VI Short Course on Fire Behaviour

Held at the VI International Conference on Forest Fire Research in Coimbra, Portugal

tǊƻYƻűŜŘ ōȅ !5!Lκ/9LC

13/14 November 2010

Contents

VI Short Course on

Fire Behaviour

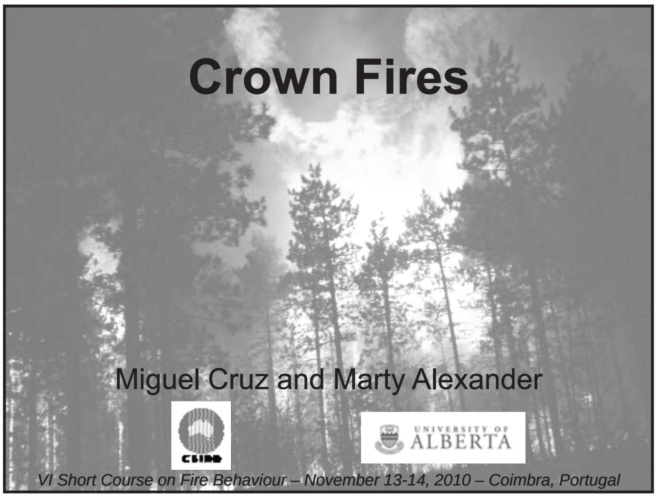
Lesson	3
Title	Crown Fires
Lecturer	Miguel Cruz and Martin Alexander

13/14 November 2010
Coimbra, Portugal

Promoted by

Associação para o Desenvolvimento da Aerodinâmica Industrial

Centro de Estudos sobre Incêndios Florestais



Outline of Presentation

I. Introduction to Crown Fires

II. Understanding of Crown Fire Behavior From Experimental Fire and Wildfire Observations

III. Crown Fire Initiation

IV. Crown Fire Propagation and Rate of Spread

V. The Use of Models for Assessing Fuel Treatment Effectiveness in Reducing Crown Fire Potential

V. Future Outlook on the Understanding and Prediction of Crown Fire Behavior

What is a "crown fire"?

A "crown fire" is defined as:

A fire that advances through the crown fuel layer, usually in conjunction with the surface fire. Crowning can be classified according to the degree of dependence on the surface fire phase.

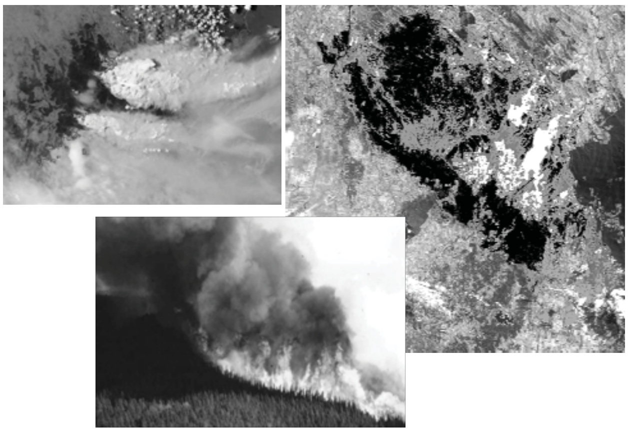
What is "crowning"?

"Crowning" is defined as:

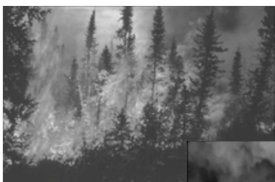
A fire ascending into the crowns of trees and spreading from crown to crown.

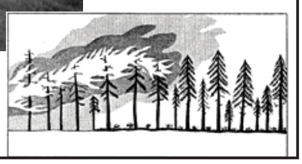
from Merrill and Alexander (1987) – Glossary of Forest Fire Management Terms

Why are crown fires significant?



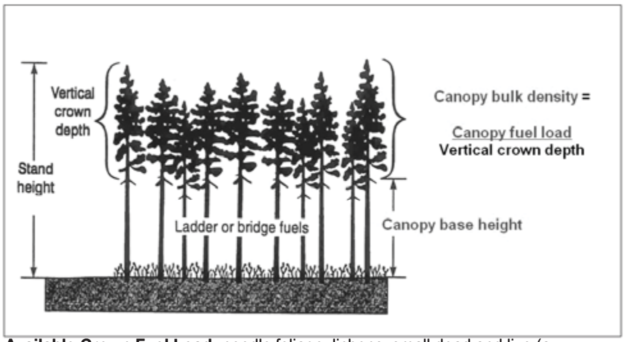
What types of crown fires are there?





See Van Wagner (1977) Conditions for the start and spread of crown fire. *CJFR*

Canopy Fuel Stratum and Stand Characteristics



Available Crown Fuel Load: needle foliage, lichens, small dead and live (a proportion) twigs < 1 cm in diameter
Ladder or bridge fuels: bark flakes, lichens, needle drape, boles branches (live & dead), understory conifers, tall shrubs

Type of Crown Fire: Passive or Dependent

Passive Crown Fires can occur under two broad situations:

- **Canopy base height and canopy bulk density are considered optimum but fuel moisture and wind conditions are not quite severe enough to induce full-fledged crowning**

- **Canopy base height and canopy bulk density are, respectively, above and below the thresholds generally considered necessary for crowning so that even under severe burning conditions full-fledged crowning is not possible, although vigorous, high-intensity fire behavior can occur.**

Type of Crown Fire: Active, Running or Continuous

Active Crown Fires are most likely to occur in forests that have:

- **Ground and surface fuels that permit development of a substantial surface fire**
- **A moderately high canopy or crown base height**
- **A fairly continuous crown layer of moderate to high bulk density and low to normal foliar moisture content**

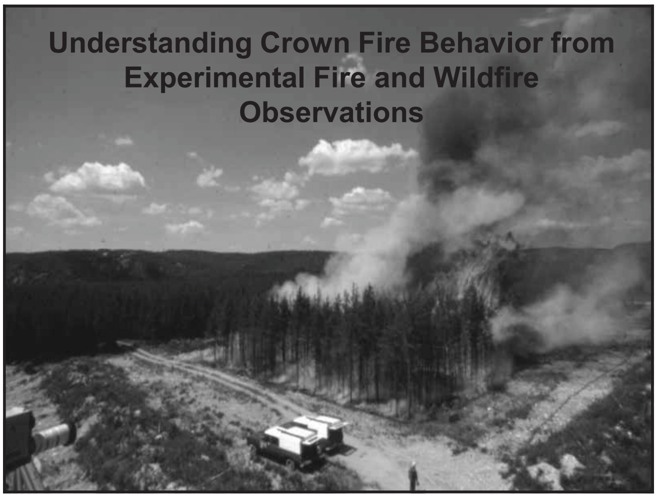
Type of Crown Fire: Independent

"The crown phase will ... No longer depend in any way on the surface phase and can run ahead on its own."
– Van Wagner (1977)

Adapted from Brown and Davis (1973)

"***In other words, the spread of crown fire independent of any surface fire is essentially ruled out as a stable phenomenon on level terrain. …***" – Van Wagner (1993)

Understanding Crown Fire Behavior from Experimental Fire and Wildfire Observations



Observing and measuring crown fire activity:

- **Key for our understanding of fire dynamics;**
- **Provides benchmark data to model development and evaluation;**
- **Reality missing in large number of simulation studies**

Case study A:
- **pine forest;**
- **Summer conditions;**
- **Fine dead fuel moisture: 4%**
- **10-m wind speed: 45 km/h**
- **ROS: 5 m/min (surface fire)**

Case study B:
- **pine forest (CBH 6.4m);**
- **Summer conditions (97th per);**
- **Fine dead fuel moisture: 3%**
- **10-m wind speed: 36 km/h**
- **Flame height: 1.4 m !!**

Red Pine Plantation, Petawawa, Ontario

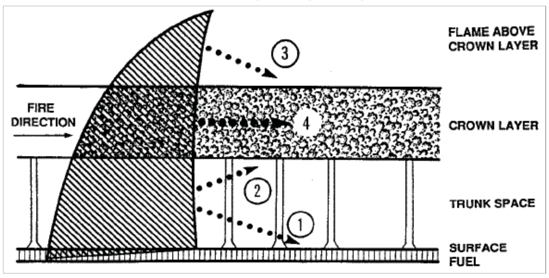
Observed fire behaviour in red pine plantations (Van Wagner 1968)


FIRE BEHAVIOUR MECHANISMS
IN A RED PINE PLANTATION:
FIELD AND LABORATORY EVIDENCE

FORESTRY BRANCH
DEPARTMENTAL PUBLICATION No. 1229

Fire	Dead fuel MC (%)	In-stand wind speed (km/h)	Foliar MC (%)	CBH (m)	ROS (m/min)	Fire type
R3	9	5.0	92	7	6.1	Surface
C6	12	6.1	95	7	27.4	Crown

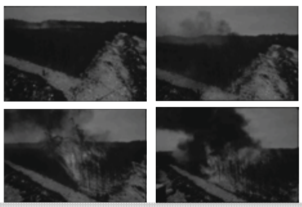
Van Wagner (1968)



Schematic diagram illustrating the four components of forward radiated heat transfer in an active crown fire: trunk space radiates to (1) surface fuels and (2) crown fuels; flame above the canopy radiates to (3) crown fuels; and flame within the crown fuel layer radiates (4) throughout the layer.

