further collaborative opportunities.

At the same time, after decades of isolation caused by the Cold War, western and Russian fire scientists began meeting to discuss research methodologies and the possibility of working collaboratively under the auspices of the International Boreal Forest Research Association (IBFRA) Fire Working Group (Stocks et al. 1997). The first products of this new initiative were an international fire conference in Krasnoyarsk in 1993 (Goldammer and Furayev 1996), followed by the Bor Forest Island Fire Experiment (FIRESCAN Science Team 1996). However, additional joint investigations were also developed, including the remote sensing of boreal fires, fire danger rating, fire behaviour modelling, and climate change, forest fire, and carbon budget impacts research. The IBFRA Fire Working Group was also involved in the early planning of the FROSTFIRE experiment in interior Alaska in July 1999 (Hinzman et al.2003)

Bringing international fire scientists together in Canada to conduct a series of replicated crown fires, using the most sophisticated and modern instrumentation and documentation techniques available, would be a major step in understanding the science of crown fires. Clearly, for a number of converging reasons, the timing was opportune, and the concept of ICFME was born.

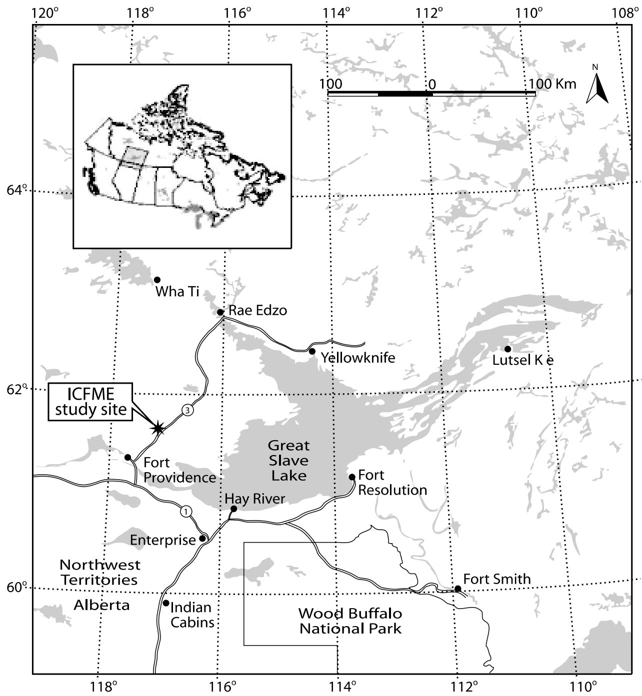
The ICFME planning phase

A reconnaissance trip to evaluate potential sites for ICFME took place in the western region of the Northwest Territories in June 1994 following discussions between the CFS and the Department of Resources, Wildlife and Economic Development within the Government of the Northwest Territories. A suitable site was located near Fort Providence close to the junction of Great Slave Lake and the Mackenzie River (Fig. 1). Discussions with the aboriginal community of Fort Providence led to their support, and the ICFME site was confirmed. The study area, located about 50 km northeast of Fort Providence, was essentially flat and surrounded by marshy shrubland. The overstory of the ICFME fuel complex resulted from a 1931 wildfire, and was dominated by jack pine (*Pinus banksiana* Lamb.) with a minor black spruce (*Picea mariana* (Mill.) BSP) component (Alexander et al. 2004). The overstory averaged 10 m in height and ~5900 stems/ha, while the dense understory black spruce component averaged ~5100 stems/ha. The site was considered ideal for supporting high-intensity crown fires under normal summer weather and fire danger conditions, based on previous experimental burning experiences in comparable fuel complexes (Stocks and Hartley 1995).

The shrub-dominated meadows surrounding the ICFME site were burned in the spring of 1995 (and partially again in 1996 and 2000) to reduce fuel loadings and lessen the likelihood of fires escaping control. Ten primary experimental burning plots (A and 1–9) were delineated in the summer of 1995, surrounded by 50-m wide cleared fireguards (Fig. 2). All plots were square, with orientation varied to accommodate some likely fluctuation in wind direction. Eight plots were 150 × 150 m, while the remaining two plots were smaller (75 × 75 m and 100 × 100 m). Intensive sampling of ground, surface and crown fuels was undertaken on all plots during the summers of 1995 and 1996. These plots were designed to accommodate the replicated series of high-intensity crown fires necessary for crown fire modeling purposes, particularly the testing and calibration of a physical model of crown fire spread (Butler et al. 2004*b*), and would be heavily instrumented and documented by CFS and United States Forest Service fire researchers.

