CFS CANADIAN FOREST SERVICE
SCF SERVICE CANADIEN DES FORÊTS
cfs-scf.nrcan-rncan.gc.ca

FOREST HEALTH: Fire Behavior Considerations

Marty Alexander, PhD, RPF
Senior Fire Behavior Research Officer
Northern Forestry Centre
Edmonton, Alberta
malexand@nrcan.gc.ca

Natural Resources Canada
Ressources naturelles Canada

Canada

Fire Behavior and the Forest Manager

“ The behavior of fires is an important factor in the growth, harvesting, and regeneration of forest crops. How often fires occur and how hot they burn affect … the … quantity of products harvested from the forest. The forest manager may influence fire behavior by the nature of his operations … it is important for forest managers to know fire behavior and to be able to evaluate the influence of forest management operations on it.” – J.S. Barrows (1951)

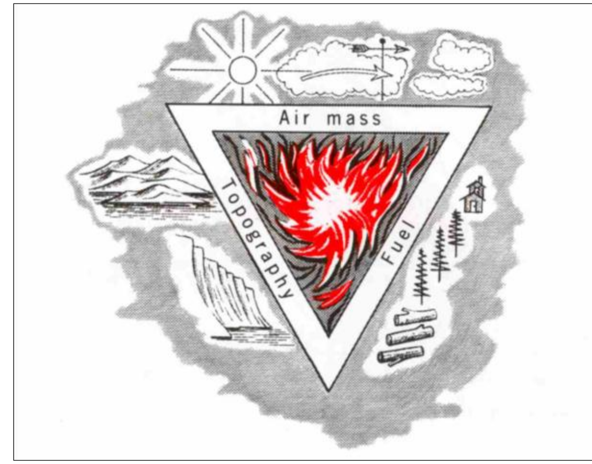
Purpose of Presentation:

Provide a overview (for the non-specialist) of relevant fire behavior terms and concepts, existing tools for predicting fire behavior at the stand level (with particular emphasis on crown fire), and finally, to offer some suggestions for future direction

Outline of Presentation:

I. Fire Behavior Fundamentals
II. Prediction of Fire Behavior
III. Conclusions and Suggestions on Future Direction

I. "FIRE BEHAVIOR 101": The Fundamentals



Fire behavior is defined as the manner in which fuel ignites, flame develops, fire spreads and exhibits other related phenomena as determined by the interaction of fuels, weather, and topography (i.e., the fire environment).

Fire Environment Factors

Fuel Characteristics:
- Quantity
- Moisture
- Size & Shape
- Depth/Height
- Arrangement

Weather Characteristics:
- Wind Speed & Direction
- Relative Humidity
- Air Temperature
- Rainfall Amounts & Duration
- Cloud Clover
- Atmospheric Instability

Topographic Characteristics:
- Slope Steepness & Aspect
- Elevation
- Configuration
- Barriers to Fire Spread


PARTS OF A FIRE
HEAD
Spot fire
Spot fire
Finger
Finger
LEFT FLANK
RIGHT FLANK
Direction of Spread
Pocket
Finger
unburned island
origin
REAR (Generally near origin)

Nominal Spread Rates for Wildland Fires

Ground or Subsurface Fires: < 0.01 m/min

Surface Backfires in Forests: 0.1 – 1.0 m/min

Surface Head Fires in Forests: 1 - 10 m/min

Crown Fires in Forests: 15 - 200 m/min

Grass Fires: up to 250 - 350 m/min

Basic Features of a Forest Fire:

It spreads …

it consumes or "eats" fuel and …

it produces heat energy and light in …

… a visible flaming combustion reaction.

Fire Intensity

$$I = H \times W \times R$$

I	H	W	R
Fire Intensity (kW/m)	Heat of Combustion (18 000 kJ/kg)	Fuel Consumed (kg/m^2)	Rate of Fire Spread (m/sec)

Fire Intensity Spectrum

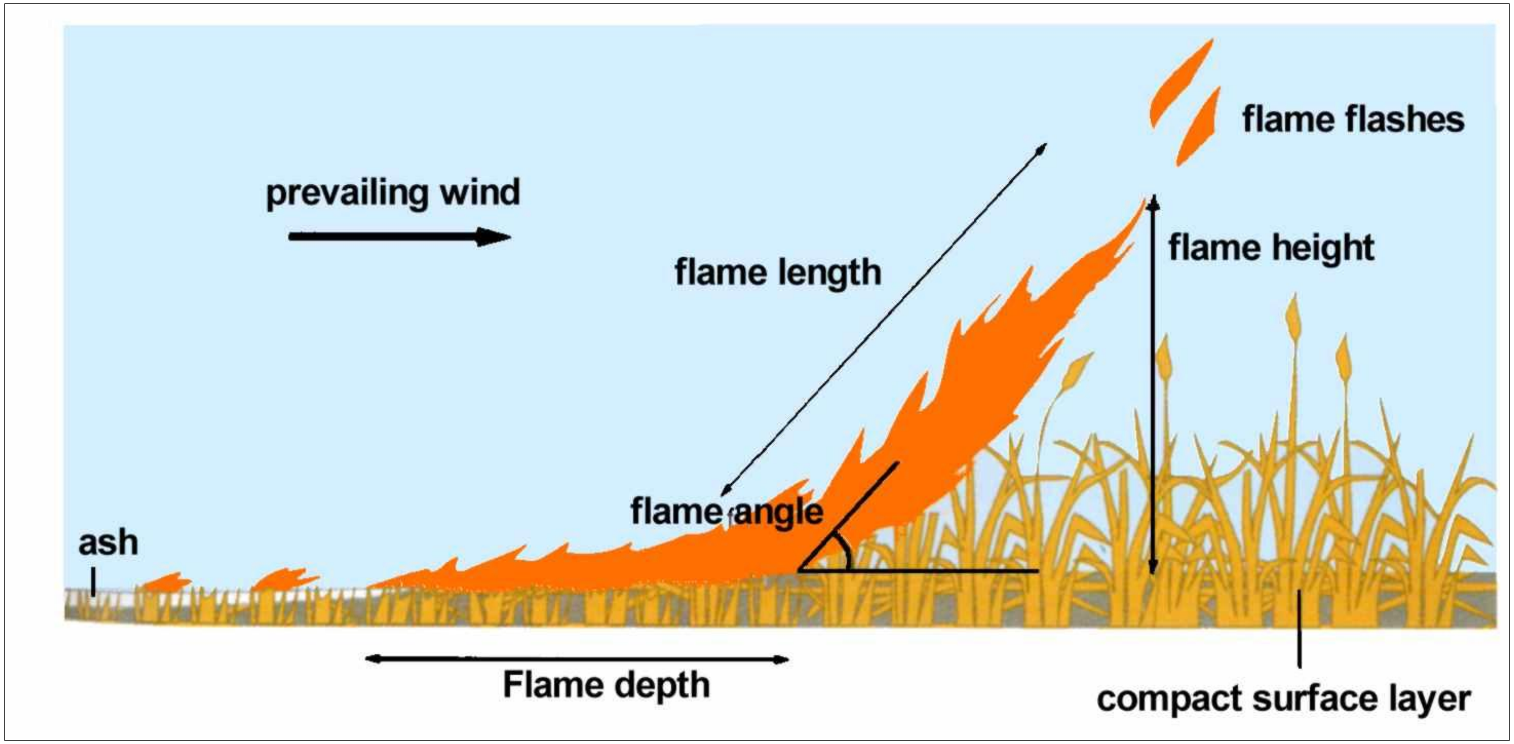
10 kW/m – Lower limit of surface fire spread

1000 kW/m – Limit of suppression capability by hand crews

10 000 kW/m – Active crown fires have developed

100 000 kW/m – Major conflagrations

Fire intensity is related to size of flames



<u>**Simple Formula for Field Use**</u>

(for surface fires & intermittent crown fires)

$$I = 300 \times (L)^2$$

***L* = Flame Length (metres)**

For active crown fires, flame height ~ 2X stand height

Extreme fire behavior represents a level of fire activity that often precludes any fire suppression action. It usually involves one or more of the following:

- **High Rate of Spread & Intensity**

- **Crowning**

- **Prolific Spotting**

- **Large Fire Whirls**

- **Well-developed Convection Column**

Comparison of Fire Behavior in a Pine Plantation under High Fire Danger Conditions

(adapted from McArthur 1965)

Fire Description and Characteristics	Stand A (pruned up to 5 m)	Stand B (unpruned)
Type of fire	Surface	Crown
Forward spread rate (m/min)	5	10
Fuel Consumed (t/ha)	18	28
Head fire intensity (kW/m)	2700	8400
Flame height (m)	2	12
Fire area @ 1 hour (ha)	4.86*	19.44*
Fire perimeter @ 1 hour (km)	0.83	165
Spotting distance (m)	<200	up to 2000

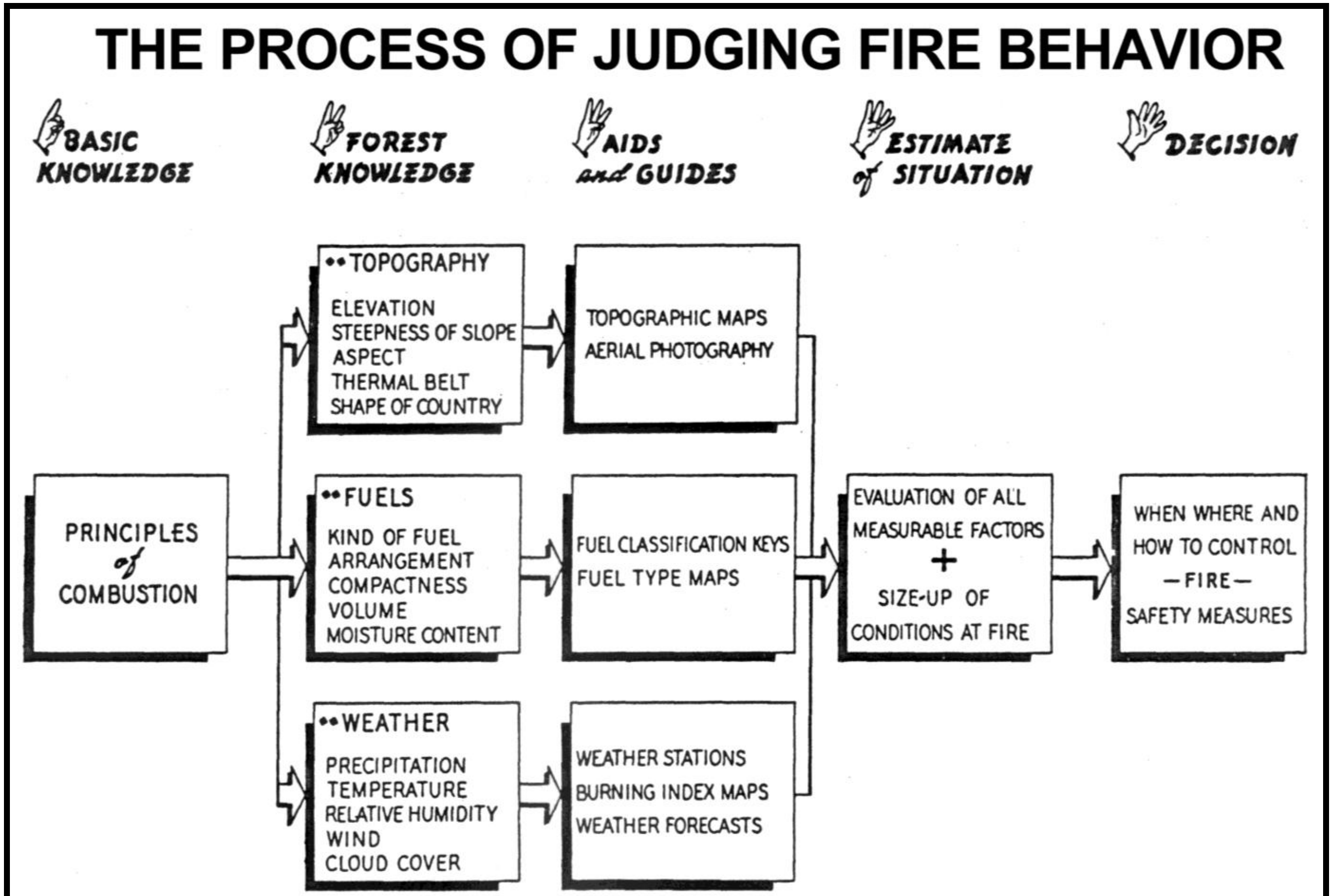
*Area enlargement = (Rate of Spread Increase)^2