Lowland Black Spruce Stand, AB

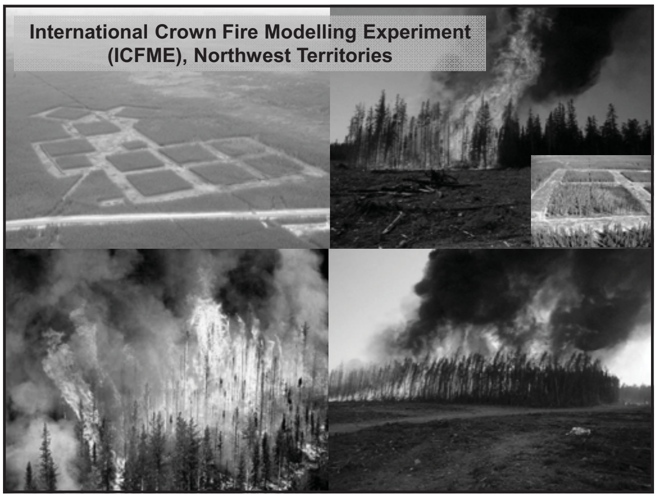
Spruce-budworm Killed Balsam Fir Stand, ON

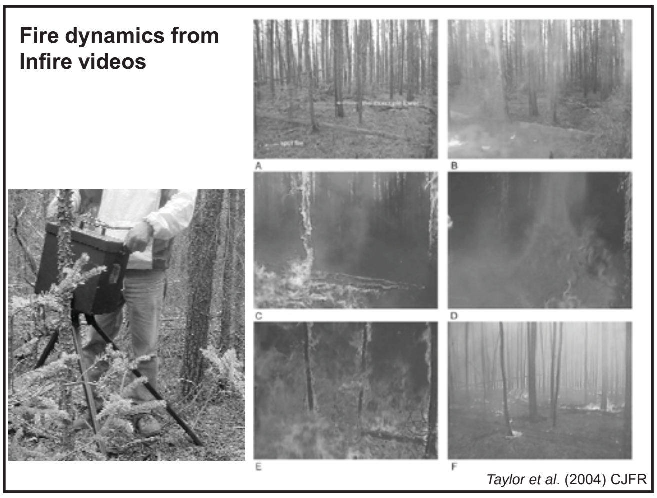


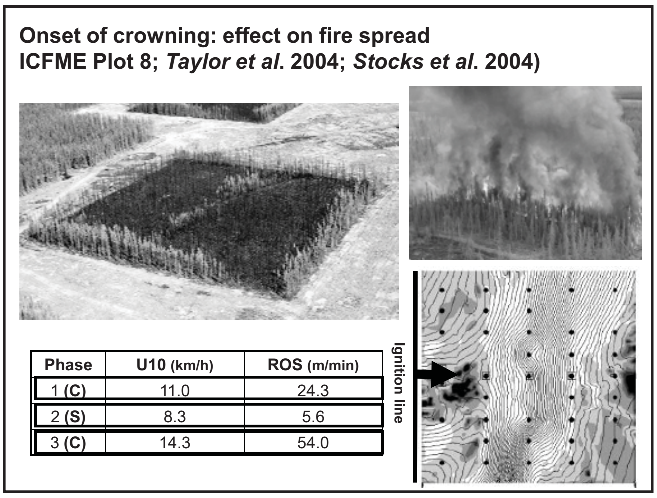
Immature Jack Pine Stand, Northeastern, ON

Plot 9 - June 19, 1999

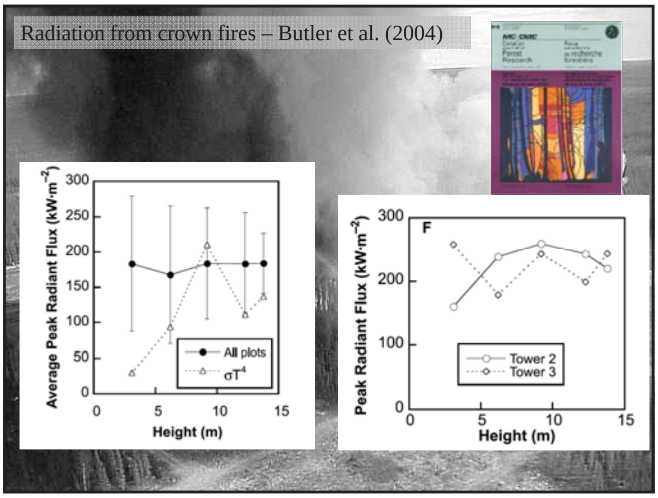
Spruce-Lichen Woodland Stand, NWT

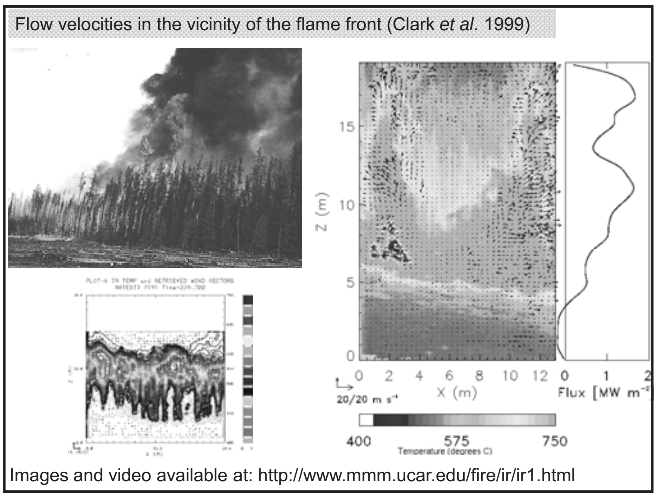


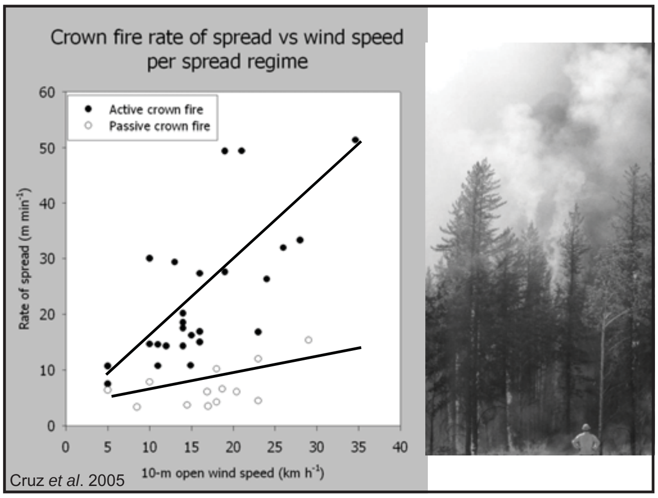




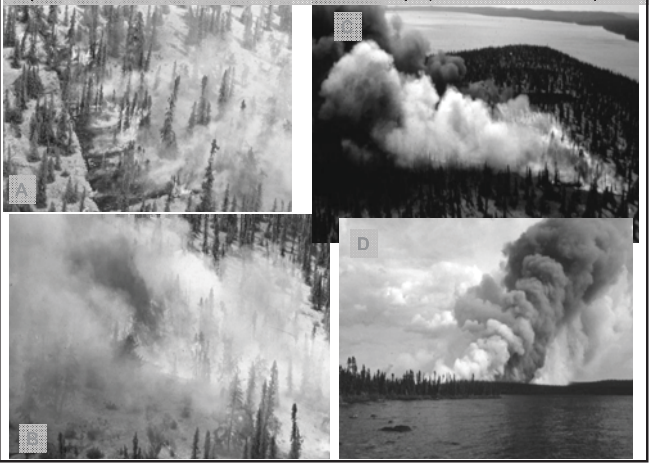
Phase	U10 (km/h)	ROS (m/min)
1 (C)	11.0	24.3
2 (S)	8.3	5.6
3 (C)	14.3	54.0

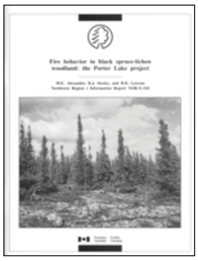


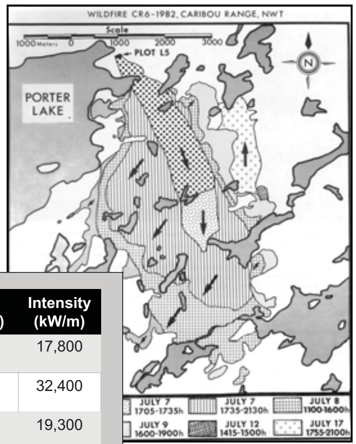




Experimental vs wildfire data: the Porter Lake escape (Alexander *et al.* 1991)





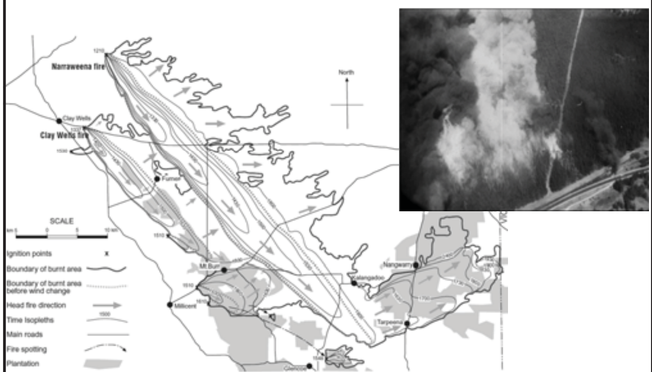


Fire	10-m wind speed (km/h)	ROS (m/min)	Intensity (kW/m)
L5	28	33	17,800
L5A	35	51	32,400
CR-6	26	32	19,300

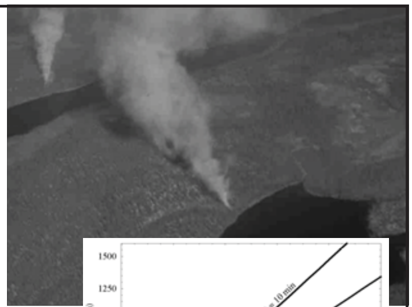
Mount Muirhead Fire, South Australia - 16 February 1983

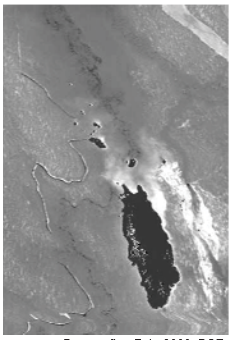
Temp: 40-44C; RH: 10-12%; with winds >80 km/h.