Two ICFME planning meetings were held in Calgary, Alberta in 1995 and 1997, which resulted in the development of logistical and research plans. Interim meetings were also held in Missoula, Montana, in 1998 and 1999 to report on preliminary results, evaluate progress, and plan future burning. As awareness of the ICFME project increased, additional researchers and organizations expressed an interest in participating. The testing and evaluation of protective fire shelters (Putnam and Butler 2004), the airborne sampling of smoke and aerosols (Cofer et al. 1998; Conny and Slater

Fig. 1. Geographical location of the International Crown Fire Modelling Experiment site in the Northwest Territories, Canada. From Alexander et al. 2004, reproduced with permission of the Canadian Forest Service, © 2004 Her Majesty the Queen in right of Canada.



2002; Payne at al. 2004), and the performance of a wildland–urban interface structural ignition assessment model (Cohen 2000) were three major additional initiatives.

Two additional burning plots, Aspen and Treated–Untreated (Fig. 2), were established adjacent to the primary plots in 1996 for preliminary analysis of the effectiveness of various fuel management treatments (i.e., pruning and thinning, hardwood fuelbreaks) on crown fire behaviour (Alexander and Lanoville 2004). Two more plots, S1 and S2 (Fig. 2), were established in 1997 to further examine the performance of protective fire shelters. At this same time, plots I1 and I2 (Fig. 2), were created to evaluate standards for community home protection from wildfire (NFPA 1991), and contained simulated house structures. Some additional smaller plots (e.g., B and DI) were established for specific purposes as ICFME progressed.

The ICFME execution phase

An analysis of recent seasonal trends in fire danger in the Fort Providence area (1982–1996) indicated that the most ideal period (or “burning window”) for the ICFME project was a three-week interval between mid-June and early July, just before the start of the Northwest Territories’ lightning fire season. An automated weather station was located at the ICFME site each season, and daily observations from this station were used to calculate fire danger conditions based on the Canadian Forest Fire Weather Index System (Van Wagner 1987). A burning prescription was developed, which in combination with a number of daily weather forecasts and small-scale test fires, was used to determine when plots would be ignited.

A network of ground, tower, and airborne instrumentation, including video cameras, was deployed within, around and above each burning plot to document various fire behaviour characteristics, including fire spread rates and patterns, spotting distances, flame front residence times, flame structure, thermal radiation, vertical temperature profiles, smoke chemistry, wind dynamics, and fuel moisture and consumption.

A total of 18 experimental crown fires were conducted at the ICFME site between 1997 and 2000 (three plots in 1997, two in 1998, seven in 1999, and six in 2000). Poor weather in 2001 prevented the burning of the final ICFME plot. All fires were ignited along the windward edge using a truck-mounted, pressurized flame thrower, and exhibited fire behaviour characteristics typical of active boreal forest crown fires, spreading at 1–5 km/h, consuming large quantities of fuel, and releasing significant amounts of thermal energy (Stocks et al. 2004). Flame fronts were commonly 2–3 times the height of the overstory, and short-range downwind spotting of firebrands was common and prolific (Taylor et al. 2004). Control and subsequent suppression of ICFME fires by the Department of Resources, Wildlife and Economic Development, fire management staff and their contract fire suppression crews ensured that no significant control problems were encountered during the ICFME project.