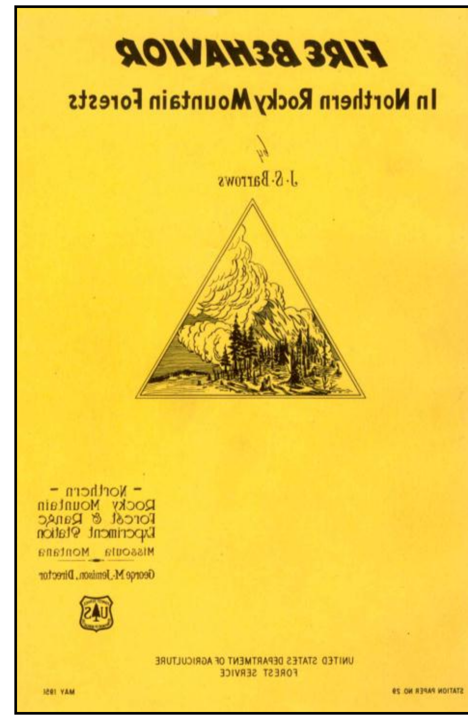
The more important fire behavior characteristics from the practical standpoint of fire suppression are:

- Forward Rate of Spread
- Fire Intensity
- Flame Front Dimensions
- Spotting Pattern (densities & distances)
- Fire Size and Shape
- Rate of Perimeter Increase
- Burn-out Time

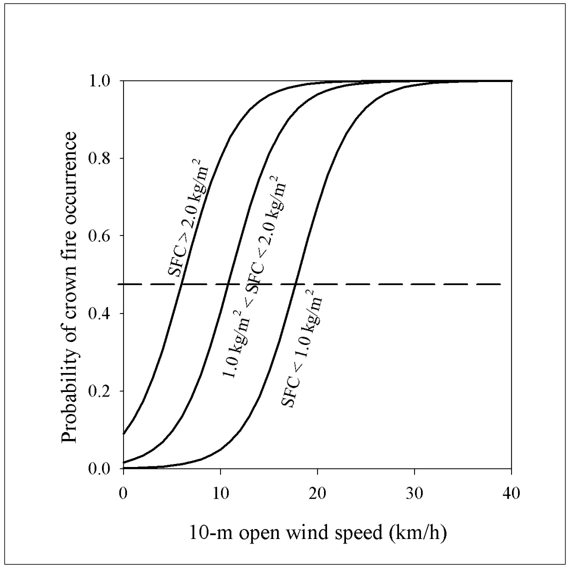
II. Predicting Fire Behavior

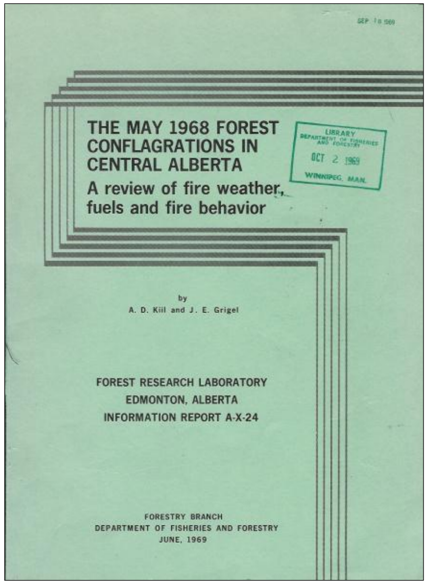
Systematic analysis that combines "art and science"





The most effective means of appraising or evaluating potential fire behavior is considered to be the coupling of <u>mathematical modelling</u> with <u>experienced judgement</u> (e.g., “expert opinion”), and published <u>case study knowledge</u> (e.g., experimental, wild and prescribed fires)




THE MAY 1968 FOREST CONFLAGRATIONS IN CENTRAL ALBERTA

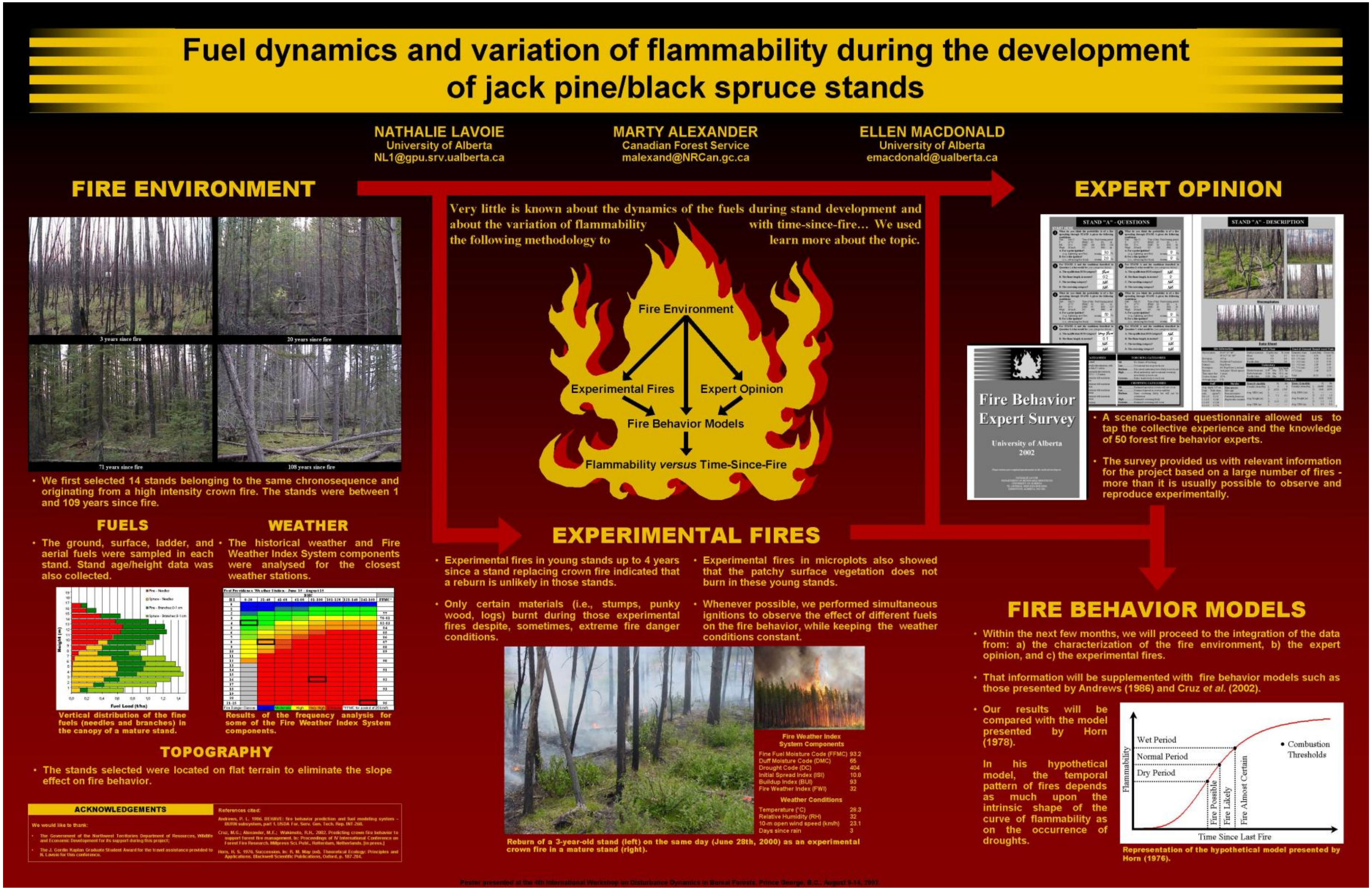
A review of fire weather, fuels and fire behavior

by

A. D. Kiil and J. E. Grigel

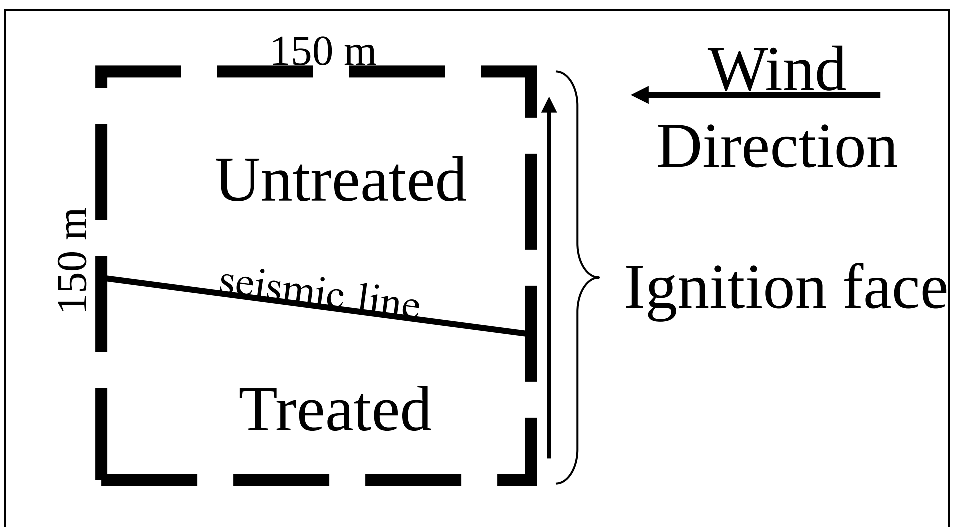
FOREST RESEARCH LABORATORY
EDMONTON, ALBERTA
INFORMATION REPORT A-X-24

FORESTRY BRANCH
DEPARTMENT OF FISHERIES AND FORESTRY
JUNE, 1969



See **Lavoie, N. 2004. Variation in flammability of jack pine/black spruce forests with time since fire in the Northwest Territories, Canada. Ph.D. Thesis, University of Alberta. 332 p.**