Radiata Pine Plantation Fuel Types; Head Fire ROS ≈200 m/min (12 km/h)

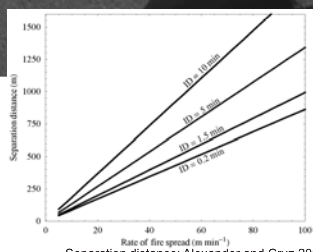


Spotting from active crown fires



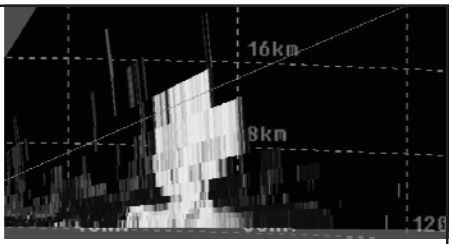


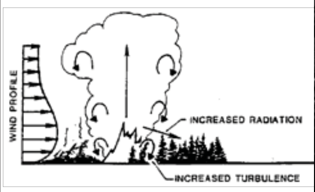
Bunyup fire, Feb. 2009; DSE

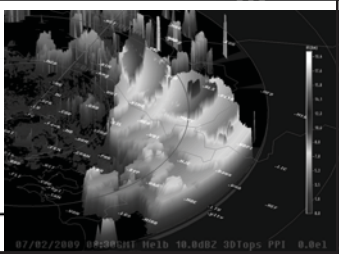


Separation distance; Alexander and Cruz 2006

Plume behaviour



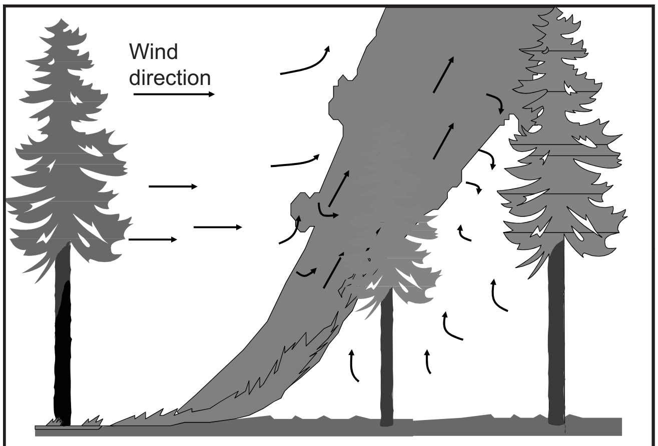




Basic Features of a Crown Fire

- Fierce radiation due to flame depth / heights (up to 50+ m).
- Sustained runs possible (e.g., 64 km in 10 hrs)
- Wide range in rate of spread (0.6 - 12 km/h)
- Very wide range in fire intensities (2500 – 100,000 kW/m)
- Flame front residence time in tree crowns at least half that of ground surface
- Contributes to medium and long-range spotting and in turn breaching of major barriers to fire spread
- High amounts of convective energy produce massive convection columns

Crown Fire Initiation



Cross section of a wind-driven surface fire

Van Wagner's (1977) Theory on Initiation of Crowning: Starting with two basic equations

Temperature rise (ΔT) at height z over a line heat source, I (after Thomas 1963)

$$\Delta T \propto I^{2/3}/z$$

Heat of ignition (h – kJ/kg) in relation to foliar moisture content (m - %) (from Van Wagner 1968)

$$h = 460 + 25.9 \cdot M$$

Replacing $\Delta T/h_o$ with an empirical quantity C yields:

$$I_o = (C \cdot z \cdot h)^{3/2}$$

where I_o is the critical surface intensity (kW/m) needed to initiate crowning and C is a criterion for initial crown combustion

Van Wagner's (1977) Criterion for Initial Crown Combustion

"The quantity C is best regarded as an empirical constant of complex dimensions whose value is to be found from field observations." – Van Wagner (1977)

A value of 0.010 was derived for C from an experimental fire in a red pine plantation (z = 6 m and m = 100%) exhibiting an intensity of ~ 2500 kW/m just prior to crowning as follows:

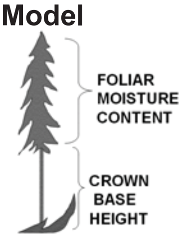
$$C = I_o/(z \cdot h)^{3/2}$$

$$C = 2500/(6 \cdot (460 + 26 \cdot (100)))^{3/2}$$

$$C = 0.010$$

Van Wagner's (1977) Crown Fire Initiation Model

Vertical fire spread into the overstory canopy will occur when the surface fire intensity (I_s) attains the critical value I_o as determined by z and m.



$I_s < I_o$:
Surface Fire

$I_s \sim I_o$: Surface Fire - Crown Fire Transition

$I_s > I_o$:
Crown Fire

Van Wagner's (1977) Crown Fire Initiation Model: Strengths and Weaknesses

Simplicity:

Only two crown fuel properties (***z*** and ***m***) and an estimate of potential surface fire intensity required as inputs

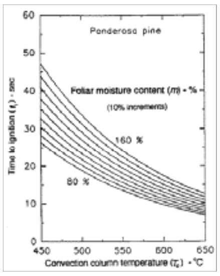
Limitations:

- Truth of the matter is, that separate ***C*** values are required for distinctly different fuel complexes – furthermore, currently used value (0.010) is essentially based on a single observation.
- Doesn't allow for variable duration of heating (presently the flame front residence time is a constant 50 sec) – thus, quite possible for two surface fires to have the same intensity but significantly different residence times (e.g., grass vs. conifer needle forest floor).
- Surface burning conditions (i.e., temp, RH, plus in-stand wind and thus fire plume angle) a constant rather than a variable.

Xanthopoulos (1990) Crown Fire Initiation Model

Comprised principally of two laboratory experiments:

• Time to ignition – convection temperature – moisture relationships for foliage of 3 conifers (ponderosa pine, Douglas-fir, and lodgepole pine); see Xanthopolous and Wakimoto (1993)



• Time-temperature profiles at different heights based on flame and convection column temperature measurements in wind tunnel fires (questions of scale effects, realism of the wind tunnel environment and real-world evaluation)

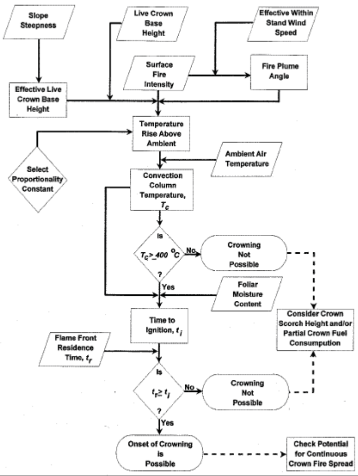
Alexander (1998) Crown Fire Initiation Model

Based on a combination of physical insights and mathematical modelling coupled with relevant field and laboratory experiments -- exemplifies the art & science of fire behavior modelling. Goal was to develop a simple algorithm to predict the onset of crowning in exotic pine plantations of Australasia.

The temperature (°C) at the live crown base height z (m) is calculated from the following equation (after Yih 1951, Thomas 1963, Van Wagner 1973, 1975):

$$T_c = T_a + \frac{k \cdot I^{2/3} \cdot \sin A_P}{z}$$

where ***k*** is a fuel complex specific proportionality constant (dimensionless), ***I*** is fire intensity (kW/m), A_P is the fire plume angle (°), and ***z*** is the live crown base height (m).

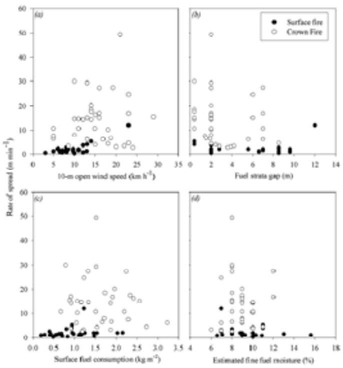


Alexander (1998) Crown Fire Initiation Model

The constant ***k*** = 16 for needle fuelbeds and ***k*** = 9 for thinning slash & dense understory vegetation; developed methodology for using crown scorch heights to derive ***k***.

Model tested favourably against 8 experimental fires and one detailed wildfire case study.