ICFME results

This special issue of the *Canadian Journal of Forest Research* is intended to present most, but not all, of the scientific results from ICFME. Papers dealing with fire behaviour present basic characteristics (Stocks et al. 2004) and new data on flame zone dynamics and energy transfer in crown fires (Butler et al. 2004*a*; Taylor et al. 2004), gathered using instrumentation never before used on high-intensity crown fires. These data are further used in validation of a physical, radiation-driven crown fire rate of spread model (Butler et al. 2004*b*). Other papers address firefighter safety (Putnam and Butler 2004) and wildland–urban interface (Cohen 2004) issues, and present data gathered for the first time on active crown fires. Additional papers deal with the production, dispersion, and deposition of charcoal from crown fires (Lynch et al. 2004), the airborne sampling of carbonaceous aerosol in boreal smoke plumes (Payne et al. 2004), and the linkages between jack pine regeneration and fire behaviour characteristics (de Groot et al. 2004).

Some ICFME participants published journal papers on their results before this special issue of the *Canadian Journal of Forest Research* was planned, and these are noted here in the interest of completeness. These include investigations of soil heating (Ryan 2002), carbon and energy fluxes (Amiro 2001), convective dynamics above crown fires (Clark et al. 1999; Radke et al. 2000), and smoke chemistry and aerosol studies (Conny and Slater 2002; Cofer et al. 1998). A listing of additional publications is available from the ICFME website at http://fire.cfs.nrcan.gc.ca/research/environment/icfme_e.htm.

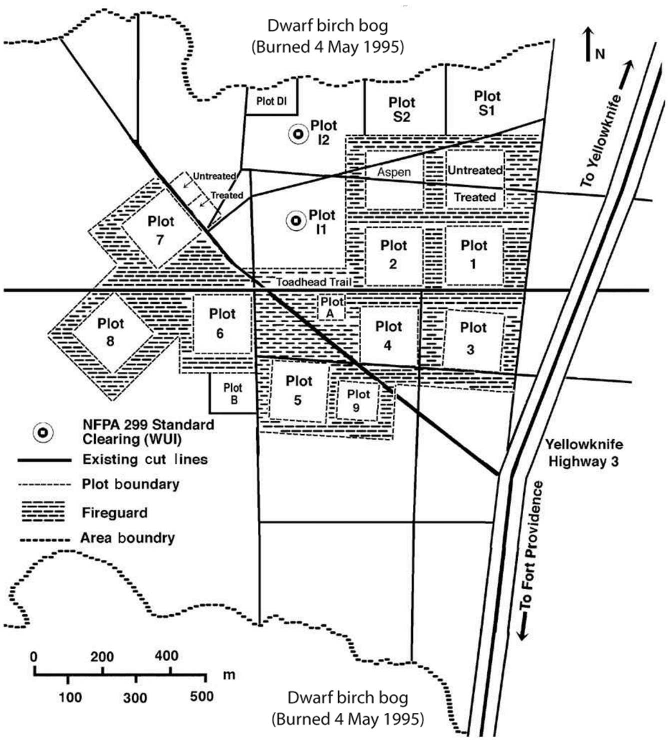


Fig. 2. Plot layout for the International Crown Fire Modelling Experiment study area. From Alexander et al 2004, reproduced with permission of the Canadian Forest Service, © 2004 Her Majesty the Queen in right of Canada.

More than 100 participants from 14 countries representing 30 different organizations were involved in ICFME. While the initial impetus for ICFME was the physical modeling of crown fire behaviour, the project also created the opportunity to examine other aspects and implications of crown fires, including linkages to certain fire impacts and effects, firefighter safety and the wildland–urban interface. ICFME provided the opportunity for both researchers and operational fire personnel to evaluate other models, theories, and systems regarding crown fire behaviour (e.g., Cruz et al. 2003, 2004), to test and examine the effectiveness of management guidelines and equipment, and to develop new fire monitoring instrumentation such as “in-fire” video cameras (Kautz 1997). The variety of concurrent objectives brought to ICFME by the diverse group of participants illustrates that multi-disciplinary undertakings of this magnitude can accommodate both applied and more basic or fundamental studies. Local community members from Fort Providence, including many students, learned from, and contributed to the ICFME project. International endeavours such as ICFME, which involve extensive cross-disciplinary collaboration, are envisaged as the approach under which most future wildland fire research will be carried out (Stocks and Conard 2000). Large-scale research projects such as ICFME require extensive planning, commitment, collaboration and trust among participating agencies (Alexander et al. 2001).

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