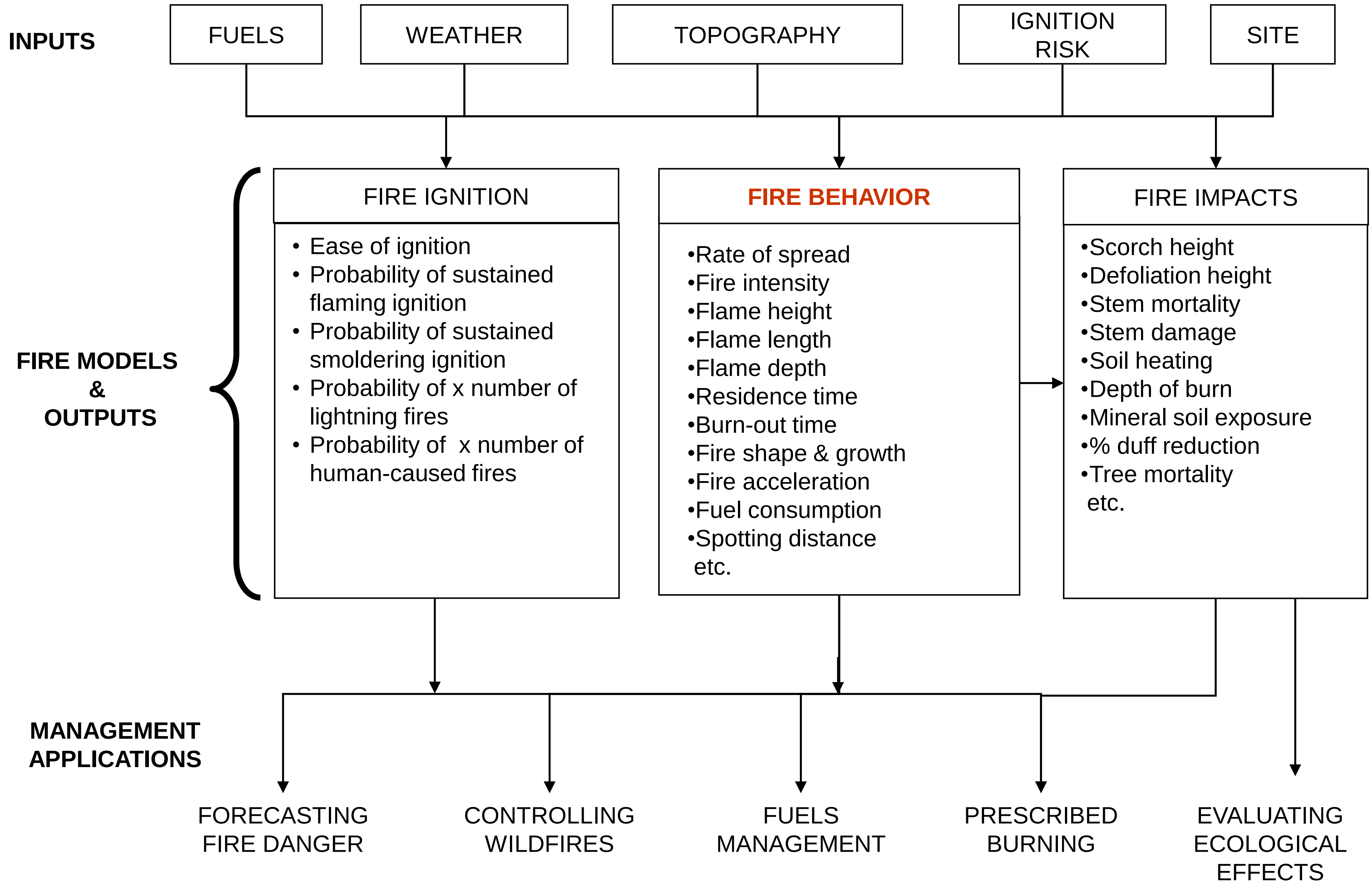
ICFME Treated/Untreated Plot, NWT – June 14, 2000



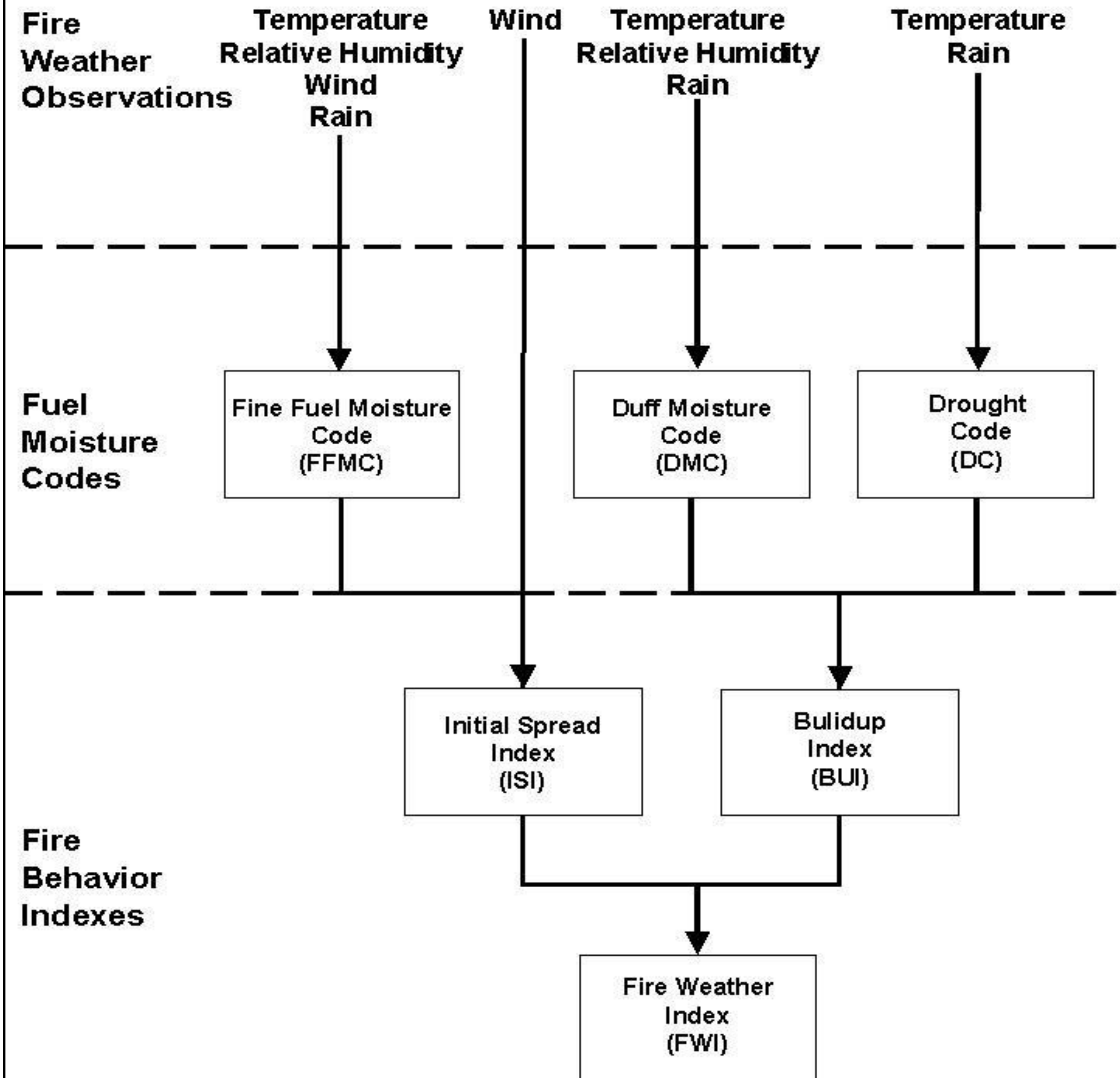
Note "prune line"

ICFME Treated/Untreated Plot, NWT – June 14, 2000

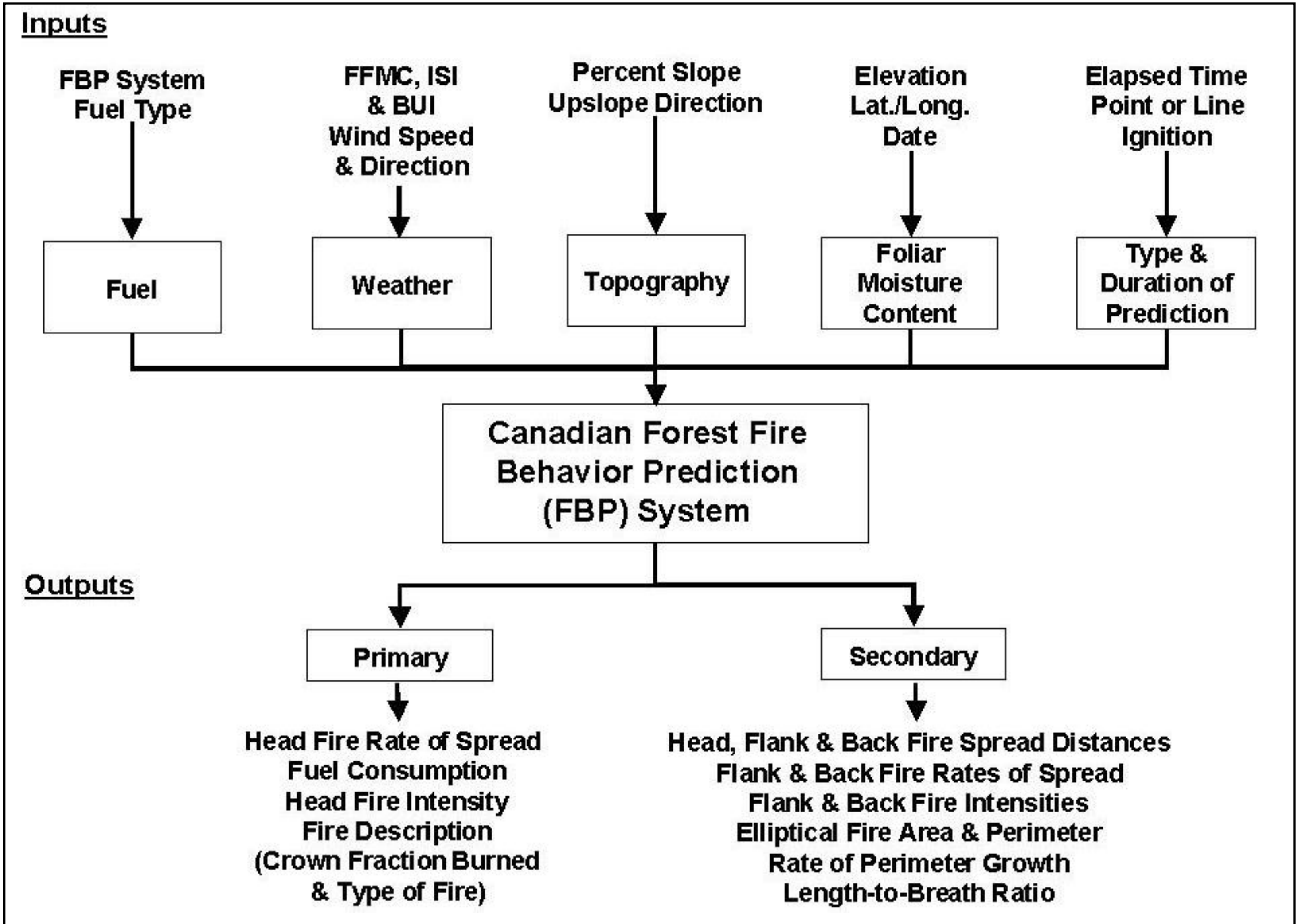
Conceptual Model of Scientifically-based Forest Fire Management