Cruz, Alexander and Wakimoto (2004) Crown Fire Occurrence Probability Model



• Comprehensive review of the literature

• Number of variables examined

• Data available for 34 surface fires & 37 crown fires (principally Canadian but a few fires from Portugal and Australia)

Cruz, Alexander and Wakimoto (2004) Crown Fire Occurrence Probability Model

Modeling the Likelihood of Crown Fire Occurrence in Conifer Forest Stands

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

October 2004 – *Forest Science*

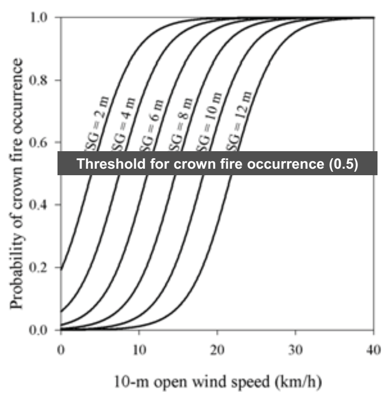
Logistic regression model requires three environmental inputs:

• 10-m open wind speed (U_{10});
• Canopy base height (CBH) or fuel strata gap (***FSG***);
• Estimated fine fuel moisture (***EFFM***); and one fire behavior description:

• Surface fuel consumption (***SFC***) class (<1, 1-2, >2 kg/m²)

Threshold for Crown Fire Occurrence judged to be 50% Probability.

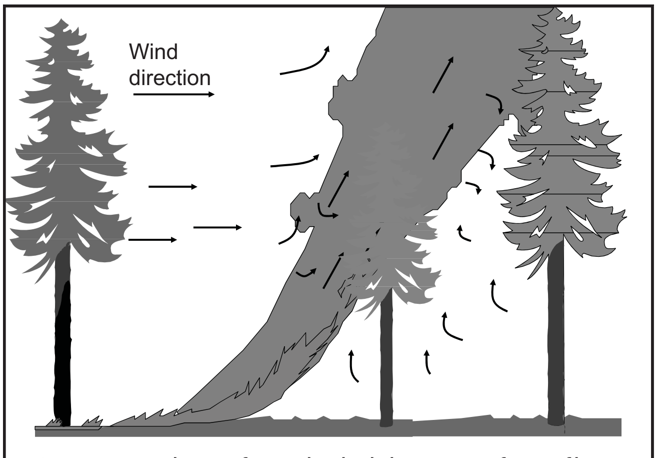
Cruz, Alexander and Wakimoto (2004) Crown Fire Occurrence Probability Model



Effect of 10-m Open Wind Speed (U_{10}) under variable Fuel Strata Gap (*FSG*)

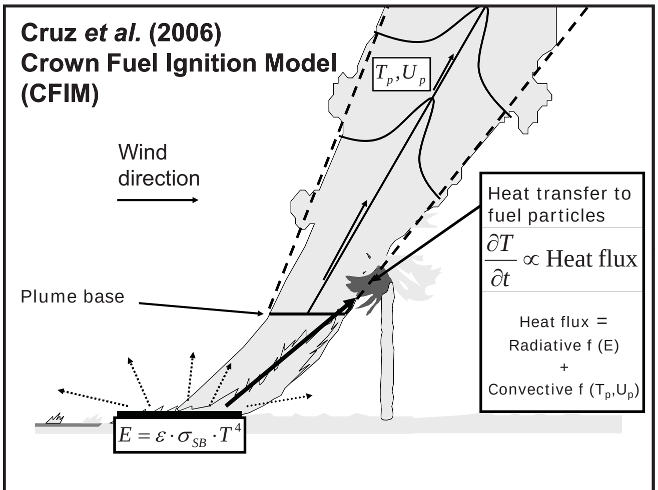
Assume:

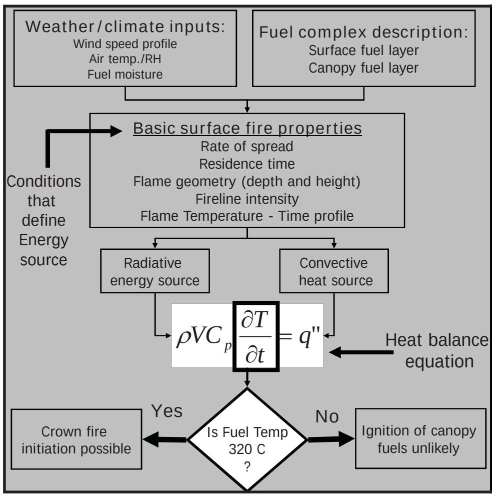
EFFM = 6%
SFC = 1-2 kg/m²



Cross section of a wind-driven surface fire

Cruz *et al.* (2006)
Crown Fuel Ignition Model (CFIM)





Cruz *et al.* (2006) Crown Fuel Ignition Model (CFIM)

Cruz *et al.* (2006) Crown Fuel Ignition Model (CFIM):

Evaluation Protocol

- Sensitivity analysis of input parameters
- Comparison against other models (Van Wagner 1977; Alexander 1998; Cruz, Alexander and Wakimoto 2004)
- Experimental fires (correctly predicted 14 of the 15 fires)

Fire name	H_F (m)	$FSG-H_F$ (m)	D_F (m)	τ_r (s)	b_{pi} (m)	U_{pi} (m s^{-1})	Max. T_f (K)	Crowing activity CFIM (Y/N)
VW67_R3	2.3	4.7	3.4	66	1.7	3.3	547	N
VW67_R4	1.1	5.9	2.3	65	1.1	2.8	392	N
VW67_R5	1.3	5.7	2.9	51	1.4	3.1	415	N
VW67_R1	2.9	4.1	6.2	57	3.1	3.9	>600	Y
BW&B_P1	1.8	0.6	3.8	77	1.9	3.4	>600	Y
BW&B_P2	1.9	0.5	4.3	77	2.2	3.5	>600	Y
BW&B_P3	1.7	0.7	3.3	75	1.6	3.2	>600	Y
McA66	1.9	8.1	6.9	104	3.4	4	490	N
VL&L_A2	1.4	0.4	2.1	55	1	2.8	>600	Y
VL&L_A4	0.9	0.9	0.88	52	0.44	2	492	N
VL&L_C2	0.3	1.5	0.53	53	0.26	1.7	398	N
PF&al_UN	2.1	2.6	5.9	98	2.9	4	>600	Y
PF&al_RX13	1.5	2.5	2.9	92	1.5	3.1	600	Y
PF&al_RX3	0.83	4.6	1.7	39	0.84	2.7	416	N
BS&al_Plot8b	1.6	3	4.5	48	2.2	3.8	>600	Y

Van Wagner's (1977) Criteria for Solid Crown Flame

Based on rearranging a simple heat balance equation (cf. Thomas *et al.* 1964) for fire spread in wildland fuel the following relation was proposed:

$$R_o = S_o/CBD$$

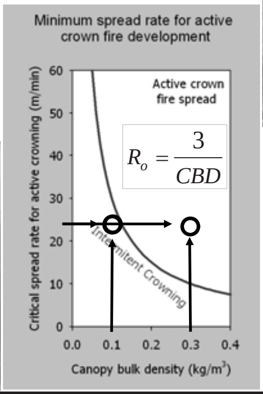
Where R_o is the critical minimum spread (m/min) in order to sustain a continuous flame front within the crown fuel layer, S_o is the critical mass flow rate for solid crown flame (kg/m²-min), and ***CBD*** is the canopy bulk density (kg/m³).

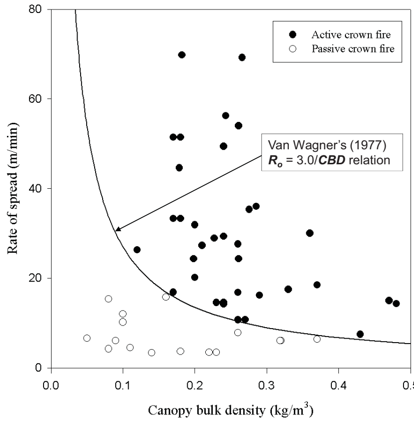
S_o is regarded as an empirical constant to be derived from field observations. Best available estimate (3.0) based on experimental fires in red pine plantations.

Passive regime

Van Wagner's (1977) theory for sustained crowning

Active regime





Experimental crown fires used in the development of the Canadian FBP System plotted.

Points of note:

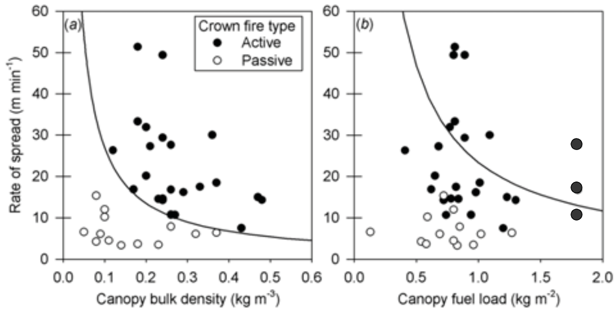
- No passive crown fires with ***CBD*** < 0.05 kg/m³
- No active crown fires with ***CBD*** < 0.11 kg/m³

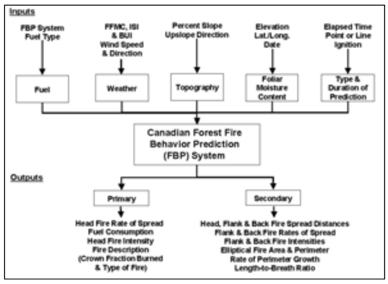
from Cruz, Alexander and Wakimoto (2005)

CSIRO PUBLISHING
www.publish.csiro.au/journals/ijwf International Journal of Wildland Fire 2009,

Flatland in flames: a two-dimensional crown fire propagation model

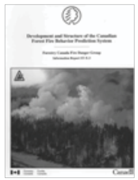
James D. Dickinson[A,D], Andrew P. Robinson[B], Paul E. Gessler[C], Richy J. Harrod[A] and Alistair M. S. Smith[C]

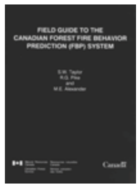




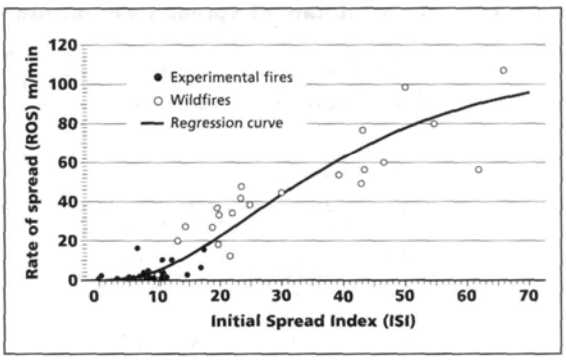
Canadian FBP System

- Interim edition in 1984
- First complete edition in 1992



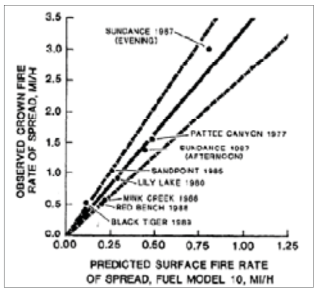


Canadian FBP System:
Surface & Crown Rate of Spread
(Natural Forest Stands)



Mature Jack or Lodgepole Pine (C-3) Fuel Type

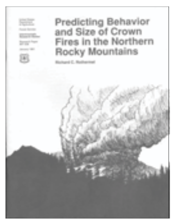
Rothermel (1991) Rate of Spread "Model" for Wind-driven Crown Fires



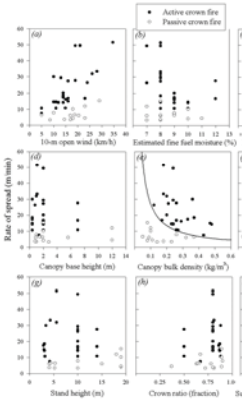
A statistical correlation between the predicted surface fire rate of spread for Fuel Model 10 (wind reduction factor 0.4) and 8 western U.S. wildfire observations

Ave. Crown Fire ROS = 3.34 x Surface Fire ROS

Max. Crown Fire ROS = 1.7 x Ave. Crown Fire ROS



Cruz, Alexander and Wakimoto (2005)
Crown Fire Rate of Spread Models




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

Cruz, Alexander and Wakimoto (2005)

Crown Fire Rate of Spread Models: The Equations

***Active Crown Fires*: *CAC* ≥ 1.0**

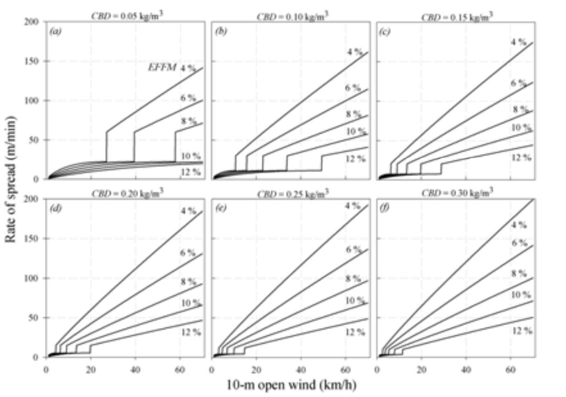
$$CROS_A = 11.02 \cdot (U_{10})^{0.9} \cdot CBD^{0.19} \cdot exp(-0.17 \cdot EFFM)$$

***Passive Crown Fires*: CAC < 1.0**

$$CROS_P = CROS_A \, . \, exp(-CAC)$$

where ***CAC*** is the criterion for active crowning dimensionless), ***CBD*** is the canopy bulk density (kg/m³), U_{10} is the 10-m open wind speed km/h), ***EFFM*** is the estimated fine fuel moisture (%), $CROS_A$ is the active crown fire rate of spread (m/min), and $CROS_P$ is the passive crown fire rate of spread (m/min).

Cruz, Alexander and Wakimoto (2005)
Crown Fire Rate of Spread Models




A radiation-driven model for crown fire spread

B.W. Butler, M.A. Finney, P.L. Andrews, and F.A. Albini

Canadian Journal of Forest Research
July 2004

In the mid to late 90s Dr.Frank Albini was supported by the Canadian Forest Service and USDA Forest Service to develop a new physically-based rate of spread model for crown fires. The testing and calibration of this model was largely the impetus for ICFME.

Dr. Frank Albini
ICFME 1997

Crown fire potential in FCCS (Schaaf *et al*. 2007; CJFR)


A conceptual framework for ranking crown fire potential in wildland fuelbeds

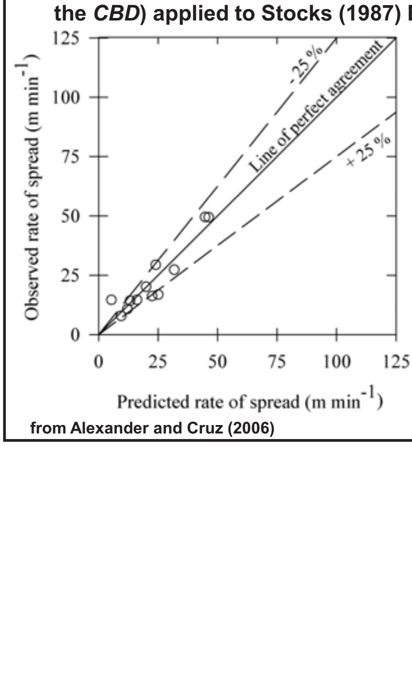
Mark D. Schaaf, David V. Sandberg, Maarten D. Schreuder, and Cynthia L. Riccardi

Reparameterization of Rothermel (1972) and (1991) models with updated linkages;

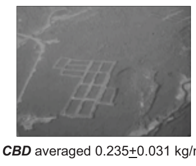
Aimed to describe crown fire potential with Fuel Characteristics Classification System.

Outputs are:
- Torching potential (TP)
- Active crowning potential (AP)
- Crown fire rate of spread

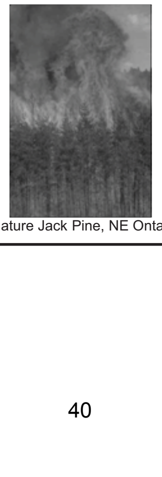
Cruz, Alexander and Wakimoto (2005) Model Form (less the *CBD*) applied to Stocks (1987) Experimental Data



from Alexander and Cruz (2006)

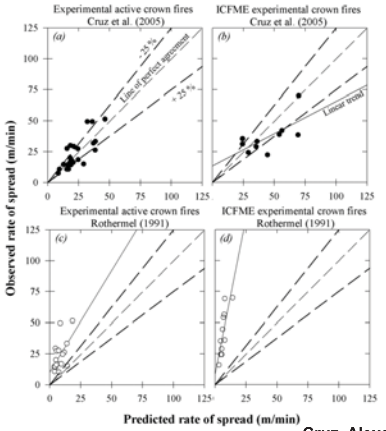


CBD averaged 0.235±0.031 kg/m³



Immature Jack Pine, NE Ontario

Model Evaluation – experimental data

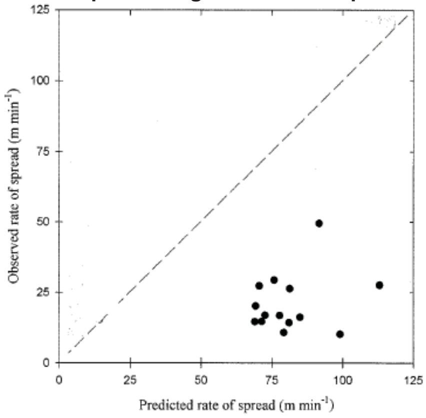


Crown Fire Rate of Spread Models: Evaluation Against Experimental Active Crown Fires

Rothermel (1991) under-predicts by a factor of 2-5 and shows little sensitivity to burning conditions.

Cruz, Alexander and Wakimoto (2005)

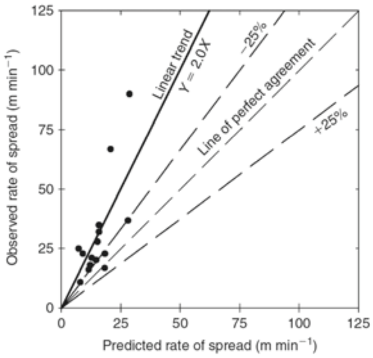
Albini Physically-based Crown Fire Rate of Spread Model: Comparison Against Other Experimental Crown Fires



This included experimental active crown fires in immature jack pine, red pine plantation, and black spruce-lichen woodland.