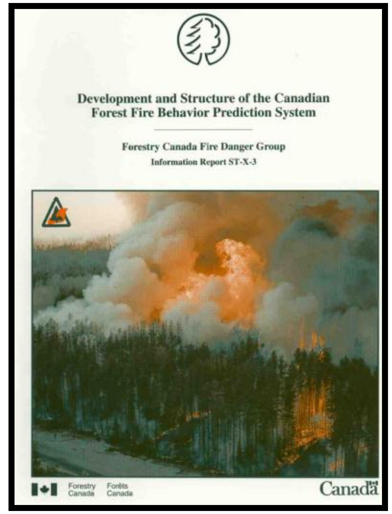
Structure of the Canadian Forest Fire Weather Index (FWI) System



Structure of the Canadian Forest Fire Behavior Prediction (FBP) System



Basis of FBP System & Documentation

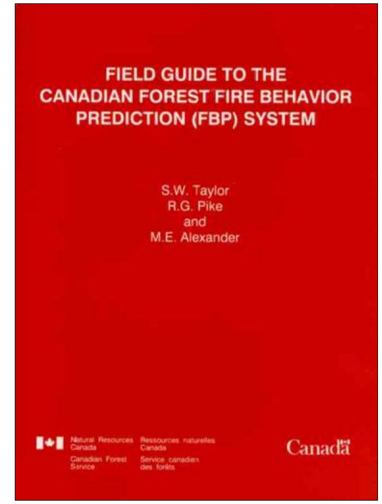

Development and Structure of the Canadian Forest Fire Behavior Prediction System

Forestry Canada Fire Danger Group

Information Report ST-X-3

Forestry Canada Forêts Canada

Canada


FIELD GUIDE TO THE CANADIAN FOREST FIRE BEHAVIOR PREDICTION (FBP) SYSTEM

S.W. Taylor
R.G. Pike
and
M.E. Alexander

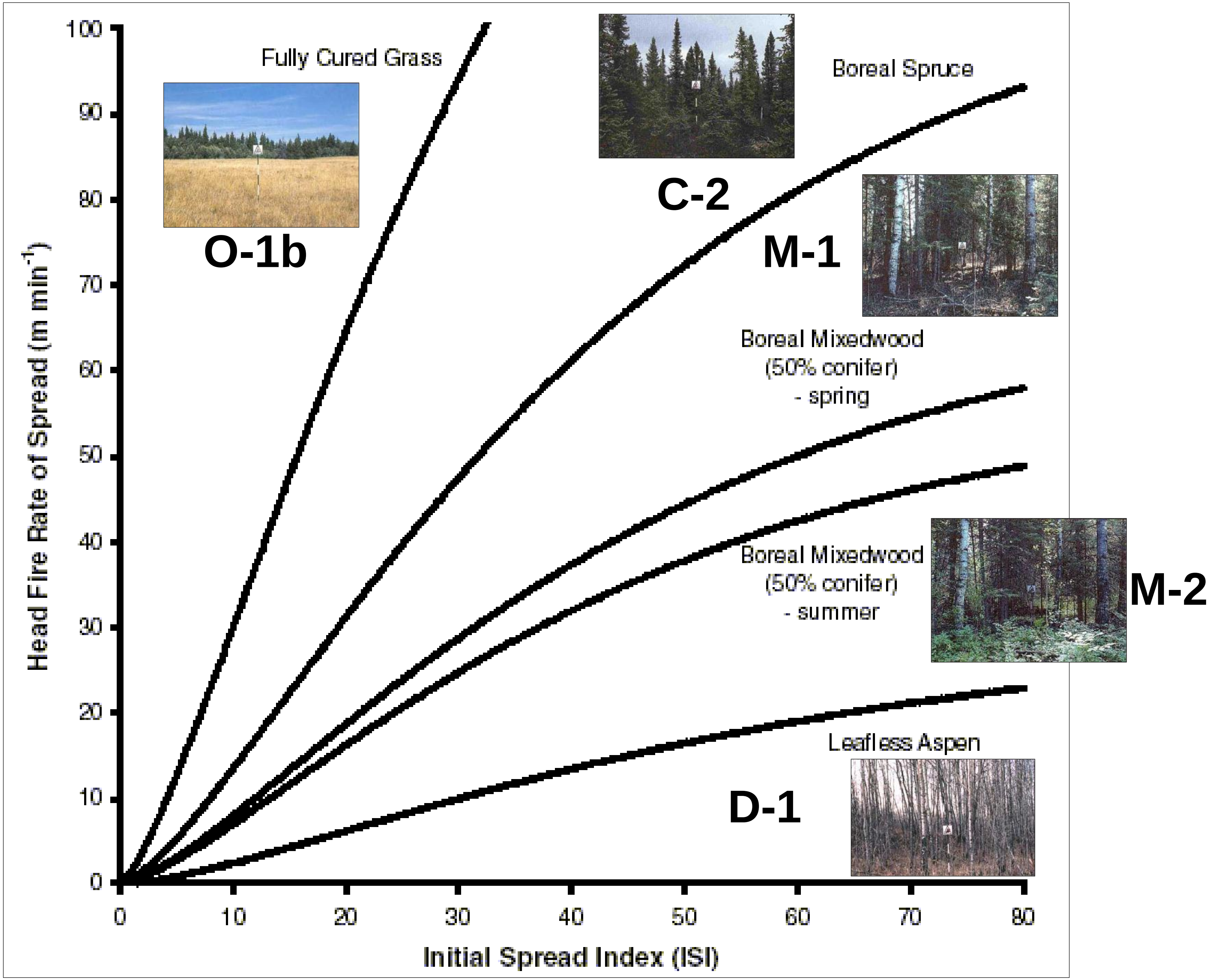
Natural Resources Canada Ressources naturelles Canada

Canadian Forest Service Service canadien des forêts

Canada

List of FBP System Fuel Types

General Category	Fuel Type	Input Modifier
Coniferous	C-1 Spruce-Lichen Woodland	-
	C-2 Boreal Spruce	-
	C-3 Mature Jack or Lodgepole Pine	-
	C-4 Immature Jack or Lodgepole Pine	-
	C-5 Red and White Pine	-
	C-6 Conifer Plantation	Live Crown Base Height
	C-7 Ponderosa Pine/Douglas-fir	-
Deciduous	D-1 Leafless Aspen	-
Mixedwood	M-1 Boreal Mixedwood-Leafless	% Conifer/Hardwood
	M-2 Boreal Mixedwood-Green	% Conifer/Hardwood
	M-3 Dead Balsam Fir/Mixedwood-Leafless	% Dead Fir
	M-4 Dead Balsam Fir/Mixedwood-Green	% Dead Fir
Slash	S-1 Jack or Lodgepole Pine Slash	-
	S-2 Spruce/Balsam Slash	-
	S-3 Coastal Cedar/Hemlock/Douglas-fir Slash	-
Open	O-1a Matted Grass	% Degree of Curing
	O-1b Standing Grass	% Degree of Curing

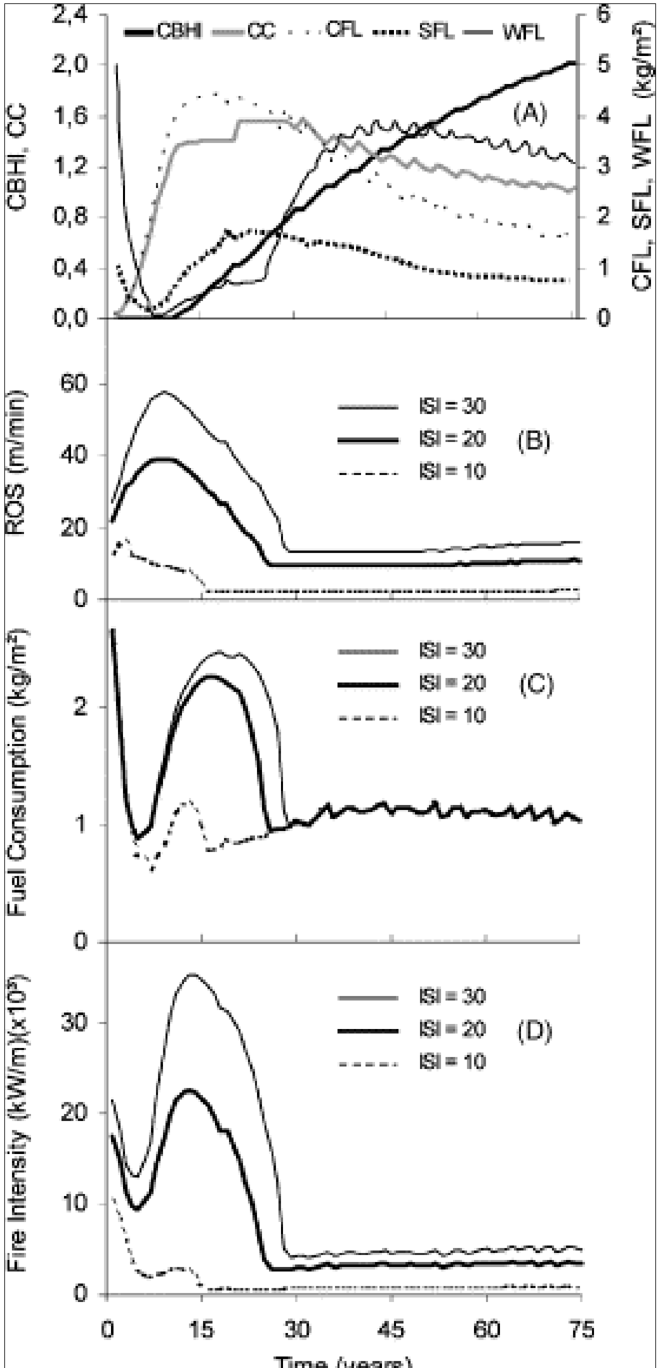


Fully Cured Grass
O-1b
C-2
Boreal Spruce
M-1
Boreal Mixedwood
(50% conifer)
- spring
Boreal Mixedwood
(50% conifer)
- summer
M-2
Leafless Aspen
D-1
Head Fire Rate of Spread (m min-1)
Initial Spread Index (ISI)
0
10
20
30
40
50
60
70
80
90
100

C-6 Fuel Type - Conifer Plantation

(Allowance for variable crown base height)

Experimental Fires in Red Pine Plantation,
Petawawa Forest Experiment Station, Ontario