Model output showed large **over-predictions**.

Schaaf et al. (2007) model: Comparison Against Experimental Crown Fires (black spruce –feather moss fuel complex)

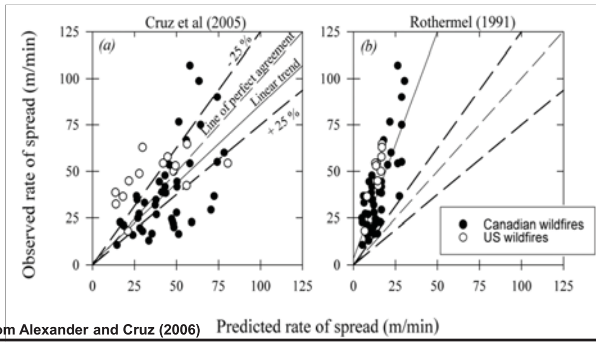


Model output showed **under-prediction trend**.

Need further evaluation against other fuel types.

Model Evaluation – wildfire data

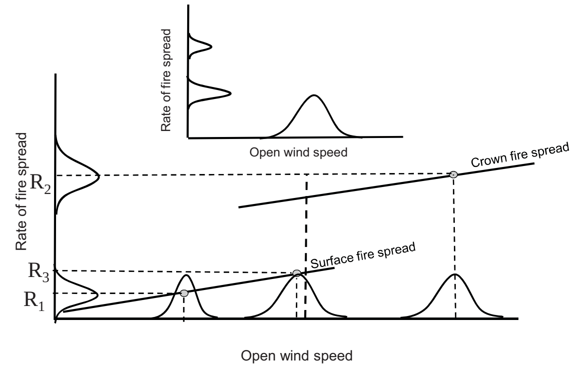
The Cruz, Alexander and Wakimoto (2005) model outputs have been compared to 57 wildfire observations (43 Canadian & 14 U.S.) obtained from case studies. The results have been quite favourable.

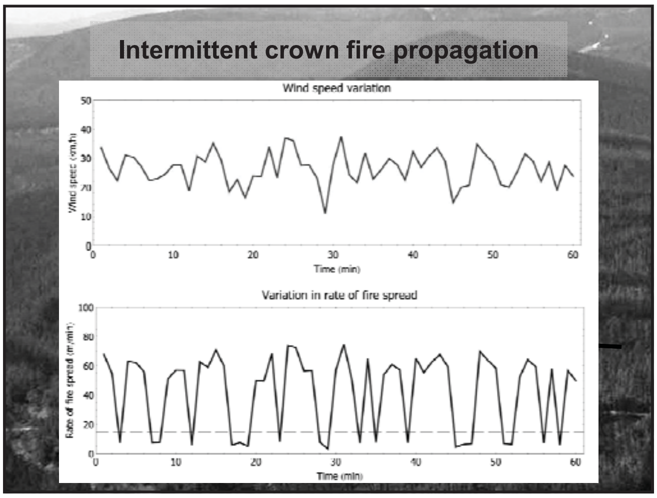


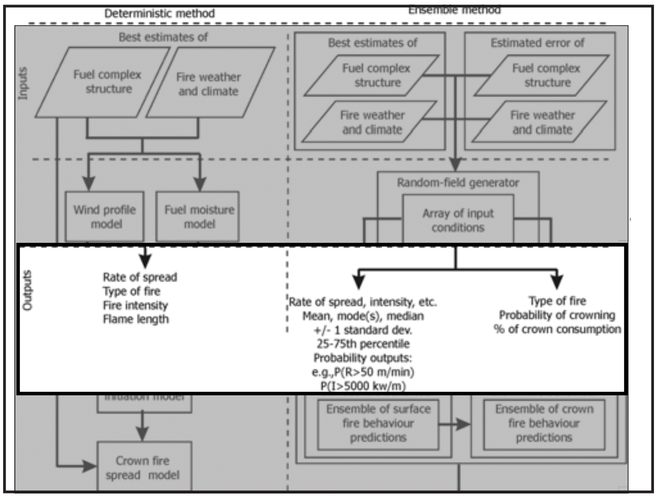
From Alexander and Cruz (2006)

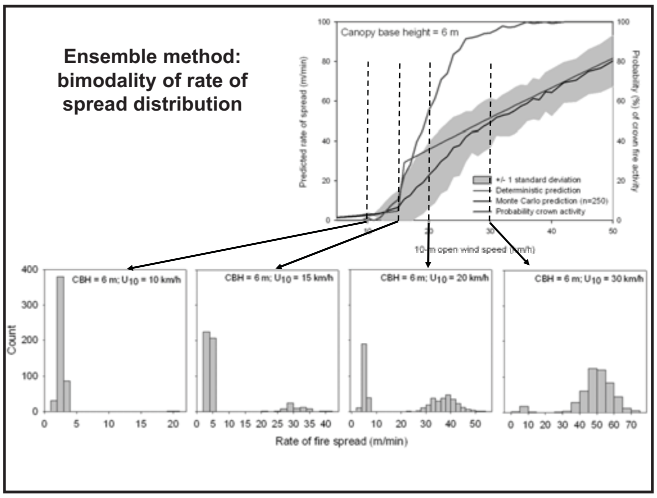
Intermittent crown fire propagation

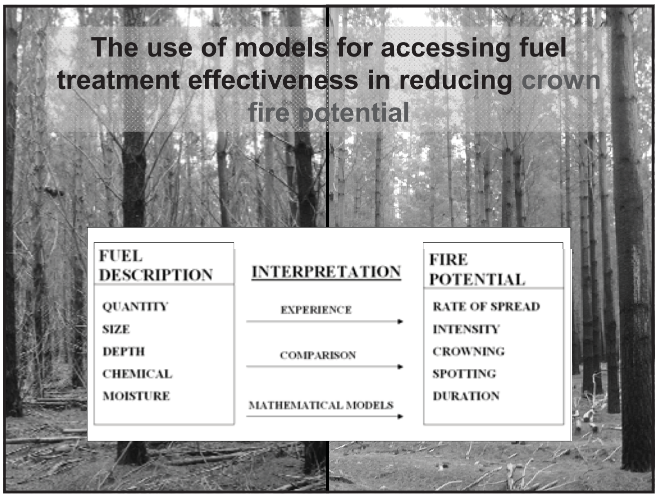
Intermittent crown fire propagation

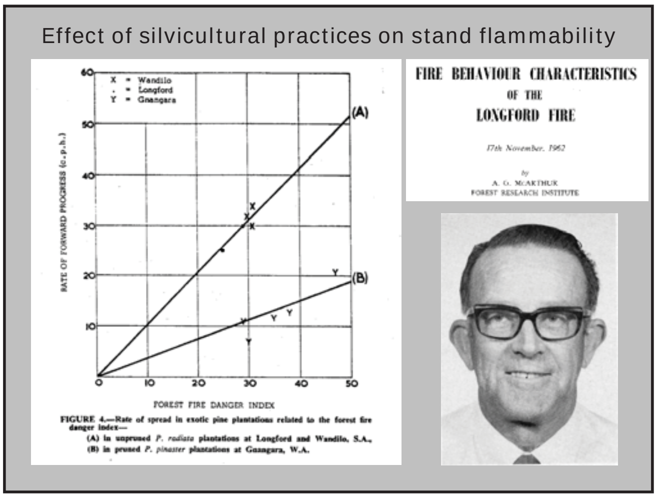


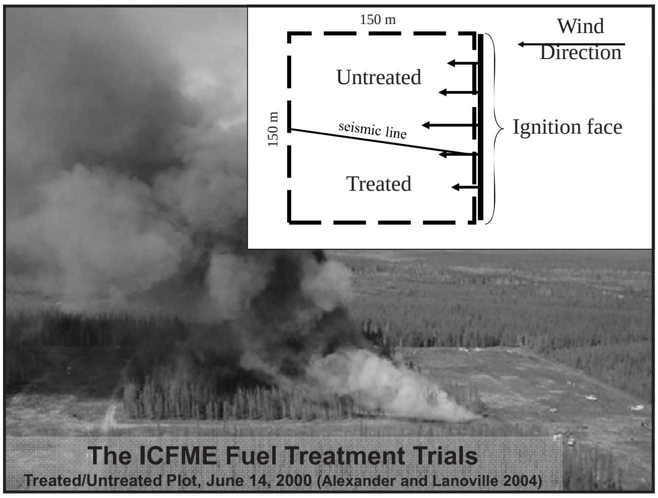

Intermittent crown fire propagation
Wind speed variation
Wind speed (km/h)
Time (min)
Variation in rate of fire spread
Rate of fire spread (m/min)
Time (min)

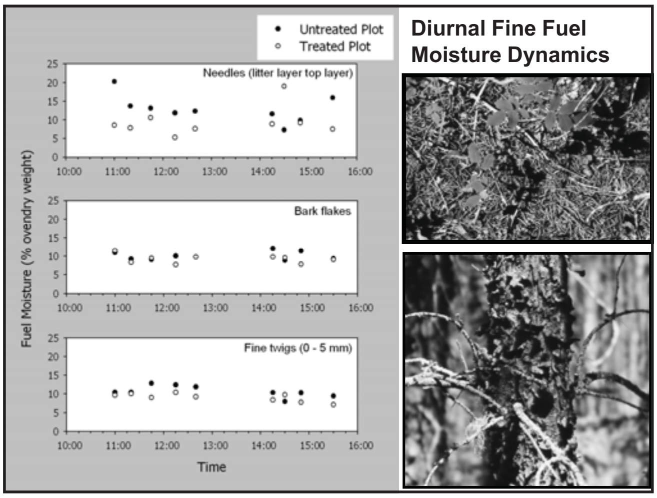

Deterministic method
Ensemble method
Inputs
Best estimates of
Fuel complex structure
Fire weather and climate
Best estimates of
Fuel complex structure
Fire weather and climate
Estimated error of
Fuel complex structure
Fire weather and climate
Wind profile model
Fuel moisture model
Random-field generator
Array of input conditions
Outputs
Rate of spread
Type of fire
Fire intensity
Flame length
Rate of spread, intensity, etc.
Mean, mode(s), median
+/- 1 standard dev.
25-75th percentile
Probability outputs:
e.g.,P(R>50 m/min)
P(I>5000 kw/m)
Type of fire
Probability of crowning
% of crown consumption
Ensemble of surface fire behaviour predictions
Ensemble of crown fire behaviour predictions
Crown fire spread model


Ensemble method: bimodality of rate of spread distribution
Canopy base height = 6 m
Predicted rate of spread (m/min)
Probability (%) of crown fire activity
+/- 1 standard deviation
Deterministic prediction
Monte Carlo prediction (n=250)
Probability crown activity
10-m open wind speed (km/h)
CBH = 6 m; U_{10} = 10 km/h
CBH = 6 m; U_{10} = 15 km/h
CBH = 6 m; U_{10} = 20 km/h
CBH = 6 m; U_{10} = 30 km/h
Count
Rate of fire spread (m/min)

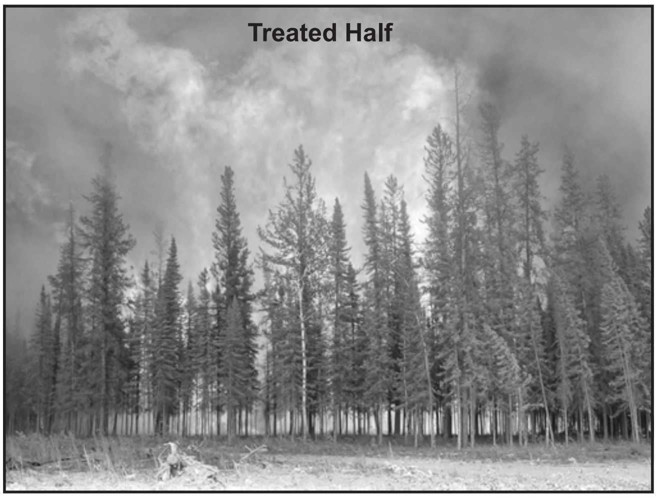

The use of models for accessing fuel treatment effectiveness in reducing crown fire potential
FUEL DESCRIPTION
QUANTITY
SIZE
DEPTH
CHEMICAL
MOISTURE
INTERPRETATION
EXPERIENCE
COMPARISON
MATHEMATICAL MODELS
FIRE POTENTIAL
RATE OF SPREAD
INTENSITY
CROWNING
SPOTTING
DURATION

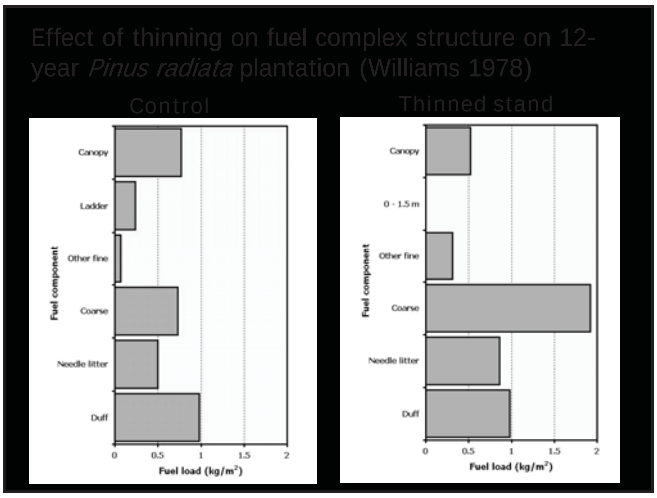

Effect of silvicultural practices on stand flammability
X = Wandilo
• = Longford
Y = Gnangara
RATE OF FORWARD PROGRESS (c.p.h.)
FOREST FIRE DANGER INDEX
FIGURE 4.—Rate of spread in exotic pine plantations related to the forest fire danger index—
(A) In unpruned P. radiata plantations at Longford and Wandilo, S.A.,
(B) In pruned P. pinaster plantations at Gnangara, W.A.
FIRE BEHAVIOUR CHARACTERISTICS OF THE LONGFORD FIRE
17th November, 1962
by
A. G. McARTHUR
FOREST RESEARCH INSTITUTE


150 m
Wind Direction
Untreated
150 m
seismic line
Ignition face
Treated
The ICFME Fuel Treatment Trials
Treated/Untreated Plot, June 14, 2000 (Alexander and Lanoville 2004)


Diurnal Fine Fuel Moisture Dynamics
Untreated Plot
Treated Plot
Needles (litter layer top layer)
Bark flakes
Fine twigs (0 - 5 mm)
Fuel Moisture (% ovendry weight)
Time


Untreated Half


Treated Half


Effect of thinning on fuel complex structure on 12-year Pinus radiata plantation (Williams 1978)
Control
Thinned stand
Canopy
Ladder
Other fine
Coarse
Needle litter
Duff
0 - 1.5 m
Fuel component
Fuel load (kg/m²)

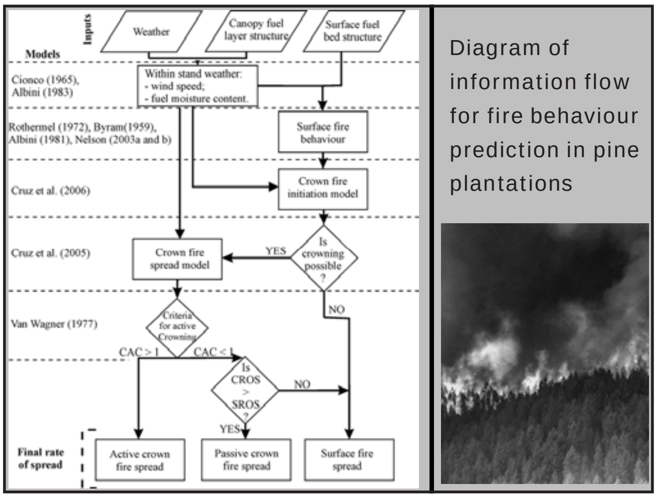
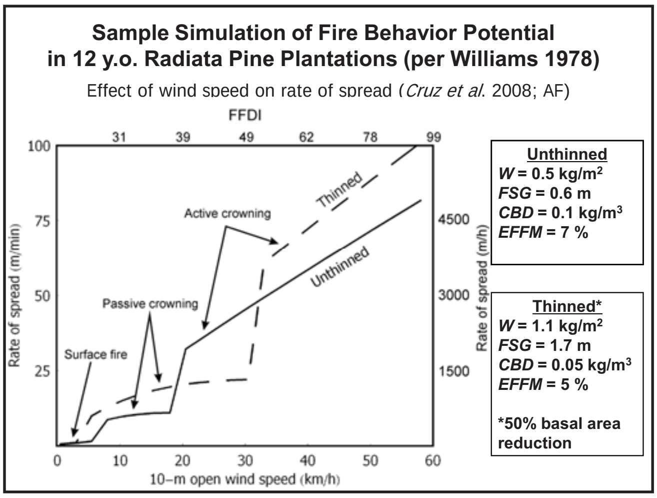


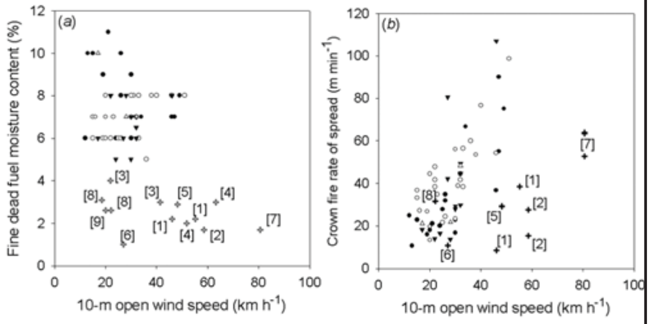
Diagram of information flow for fire behaviour prediction in pine plantations
Inputs
Weather
Canopy fuel layer structure
Surface fuel bed structure
Models
Cionco (1965), Albini (1983)
Within stand weather: - wind speed; - fuel moisture content.
Rothermel (1972), Byram(1959), Albini (1981), Nelson (2003a and b)
Surface fire behaviour
Cruz et al. (2006)
Crown fire initiation model
Cruz et al. (2005)
Crown fire spread model
YES
Is crowning possible ?
NO
Van Wagner (1977)
Criteria for active Crowning
CAC > 1
CAC < 1
Is CROS > SROS ?
YES
NO
Final rate of spread
Active crown fire spread
Passive crown fire spread
Surface fire spread

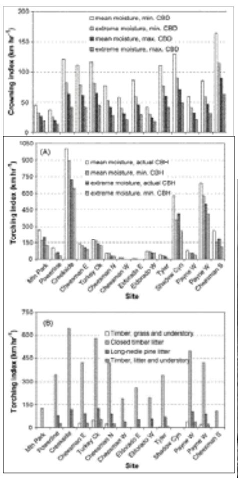

Sample Simulation of Fire Behavior Potential in 12 y.o. Radiata Pine Plantations (per Williams 1978)
Effect of wind speed on rate of spread (Cruz et al. 2008; AF)
FFDI
Rate of spread (m/min)
Rate of spread (m/h)
10–m open wind speed (km/h)
Surface fire
Passive crowning
Active crowning
Thinned
Unthinned
Unthinned
W = 0.5 kg/m²
FSG = 0.6 m
CBD = 0.1 kg/m³
EFFM = 7 %
Thinned*
W = 1.1 kg/m²
FSG = 1.7 m
CBD = 0.05 kg/m³
EFFM = 5 %
*50% basal area reduction

Systems available to evaluate crown fire potential

Crown fire potential: a critique of current approaches and recent **simulation studies**

Cruz and Alexander (2010), *IJWF*





The under-predictions in the critical surface fire intensity for the onset of crowning coupled with the under-predictions in Rothermel's (1991) crown fire rate of spread model have lead to highly questionable results (e.g., Hall and Burke 2006).