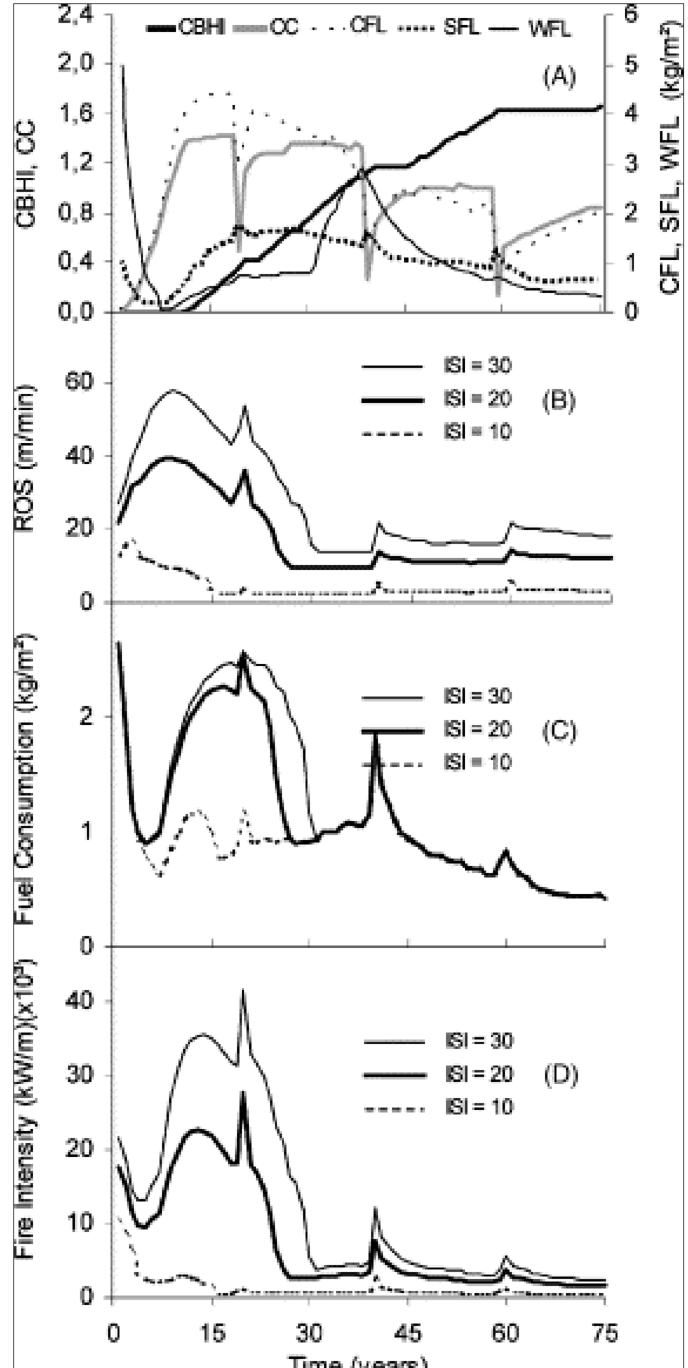


Bilgilli (2003)

No treatment
(2 x 2 spacing)

Treatment: thinnings at 20, 40 & 60 yrs – 30, 50 & 50% of trees removed

CBH – Crown Base Height
CC – Crown Closure
CFL – Crown Fuel Load
SFL – Surface Fuel Load
WFL – Woody Fuel Load

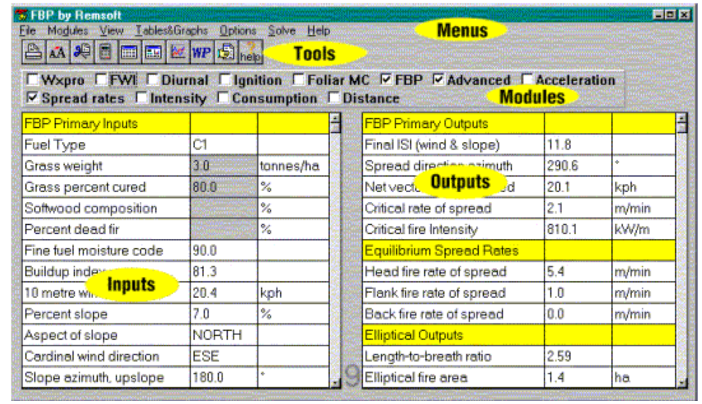


Limitations of FBP System Fuel Types

- **Some allowance for seasonal changes in flammability and stand composition**
- **Fuel types are static and not "dynamic" in nature (i.e., no variation in fuel complex structure and fire behavior with stand age *per se*)**
- **Except for C-6, the emphasis todate has been on natural fire-origin forest stands**
- **There is at present no capacity to alter any crown fuel characteristics, other than crown base height in C-6**
- **Slash fuel types reflect logging methods and utilization standards of the 1960s**

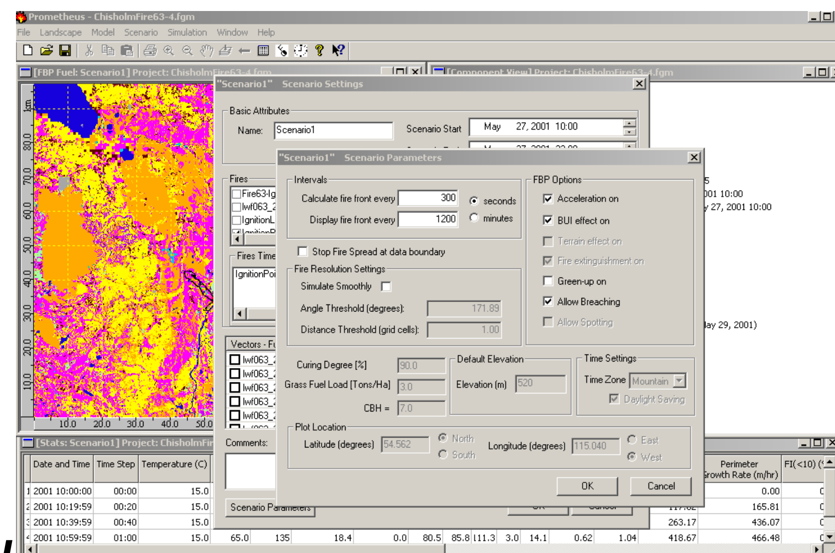
FBP System Software

Behave by Remsoft®



http://www.remsoft.com/

PROMETHEUS – Canadian Wildland Fire Growth Model



http://www.firegrowthmodel.com/

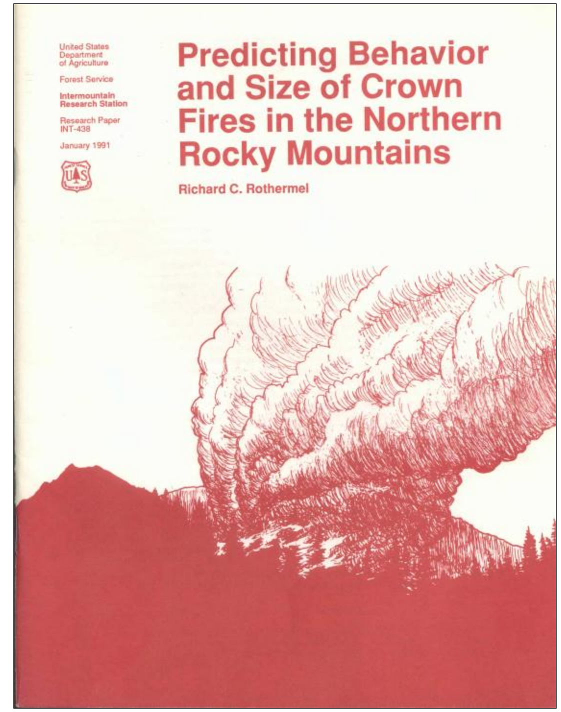
U.S. Fire Behavior Predicition System

http://www.fire.org

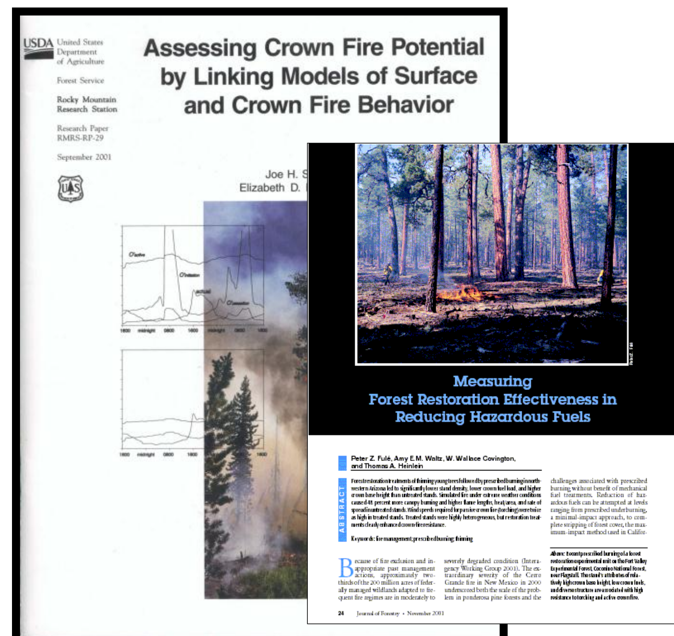
- **Based largely on Rothermel's (1972) surface fire rate of spread model involving laboratory test fires and physical theory (some empiricalism)**

- **Limited validation**
- **Does not consider duff layer**

BehavePlus System now includes Rothermel's (1991) crown fire rate of spread model which is based on an empirically derived multiplier (3.34) between the predicted surface fire rate of spread and a limited number of wildfire observations (8).



Nearly all simulations undertaken in the U.S. regarding the impacts or effectiveness of fuel treatments on fire behavior involve the BehavePlus System (or its derivatives – NEXUS, FARSITE, Fuel Management Analyst), and the Rothermel (1991) model.