Topics Considered Worthy of Investigation/Study:

❑ Vertical fire spread (critical ***CBD***) into the overstory canopy, including ladder fuel effects (e.g., bark flakes).

❑ Foliar moisture content (***m***) effect on crown fire rate of spread

❑ A physically-based model for predicting crown fire cessation

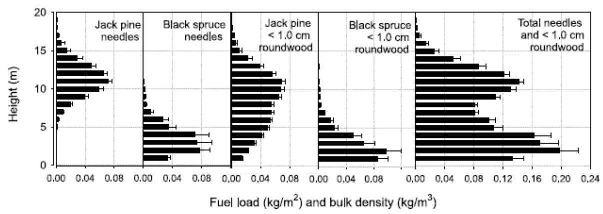
❑ Model for predicting crown fire flame height model

❑Additional emphasis placed on the prediction of surface fire rate of spread and flame front characteristics (e.g., residence time, intensity).

How to define Crown Base Height (CBH)?

Van Wagner's (1977) Assumptions:

• "*Vertical spread of fire into the overstory canopy is for practical purposes independent of the canopy bulk density*".



Minimum Crown Bulk Density to Define the *z* (CBH)

• Sando and Wick (1972) – 0.037 kg/m^3

• Williams (1977) – 0.074 kg/m^3

• Scott and Reinhardt (2001) – 0.011 kg/m^3

…but little or no laboratory research to quantify threshold value

Foliar Moisture Content (*m*) Effect on Crown Fire Rate of Spread

$$ROS = ROS' \cdot \left(\frac{FME}{FME_0} \right)$$

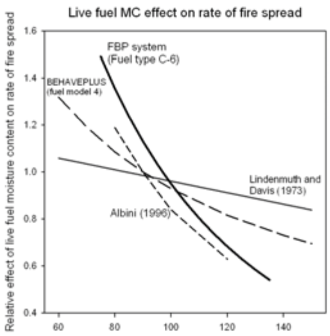
$$FME = \frac{(1.5 - 0.00275 \cdot m)^4}{460 + 25.9 \cdot m}$$

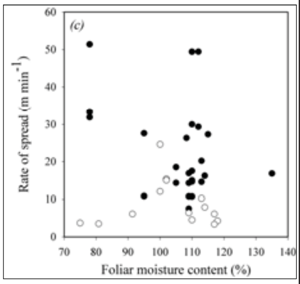
Red Pine Plantation Experimental Fires (***SH*** = 15 m)

Exp. Fire	Spread Rate (m/min)	Fire Intensity (kW/m)	***m*** (%)	Flame Height (m)
C4	16.8	21,000	135	19.8
C6	27.4	22,500	95	30.5

Effect of Live Fuel Moisture on Crown Fire Rate of Spread in Shrublands and Conifer Forests

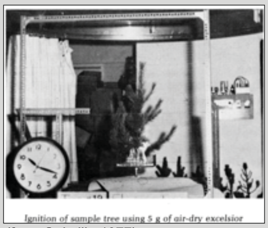
Lindenmuth & Davis (1973) is empirical (field data) and BehavePlus, FBP System and Albini (1996) are theoretical



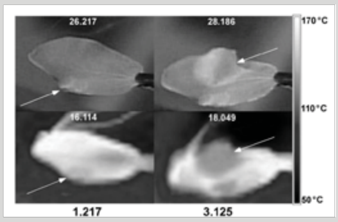


- Cruz et al. (2005) dataset;
- Orthogonality issues – FMC significantly correlated with U10

Can laboratory scale experiments replicate the flow temperature/velocities and radiation environment determining live fuel ignition and combustion in crown fires?



(from Quintilio 1977)



(from B. Pickett 2008)

Flame dimensions in crown fires

Byram (1959) indicated that his fire intensity-flame length equation would under-predict the flame length for "… *high intensity crown fires because much of the fuel is a considerable distance above the ground*."

He suggested, on the basis of personal visual estimates, that "… *this can be corrected for by adding one-half of the mean canopy height* …" to the flame length value obtained by his equation. Thus, the equation for crown fire flame lengths (L_c) taking into account stand height (***SH***) becomes :

$$L_c = 0.0775 \cdot (I)^{0.46} + (SH/2)$$

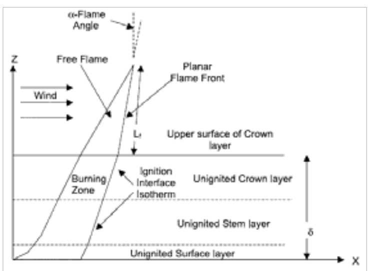
Rothermel (1991) suggested using Thomas' (1963) relation to estimate the flame lengths of crown fires from fire intensity:

$$L_c = 0.0266 \cdot (I)^{2/3}$$

More recently Butler *et al.* (2004) proposed the following relation for calculating the flame lengths of crown fires from fire intensity:

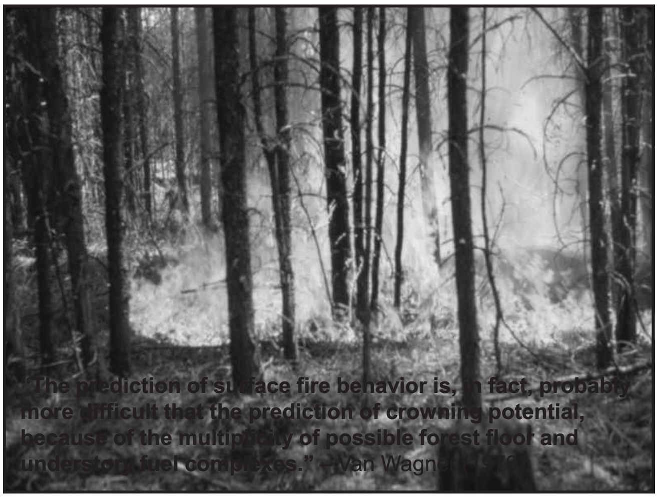
$$L_f = 0.0175 \cdot (I)^{2/3}$$

Where L_f is the flame length measured from the upper surface of the fuel array.



None of these methods seem to work consistently well based on comparisons against experimental crown fires undertaken in Canada. Take, for example, the following experimental crown fires in red pine plantations (***SH*** = 15 m) documented by Van Wagner (1977).

		------------- Predicted L_c (m) ---------		
Exp. Fire	**Obs. L_c (m)**	**Byram (1959)**	**Thomas (1963)**	**Butler *et al.* (2004)**
C4	**19.8**	**15.1**	**20.2**	**28.8**
C6	**30.5**	**15.3**	**21.2**	**29.4**



Crown Fire Behavior Characteristics and Prediction in Conifer Forests: A State of Knowledge Synthesis

- Martin E. Alexander, University of Alberta
- Miguel G. Cruz, CSIRO
- David L. Peterson, USDA Forest Service
- Nicole M. Vaillant, Western Wildland Environmental Threat Assessment Center

- Synthesis project funded by the U.S. Joint Fire Sciences Program.
- The focus of the project is to synthesize available information on crown fire behavior related to conifer forests.
- The synthesis will be global in nature and is intended for multiple audiences - from fire fighters to university professors.
- Website: http://www.fs.fed.us/wwetac/projects/alexander.html

Key Take-home Messages

- Know the literature, including the "older stuff".
- Question things. Be skeptical.
- Insist on realism (Do these results make sense? Is this what I would expect given the burning conditions?).
- Appreciate that fire researchers and fire modellers are often reluctant to point out the weaknesses in their models and systems for fear of them not being accepted.
- If you are a researcher or modeller, ensure that you try and obtain first-hand experience in the field.
- And if you are a researcher or modeller, bear in mind that you have a social responsibility when it comes to your work.

CITATION:

Cruz, M.G.; Alexander, M.E. 2010. Crown fires. Pages 30-46 *in* VI Short Course on Fire Behaviour, 13-14 November 2010, Coimbra, Portugal. Association for the Development of Industrial Aerodynamics, Forest Fire Research Centre, Coimbra, Portugal.