New Models for Assessing Crown Fire Hazard

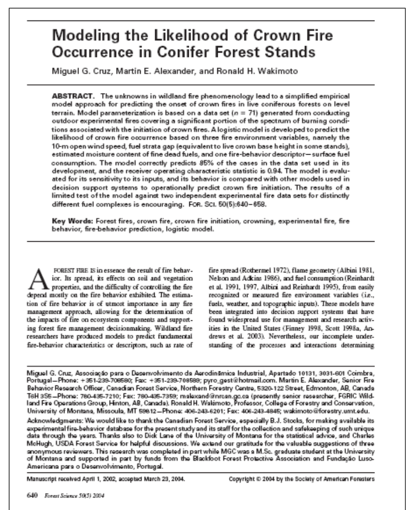
Re-analysis of the experimental data used in the development of the Canadian FBP System undertaken by M.G. Cruz (Univ. MT/ADAI Portugal), M.E. Alexander & Ron Wakimoto (Univ. MT) in 1999-2005 has lead to the development of more generic-based models for predicting crown fire initiation and spread in conifer forest stands

Definition of a Fire Behavior Model Evaluation Protocol: A Case Study Application to Crown Fire Behavior Models

Miguel G. Cruz[1], Martin E. Alexander[2], and Ronald H. Wakimoto[3]

Assessing the probability of crown fire initiation based on fire danger indices

by Miguel G. Cruz[1], Martin E. Alexander[2] and Ronald H. Wakimoto[3]



Modeling the Likelihood of Crown Fire Occurrence in Conifer Forest Stands

Miguel G. Cruz, Martin E. Alexander, and Ronald H. Wakimoto

Development and testing of models for predicting crown fire rate of spread in conifer forest stands

Miguel G. Cruz, Martin E. Alexander, and Ronald H. Wakimoto

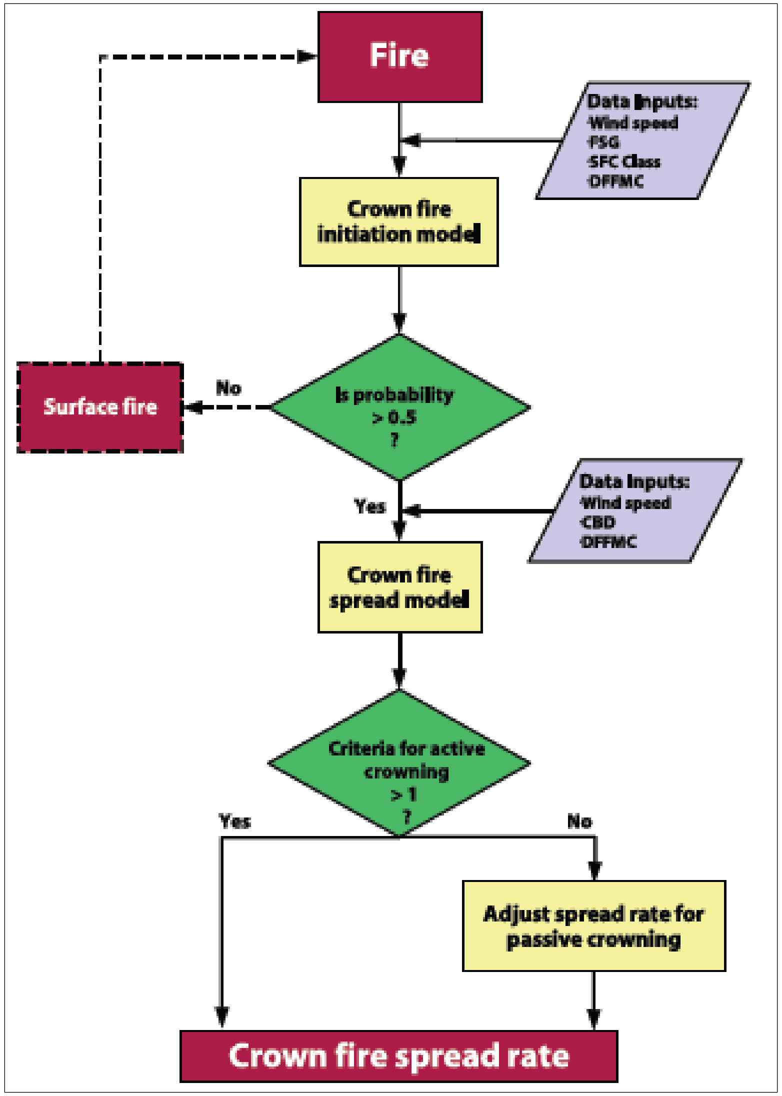


Diagram of information flow for predicting crown fire initiation* and spread potential based on the models developed by Cruz, Alexander and Wakimoto (2004, 2005).

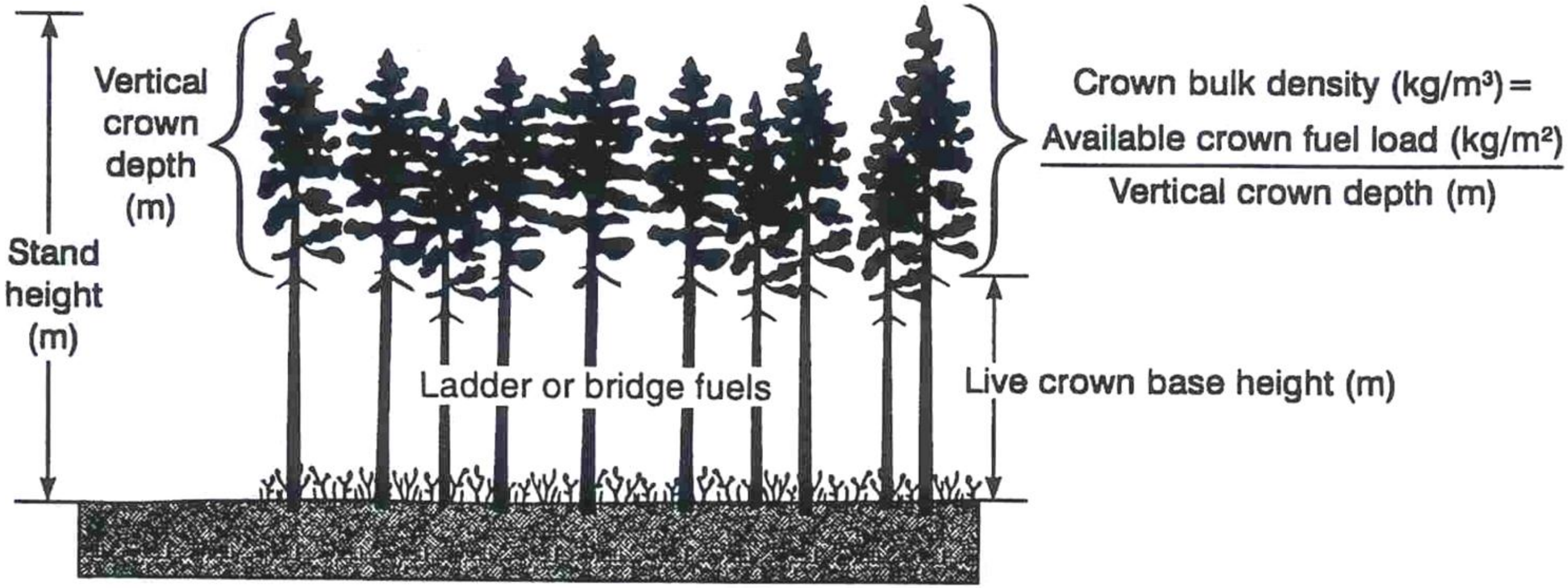
***Alternatively, crown fire initiation can be predicting using crown base height, 10-m open wind speed, and FWI System components (Cruz, Alexander and Wakimoto 2003)**

Model Inputs

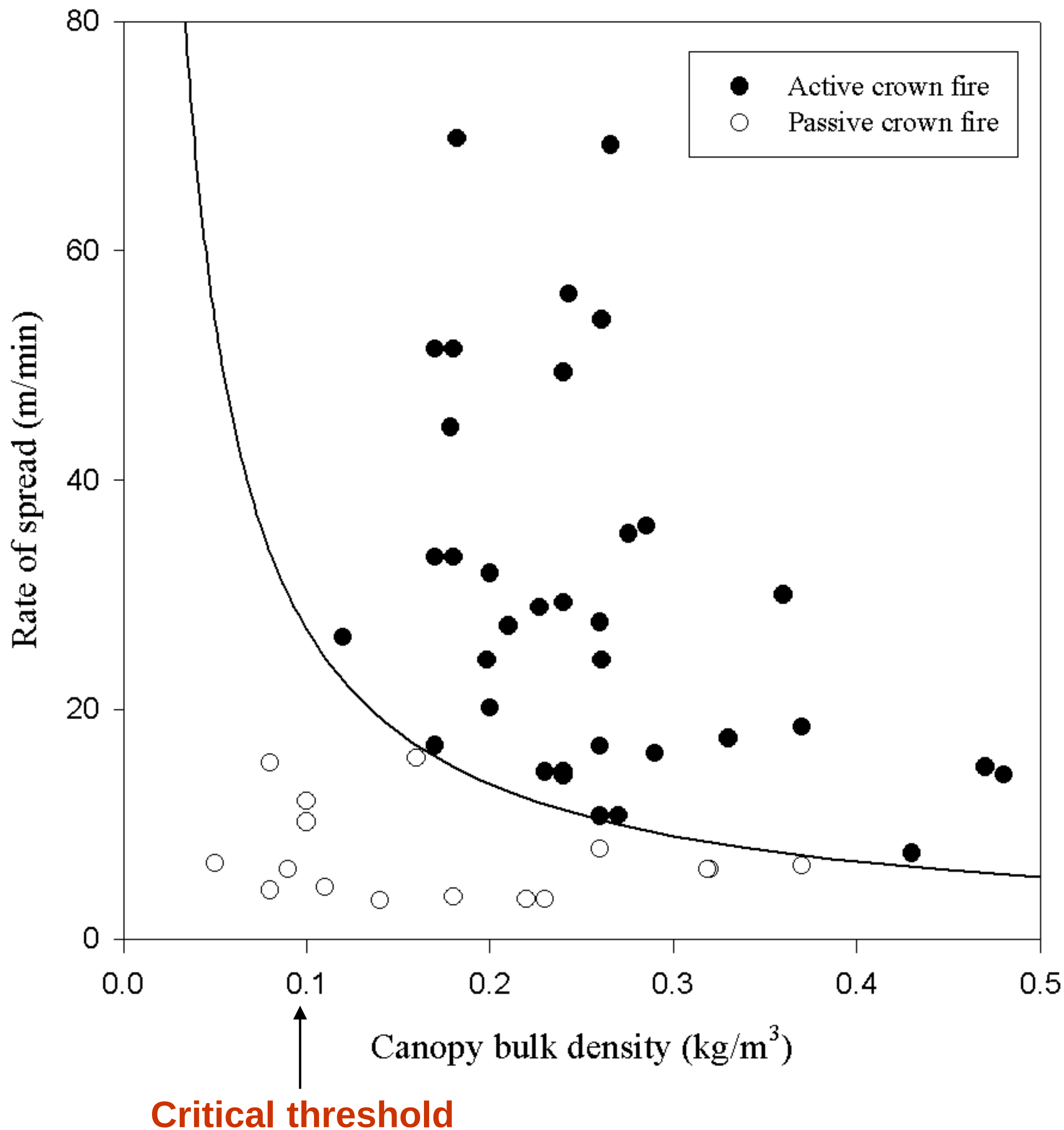
- **Estimated Fine Fuel Moisture (determined from air temperature, relative humidity, time of year & day, and degree of shading)**
- **Surface Fuel Consumption (<1, 1-2 or > 2 kg/m^2)***
- **Fuel Strata Gap or Canopy Base Height***
- **10-m Open Wind Speed**
- **Canopy or Crown Bulk Density***

***These three characteristics of a forest stand or fuel complex are subject to manipulation by silvicultural and other vegetation management techniques**

Canopy or Crown Bulk Density Concept



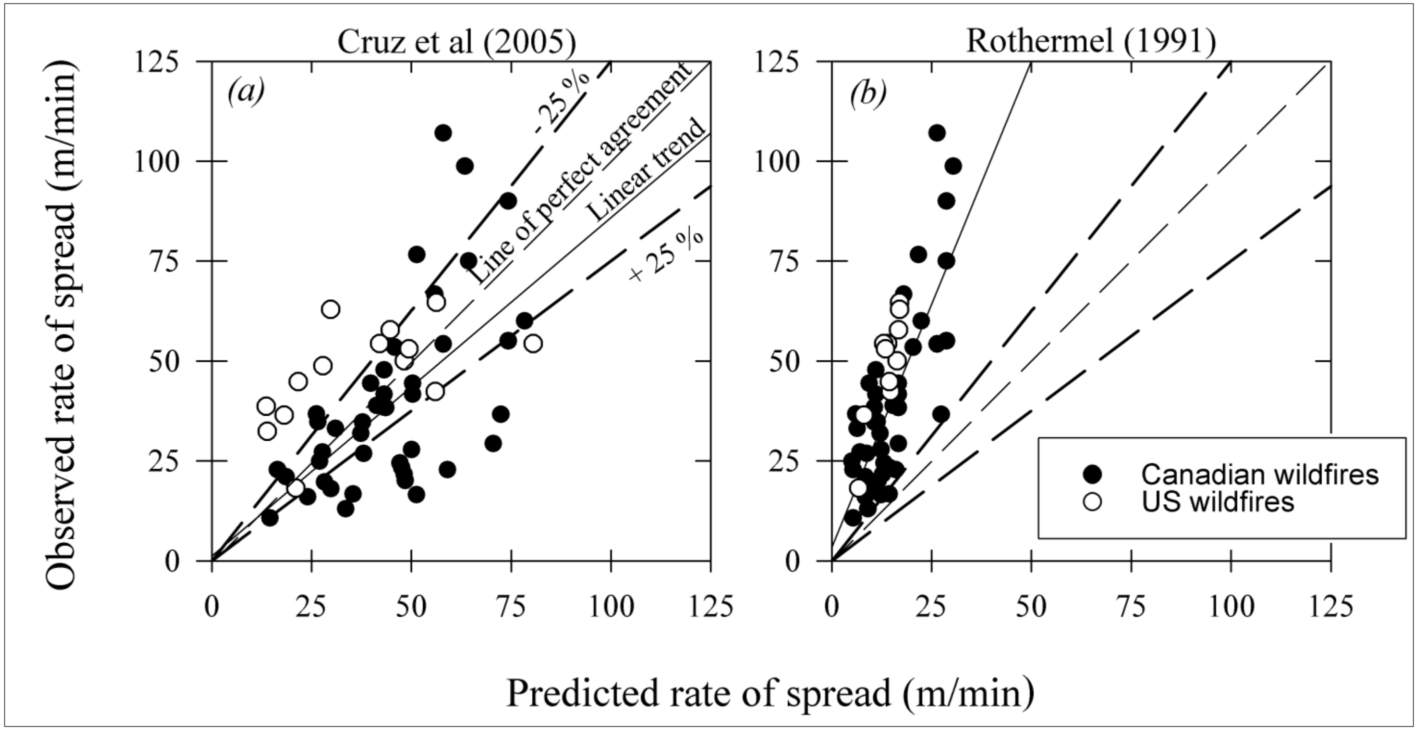
Available crown fuel load determined from stand data (i.e., number of stems per hectare by DBH size class) and foliage/twig vs. DBH relationships

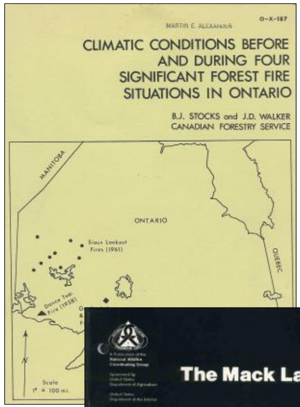


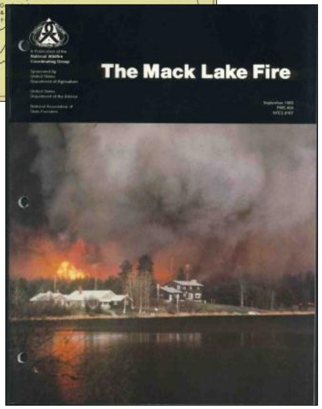
Van Wagner's (1977) critical minimum spread rate criterion for active or continuous crowning as related to canopy bulk density (curve) in relation to experimental crown fire data

Model Evaluation

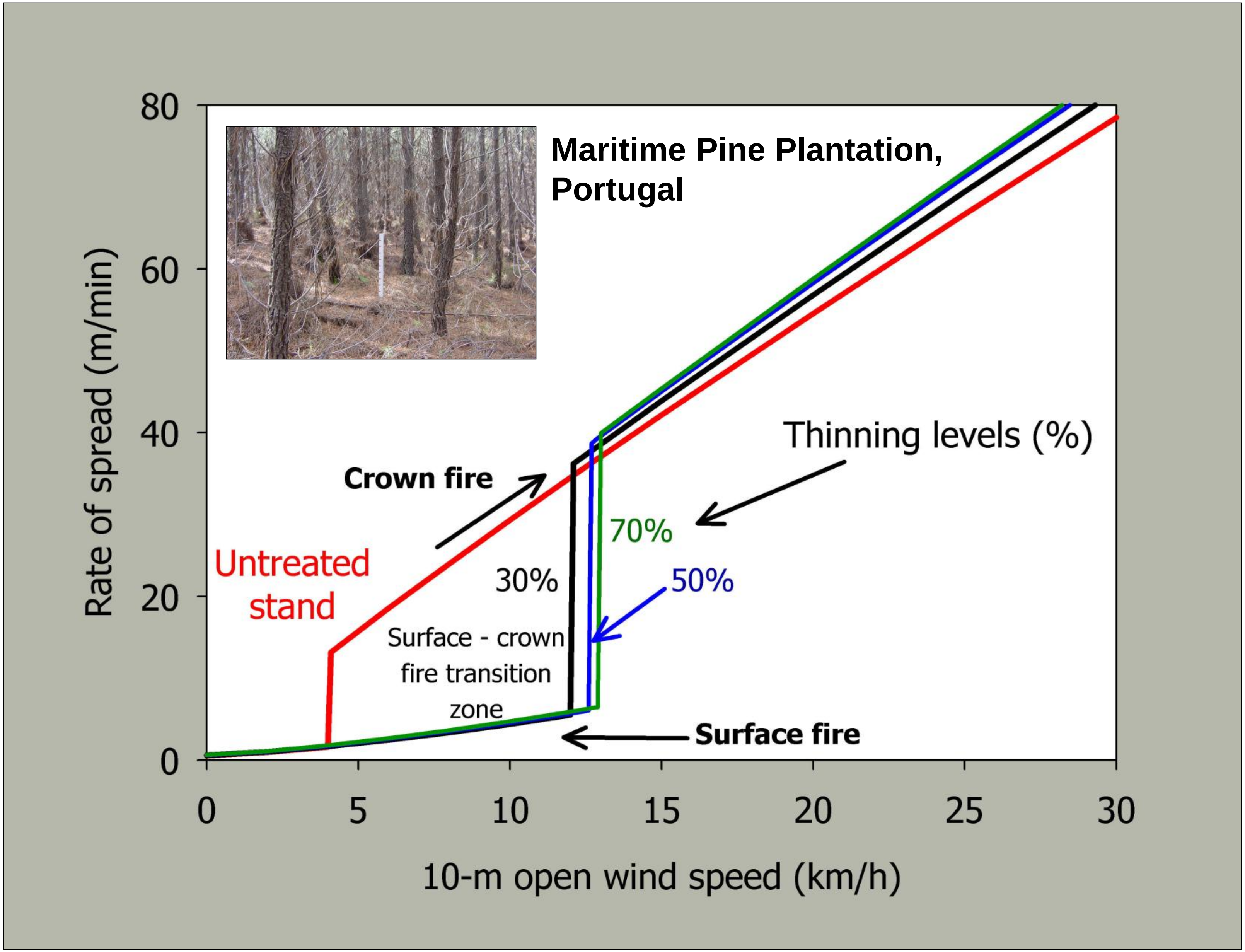
The Cruz, Alexander and Wakimoto (2003, 2004, and 2005) model outputs have been compared to two independent experimental datasets (ICFME & Porter Lake) as well as 57 wildfire observations (43 Canadian & 14 U.S.) obtained from case studies. The results have been quite favourable.







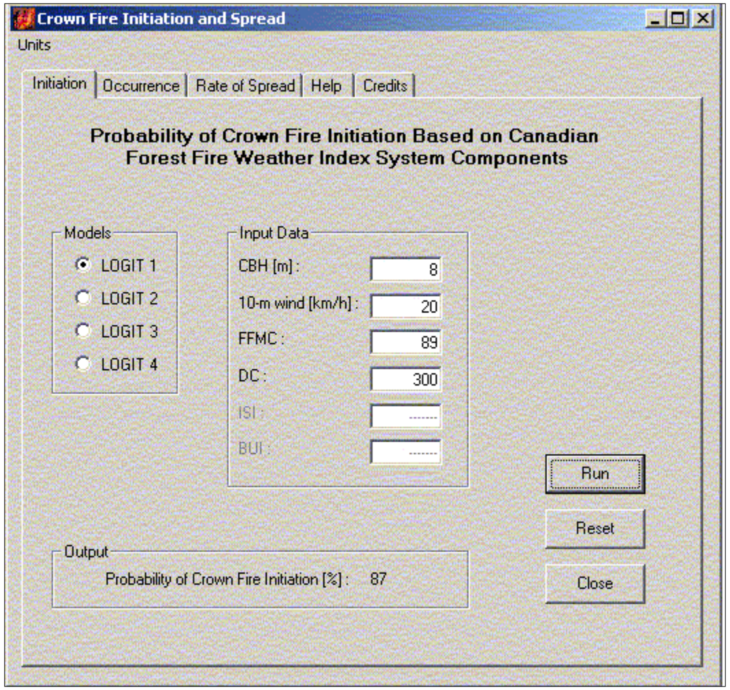
Simulation Using the Models Contained in CFIS

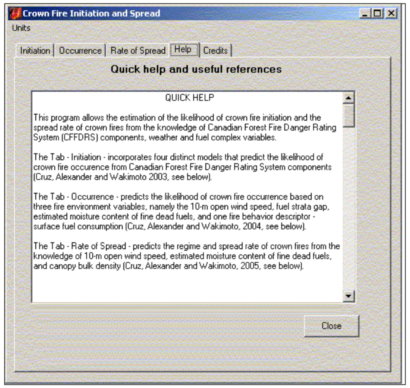


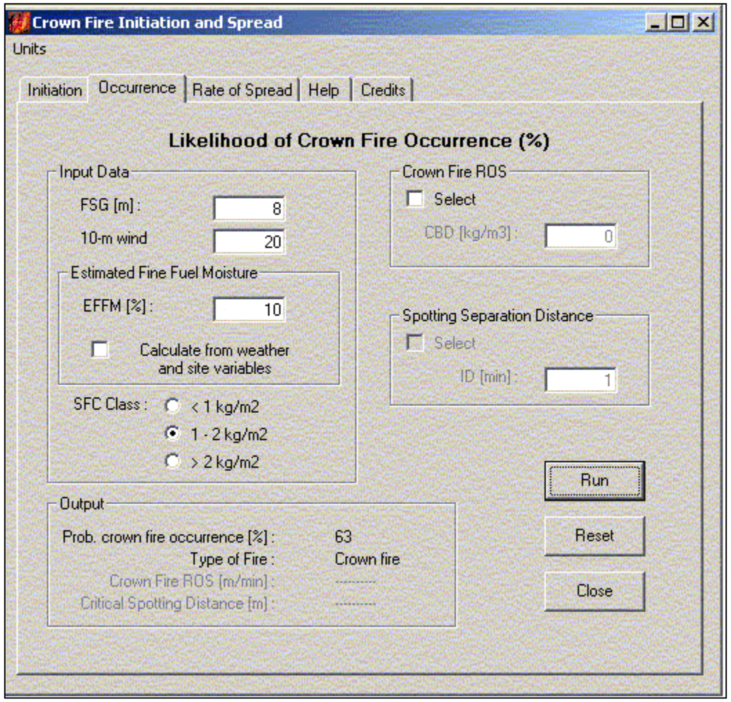
Cruz, Alexander and Wakimoto (2003, 2004, 2005) crown fire behavior models have now been incorporated into a software package

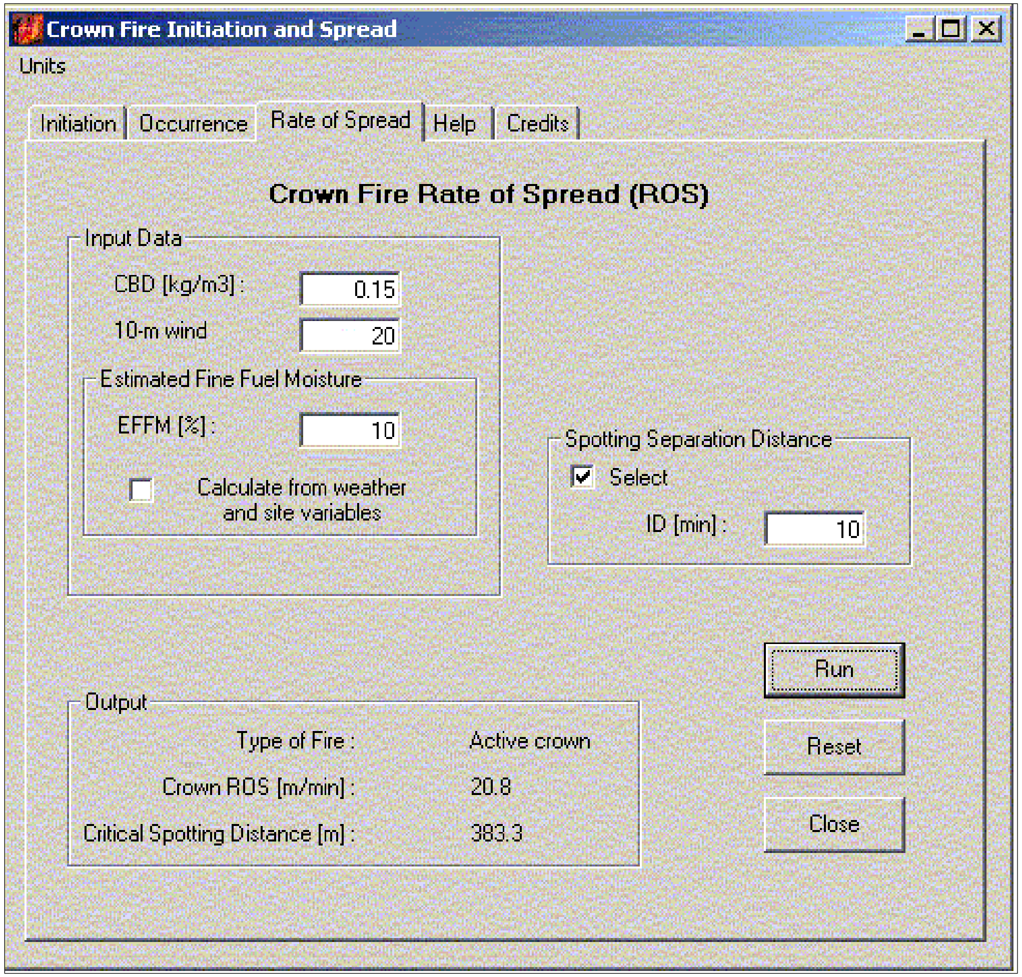
http://www2.dem.uc.pt/antonio.gameiro/ficheiros/CFIS.exe

Screen captures from CFIS

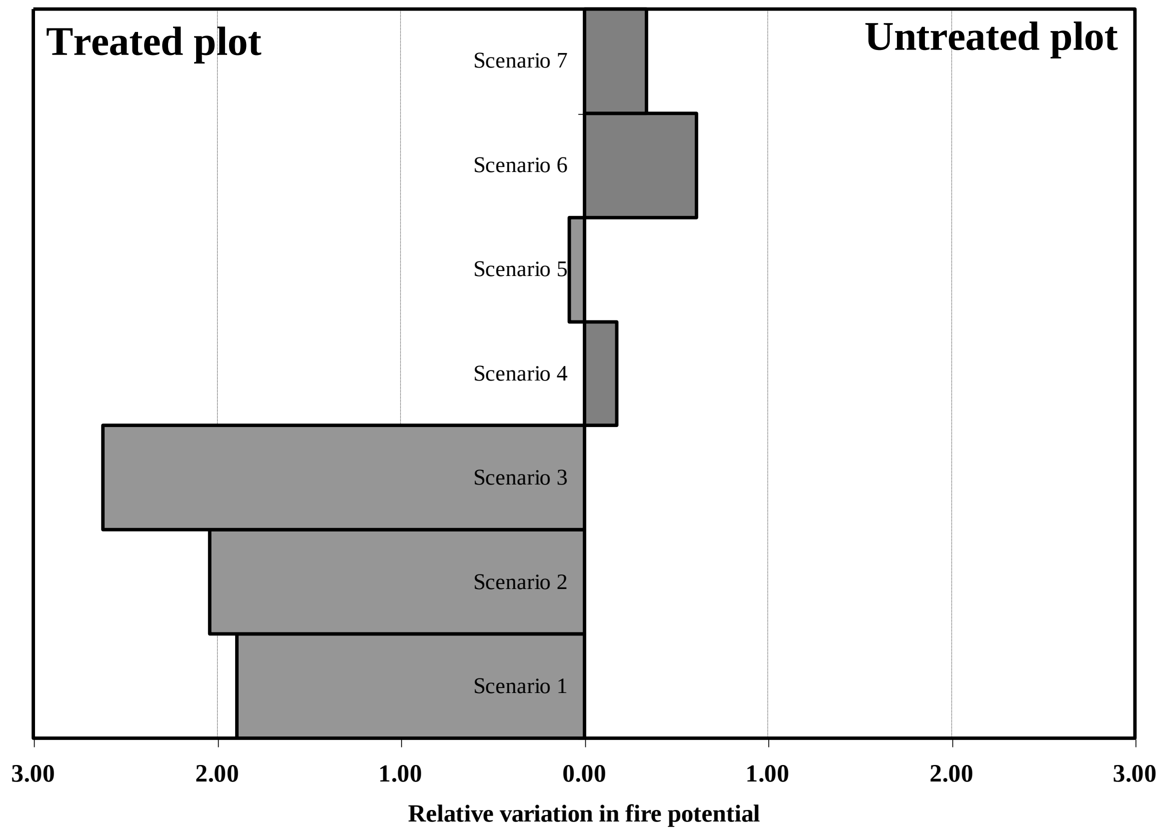








Relative Increases in Fire Intensity and Crowning Potential due to fuel manipulation in a Lodgepole Pine Stand* near Whitecourt, AB (as described by Dam 2000) based on various fire behavior models



*Dam, J. 2000. Effects of thinning in fire behavior: a case study in lodgepole pine in Canada. M.Sc. Thesis, Wageningen University, Holland. 60 p.

III. Conclusions & Some Suggestions for the Future

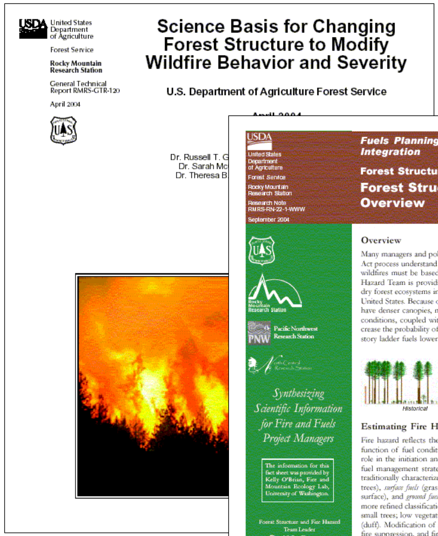
- Fire behavior is a multi-faceted subject area
- While acknowledging that the processes involved are complex with numerous controlling factors, qualitatively we know a great deal about fire behavior
- Fire behavior research and associated model development has matured greatly in recent years
- Rudimentary modelling of fire behavior potential in relation to post-harvest stand development is now possible; such efforts will no doubt identify critical knowledge gaps and research needs

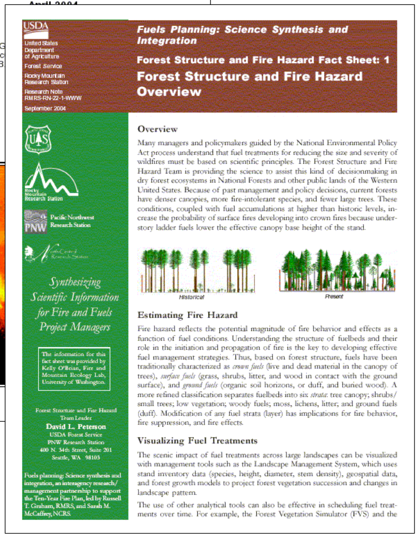
continued …

- **We know nothing specific about fuel and fire behavior characteristics in young, post-harvest stands in western Canada**

- **Existing knowledge should be summarized and made available to managers & other researchers in order to continue the process of communication across disciplines**

Examples





- **Consider extension of the *Forest Vegetation Simulator* to post-harvest stand development as a means of integrating and "housing" our collective knowledge, not just for fire considerations**

Fire behaviour as a factor in forest and rural fire suppression

Martin E. Alexander

Forest Research Bulletin No. 197
Forest and Rural Fire Scientific and Technical Series
Report No. 5

NEW ZEALAND FIRE SERVICE COMMISSION

forest research

NATIONAL RURAL FIRE AUTHORITY

... *further major advances in combating wildfire are unlikely to be achieved simply by continued application of the traditional methods. What is required is a more fundamental approach which can be applied at the design stage … Such an approach requires a detailed understanding of fire behaviour* **...**

Drysdale (1985)
Introduction to Fire Dynamics

Acknowledgments

Wildland Fire Operations
Research Group

Miguel Cruz
CSIRO Australia

Ron Wakimoto
University of Montana

Thank you for your attention! ☺

See Supplementary Handout. Questions?